TECHNICAL NOTES

UNITED STATES ARMY
SCHOOL OF MILITARY AERONAUTICS

UNIVERSITY OF ILLINOIS

[illegible]

Training Section
Ground Schools Branch.

October 24, 1918.

MEMORANDUM FOR ALL SECTIONS.

Subject: Course of Ground Instruction for Officers Taking Flying Instruction at Bolling Field.

1. The instruction will be under the supervision of the Ground Schools Branch, with laboratory assistants provided by the Mechanical Instruction Branch.

2. The course will begin Monday, November 4, 1918, and will continue for seven weeks. Classes will be held from 7 to 9 P. M. on Mondays, Wednesdays, and Fridays, and on Tuesdays, Thursdays, and Saturdays.

3. Examinations will be held on each subject at the conclusion of the week in that subject. Officers who pass satisfactory examinations in all subjects and complete the regular flying course at Bolling Field may be rated as Pilot (old R.M.A.).

4. The course in AIRPLANES will consist of 12 hours instruction covering the following subdivisions of the subjects:

Theory of Flight (lecture). . . . . 2 hours
Rigging . . . lecture . . . 2 hours
Laboratory. . 2 hours. . . 4 hours
Inspection and Repair (laboratory) . . . 4 hours
Types of Machines (lecture) . . . . 1 hour
Examination. . . . . 1 hour
12 hours

5. Following the course in AIRPLANES there will be [illegible] in AIDS TO FLIGHT subdivided as follows:

Instruments (lecture) . . . .
Meteorology (lecture) . . . .
Navigation (lecture) . . . .
Examination . . . .

6. Following the course in AIDS TO FLIGHT [illegible] course in ENGINES subdivided as follows:

Principles (including types) . .
[illegible] . . . .
[illegible] . . . .

TECHNICAL NOTES

PREPARED FOR THE

UNITED STATES ARMY
U. S. SCHOOL of MILITARY AERONAUTICS
UNIVERSITY of ILLINOIS

BY
THE TECHNICAL STAFF
1918

PREFACE

In a course of intensive training such as is given at the Schools of Military Aeronautics, it is difficult for the cadets to absorb information as rapidly as it is imparted by the instructor in the lecture room or laboratory. Hence it is desirable that cadets be furnished with a syllabus containing the essentials of the several courses arranged in the order of presentation in class, so that during their study periods cadets may have the means at hand for reviewing the work of the day, for obtaining a better understanding of the principles explained, and for arranging their notes on the subject matter in a more orderly manner than would otherwise be possible. It is with these objects in view that this volume of "Technical Notes" is prepared.

Each chapter is preceded by a short outline which gives the main divisions and sub-divisions of a subject. Since instruction is given in accord with the outlines as herein presented it is unnecessary for the cadet to make an outline. His note-keeping is aided and reduced to a minimum, thus making it possible for him to follow the class-work closely. Such personal notes as he does take, however, should be classified under the headings used in this volume.

Each subject is covered as fully as is consistent with the aims of the School. At the same time the sub-divisions of each subject are presented as briefly as is consistent with clearness. The aim throughout is to present the information more in the form of a syllabus than in that of a treatise.

In a few instances, illustrations from other books are used. Where this is done, credit is given to the author. Acknowledgment of our indebtedness is hereby made to these gentlemen whom we trust will pardon the unauthorized use of their work in the present emergency.

ACADEMIC BOARD, S. M. A., U. OF I.

Urbana, Illinois, June, 1918.

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Chapter I—Airplanes

Chapter II—Cooperation with the Artillery

Chapter III—Engines

Chapter IV—Gunnery

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Chapter VII—Meteorology

Chapter VIII—Signalling

CHAPTER I.

AIRPLANES

OUTLINE

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        2. Efficiency
    - B. Airplane Performance
    - C. Airplane Equilibrium
    - D. Types of Machines
        1. Introduction
        2. Land and Water Machines
        3. Classification as to Number of Planes
        4. Classification as to Position of Propeller
        5. Military Machines
        6. Recapitulation
    - E. History of Aviation
2. Nomenclature
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        1. External
        2. Internal
    - B. Fuselage or Body (Nacelle on Pushers)
        1. External
        2. Internal
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3. Elements of Airplane Design
    - A. Introduction
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        1. Three General Types
        2. Choosing among these Three Types
    - C. General Conclusions as to the Materials which will be required
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        2. Necessity for Lightness
        3. Airplane Material must be Reliable
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        5. Occasional Necessity for Special Properties

D. Data Relative to the Recognized Airplane Materials
   1. Woods
   2. Steel
      a. Mild Steels
      b. Alloy Steels
   3. Metals other than Steel
   4. Wires and Cables
      a. Aircraft Wire
      b. Aviator Strand
      c. Aviator Cord
   5. Covering Material
      a. Fabric
      b. Coating
   6. Miscellaneous Materials

E. Fitness of Certain Materials for Certain Classes of Parts
   1. Woods
   2. Steels
      a. Mild Steels
      b. Alloy Steels
   3. Metals other than Steel
   4. Wires and Cables
      a. Aviator Wire
      b. Aviator Strand
      c. Aviator Cord

F. Necessity for Streamline Form of Parts

G. Design of small Parts Capable of General Application
   1. Wire and Cable Tension Members
      a. End Connections
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   3. General Design of Metal Fittings
      a. Stamped Fittings
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H. Actual Design of the Various Elements of the Machine
   1. The Wings
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      b. The Fuselage of the Tractor Monoplane
      c. The Pusher Biplane
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   5. The Tail

4. Assembly

   A. Undercarriage
   B. Center Section
   C. Tail
   D. Wing

5. **Alignment**
   - A. Fuselage
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   - C. Center Section
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   - F. Ailerons

6. **Propellers**
   - A. Manufacture and Structure
   - B. Inspection
     1. Balance
        - a. Static Balance
        - b. Dynamic Unbalance
     2. Trackage
     3. Pitch Angle and Pitch
     4. Camber
     5. Joints
     6. Condition of Surface
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CHAPTER I.

AIRPLANES

1. THEORY OF FLIGHT

A. AIRPLANE WINGS

1. Lift An airplane is supported by the air just as surely as an automobile is supported by the pavement. The supporting force is called *lift*. (See Fig. 101) The lift is obtained by drawing the wing through the air thus allowing the small particles in the air to strike the wing and bounce off. In bouncing off they exert upward forces the sum of which is the lift. The resistance which the wing offers to being drawn through the air is called *drift*.

The lift may be varied by changing the angle of incidence. Increasing the angle of incidence will increase the amount of air striking the wing and will increase the lift until an angle of about 15° is reached. At this angle the lift decreases as the angle of incidence is increased. This is called the stalling angle.

The lift will vary as the density of the air which strikes the wing varies. Density of air means the weight of the air. The heavier the air the more air particles it contains, and therefore the greater the upward force given to the wing. The denser the air the greater the lift will be.

The velocity of the air affects the lift because it affects the number of air particles which strike the wing in a given period of time. The greater the velocity the greater the number of reactions in a given time and the greater the lift. The lift varies with the square of the velocity.

The greater the area of the wing the greater the lift because the total upward force on the wing depends on the total area of the wing which the air may strike.

There is an interdependence of angle of incidence and velocity. As an airplane maintains its usual horizontal flight through the air there must at all times be a total lift equal to the weight of the machine. The density of the air will be constant because of the horizontal flight and the wing area will be constant. But if the speed is changed the lift is changed and in order to bring the lift back to a value equal to the weight, the angle of incidence must be changed. As the speed is increased the angle of incidence is decreased and as the speed is decreased the angle of incidence is increased. The limit of increasing the angle of incidence is the above mentioned 15° where increase of lift is not obtained.

2. Efficiency A good wing is a wing which will give the greatest lift with the least drift. This kind of a wing would be the most efficient so efficiency is defined as lift/drift. This maximum lift/drift occurs at small angles (1½°–8°) because the wing is not tilted enough to allow very much of the total force of the air to go into drift.

The particular shape of the wing would naturally have some effect on the efficiency of the wing, the same as the shape of a body will affect the resistance of that body. In general, wings are thick toward the front and taper down a curve to a thin trailing edge.

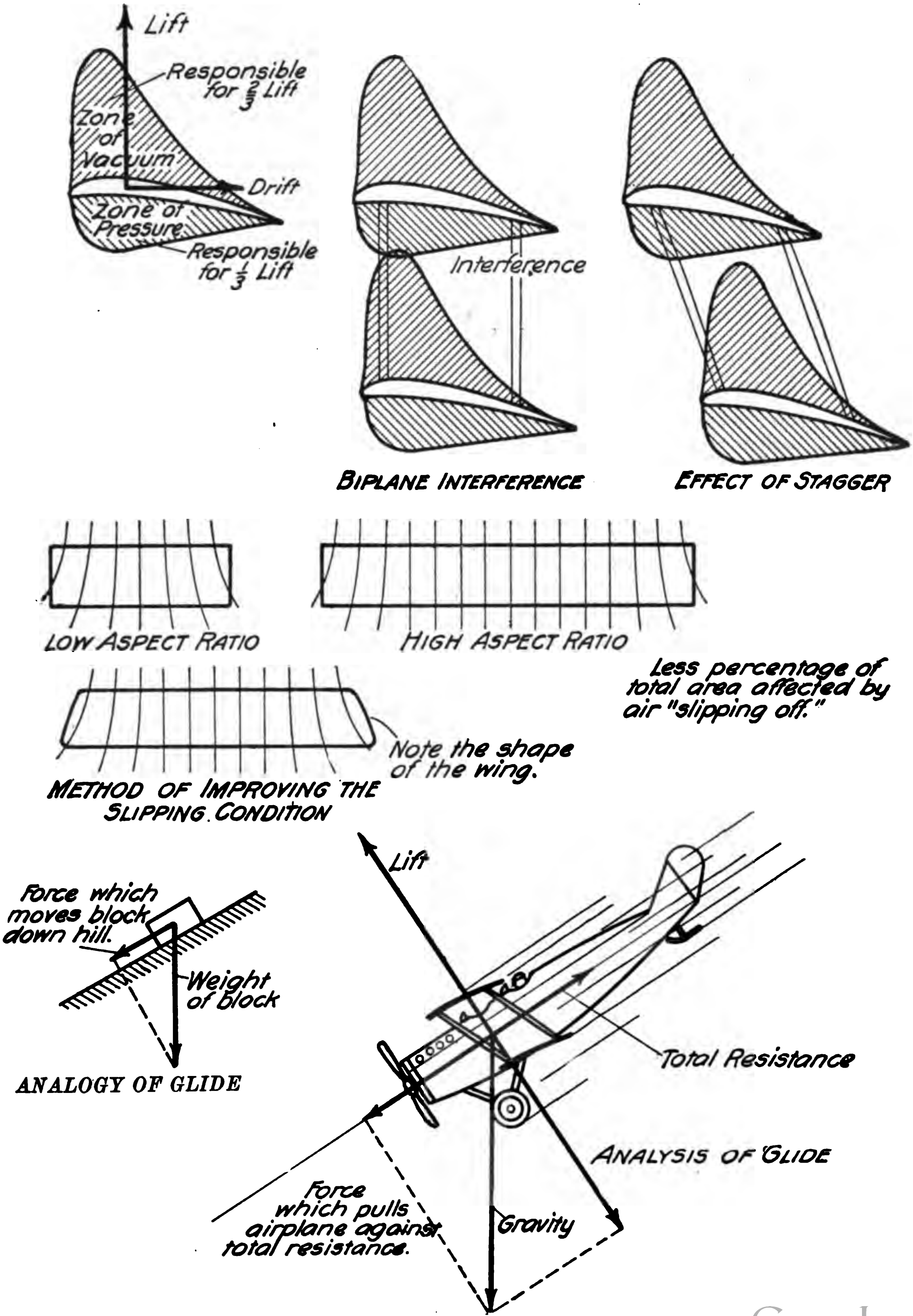

Lift
Responsible for 2/3 Lift
Zone of Vacuum
Drift
Zone of Pressure
Responsible for 1/3 Lift
Interference
BIPLANE INTERFERENCE
EFFECT OF STAGGER
LOW ASPECT RATIO
HIGH ASPECT RATIO
Less percentage of total area affected by air "slipping off."
Note the shape of the wing.
METHOD OF IMPROVING THE SLIPPING CONDITION
Force which moves block down hill.
Weight of block
ANALOGY OF GLIDE
Lift
Total Resistance
ANALYSIS OF GLIDE
Force which pulls airplane against total resistance.
Gravity

FIG. 101

Above a wing is a zone of reduced pressure which produces two-thirds of the lift. (See Fig. 101) Below the wing is a zone of increased pressure responsible for only one third of the lift. When one wing is placed directly above the other its zone of increased pressure interferes with the zone of reduced pressure of the other. (See Fig. 101) In order to partially obviate this the wings are staggered.

The aspect ratio is defined as the span/chord. A stream of air naturally follows the path of least resistance; therefore the air will not only escape over the trailing edge but also over the ends. This means loss of lift. But, a smaller percentage of the total area is affected on a high aspect ratio wing. Therefore, the higher the aspect ratio the higher the efficiency.

B. AIRPLANE PERFORMANCE

Resistance is impediment to motion. Resistance depends upon the shape and speed of a body. The body which offers the least resistance will be so shaped that few eddies will be caused by the rush of air. The air is easy to split asunder with little eddying but it does not unite until some distance behind the body. This is why a streamline section has a blunt nose and long sharp tail. The resistance of a body varies as the square of the speed. The thrust of the propeller overcomes the total resistance of the machine. Since it takes power to drive the propeller the greater the total resistance and speed the greater the power required. The maximum speed of an airplane then is that velocity at which the power available is equal to the power required to drive the propeller. If at any time there is more power available than required to fly the machine at any particular speed then that excess power may be utilized to climb. The climbing ability of an airplane therefore depends mostly upon excess power. An airplane climbing is the same as an automobile climbing a hill.

At all times there must be a force pulling the machine forward equal to or greater than the total resistance. If the motor stops this force is lost. It can only be regained by borrowing some of the force of gravity. This is accomplished by gliding downward. The angle at which the airplane approaches the ground is the gliding angle. An airplane in a glide is the same as a sled coasting down hill. (See Fig. 101)

C. AIRPLANE EQUILIBRIUM

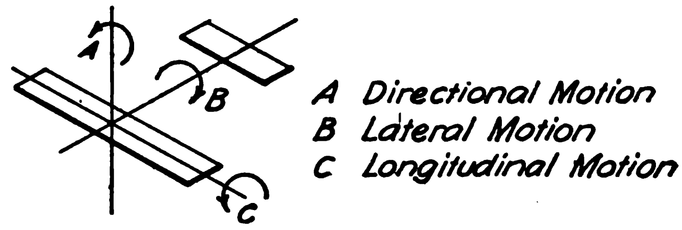
The fundamental principle of airplane equilibrium is the correct position of the four forces, thrust, center of resistance, gravity, and center of lift. The tendency of the machine to dive due to thrust and center of resistance must be counteracted by the tendency to rear due to gravity and center of lift. (See Fig. 101)

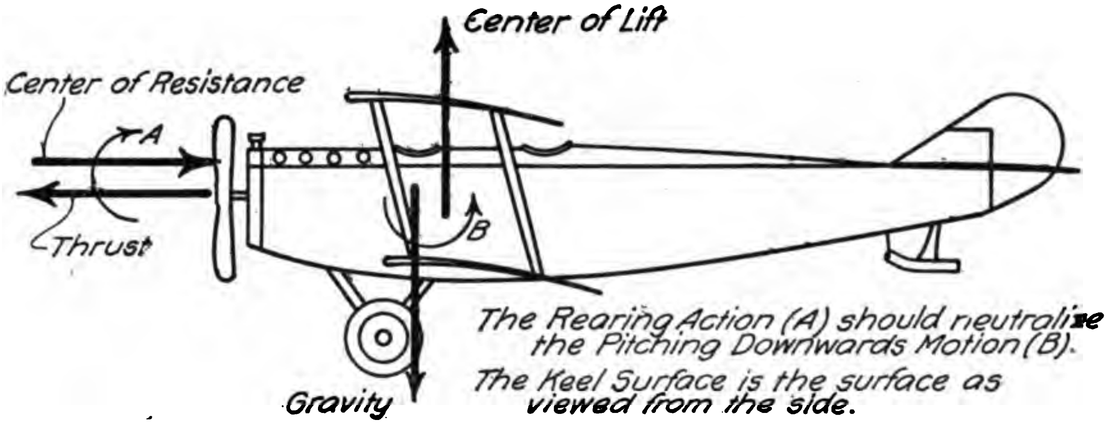
Longitudinal stability is aided by the decalage. Due to the fact that the angle of incidence of the wings is greater than that of the horizontal stabilizer the airplane tends to come back to an even keel when disturbed by some external force. The elevator controls longitudinal motion. (See Fig. 102)

Lateral stability is aided by the dihedral angle. When the airplane rolls over, the low wing lifts more than the high one because the low one is nearly horizontal. (See Fig. 103) The ailerons control lateral motion.

Directional stability is aided by the keel surface of the airplane. The keel surface is the silhouette view of the side of an airplane. This is sometimes called "weather cock" stability because a weather cock must have more keel surface behind its axis than in front; otherwise it would not head into the wind. An airplane then must have more keel surface behind the center of gravity than in front. The rudder controls directional motion.

Banking is one of the many combinations of the three motions. It combines lateral motion with directional motion. If a turn in the air is made without





THE FOUR FUNDAMENTAL FORCES

ILLUSTRATING WHY MORE KEEL SURFACE SHOULD BE BEHIND THE VERTICAL AXIS

THE HORIZONTAL VEE PRINCIPLE

FIG. 102

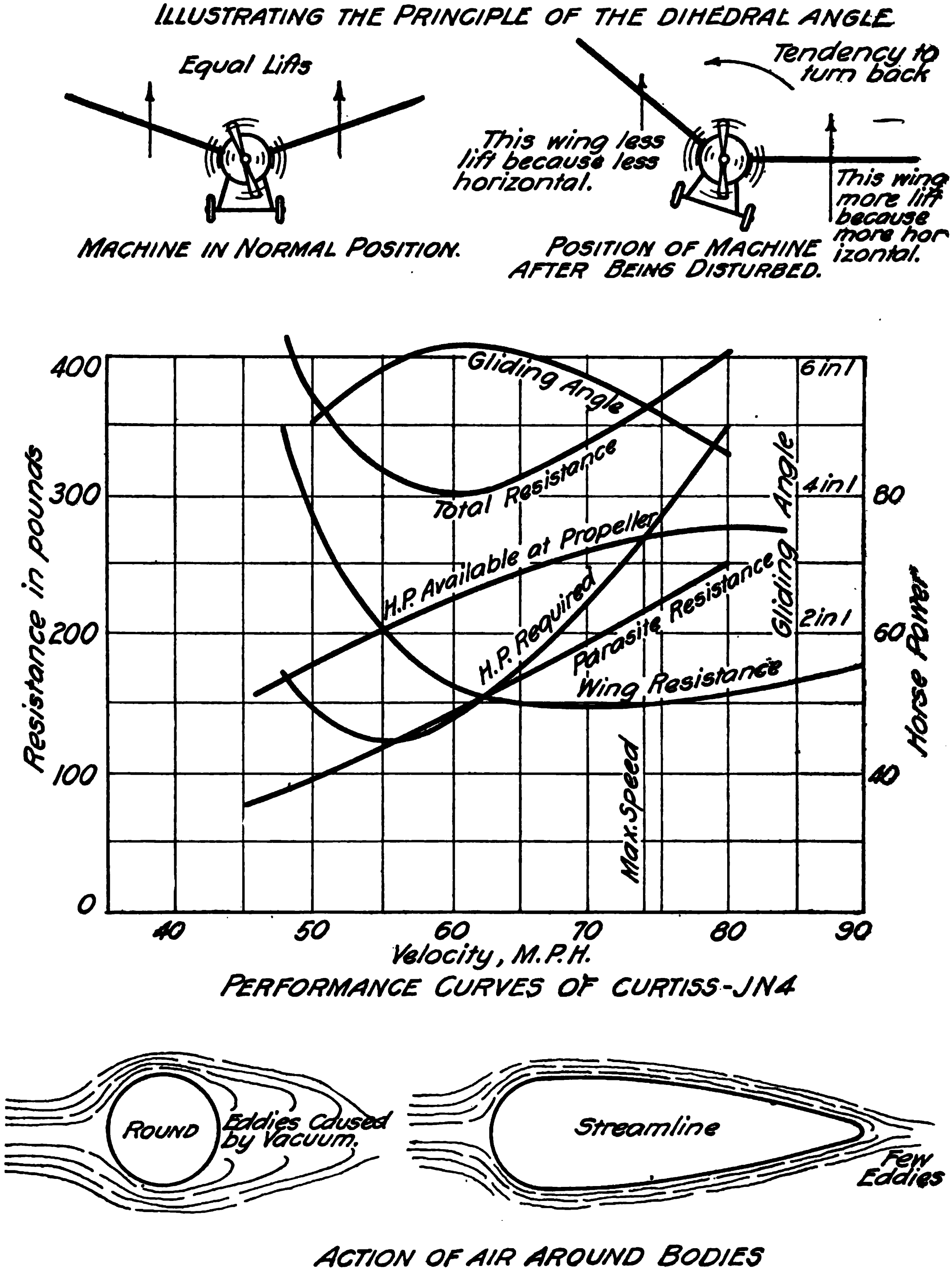

ILLUSTRATING THE PRINCIPLE OF THE DIHEDRAL ANGLE
Equal Lifts
Tendency to turn back
This wing less lift because less horizontal.
This wing more lift because more horizontal.
MACHINE IN NORMAL POSITION.
POSITION OF MACHINE AFTER BEING DISTURBED.
Gliding Angle
Total Resistance
H.P. Available at Propeller
H.P. Required
Parasite Resistance
Wing Resistance
Max. Speed
6 in 1
4 in 1
2 in 1
Resistance in pounds
Horse Power
400
300
200
100
0
80
60
40
40
50
60
70
80
90
Velocity, M.P.H.
PERFORMANCE CURVES OF CURTISS-JN4
ROUND
Eddies Caused by Vacuum.
Streamline
Few Eddies
ACTION OF AIR AROUND BODIES

FIG. 103

banking the skidding effect is called side slip. A spiral nose dive is a combination of all of the motions.

Airplanes sometimes do not correctly regain their even keel. They sometimes oscillate back and forth longitudinally due to the inertia of the tail. Damping is the stamping out of these oscillations. This is accomplished by making the fuselage as short and light as possible thereby making the inertia of the fuselage less.

D. TYPES OF MACHINES

1. Introduction The classification of airplanes into very definite and fixed groups is a rather difficult matter, since there is such a variety in construction and design, and since one machine may possess features that will place it under two or three different headings. So that any classification attempted will necessarily be general, and based on some fundamental principle of use or design, tho the overlapping of classes may lead to some slight confusion. With some form of classification however, the identification of the various airplanes becomes an easier matter, since it is always easier to see some definite thing in the construction of a plane if one knows what to look for.

2. Land and Water Machines The broadest and simplest classification of machines divides them into the two groups of land and water machines, that is, machines so designed that they may alight on the land, or so designed that they may alight on the water. Considering the former class, it will be seen that the main requisite is some form of landing gear that will permit of rolling or sliding motion on fairly smooth ground. So that the use of an undercarriage embodying wheels or skids is sufficient to class a plane as a land machine. In the water machines, all that is required is some form of undercarriage that will float on the water and have buoyancy enough to support the weight of the machine, yet will also offer a minimum resistance to motion on the surface. There are two principal types of water machines. The seaplane, or flying machine adapted to lighting on the water, is exactly similar to a land machine except that the wheels are replaced by floats or pontoons of proper design. Most land machines are so constructed that the wheeled gear may be detached and replaced by a float construction. The use of one or two pontoons is a matter of designers' preference. Several typical seaplanes in American practice are the Curtiss N-9, the Thomas seaplane, the Burgess seaplane, and the Aeromarine hydroaeroplane. This latter term is as general as the term seaplane, and the type of machine is often referred to merely as a "hydro". The second type of water machine is really a boat so designed that it will rise out of the water and fly in the air. The hull is similar to that on a hydroplane, and all points of design are modified to give the machine good stability and control when operating on water. Typical examples of the flying boat are the Curtiss model "F," the Curtiss "America" and "Canada" types, and the Curtiss H-12.

3. Classification as to Number of Planes A second very general classification divides airplanes according to the number of supporting surfaces. The simplest is naturally the monoplane, or single surfaced machine. This type has certain advantages in speed and handiness of control, but is gradually being displaced by the small biplane which has greater advantages in the matter of structural strength. Typical monoplanes are the earlier Bleriot and Nieuport machines, the Morane, and the Fokker. The second class is the machine carrying two main surfaces, or the biplane, which is the most familiar type, being known in the first Wright machines and coming down thru the Farman and Curtiss types to its present high stage of development in the Caudron, Caproni, Gotha, Sopwith, S. P. A. D., Nieuport, etc.

This type has advantages in constructional strength, surface capacity without excessive span, and adaptability to various needs that assures its being the prominent type of plane for all time. The third division is the multiplaned machine, of which the triplane is the only practical example. This type has only recently found its place in modern construction, for the inefficiency of the surfaces, the great height of the structure, and various difficulties in construction have led many to consider it impractical. Yet in the latest Caproni machines this form has been found very good, giving great weight-carrying capacity and reliability without any very difficult design. Some smaller speed planes, such as the Curtiss triplane scout and the Sopwith triplane are proving that the triplane type need not be confined to the large machines only, tho it is in the latter class that it will find its greatest application.

4. Classification as to Position of Propeller As the third general classification, airplanes may be divided into groups based on propeller position. This sub-divides naturally into three main classes—the tractor type, with the propeller ahead of the main planes; the pusher type, with the propeller behind the main planes; and a combination type, in which it is sought to retain the advantages of both tractor and pusher by some modification in design. In the first class, the propeller or propellers are so situated that they pull the machine thru the air much as a locomotive draws a train of cars, with the same inherent idea of stability. This construction has advantages in the more efficient streamlining of the body—the fuselage—and in many ways gives the most satisfactory results. For the modern fighting and observation planes however, there is the disadvantage that the observer and pilot sit well back in the body, under the planes, and so have their vision cut off in certain directions, as well as having the propeller obstructing the range of gun-fire. Yet this type continues the favorite for many uses, and the finest types of machines—Nieuport, Curtiss, Vickers, Albatross, Fokker, etc.—are all of this class. It is with the idea of giving a better arc of fire and a wider range of vision that the pusher type of machine is being developed. Structurally this type is inferior to the tractor, for the body—nacelle—is not so efficiently streamlined, and the outriggers or booms supporting the tail present a point of weakness and greater head resistance. Yet where speed is not a prime requisite, and where good arc of vision is imperative, this type is superior. Therefore the observation and bombing machines of the present time use this design, and the Farman, Voisin, F. E., and De Havilland are most valuable. If a machine could be designed that would have the structural advantages of the tractor and the observational advantages of the pusher, it would be most desirable. To this end certain machines such as the Caudron, Gotha, Handley-Page and Caproni have a motor and propeller arrangement that is desirable in many respects. The machines mentioned are the multi-motored planes, and in the Caudron each of the two motors is carried out on the planes in separate streamlined shells, while the main nacelle, carrying the fuel tanks, men and supplies much resembles the tractor fuselage, except that the observer sits at the front end, as in the pusher nacelle. In the Gotha twin-motor machine is found a very similar construction, and also in the twin Handley-Page. In the Caproni three-motored machine however, the two motors driving tractor propellers are carried in regular tractor fuselages about one-third of the distance from each end, while the third motor drives a pusher propeller, and is carried in a main body or nacelle at the center of the planes. In this nacelle are also the supplies, tanks and men, so that all the observational advantages of the pusher are obtained, while the fuselage construction for the other two motors serves to support the tail and so give the structural tractor advantages. It is this overlapping of the pusher and tractor types that tends to lead to confusion in the matter of classification.

5. **Military Machines** For the last general classification of machines they are grouped according to their use for military operations. As the main sub-divisions they are classed as Reconnaissance, Fighting, Bombing and Training machines. The first use of airplanes for war purposes was as reconnaissance or observation means, and the French attest their value during the battle of the Marne. These first planes were of course crude compared to those now in use for this purpose, and the development has been specialized and rapid, so that now the Farman, Voisin, Caudron and F. E. bear small resemblance to the first small fliers. The later observation planes carry special cameras, trained observers, and protective guns. They are designed for good climbing capacity, for speeds up to 100 m.p.h., for clear arc of vision and for good carrying capacity. But tho the primary use for airplanes in the war has been for the purpose of observation, yet there speedily developed the realization that the airplane must have some means of defense, or it could be driven down by an armed enemy plane, and so lose its observational value even if it were not destroyed. Thus the planes began to arm with rifles and machine guns, and the natural outcome was the development of a purely fighting type of machine, carrying two or more quick-firing guns and with a speed and manoeuvering ability that made it most deadly to the slower, heavier observation machines. This fighting type represents the acme of airplane design and construction, with its high-powered, light weight engine, its minimum factor of safety, its high rate of climb and tremendous speed, and its ease of control and ability to perform all manner of "stunts". The S. P. A. D., Sopwith, Nieuport, Morane, Fokker, Albatross Scout, and Halberstadter are all of this type, carrying usually only the pilot, and as deadly as wasps. This fighting type is of course a special development, and really of no great utility except as it serves to protect the observation and bombing planes. These latter—the bombers—are gradually beginning to assume greater importance as an arm of offense, for they penetrate the land defenses of the enemy and attack where least expected. They are heavy, moderately fast machines capable of carrying loads up to two or two and a half tons of bombs. They carry generally several protective guns, for their operations involve flights of too great duration for the fighting machines to accompany them. Even so they would be vulnerable to the attacks of the enemy fighters but for the fact that these bombing squadrons have developed a flying formation that leaves no single machine open to individual attack, and the combined fire of the squadron is usually too much for the attacking fighters, just as a fleet of cruisers can protect itself against a superior number of destroyers. These large bombers, such as the Gotha, Caudron, and Handley-Page or Caproni can make flights of four hundred to six hundred miles, carrying tons of explosives to drop on ammunition depots, aerodromes, railway centers and industrial centers of the enemy, and being usually of the multi-motored type can manage to survive pretty severe anti-aircraft fire and return to their base. The bombing type will in peace times become the carrier of costly merchandise, or the passenger airship.

A type of machine that is gradually becoming specialised is the military training plane. For the work of training thousands of embryo aviators a machine is needed that has standard control, a reliable motor, a good degree of inherent stability, and the structural strength to stand the severity of amateur landings. Such a machine is the Curtiss JN-4, and the Standard J-1 in America, or the B.E.-2C in England. These machines do not need climbing ability or speed, they do not demand refinement of construction or perfection in design, yet they are valuable for the one purpose of teaching the fundamentals of airplane control.

6. **Recapitulation** It will be noted that many of the machines fit into several of the general classifications, and that the last classification and the first classification are general enough to include any machine that may be designed to travel in the air. Yet certain necessities of use as a rule involve certain necessities of construction or design, and the habit of analysing the use for which a machine is intended will in time lend greater facility in identifying the various makes of machines—a faculty that is much needed in the present war times, when the pilot of a machine must be able in a few seconds to positively state whether a machine is friend or foe, and that often under adverse conditions. Ability in observation implies intelligent application of knowledge.

E. HISTORY OF AVIATION

Four important men, dates, and achievements in the history of aviation are:—

Lilienthal—1893—Camber.
Chanute—1896—Biplane Truss.
Wright Bros.—1903—Stability.
Nieuport—1909—Fuselage.

Lilienthal was a German who made extensive experiments with gliders. He discovered that a wing with camber was more efficient than a flat wing. Lilienthal was killed in a glide, having lost control of his apparatus while some distance from the ground.

Chanute was a Chicago civil engineer who applied the principles of bridge construction to the airplane. Instead of only one surface Chanute used two surfaces rigidly braced together. He is called "The Father of the Biplane".

The Wright Bros. were bicycle repairmen in Dayton, Ohio. When they heard of the death of Lilienthal they commenced thinking over the problem. They did not like Lilienthal's method of balancing the glider, namely, by shifting the pilot's weight. After experimenting for some time they found that they could control the longitudinal balance by means of surfaces supported some distance in front of the lifting planes. These they called elevators. They observed that the birds maintained their lateral balance by warping their wings so they tried that method on their gliders. It proved to be successful. They found that they had to use a rudder which operated with the wing warping control to counteract the increased wing resistance of the warped wing. With gliders of this type they experimented for three years at Kitty Hawk, N. C. After becoming proficient in the manipulation of the apparatus they installed a motor and on Dec. 19, 1903, made the first flight with a heavier than air machine propelled by a motor. Their success was due to their solution of the problem of stability.

Nieuport recognized that in order to obtain speed the resistance had to be reduced. He then brought out a machine with no open structure of the airplane exposed to the resisting action of the air. This type of structure gave to the airplane a distinct body. The fuselage is associated with Nieuport.

2. NOMENCLATURE

A. WINGS

1. External

Right and left
Wing panel
Leading edge
Trailing edge
End edge
Fabric
Dope
Mast
Mast wire
Wing skid
Aileron
Aileron control horn
Aileron control wire
Aileron balance wire
Interplane strut
Flying wire
Landing wire
Diagonal wire

Follow-thru wire
Drift wire
Wing fitting
Strut socket
Sidewalk
Wing hinge
Wing hinge pin

2. **Internal**

Wing hinge
Wing beam (spar)
Compression rib
Compression strut
Filler rib
Filler web
Cap strip
Drift wire
Anti-drift wire
Internal fitting
Turnbuckle
Terminal
Stringer
Nose veneer
Leading edge
Trailing edge
End edge
Box rib

B. FUSELAGE OR BODY

1. **External**

Cowl
Cockpit
Windshield
Covering
Turtleback
Tail skid

2. **Internal**

Longeron
Strut
Ferrule
Fire screen
Fitting (clip)
Stay wire
Engine bearer
Floor board
Nose plate
Foot bar
Control frame
Seat rail
Tail post

C. UNDERCARRIAGE, CHASSIS, OR LANDING GEAR

Wheel
Tire
Axle
Strut
Bridge
Cross strut
Fairing
Stay wire
Saddle
Shock absorber cord

D. TAIL, OR EMPENNAGE

Horizontal stabilizer
Vertical stabilizer (fin)
Elevator (flipper)
Rudder
Brace
Control horn
Control wire
Brace wire
Shackle
Tail skid

E. CONTROL SYSTEM

Control wheel
Control bridge
Joy stick
Rudder bar
Stick
Dep.

F. GENERAL TERMS

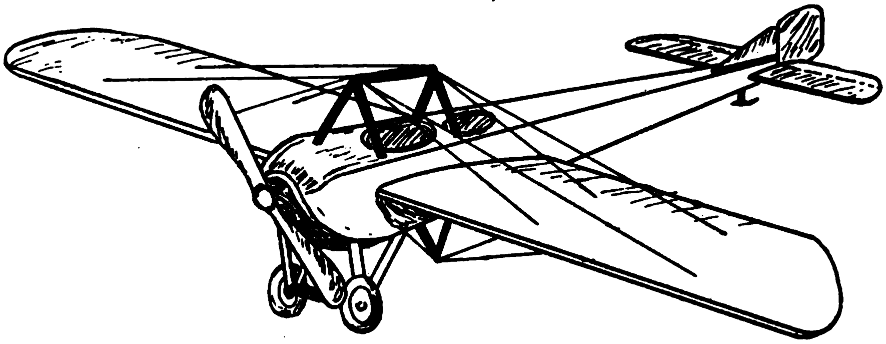
Aerofoil
Angle of incidence
Bank
Cabane
Camber
Center of gravity
Center of pressure
Chord
Crash
Dihedral
Dive
Drift
Droop
Gap
Glide
Lift
Motion
  Lateral
  Longitudinal
  Directional
Nacelle
Overhang
Propeller
Pusher
Side-slip
Skid
Span
Spin
Spiral
Stall
Stagger
Stability
Streamline
Stress
Stunt
Sweep-back
Taxy
Thrust
Torque
Tractor

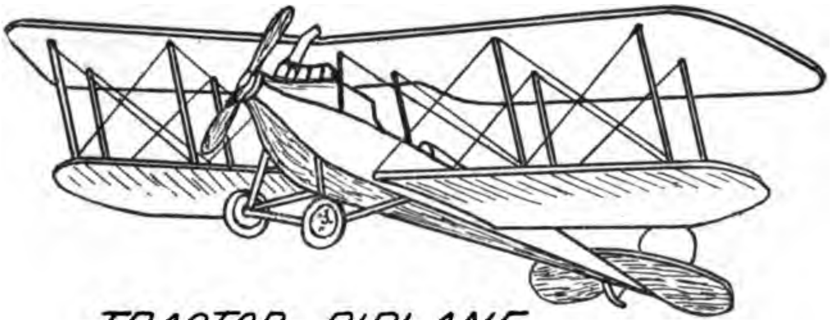
3. ELEMENTS OF AIRPLANE DESIGN

A. INTRODUCTION

The problem of design is that of incorporating into a practical machine the theoretical elements which are shown to be necessary by a study of the Principles of Flight. These elements are:

1. The Wings
2. The Propeller
3. The Engine
4. The Horizontal Stabilizer
5. The Vertical Stabilizer
6. The Control Surfaces and Rigging


TRACTOR MONOPLANE


TRACTOR BIPLANE

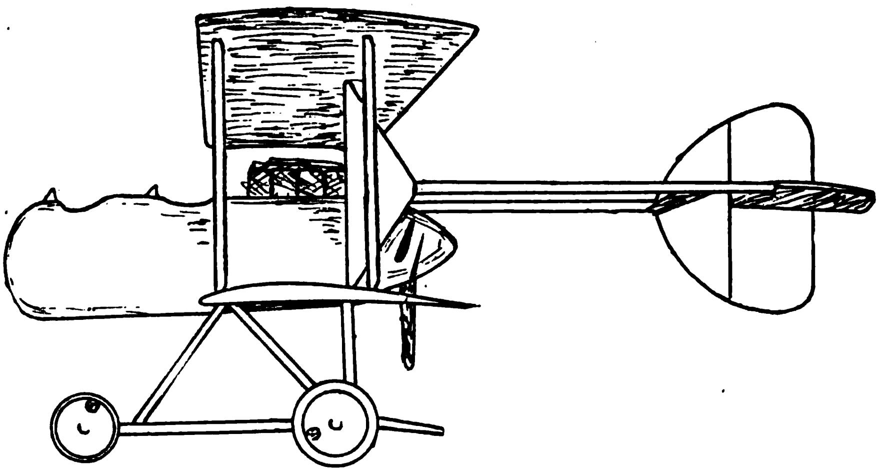

PUSHER BIPLANE

Fig. 104

B. DECISION AS TO THE GENERAL FORM OF THE MACHINE

1. **Three general types** We find that about ninety-five per cent of the machines which are built today may be classified into three general types. These are:

a. The Tractor Monoplane
b. The Tractor Biplane
c. The Pusher Biplane

These three types are illustrated by Fig. 104. We shall consider that the greater part of the problem of decision as to the general form of the machine has already been solved for us in the selection of these three types.

2. **Choosing among these three types** Whether in any particular case we should select a monoplane or a biplane, a tractor or a pusher, would depend largely on the purposes for which the machine was to be used.

C. GENERAL CONCLUSIONS AS TO THE MATERIALS WHICH WILL BE REQUIRED

1. **Necessity for rigidity and strength** Our wings receive the upward force or lift of the air distributed more or less uniformly over their surfaces, whereas the weights or loads which this lift supports are concentrated at points within the body. This means that the wing structure must possess the strength and stiffness necessary to transmit the lift to the points where the wings are attached to the body. Similar reasoning would show the necessity for strength and stiffness in the body itself, in the stabilizers and in the structure connecting them with the wings, in the control surfaces and in the rigging for their operation. In short, our structure must be possessed of a certain amount of rigidity and strength throughout.

2. **Necessity for lightness** A study of the Principles of Flight shows that a set of wings of a certain size, moving through the air at a certain velocity, will produce a certain amount of lift, and no more. We must take the total lift which we expect to obtain from our wings, subtract from it the weights of the useful loads which we expect to carry, and select our materials in such a way that the weight of the structure itself will be kept within the remainder.

3. **Airplane material must be reliable** One way of securing lightness is by cutting down the sizes of our parts until there is left in them only a moderate surplus of strength over that which will actually be demanded. This makes it necessary to select materials of high character. We note *reliability* as the first requisite of airplane material.

4. **Airplane material must possess a high strength-weight ratio** It is obvious that having set down the requirement of reliability, our next demand would be that our materials must be those giving us the greatest amount of strength in proportion to the weights employed. The second requisite of airplane material is a *high strength-weight ratio.*

5. **Occasional necessity for special properties** For certain parts we may require such special properties as compactness, non-corrosiveness, ductility, etc., and we may find it necessary to sacrifice strength or lightness in order to secure these properties.

D. DATA RELATIVE TO THE RECOGNIZED AIRPLANE MATERIALS

We find that almost the entire field of present practice is covered by a comparatively small number of materials which, of course, satisfy the requirements stated under Section C.

For convenience, we may divide materials into the following general classes:

1. Woods
2. Steel
3. Covering Material
4. Metals other than steel
5. Wires and Cables
6. Miscellaneous Materials

1. **Woods** Table I below gives the names and a few of the physical properties of the woods which we may consider for airplane construction.

TABLE I—PHYSICAL PROPERTIES OF WOODS

Wood	Weight lb. per cu. ft.	Mod. of Rupt. lb. per sq. in.	Comp. Strength lb. per sq. in.	Strength-weight Ratio
Spruce	27	7,900	4,300	159
White Pine	27	7,400	4,500	167
Port Oxford Cedar	31	10,300	5,300	171
Ash	40	12,700	6,000	150
Rock Elm	44	12,500	5,800	132
Oak	46	12,000	5,900	128
Hickory	50	16,300	7,300	146

2. **Steel** For this material it will be sufficient to mention two broad classifications—

a. Mild Steels
b. Alloy Steels.

a. Mild steels The composition of the mild steels used for airplane parts will run about the same as that of ordinary structural steel. The tensile strength is from 60,000 to 70,000 lb. per sq. in., and the weight about 490 lb. per cu. ft. The strength-weight ratio figures out about 135.

b. Alloy steels By an alloy steel we mean one containing one or more "special" elements such as nickel, chromium, and vanadium. These elements act to make the material harder, stronger, and tougher than the "mild" variety. The tensile strength of most alloy steels will run about 100,000 lb. per sq. in. while the density is practically the same as that of mild steel. The strength-weight ratio is accordingly higher—about 204.

3. **Metals other than steel** The use of metals other than steel is practically limited to those which appear in Table II following:

TABLE II—PHYSICAL PROPERTIES OF METALS OTHER THAN STEEL

Metal	Weight lb. per cu. ft.	Tensile Strength lb. per sq. in.	Strength-weight Ratio
Aluminum Alloy	160	18,000	112
Brass	523	40,000	76
Bronze	552	67,000	123

4. **Wires and cables** These are made from steel, but are worthy of consideration as a separate materials group. This group is divided into three principal classifications (see Fig. 105) as follows:

a. Aircraft wire A solid steel wire closely resembling piano wire.

TABLE III—PHYSICAL PROPERTIES OF AIRCRAFT WIRE

Gauge No. (Brown and Sharpe)	Decimal Diameter	Tensile Strength	Weight lb. per 100 feet
14	.064"	830	1.10
12	.081"	1,300	1.74
10	.102"	2,000	2.77
8	.128"	3,000	4.40

b. Aircraft strand The result of twisting a number of wires tightly together.

TABLE IV—PHYSICAL PROPERTIES OF 19 WIRE AIRCRAFT STRAND

Diameter in inches	Tensile Strength	Weight per lb. per 100 feet
1/8	2,100	3.50
5/32	3,200	5.50
3/16	4,600	7.70
7/32	6,100	10.00
1/4	8,000	13.50
5/16	12,500	20.65

c. Aircraft cord The result of twisting several strands together, known as "7x19", "7x7", or "6x7 Cotton Center", depending on the construction.

TABLE V—PHYSICAL PROPERTIES OF AIRCRAFT CORD

Diameter in inches	7x19		7x7		6x7 Cotton Center	
	Tensile Strength	Weight lb. per 100 ft.	Tensile Strength	Weight lb. per 100 ft.	Tensile Strength	Weight lb. per 100 ft.
1/8	2,000	2.88	1,350	2.45	1,150	2.20
5/32	2,800	4.44	2,600	4.67	2,200	4.20
3/16	4,200	6.47	3,200	5.80	2,750	5.30
7/32	5,600	9.50	4,600	8.30	4,000	7.43
1/4	7,000	12.00	5,800	10.50	5,000	9.50

5. Covering material

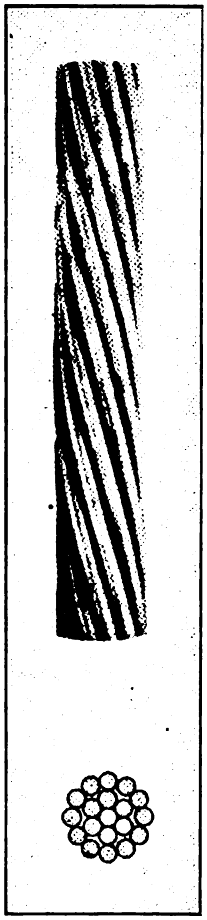
a. Fabric The standard is unbleached linen weighing about four ounces per square yard and having a strength of from 60 to 70 pounds per inch of width. There is high probability that linen will be replaced soon by some cotton substitute, due to scarcity of the former material.

b. Coating The material used is commonly called *dope*. Dope is a cellulose solution of some sort. It adds strength and makes the linen taut, air tight, and water proof. The usual application is about four coats of dope followed by two coats of spar varnish.

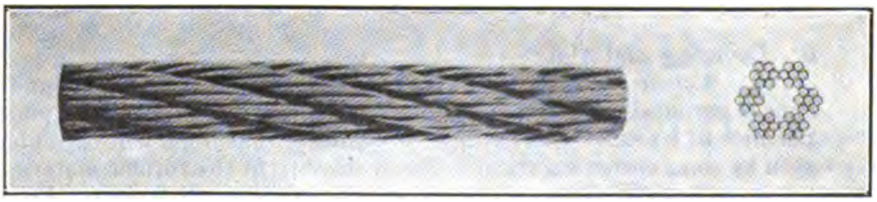
6. Miscellaneous materials Under this heading it will be sufficient simply to mention such items as rubber, used in various shock absorbing devices, leather, used for straps, etc., upholstering materials used about the seats and cockpits, and sheet copper, used for bindings or *ferrules* for the ends of struts. We shall mention also the use of various coating materials

7x19

7x7



19 Wire Strand



6x7 Cotton Center

Fig. 105

other than dope; chief among these are varnishes for the wooden parts, copper plating, nickel plating, and various paints and enamels for the metal parts.

E. FITNESS OF CERTAIN MATERIALS FOR CERTAIN CLASSES OF PARTS

1. Woods Woods are fitted to take *compression,* or stress tending to shorten or telescope a part along its own axis. The compressive strength of a material in lb. per sq. in. is the amount of load required to crush a block of the material, for each square inch of cross section which we have resisting the load. The compressive strengths of our various woods are shown in the tables. The compressive strengths of the metals are not given but they are, roughly speaking, the same as the tensile strengths. We see that weight for weight our woods give us greater compressive strength than any other of our materials except alloy steels. A part which is subjected to compressive stress is usually called a strut. Now a peculiar thing about a strut is that if it is very long in proportion to its sectional dimensions, it will buckle sideways and either break under a relatively low load or else allow its ends to move far enough toward each other to make it worthless in our structure. Wood struts can be made large enough at the center to prevent the side buckling without unreasonable addition of weight, but this would not be true of steel struts, unless they were made tubular in shape, which is a possibility.

Woods are also fitted to take *bending* stresses. A part which is subjected to bending has compressive stresses in its concave half and tensile stresses in its convex half. These stresses are greatest at the outer faces of the part and less toward the center. We would expect all of this from the effect of the load on the lengths of the fibers, as illustrated by Fig. 106.

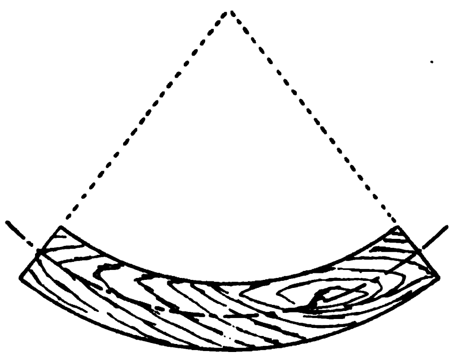


Fig. 106

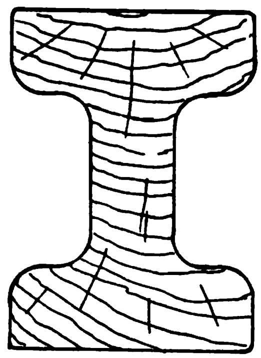


Fig. 107

On account of the particular distribution of stresses in a part subjected to bending, the center can be cut away, decreasing the weight in greater proportion than the strength. The result of such cutting away is a section of which Fig. 107 is typical.

Wood parts are easily shaped to such sections as these. In making bending tests of wooden parts in materials testing laboratories there is recorded a sort of theoretical compressive or tensile strength, which is called the *Modulus* of *Rupture,* and is expressed in lb. per sq. in. The modulus of rupture is significant to us in that it is a measure of the ability of a material to withstand bending loads.

The question of which woods are suitable for struts and parts subjected to bending would naturally be determined from an examination of the table. We notice that the first three woods, the soft woods, are stronger, weight for weight, than the last four, the hard woods. The data given favor the cedar, but there are other reasons why spruce is preferred above all others. Spruce can be obtained in straight-grained pieces of great length and is not only strong but very stiff. It may be said that spruce is perhaps the most important single airplane material. The heavy demand for spruce makes it possible, however, that Port Oxford Cedar, White Pine, and even Douglas Fir may soon come into fairly general use as substitutes.

Sometimes it seems advisable to use hard wood parts in order to secure great strength or toughness without making the parts unduly bulky. This is a case of sacrificing strength-weight ratio in order to secure compactness. Our table shows that ash would be the logical selection here. Practice bears this out; ash is by far the most important hard wood, although it is possible that it will be replaced to some extent by Rock Elm, on account of scarcity. Hickory is occasionally used where very great strength or toughness is desired.

2. Steels

a. Mild steels Steels have the property of being uniformly strong against compressive stress and tensile stress. The latter is that type of stress which tends to elongate a part or pull it in two along its own axis, the tensile strength of a material in lb. per sq. in. being the amount of load required to pull a bar of the material in two, for each square inch of cross section which we have resisting the pull. Because of the uniformity mentioned, steels are particularly fitted for the manufacture of *fittings* for rigidly connecting various parts. Such fittings are often subjected to different types of stresses in different regions or at different times. To secure lightness, steel in the *sheet form* is often employed, different parts being stamped out, bent to shape, and then brazed or welded together. While alloy steels possess the higher strength-weight ratios, they are so hard that they cannot be bent in the way described; so we resort to the use of mild sheet steel which is sufficiently ductile.

b. Alloy steels Alloy steels are mostly used in the *bar form*, from which they can be reduced to such parts as bolts, hinge pins, and turnbuckle ends by machining operations which are not prevented by the hardness of the material. They find some use also in the shape of *forged fittings*; as a rule, however, stamped fittings of mild sheet steel will give us the necessary strength at the expense of less weight.

Parts made from alloy steels are frequently *heat treated* after machining, to give them still greater strength and toughness.

3. Metals other than steel Aluminum is used wherever some light weight part that will keep its shape but will not have to withstand any great amount of stress is wanted.

Brass and bronze are used principally for turnbuckle barrels because of the excellent wear of the threads which is obtained. It will be remembered that the ends which screw into the barrels are alloy steel. Occasionally brass or bronze is used for the manufacture of such parts as bolts and hinge pins for seaplanes and flying boats. Whenever this is done it is a case of sacrificing strength-weight ratio to secure non-corrosiveness.

4. Wires and cables The great superiority of this material is, of course, for all parts which are subjected to pure tension.

a. Aviator wire For its size, the solid wire is the strongest material of this class. It is used therefore, except where we require more flexibility than it possesses. We can not use it in large sizes because it becomes impossible to form the necessary end loops.

b. Aviator strand Where tension members must be handled frequently, or coiled up, as with the wires of the wing trusses, we use the strand, which is next in strength to the solid wire, and more flexible.

c. Aviator cord Where we require even more flexibility than strand can give us, we resort to the use of cord. This material is the least strong and the most flexible of all. It is particularly useful for control wires.

F. NECESSITY FOR STREAMLINE FORM OF PARTS

We are now almost ready to begin the actual decision as to methods of building up the different elements of our machine and selection of materials for the various parts decided upon. Before doing this it will be well for us to consider one item which has not been mentioned as yet. Every external part of our machine is going to offer *head-resistance,* that is, it will require a certain amount of force to move each part through the air at the velocity of our machine. Now since every bit of this force must be counter-balanced by propeller thrust in addition to that necessary to overcome the drift on the wings, and since every bit of additional propeller thrust means additional engine power, it behooves us to keep down the head-resistances of our external parts as far as possible.

It is known that the resistance which a body meets in passing through the air is largely due to the eddy currents of air which are set up around the body. The left hand body of Fig. 108 is surrounded by such currents.

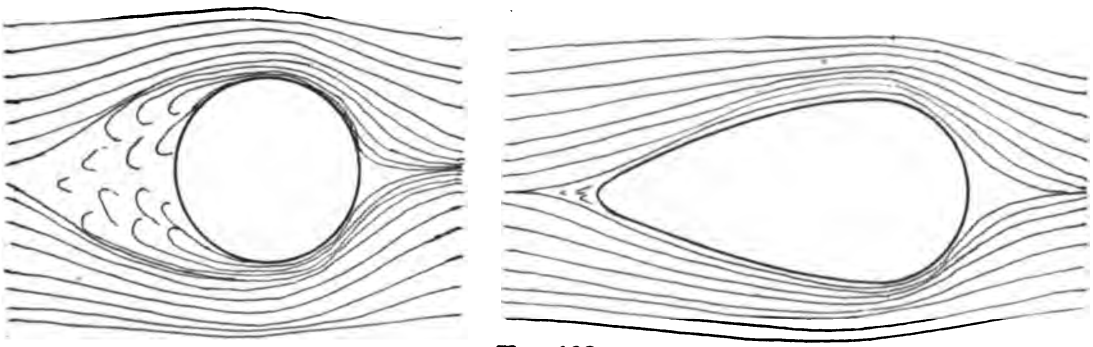


FIG. 108

The body on the right is of such shape, however, as to be practically free from eddy currents. A body of this shape is known as a *streamline* body, and area for area its resistance in passing through the air is the practical minimum. We must make the attempt to design the external parts of our machine, both large and small, in such a way that their sections approach streamline forms to as great an extent as is practical.

G. DESIGN OF SMALL PARTS CAPABLE OF GENERAL APPLICATION

In taking up the actual design of our machine we shall find it convenient first to settle upon the forms of certain items which we shall be able to apply generally over our entire machine. These items may be grouped under several different heads, as follows:

1. **Wire and cable tension members** These will of course be made up in units of definite lengths. Each unit, including whatever fastening devices are permanently assembled with it, is called a stay.

a. End connections In making up stays from wire, strand, and cord, different end connections are used for each. The methods of construction of some of these are clearly shown by Fig. 109.

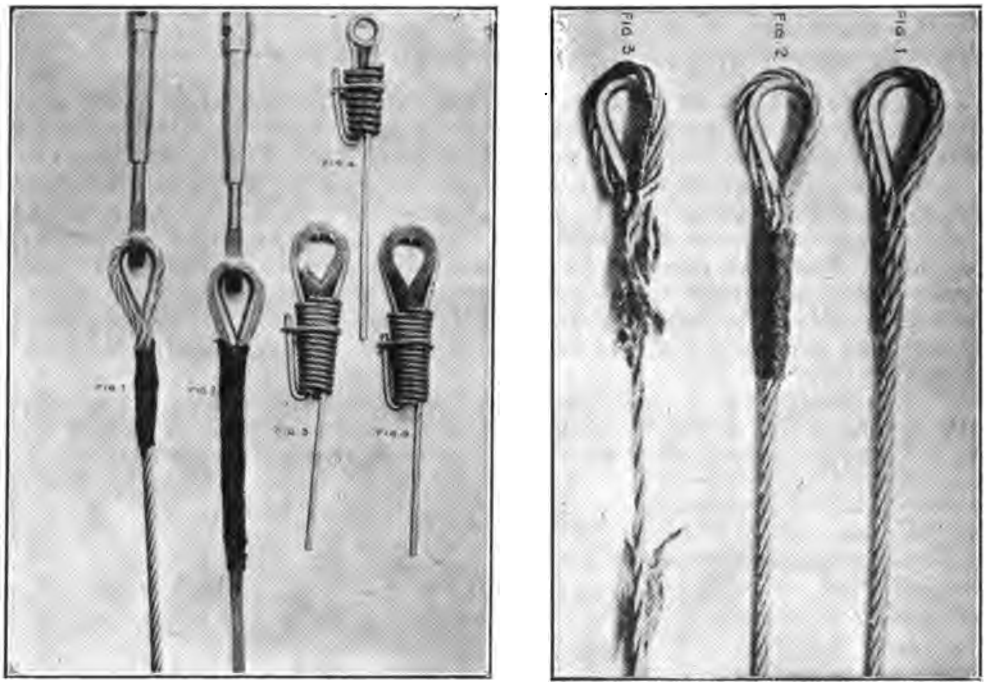


Fig. 109

The *ferrules* used in forming end connections of Aviator Wire stays are themselves made of Aviator Wire. The detail form is shown clearly by Fig. 110.

The *thimbles* used in forming end connections of Aviator Strand and Aviator Cord stays are stamped from galvanized steel. A typical thimble is shown in Fig. 111.

b. Turnbuckles One end of a stay always includes a *turnbuckle,* which is capable of adjusting the length by means of right and left threads. It is important in connecting a turnbuckle that both ends be started into the barrel at the same time; otherwise the full adjustment cannot be realized. It is also important that the ends be screwed into the barrel far enough that all threads are completely covered when the full load is applied. When a turnbuckle is finally adjusted after setting up the machine, it is wired for the purpose of preventing its loosening up. The wire so used is called a *safety-wire.* Fig. 112 shows a turnbuckle with the safety-wire properly applied. The barrel

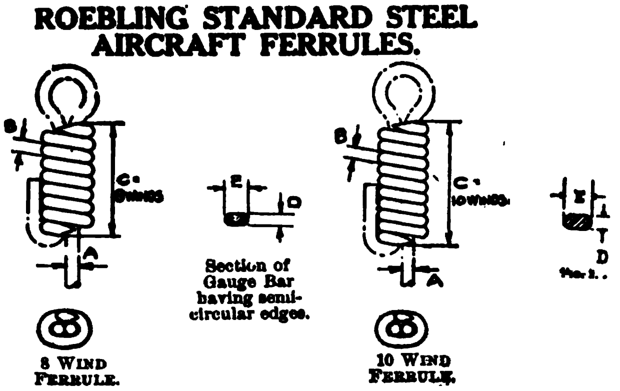


FIG. 110

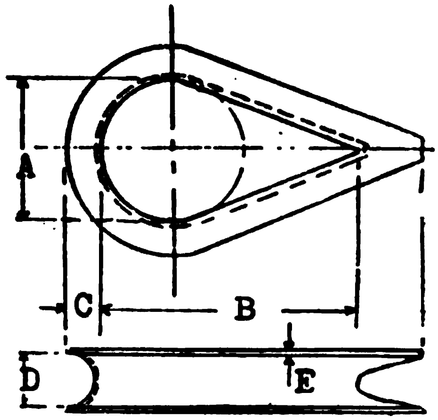


FIG. 111

of the turnbuckle is made of brass or bronze, while the ends are made of alloy steel. The standard material for the safety-wire is copper.

c. *Shackles* At the opposite end of a stay from the turnbuckle, the eye is usually formed about a small steel forging called the *shackle.* Fig. 113 shows examples of the use of shackles.

2. **Hinge and clevis pins, bolts, nuts, cotter pins** For fasteners a great many hinge pins, clevis pins, hex head bolts, and eyebolts of practically standard designs are of course used, these parts being practically always made from alloy steel, heat treated.

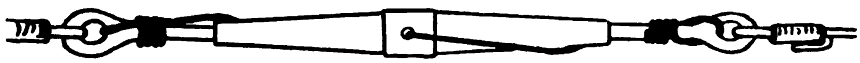


FIG. 112

Nuts are usually slotted for cotter pins, or *castellated,* as we say. The material for nuts is occasionally a mild bar steel, being case-hardened after the machining operations are over although best practice is to make these of $3\frac{1}{2}\%$ nickel steel. The cotter pins are usually the standard commercial article, made from spring steel.

3. **General design of metal fittings** While fittings for different uses have, of course, rather different forms, certain similar features in the designs are noticeable throughout. Some of these similar features will be observed from a study of the fittings shown in Fig. 113.

a. *Stamped fittings* These are usually made from one or more stampings of mild sheet steel, bent to the proper shapes, and brazed or welded together. "Open-work" or lightening holes are characteristic of these parts.

b. *Forged fittings* These are not so common as they are usually heavier. Drop forgings of either mild or alloy steel may be used. The latter are stronger, weight for weight, but more expensive.

c. *Stampings and forgings used together* Occasionally it is found convenient to make up a fitting by welding or brazing one or more forgings to one or more stampings.

4. **Ferruling of struts** It is characteristic of airplane construction that wherever we have a strut fitting into a clip or socket of any sort, the

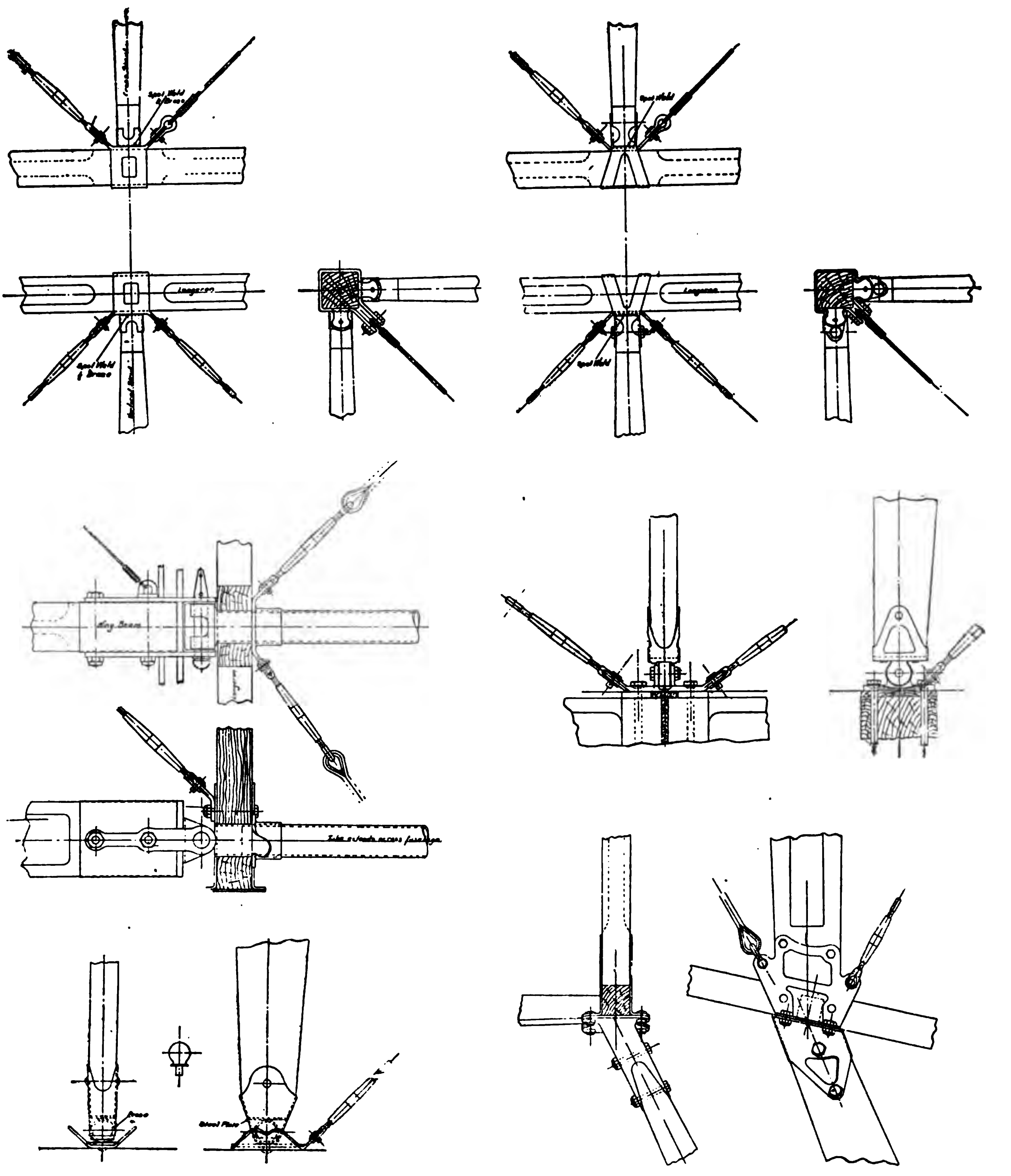


FIG. 113

Costello

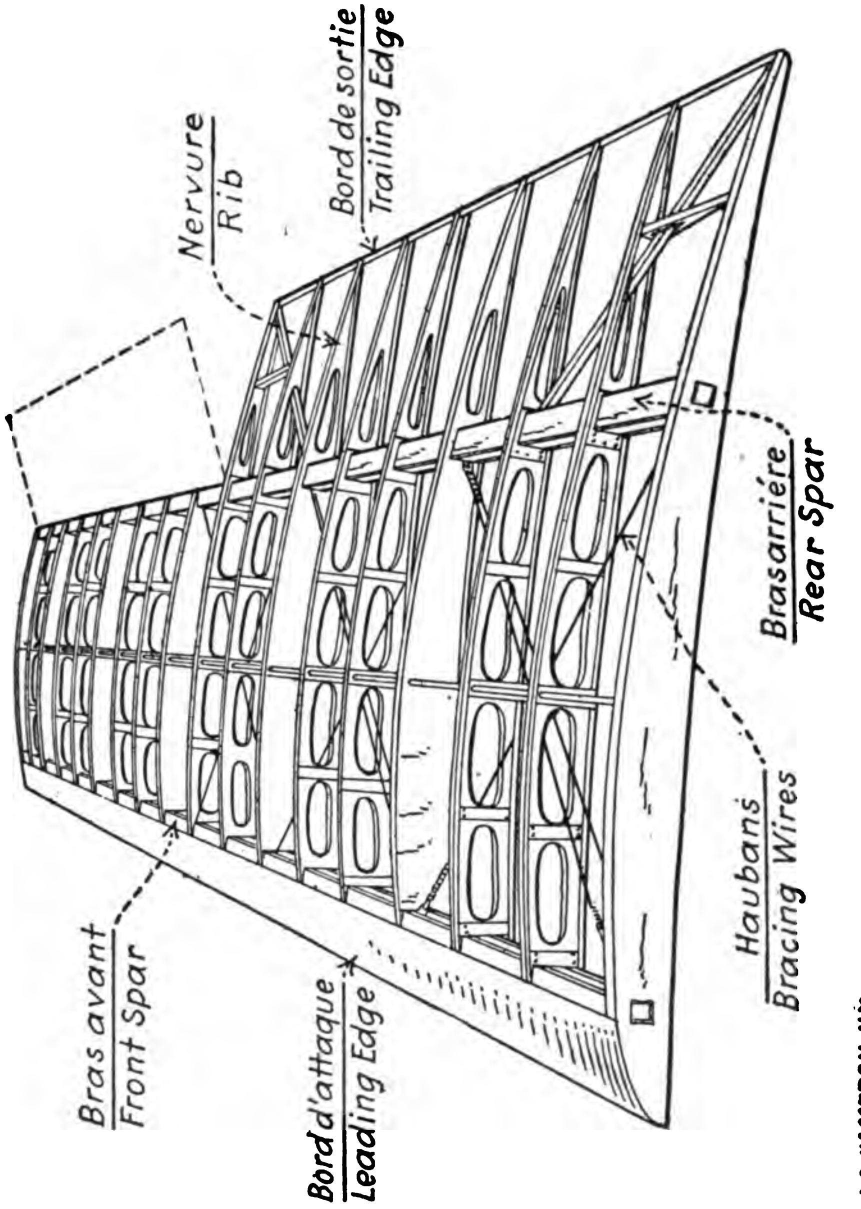


Fig. 114

end of the strut is usually banded with sheet copper. The band is called a ferrule. The purpose of the ferrule is, first, to prevent the end of the strut from splintering, and, second, to distribute the bearing pressure of whatever bolts are used over a somewhat greater area of the wood.

5. Protective coatings

a. Wood parts Wood parts are always coated with shellac or clear varnish only. Paint would conceal imperfections in the wood, and allow them to pass unnoticed.

b. Steel parts Steel parts are practically always given some sort of a "rust-proof" coating. It is the practice of one prominent American manufacturer to copper-plate every steel part. For the sake of appearance, nickel-plating or enamel of some sort is then applied over the copper.

H. ACTUAL DESIGN OF THE VARIOUS ELEMENTS OF THE MACHINE

We are now through with all preliminary considerations and may proceed at once to the work of direct design. This will include the selection of the construction to be employed for each element of the machine, as well as that of the materials to be used for the various parts. We shall, of course, take up one element at a time.

1. **The wings** The usual method of construction is clearly shown by Fig. 114. The exact relationships of the different parts are shown more in detail by Fig. 115. The covering transmits the lift of the air to the ribs, which in turn transmit it to the spars. From the spars it will be transferred to the wing struts and the truss wires at their points of attachment, and it will finally be delivered by the wing trussing system to the body. It will be seen that both the spars and the ribs are subjected to bending loads; they are therefore usually made of wood in approximations to the section shown by Fig. 107. Fig. 115 shows a typical rib design and the methods of rib attachment.

The materials commonly used for the various parts are listed below:

Spars—Spruce, sometimes ash or steel tubing.
Ribs:
  Compression
    Webs: Spruce. Cap strips: Spruce
  Filler
    Webs: White pine. Cap strips: Spruce
Leading Edge—Spruce
Trailing Edge—Steel tubing or steel cord
End Edge—Ash
Drift and Anti-Drift Wires—Aviator Wire
Stringers—Spruce or white pine
Nose Veneer—Two- or three-ply wood veneer
Small Wooden Braces (Miscellaneous)—Spruce, sometimes yellow pine
Metal Fittings—Mild sheet steel.

As indicated above, steel has been used for spars, although the practice is not by any means general. The principal reason for the non-adoption of steel for these parts is that the weight of steel is greater than that of equivalent wood parts.

The use of steel has not been limited to spars, for there have been instances where all-metal wings have proved quite successful, and as the supply of available wood becomes less, we may expect to see more and more steel used.

In Fig. 114 it will be noticed that the tail portion of the wing is discontinued at the outer end. This is for the purpose of inserting a hinged flap called the aileron. The aileron usually has a thick wooden leading edge which serves as its only spar, and ribs, trailing edge, and small parts of the same materials as employed in the wing proper. After the aileron is covered it is equipped with vertical steel struts or levers called horns for attaching the operating cables. These are mounted and connected in the same way as shown for the tail surfaces in Fig. 118. The horns are usually made up by brazing together several mild sheet steel stampings. Aviator Wire is commonly employed for tying the horns to the trailing edges.

2. **The wing truss** The general method of trussing a monoplane may be seen in Fig. 104, and the general truss construction of biplanes is too familiar to need further discussion as regards form.

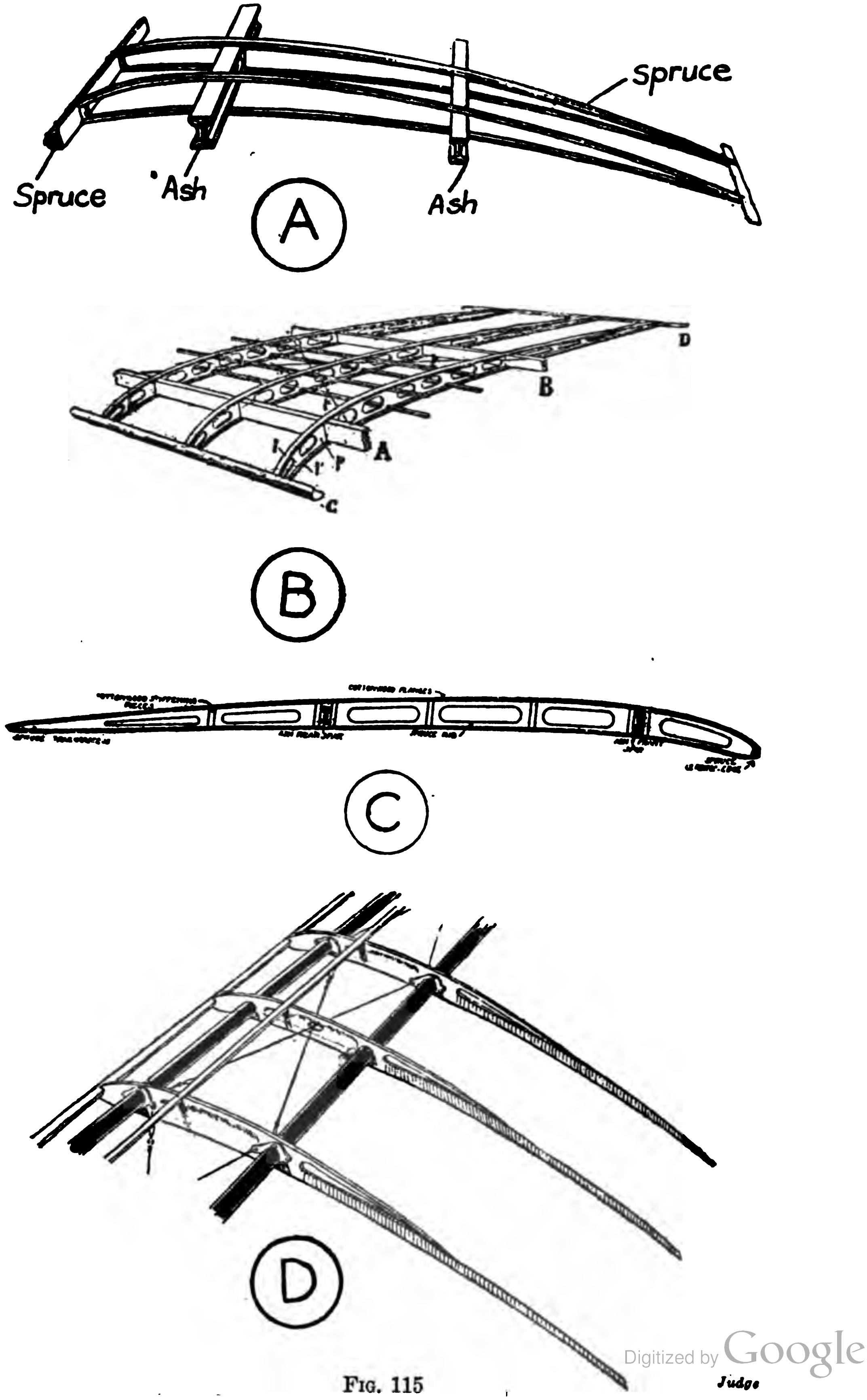


FIG. 115 *Judge*

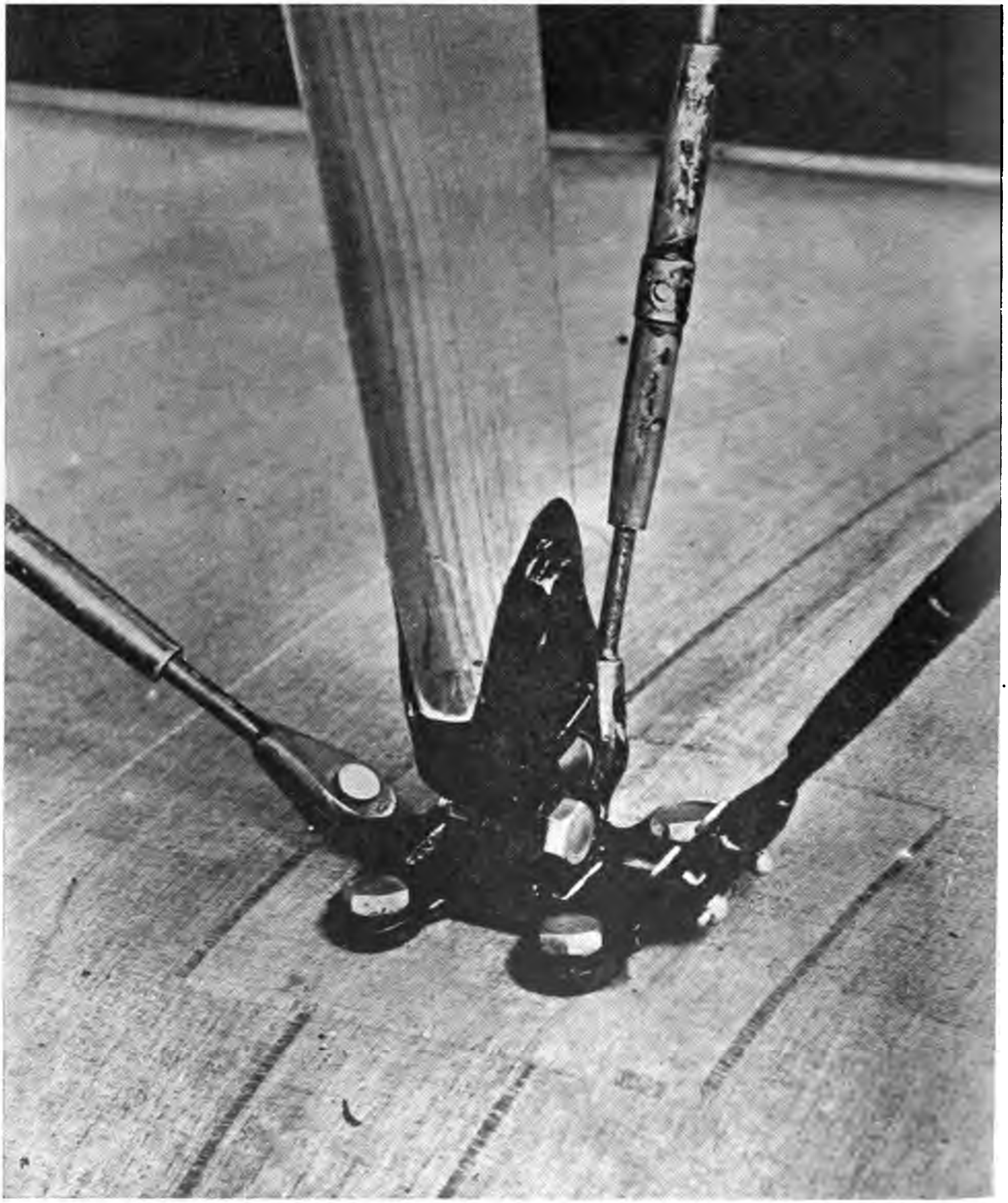


Fig. 116

As to the materials of a wing truss, these are practically determined by general considerations already discussed. The wires must be flexible enough to handle easily and to make coiling possible. Aviator Wire would not permit this; therefore we use Aviator Strand. The various struts are, of course, compression members, and are consequently made of spruce. Spruce is easily worked also, and lends itself to streamline shaping. The use of tubular steel struts can not be said to have progressed further than the experimental stage.

A typical method of fastening the strut to the wing spar is shown by Fig. 116. In this particular case the strut socket is made up by brazing or welding a stamping and a forging together, while the bearing plate is a single forging. Often the bearing plate is made up from several stampings, and includes a socket which takes the end of the strut directly. The bearing plate is practically always fitted with lugs or jaws for taking the turnbuckles of the stays of the truss.

3. **The body** We shall discuss rather in detail the fuselage of the tractor biplane since this will give us a good insight into the general principles involved in the design of all bodies. It will suffice simply to mention certain peculiarities of the monoplane and the pusher bodies.

a. The fuselage of the tractor biplane A good idea of the usual construction may be obtained from Fig. 117. Our fuselage is essentially a long girder which is supported by the wings at their points of attachment and which is loaded at the points where the engine, the occupants, and the tail are located. The heavy stresses in our fuselage are naturally in the front half; the rear half does nothing but support the tail and transmit air forces from it to the main supporting surfaces. Reduced to its elements our fuselage consists of the long members at the corners or the longerons, the vertical and horizontal cross pieces or struts, the sockets for attaching the struts to the longerons, and the bracing wires. The longerons are subjected to high stresses but for convenience in construction it is highly desirable to keep their sectional dimensions down; so we resort to the use of hard wood, usually ash. This is a case of sacrificing strength-weight ratio to secure compactness. Sometimes we splice the longeron about mid-way of its length, using spruce for the rear half. The struts are all held under compression by the system of wiring, and are therefore made of spruce. The strut sockets are ordinarily formed from mild sheet steel. For the brace wiring in the rear half of the fuselage, we usually employ Aviator Wire. In the front half where air stresses are high, however, the wire if employed would have to be of such size that its stiffness would practically prevent the formation of the end loops necessary for fastening it. This forces us to select Aviator Strand or Aviator Cord for this region.

Of course, there are certain modifications of most of these basic parts. The vertical strut at the extreme rear becomes the tail post, which is often subjected to severe shocks, and is usually made of ash. The vertical struts at the points where the wings are attached and where the rear ends of the engine beds rest are necessarily heavy, but they are still struts and usually they are made of spruce. The two horizontal struts at the points of attachment of the lower wings are subjected to extreme tension because of the lift acting on the wings, and for this reason are made of hard wood or often of steel tubing. Where steel tubing is used the wing hinges are commonly forgings which are welded to the tubes. The tension is then transferred from one wing over to the other without being imposed to any degree whatever upon

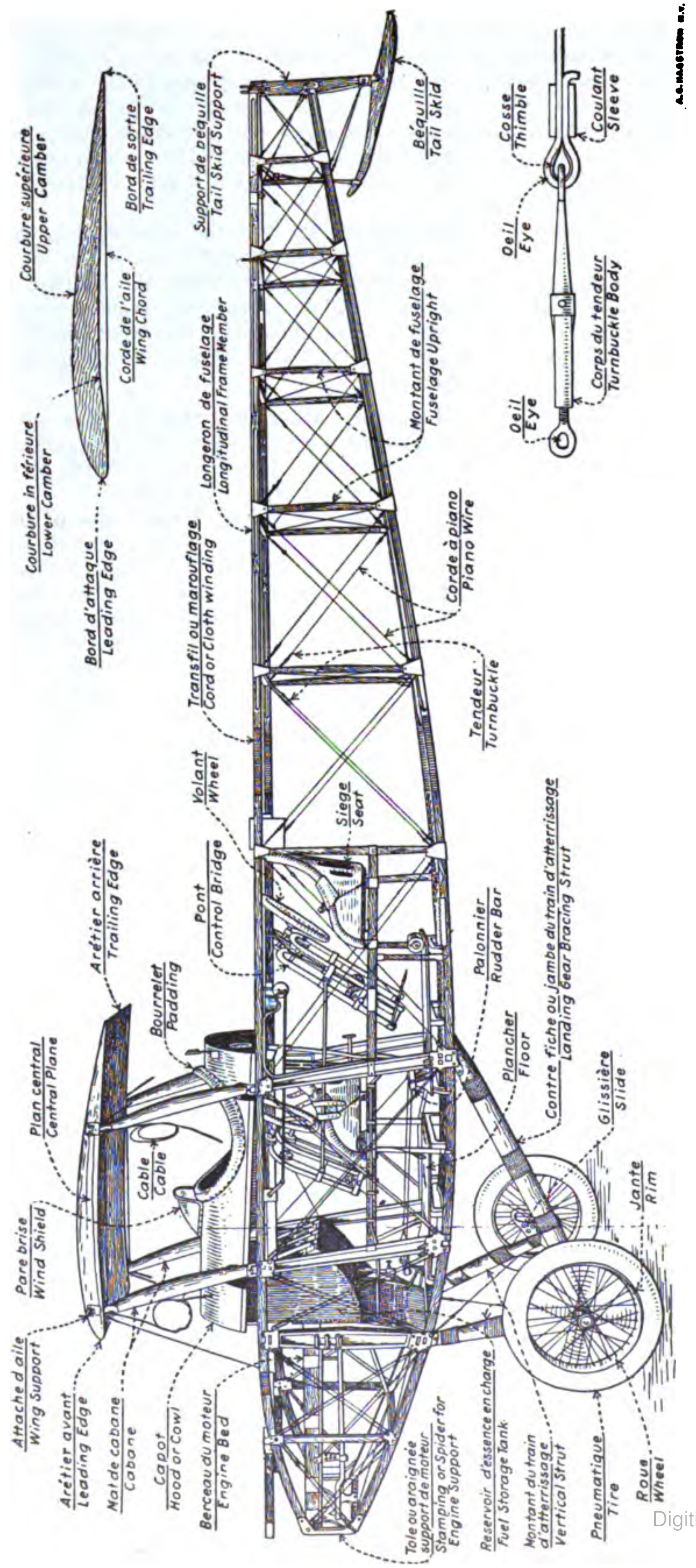

Attache d'aile
Wing Support
Arêtier avant
Leading Edge
Mat de cabane
Cabane
Capot
Hood or Cowl
Berceau du moteur
Engine Bed
Tole ou araignée support de moteur
Stamping or Spider for Engine Support
Reservoir d'essence en charge
Fuel Storage Tank
Montant du train d'atterrissage
Vertical Strut
Pneumatique
Tire
Roue
Wheel
Pare brise
Wind Shield
Cable
Cable
Plan central
Central Plane
Bourrelet
Padding
Arêtier arrière
Trailing Edge
Pont
Control Bridge
Volant
Wheel
Siege
Seat
Palonnier
Rudder Bar
Plancher
Floor
Contre fiche ou jambe du train d'atterrissage
Landing Gear Bracing Strut
Glissière
Slide
Jante
Rim
Bord d'attaque
Leading Edge
Courbure in férieure
Lower Camber
Corde de l'aile
Wing Chord
Courbure supérieure
Upper Camber
Bord de sortie
Trailing Edge
Transfil ou marouflage
Cord or Cloth winding
Longeron de fuselage
Longitudinal Frame Member
Support de béquille
Tail Skid Support
Tendeur
Turnbuckle
Corde à piano
Piano Wire
Montant de fuselage
Fuselage Upright
Béquille
Tail Skid
Oeil
Eye
Corps du tendeur
Turnbuckle Body
Oeil
Eye
Cosse
Thimble
Coulant
Sleeve
Pagé-Montariol

FIG. 117

the fuselage structure. At the very nose of the body both horizontal and vertical struts are discarded, their place being taken by the nose plate, which is ordinarily a single stamping of mild sheet steel.

Mounted in the fuselage we have certain accessories. Among these are the seats with their mountings, the floor boards, the control operating devices, the instrument boards, the fuel tanks, the sheet aluminum fire-screen between the fuel tanks and the engine, and the engine beds. The latter must be very strong and in order to keep down their size they are frequently made of ash. They are parts subjected to bending and are therefore often hollowed out to the I-beam section of Fig. 107. The Curtiss Company makes the beam rectangular in section, but laminates it, using layers of ash at the top and bottom, and layers of spruce in the center.

The rear half of the fuselage is usually enclosed in a permanent linen covering, except at the top, where we ordinarily find the fuselage cover, a light detachable wooden structure for streamlining out the arched upper portion of the body. The fuselage cover is in turn "roofed over" with linen. For housing over the cockpits and all round the engine, we use light sheet metal parts called the cowls; these are practically always stamped from sheet aluminum.

There are two variations from the conventional design which are worthy of mention. The fuselage is sometimes made a continuous circular shell, say of five-ply wood-and-canvas veneer, this shell being braced at intervals of its length by steel "bulkheads". The other variation is the use of steel tubing for practically the entire structure. This has not become common because it usually means increased weight, decreased flexibility, and high manufacturing cost.

b. The fuselage of the tractor monoplane The construction of this body is practically identical with that of the biplane, and a general consideration of the details involved will show that the location of the wing hinges would be the only item causing material changes in the design.

c. The pusher biplane Here the fuselage degenerates into the nacelle, as is shown by Fig. 104. The construction of the nacelle is practically the same as that of the fuselage, save that lighter parts and sometimes weaker materials are employed.

The structural functions of the tractor fuselage are in the pusher assumed by the system of outriggers connecting the wings with the tail. The outriggers are usually tied together by means of horizontal and vertical struts, and braced by means of diagonal wiring. The outriggers and struts are made sometimes of wood, sometimes of steel, and sometimes of bamboo. The wiring is usually of Aviator Strand.

4. The landing gear This part of the machine is of course necessary for support when standing on the ground and for partially absorbing the shock of landing. It must resist not only the upward shock of landing but also the horizontal force tending to sweep the machine backward when running on the ground. The simplest design for withstanding such forces seems to be a combination of a continuous axle carrying two wheels, a pair of V-struts running from the lower side of the body down to the axle, and an elastic connection between the axle and the system of struts. To make the system of struts rigid it is necessary to add cross struts or braces connecting the apexes of the two "V's", and diagonal bracing wires. The general scheme is illustrated in Fig. 117. The struts of course are attached to the fuselage at their upper ends by steel sockets, and the two members going to make up one "V" are tied together at their lower ends by means of a complicated steel piece which we may call the bridge. The axle must be connected to the strut system in such a way that it can move upward freely, but not backward. This is usually accomplished by running the axle through a long vertical slot in the bridge, and then tying it down against the bottom of this slot with several turns of a heavy rubber cord. At the point where the cord passes over the axle it is usually confined within a "floating" metal saddle of some sort. The axle is sometimes restrained from moving backward by means of a system of steel levers or "radius-rods" instead of by a slot.

The materials commonly employed for the various parts are as follows:

Strut Sockets—Mild sheet steel.
Struts—Spruce, ash, or steel tubing with wood "fairing".
Bridge—Mild sheet steel.
Cross Struts—Spruce, or steel tubing with wood "fairing".
Brace Wiring—Aviator Strand.
Axle—Mild or alloy steel tubing.
Shock Absorber Cord—Made up of many fine strands of rubber bundled together and enclosed within a fabric cover.
Wheels—Much like automobile wire wheels except that the bearings are plain, no balls or rollers.
    Hubs—Formed from steel. Bronze bushings.
    Spokes and Nipples—Steel.
    Rims—Steel.
Tires—Usually of "stubby" proportions, e.g., 26"x4".
    Casings—Plain clincher cord casings. Very light treads.
    Tubes—Same material as automobile tubes.

Types of landing gears other than that above described are frequently used, particularly with the heavier machines, where we may find pneumatic or glycerine shock absorbers, and often a complicated multiple-wheel structure.

5. The tail. The standard arrangement is that illustrated by Fig. 118. The horizontal stabilizer is mounted directly on top of the rear end of the fuselage, and the vertical stabilizer on top of that. The horizontal stabilizer is braced to the bottom of the fuselage with stays of Aviator Strand or with braces which are frequently of steel tubing with wood "fairing". The peak of the vertical stabilizer is usually braced by stays of Aviator Strand.

The construction of the tail units themselves follows very closely the general idea of the wings and the ailerons. One rather distinctive feature, however, is the absence of any interior wiring, diagonal wooden webs being commonly employed to give whatever bracing of this nature is required. Another feature is the frequent employment of steel tubing for both leading and trailing edges.

The tail skid is obviously for the purpose of keeping the rest of the tail off of the ground. It is usually made of ash or hickory, protected on the lower side by a steel shoe. The skid is sometimes mounted as shown in Fig. 117. In this case the metal fittings would be formed from mild sheet steel. More recently, however, the tail skid has been pivoted to the fuselage forward of the tail post, to reduce breakage caused by heavy landings. The forward end of the tail skid is usually connected with some sort of a shock absorbing device located within the fuselage. The elasticity is practically always obtained from rubber cord identical with that used in the landing gear.

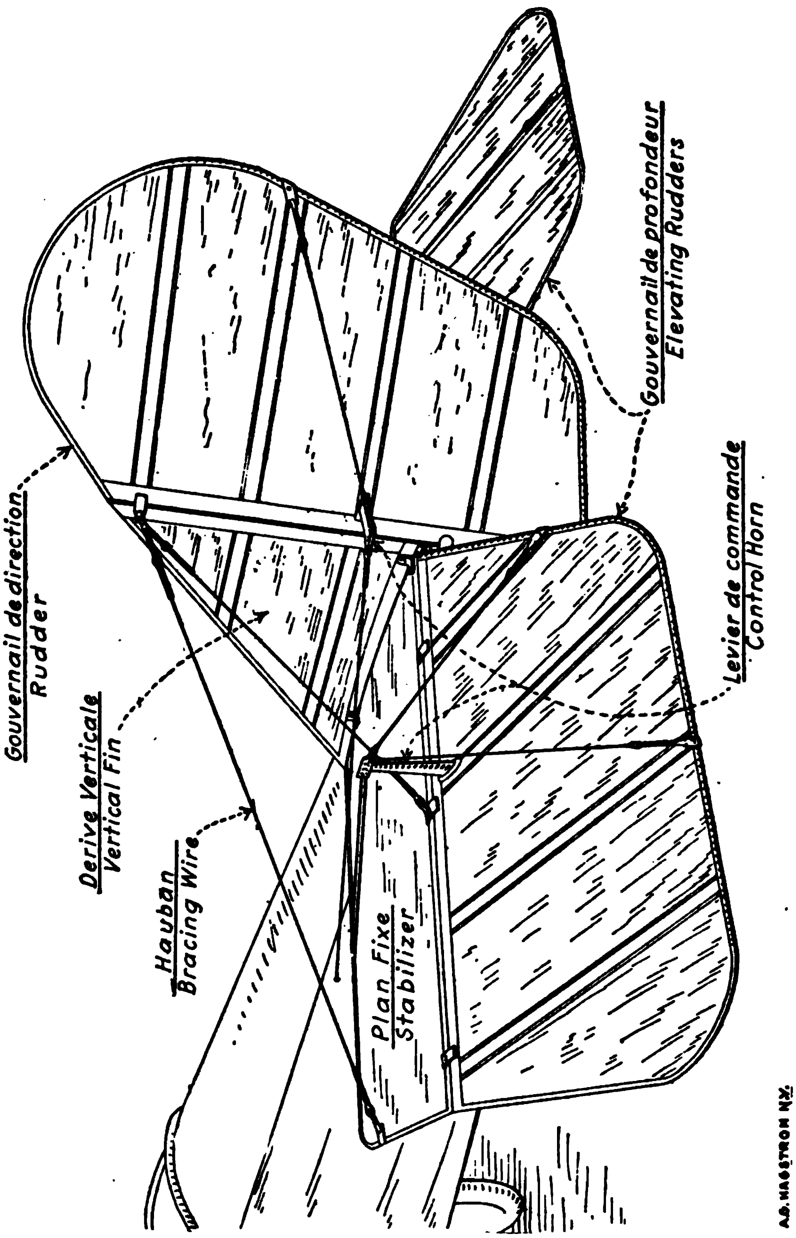


FIG. 118

4. ASSEMBLY

A. UNDERCARRIAGE

1. Bolt wheels to axle.
2. Attach tail skid.
3. Lift fuselage onto horses or raise it by hoist high enough to let landing gear run under it.
4. Bolt landing gear struts to fuselage, and attach cross-bracing wires.
5. Align.
6. Safety turnbuckles and nuts.

B. CENTER SECTION

1. Insert struts in sockets on center section.
2. Pick up assembled center section and struts and bolt struts into sockets on the longerons.
3. Fasten wires.
4. Align.
5. Safety.

C. TAIL

1. Attach horns to control surfaces.
2. Attach horizontal stabilizer and its braces or cables.
3. Attach vertical stabilizer and its braces or cables.
4. Align both stabilizers.
5. Safety turnbuckles and nuts.
6. Attach rudder and its control cables.
7. Attach elevators and their control cables.
8. Cotter nuts and hinge pins.
9. Align rudder and elevators.

D. WING

1. Unpack upper and lower panels.
2. Attach horns and brace wires to ailerons.
3. Set upper and lower panels on leading edges about a strut's length apart.
4. Attach intermediate pair of struts and their diagonal wires. (Makes wing self-supporting.)
5. Attach other struts and diagonal wires.
6. Attach flying and landing wires.
7. Attach wing skid, masts, and ailerons.
8. Hang assembled wing to body.
9. Align.
10. Safety.

5. ALIGNMENT*

A. FUSELAGE

1. Set bare fuselage on horses placed well forward.
2. Level up top longerons lengthwise and crosswise in fourth bay by adjusting horses and side bracing wires.
3. Repeat for each of the other bays back to the tail thus getting top longerons in same plane all along.
4. Stretch string from center of nose plate over top of fuselage and adjust cross bracing wires between top longerons until centers of top horizontal struts line up.
5. Adjust transverse and bottom bracing wires at each set of struts until a plumb-line dropped from top longeron just touches the lower longeron, being careful to keep top longerons level crosswise.
6. Set engine beds equidistant from each other and from sides of fuselage at both ends.
7. Adjust wires in front two or three bays until fuselage is square at each station and engine beds are level lengthwise and crosswise.
8. Check every bay and the stern post.

*See figures 119 and 120.

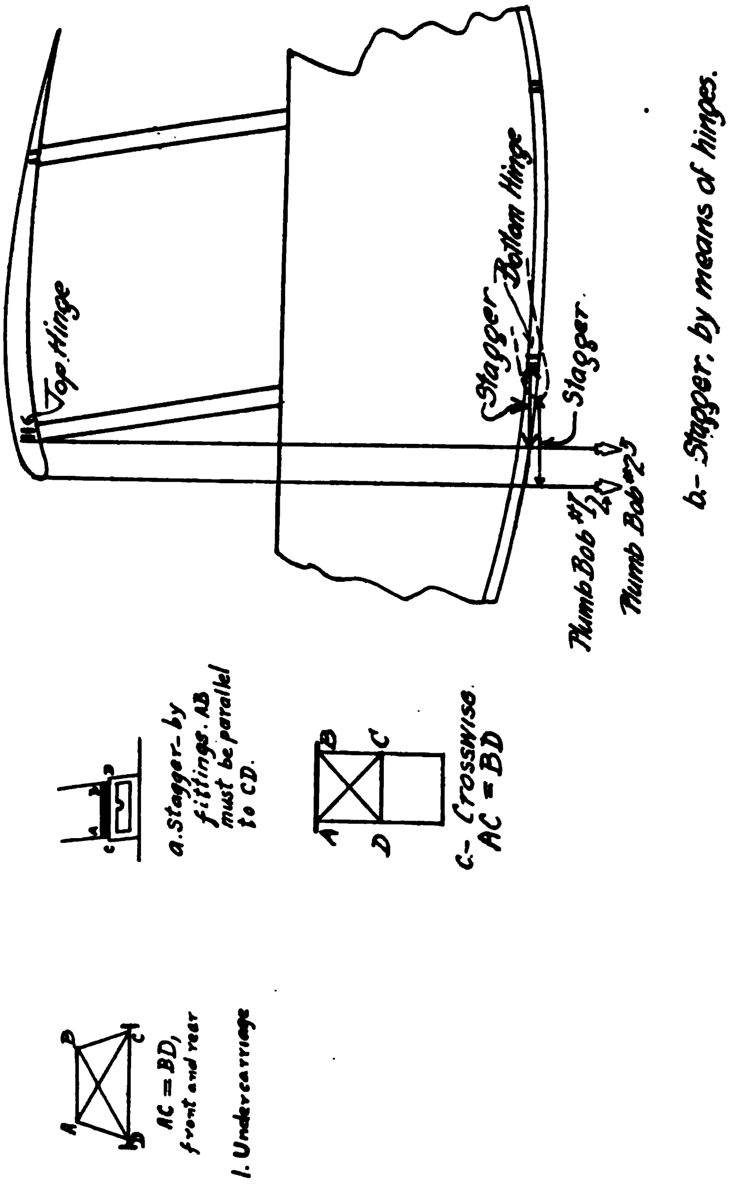


FIG. 119

B. UNDERCARRIAGE

1. Make front crossbracing wires on undercarriage same length.
2. Make lengths from rear wing hinge to axle the same on both sides of fuselage.
3. Safety turnbuckles.

C. CENTER SECTION

1. Tighten and equalize follow-thru wires.
2. Set fuselage in flying position.
3. Set stagger by dropping plumb-line from leading edge or hinge face and measuring back to lower front hinge, on both sides of fuselage.

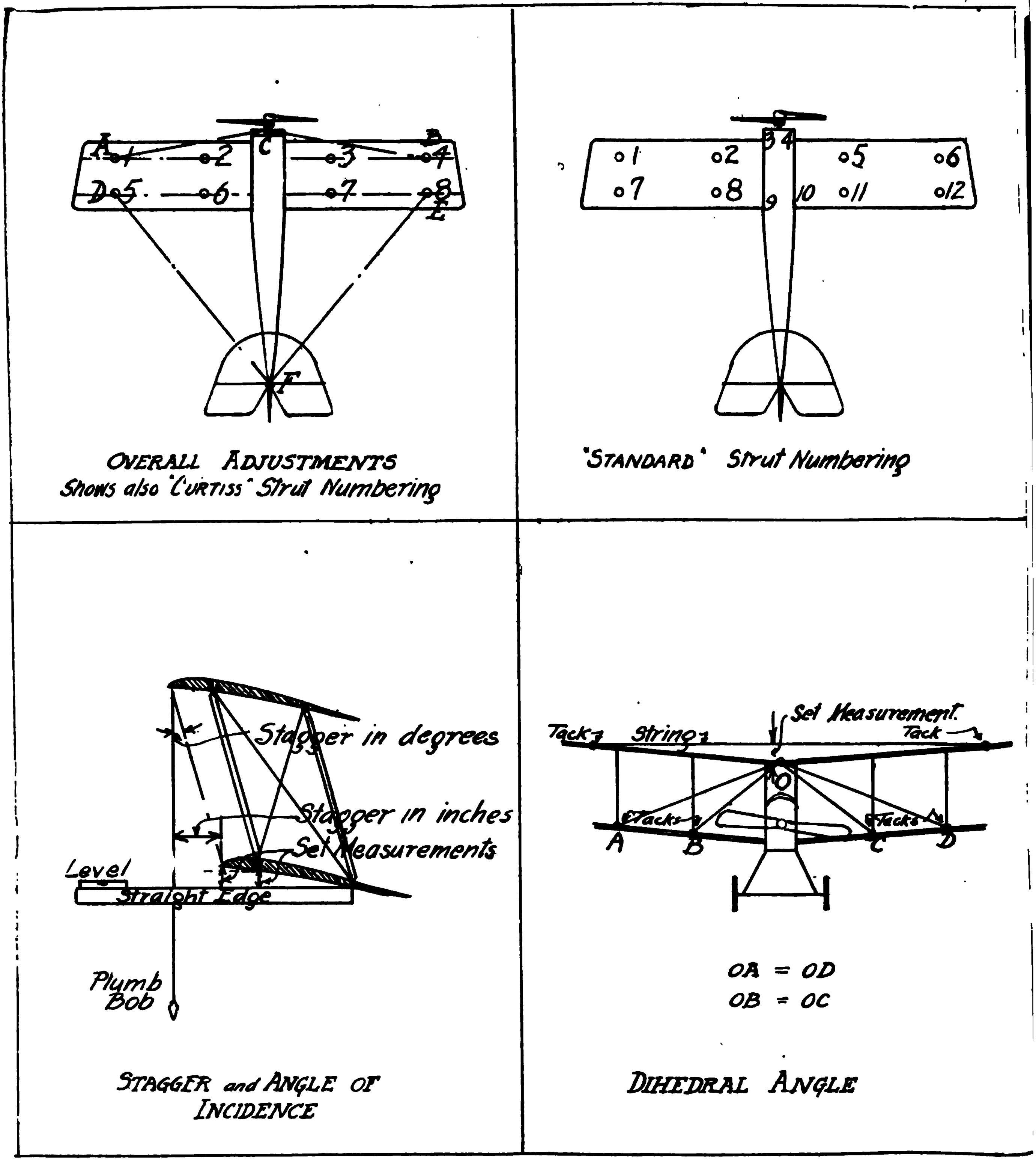

OVERALL ADJUSTMENTS
Shows also "CURTISS" Strut Numbering
"STANDARD" Strut Numbering
Stagger in degrees
Stagger in inches
Set Measurements
Level
Straight Edge
Plumb Bob
STAGGER and ANGLE OF INCIDENCE
Set Measurement
Tack
String
Tacks
OA = OD
OB = OC
DIHEDRAL ANGLE

FIG. 120

4. Set center section square over fuselage by equalizing diagonal bracing wires. Check by measuring distances from plumb-line to center section and to top and bottom longerons; they should be equal.

5. Safety turnbuckles.

D. TAIL

1. Level fuselage crosswise.
2. Level horizontal stabilizer by adjusting brace wires, if any.
3. Plumb vertical stabilizer or line up rudder hinges on it and tail post.
4. Set control bridge in neutral and line up elevators with horizontal stabilizer.
5. Set rudder bar in neutral and line up rudder with fin.
6. Safety turnbuckles.

E. WING

1. Get leading edges straight.
2. Get both wings same height.
3. Put in dihedral, if any, by stretching string between masts (or between tacks placed in leading edges of top panels near the outer struts) and adjusting landing wires until string is at required distance above the wing beam (or tack in leading edge of center section).
4. Align trailing edge by vetting, i. e., by sighting under leading edge and moving eyes up or down until trailing edge is just visible next the fuselage. Then the whole trailing edge should just be visible. Check by setting one corner of straight-edge under rear spar, leveling up straight-edge and measuring up from it to under side of leading edge or front spar. This measurement should be the same under the intermediate and outer struts as it is next the fuselage.
5. Droop left wing, if motor is clockwise, to counteract the propeller torque. Use straight-edge and level as in 4, and make measurement under outer struts ⅜ inch more than at the fuselage.
6. Check stagger in front of each set of struts and next to fuselage.
7. Get up on a ladder and by vetting check top panels for straightness of leading edge and alignment of trailing edge.
8. Re-check all measurements.
9. Safety turnbuckles and nuts.
10. Make following over-all measurements:
    a. Measure distance from propeller hub to points on bearing plate at outer front strut on both wings. These lengths should be equal to within ⅛ inch.
    b. Measure distance from stern post to similar points on rear of wings. These should be equal to within ¼ inch.

F. AILERON

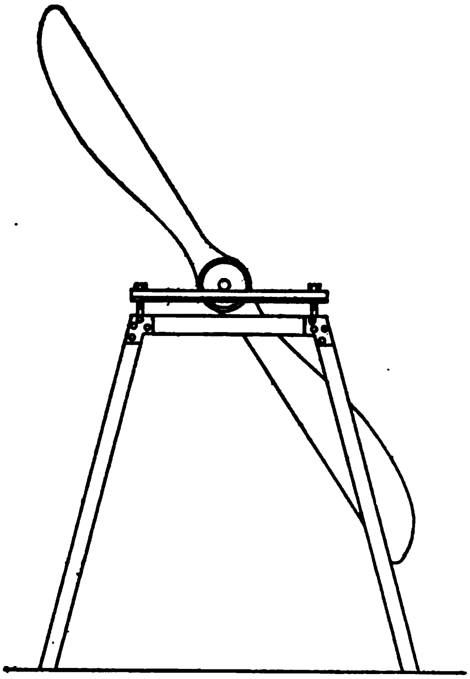
1. Adjust balance wire so that each aileron droops ¼ to ½ inch below trailing edge of wing.
2. Tighten control cables so that they do not bind on the drum but are not loose enough to allow wheel to turn without moving ailerons.

6. PROPELLERS

A. MANUFACTURE AND STRUCTURE

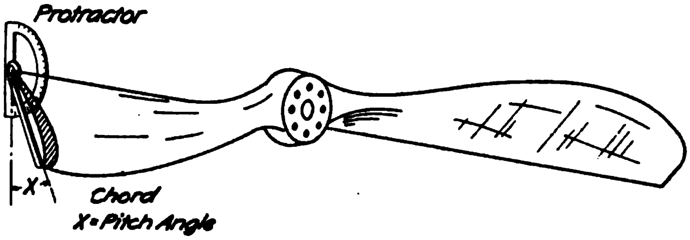
Propellers are made with two, three or four blades. The widest part of the blade is usually at about six-tenths of its radius. The maximum width is about one-tenth to one-fifteenth the diameter of the propeller. The thickness

PROPELLERS



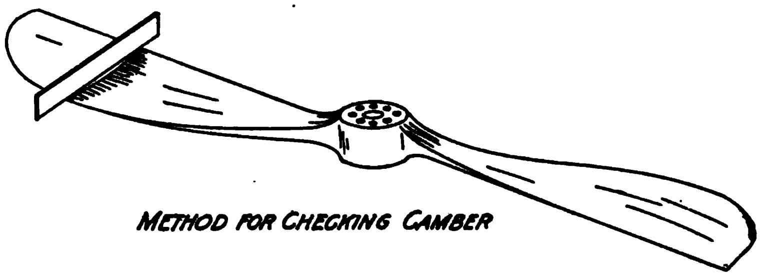
PROPELLER BALANCING STAND FOR DETERMINING STATIC BALANCE

Fig. 121



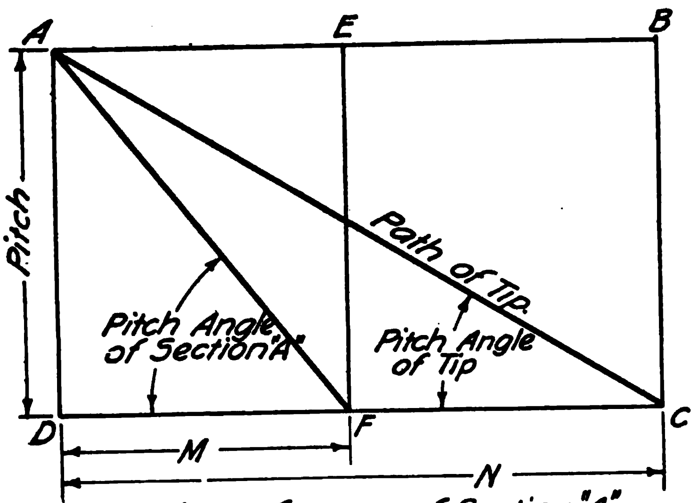
METHOD OF MEASURING PITCH ANGLES WITH PROTRACTOR

Fig. 122



METHOD FOR CHECKING CAMBER

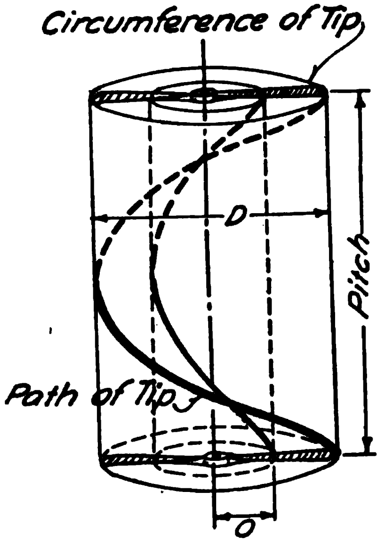
Fig. 123



M = Circumference of Section "A" = One Half Circumference of Tip.

N = Circumference of Tip.

Fig. 124



O = Distance to Section A, $\frac{1}{2}$ way out to Tip.

Fig. 125

of the blade near the hub is very great, but diminishes rapidly to about half blade length and then gradually to the end. This increased size near the hub is for strength. The cross section of a propeller assumes somewhat the same shape as a wing section. In fact the propeller is nothing more than a wing travelling in a helical path, every point of which has different velocities due to the varying distance of the sections from the axis. Since the velocity increases along the blade, the lift or in this case the thrust would increase too. To make this thrust equal along the blade the angle of incidence or the Pitch Angle must become smaller along the blade.

The propeller is built up from five to ten laminations according to size. The laminations are laid out and sawed to outline. They are then surfaced to the required thickness and slightly roughened by tooth planing. After warming they are assembled together with the best hide glue and firmly clamped. The entire process is carried on in a room at 100° F. After 18 to 24 hours the clamps are removed and the center hole bored. The propeller is now left for ten days to dry. After drying the propeller is placed on a horizontal table and carved to shape. A few days are given it to dry then it is given a finish and balanced.

B. INSPECTION

To the pilot the inspection of propellers is the most important phase of the whole subject, because the success of the flight depends a great deal upon the dependability of the propeller. The propeller is usually the last thing gone over on a machine and the tendency is to slight it.

1. **Balance** The correct balance of the propeller is the most important consideration if good running is to be obtained. A propeller which is out of balance a small amount will destroy the crank-shaft in a few hours. Vibration is the result of *unbalance* and vibration is the worst enemy of materials. Vibration causes materials to crystallize and break off. It therefore behooves the pilot to see that the propeller is correctly balanced.

a. Static balance is all that the name implies: it is balance when stationary, not rotating. That is, the propeller should be balanced when it is placed on a stand such as shown in Fig. 121. It should stay in any position desired. This is the test for static balance. This means that the centrifugal force of the blades due to rotating the propeller will be equal and no vibration should result.

b. Dynamic unbalance refers to a propeller which even though it has been balanced statically still continues to vibrate. This is due to the centers of gravities of the blades not being in the same plane. If the pedals of a bicycle are rotated fast without the chain the frame is seen to shake back and forth. This is because the pedals are rotating in different planes. The centrifugal forces even though they are the same, act in different planes and do not counteract each other. This can be tested only by running the propeller at high speeds and observing whether the propeller vibrates or "flutters."

2. **Trackage** Each point on the trailing edge of a blade should track with the corresponding point on the other blade. This can be checked on the parallel bar testing stand used for static balance. Bring the point in question around to graze some fixed point, then turn the propeller completely through a half turn and see if the corresponding point on this blade grazes the same point. This should check within 1/16 inch and will in a measure show something about the dynamic balance.

3. **Pitch angle and pitch** The pitch angles of the blades at various points should be checked up. This is done as indicated in Fig. 122. The

propeller is mounted horizontally on a level face plate, a stub axle set securely on the face plate going through the axle hole in the hub of the propeller. Then at fixed distances, say about every foot from the center, the pitch angle which the blade makes with the level face plate is measured by means of a protractor.

Imagine a propeller rotating in a paper cylinder (Fig. 125). The tip of the blade would describe the helical path shown on the cylinder. A point on the blade at A would have its helical path on a smaller cylinder because its diameter is less. If the cylinders are cut and spread out the markings would appear as shown in Fig. 124. ABCD is the large cylinder spread out and AEFD is the small cylinder spread out. The path is now shown as a straight line. The pitch is the same for section A as it is for the tip. If it was not the thrust would be different for the two sections and the blade would tend to bend. The line DF is the circumference of section A and the line DC is the circumference of the tip. It now should be evident that the pitch angles as shown by this diagram should check those measured by the method of Fig. 122.

4. **Camber** The camber or curvature of the blades should be equal and should decrease evenly towards the tips of the blades, and the greatest depth of the curve should, at any point, be approximately at the same percentage of the chord from the leading edge as at other points.

It is difficult to test the top camber without a set of templates, but a fairly accurate idea of the concave camber can be secured by slowly passing a straight edge along the blade as shown in Fig. 123. The camber can now be easily seen, and as the straight edge is passed along the blade, the observer should look for any irregularities of the curvature, which should gradually and evenly decrease towards the tip of the blade.

5. **Joints** The usual method for testing the glued joints is by revolving the propeller at a greater speed than it will be called upon to make during flight, and then carefully examining the joints to see if they have opened. This test might be made when the propeller is mounted on the engine, but it is not a very convenient test to make especially in the field. Under either circumstance, test or no test, all the joints should be examined very carefully, trying by hand to see if they are quite sound. Inspect a propeller, the joints of which appear to hold any thickness of glue. Sometimes the joints in the boss may open a little, but this is not dangerous unless they extend to the blades, as the bolts will hold the laminations together.

6. **Condition of surface** The surface should be very smooth, especially towards the tips of the blades. Some propeller tips have a speed of over 30,000 feet a minute, and any roughness will produce a bad drift or resistance and lower the efficiency. The best propellers have copper tips covering the ends of the blades. These tips protect the propeller from the splitting action of weeds and grass and offer some security against damage from moisture. However to insure against any moisture collecting on the inside of the tip, holes are drilled in the ends to allow the centrifugal force to throw out what moisture might collect. All metal tipping should be inspected to see that the metal lies close to the wood, that nails or rivets have not split the blade, and that solder is placed smoothly and properly. Propeller hubs should be pressed into propellers on an arborpress, and great care should be taken to see that the wood has not been injured in the process. The hub should be inspected for flaws.

7. **Mounting** Great care should be taken to see that the propeller is mounted quite straight on its shaft. Test in the same way as for trackage. If it is not straight, it is possibly due to some of the propeller bolts being too slack or to others having been pulled up too tightly.

7. REPAIR

A. WINGS

Very few repairs are made to the internal parts of a wing panel which do not necessitate the complete removal of the fabric; also it is often necessary to remove the fabric for inspection, because damage to a panel cannot be located with covering in place. The covering when once removed cannot be used again.

The fabric used for wing panel covering is usually the best grade of Irish linen; some cotton is used but is not as satisfactory as linen. Grade A linen should weigh not more than 4.5 ounces per square yard, have a thread count of 90 to 105 threads per inch, be capable of withstanding a tensile stress of 75 pounds per inch of width, and be free from all imperfections in thread and weave.

The fabric is attached to the wing panels by sewing. Stitches from 4 to 6 inches apart are taken around the rib, thru the top and bottom covering. The connecting thread is always carried on the convex surface. After sewing, a 2-inch strip is doped down on both top and bottom for reinforcement and protection of the thread and to reduce skin friction.

Dope is a cellulose acetate or nitrate lacquer with which the fabric is coated. The chief function of the dope is to tighten up the fabric, and give a taut, smooth, weatherproof surface, resistant to the weather and preferably also to oil and gasoline. It also adds to the tensile strength of the fabric and prevents the tension changing with the hygroscopic conditions of the atmosphere. The solvents for dope which are commonly used are acetone and tetrachlorethane. Dope is highly inflammable and poisonous. Care should be taken to keep it away from fire, and the vapors, which are heavier than air, should be allowed to escape thru openings in the floor. Moisture is very detrimental to dope; it should therefore always be used in a dry place and applied when the fabric is dry.

Spar varnish protects the dope, makes the covering more weatherproof, and gives the covering a smooth finish, thereby reducing skin friction.

The most frequent repair work done on a wing panel is the patching of the fabric. Most of the ruptures will be tears or long narrow slits because of the weave of the fabric. In case of the long narrow slits a few stitches may be taken before the patch is applied. The hole or slit should first be trimmed out to remove the loose ends of the threads. The dope and varnish must then be removed from where the patch is to stick on. This can be done in two ways; first, by applying dope remover; and second, by applying new dope. The new dope softens the old dope because it is an unsaturated solution while the dope remover is nothing more than the pure solvent. The old dope when soft may be scraped off.

Patches should be rectangular that the edges may be frayed out so the dope can hold the patch better. The lap varies from ¾ inch on small patches to 2½ inches on large ones. A fabric patch is attached with dope instead of glue because dope gives sufficient adhesion, gives a patch homogeneous with the repaired surface, is waterproof, and by shrinking makes a very smooth repair.

Dope is brushed on the fabric around the hole and on the underside of the patch. The patch is then placed on the hole, care being taken to stick down the edges evenly. One coat of dope is placed over the patch and allowed to stand. As soon as it is dry another coat may be applied, and so on. In all, about four coats are sufficient. One or two coats of weatherproof varnish should be applied to make the job thoroughly weatherproof, and to reduce skin friction.

The most frequent wood replacement or wood repair is that of the ribs. Each rib web is made in three sections; nose, intermediate, and tail. These sections are held together and in place by cap strips, which can be removed without disturbing the beams. Stringers run lengthwise of the panel to hold the intermediate web in place when stressed.

To remove the intermediate section of a rib, the drift and anti-drift wires must first be removed. The stringers are then cut diagonally with the expectation of splicing in new sections. In replacing the intermediate section of a rib, the web is first placed in position, and the cap strips tacked and glued in place. A new section of stringer is spliced in by gluing the diagonal cuts together, and wrapping with copper wire, which is soldered over to form a sleeve. The drift and anti-drift wires are replaced and the alignment of the panel checked. The veneering if injured is replaced only at the section damaged. Nose sections of the rib web should be distributed along the repair for reinforcement. The method of repairing the trailing edge depends upon the material of which it is made. Broken wires are always replaced. Fittings must be replaced unless facilities are at hand to test the repaired members before they are placed in service.

The wing beam, if damaged, is never repaired. It is too important a member to trust after having been repaired so a new one is always put in place.

Care should be taken to see that all wooden parts have at least two coats of weatherproof varnish, and that all metallic parts are well enameled before the fabric is replaced.

B. LONGERONS

The longerons are the most important members of the fuselage, and for this reason longeron splicing is a highly specialized type of work. Every break in a longeron necessitates at least one splice. Ash is the wood spliced in, even when that part of the longeron repaired is made of spruce. A diagonal cut, of not less than eleven inches on the horizontal, is made on each side of the break. The use of a miter box is advisable in order that the longeron and piece to be spliced in may be most conveniently cut to the same angle. The surfaces of the splice must be as smooth as possible and perfectly flat so they will come in contact with each other at all points.

Glue which has been approved by Signal Corps inspection should be used if possible. If this is not obtainable, use the best grade of hide glue. The glue is prepared for use by first putting in cold water until thoroughly soaked and softened. Between 28 and 36% by weight of glue is the amount generally used. When the glue is soft it should be melted over a water bath, the temperature not being allowed to go above 150° F. The glue pot should be kept covered as much as possible in order to prevent the formation of a skin or scum over the surface of the glue. Glue should always be applied at a temperature between 140° and 150° F. Always use fresh glue, i.e., glue which has been prepared on the same day it is used.

Be sure that the wood is dry and both pieces are at the same temperature.

The joint is first sized, i.e., a coating of glue is spread over the surfaces and allowed to stand a few minutes before the sticking coat is applied. This will prevent the glue used to stick the joint from soaking into the wood. Care should be exercised in clamping to see that the surfaces match. The pressure applied should be at least 100 lbs. per square inch. After thoroughly drying (about 24 hrs. at temperature of 85° F.) the clamps may be removed and a light cut taken over the joint with a wood plane to ascertain if a thin layer of glue has been obtained. A good joint shows no glue and can scarcely be detected except by the variation in the grain of the wood. The joint is now wrapped with whip cord. In order to make the cord secure, so that if any one turn should break the entire wrapping will not come off, a knot or half-hitch is taken in each turn. The cord is covered with a coat of glue. Sometimes an additional wrapping of linen tape and another coating of glue are applied.

Always varnish the finished splice when dry. A well made glued splice is as strong as the wood.

Bolts are sometimes used in addition to the glue, and when used should divide the joint in equal sections. They should be put in place and tightened up at the same time the clamps are put on.

All repairs made to the fuselage, with the exception of the longerons, are by replacement.

C. SOLDERING

The alloys used for joining other metals with the aid of heat are called solders. The variety and number are considerable, but are easily divided into two general classes, namely, "hard" and "soft" solders.

Hard solders are alloys of zinc, copper, silver, etc., which melt at fairly high temperatures.

Soft solders are alloys of tin, lead, bismuth, etc., which melt at comparatively low temperatures.

Soft solder is used extensively in the construction and repair of airplanes because of its extreme handiness of application and because the heat of working is not high enough to appreciably weaken the metals joined.

The theory of soft soldering is that the solder adheres to, but does not unite with, the surface of the metal unless the latter has a melting point lower than that of the solder. In fact soldering usually consists of uniting two or more pieces of similar or dissimilar metals by means of another metal of lower melting point. That constitutes soldering; all the rest of the operation is detail, which may be varied to suit conditions.

The following are the commercial soft solders:

	Lead	Tin	Melting point
Hard	1	2	340°F
Medium	1	1	370°F
Soft	2	1	400°F

Medium or "Half and Half" is the most generally used solder and is the solder used in airplane construction and repair.

Before solder will stick the surface must be free from dirt, grease, oxide, or any foreign substance which will prevent the adherence of the solder. The surface may be cleaned and brightened by scraping or rubbing with sand paper or emery cloth. To remove the oxide a flux is applied to the surface of the metal just before soldering.

One of the most important considerations in work of this sort is the employment of the proper flux. However satisfactory a flux may be in soldering various parts its use is prohibited if it is of a corrosive nature as it may cause corrosion of the parts soldered after the soldering has been done. Rosin is the best non-corrosive flux for use on airplanes. It may be prepared by dissolving in alcohol. Other fluxes are salammoniac, zinc chloride, boracic acid, etc., all of which are more or less corrosive. The main prerequisite of a good airplane flux is that it be non-corrosive and yet perform its functions satisfactorily.

Solder is used in an airplane in the construction of tanks and radiator, connections on fuel and water lines, electrical connections, and the end connections on all stay wires.

Under no circumstances should any great reliance be placed upon it for mechanical strength, although it may add to the strength of a joint by its adhesive qualities and by filling up voids and thereby stiffening the joint. Its function in the construction of tanks, radiators, and connections on fuel and water lines is to fill up the voids and make the joints tight. The usual method of applying the solder in this construction is by the use of the so-called "soldering-iron" (see Fig. 126 B) which is really a copper bit placed on the end of an iron handle.

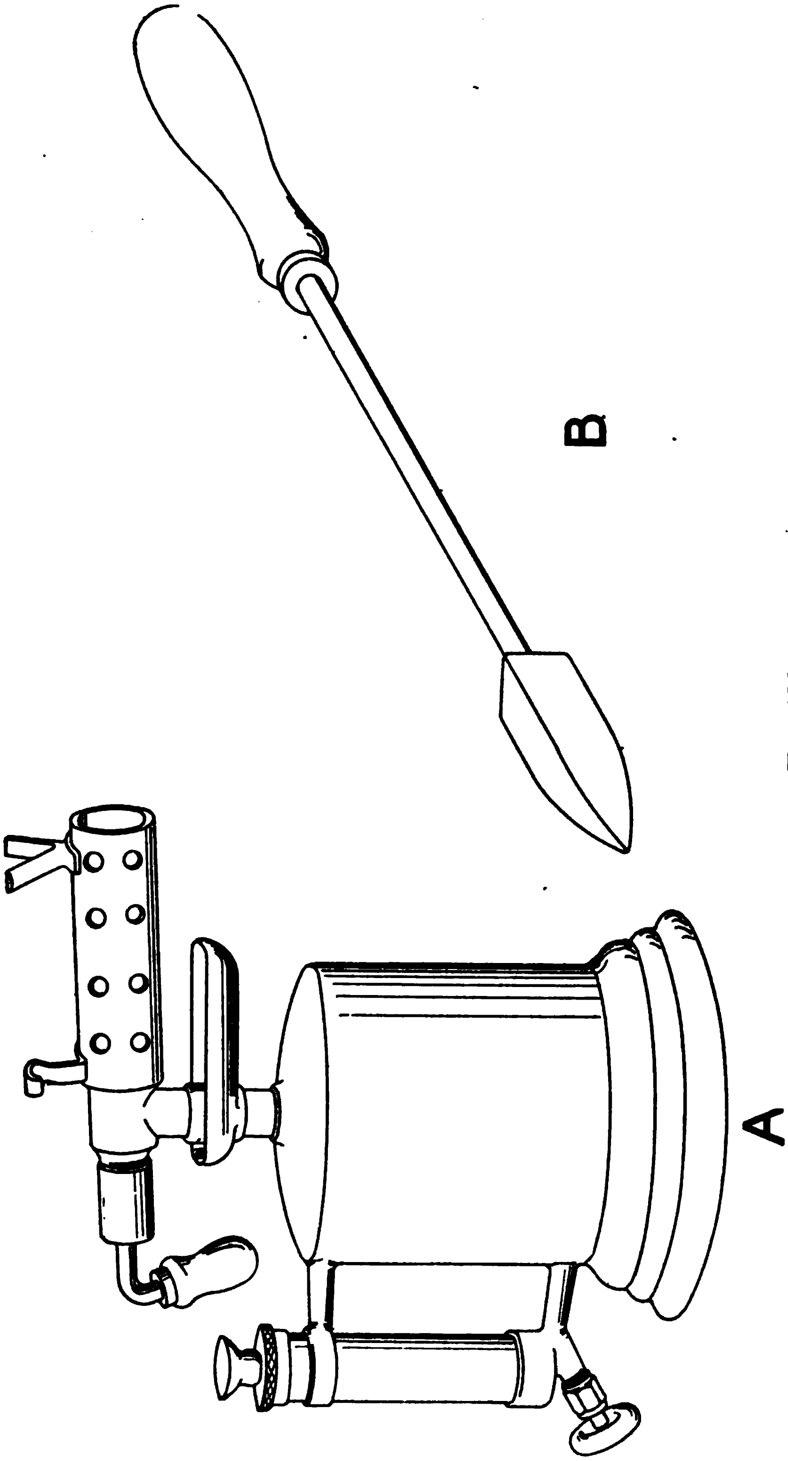


Fig. 126

Before a soldering-iron can be used, the tapered part of the bit must be coated with solder by the process known as "tinning". This is done by heating the bit and applying flux and solder to the surfaces. A bit can never remain in good condition if it is overheated. Once a bit is made red hot the solder will be burned off and its usefulness is gone until it has been re-tinned; overheating will also cause the copper to become rough or pitted. Heating in a soft coal fire is detrimental.

When using, the heat of the soldering-iron melts the solder and heats the surface so that the solder will adhere, the bit being so manipulated that the solder is placed in the desired places. The soldering-iron may be heated electrically by a heating element placed inside the bit, or it may be of the more common kind which is heated by a blow torch or fire pot.

The blow torch, Fig. 126 A, is used to produce a hot flame for heating the soldering copper, melting solder, etc. Gasoline, the fuel used, is maintained under pressure by means of an attached air pump. This type of torch burns with a blue flame of intense heat.

Electrical connections are soldered to hold the parts more firmly in place and to reduce the contact resistance.

Solder is used extensively in making end connections in stay and control wires. These wires are never repaired but always replaced. The replacing of a wire necessitates the making of two end connections, the type of end connection used depending upon the kind of wire.

Aviator wire is a solid wire used for stays, and is always replaced if it is worn, kinked, or shows signs of corrosion. When replacing, first ascertain the correct length, making allowance for the wire used in the end connections.

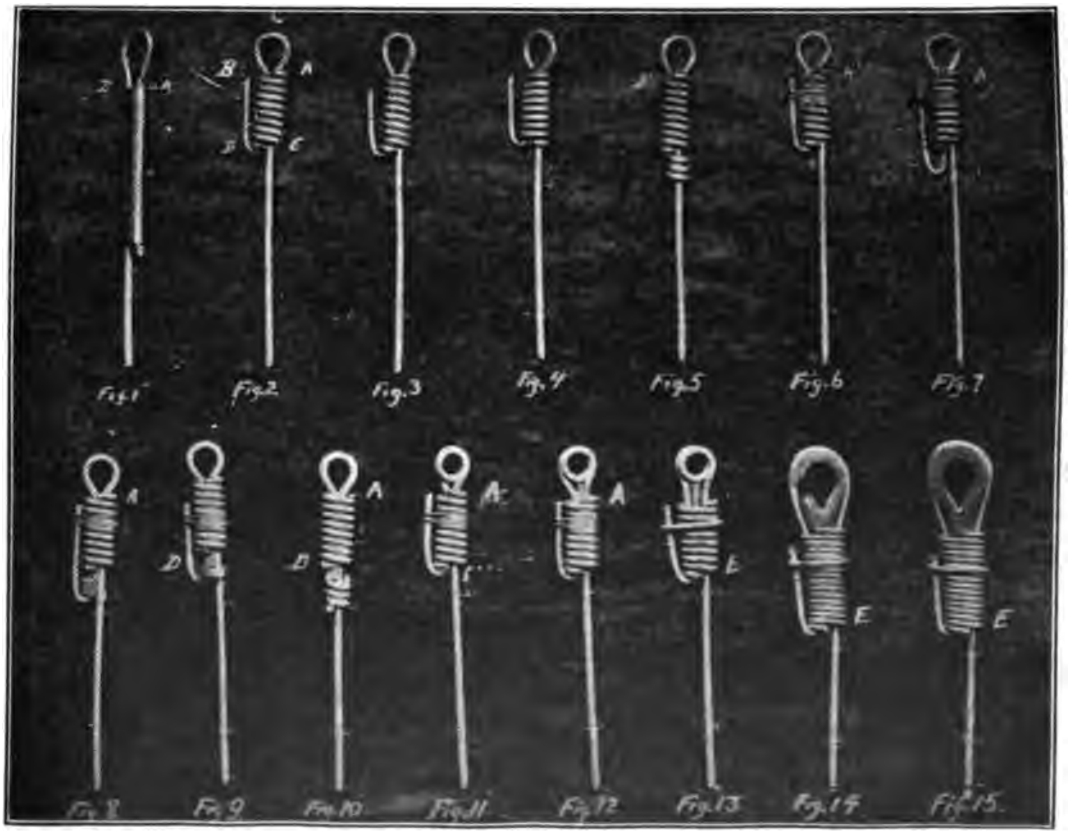


Plate A

The "ferrule" end connection used in aviator wire is shown in Fig. 2, Plate A. This consists of a snugly fitting oval wire ferrule made up from the same sized wire as that upon which it is used. Eight to ten convolutions constitute the standard length. The ferrule is slipped on the wire first, the eye is then formed, care being taken to make it as nearly round as possible, and with the radius of the curve at A and B the same as the radius at C. The ferrule is then slipped back to the shoulders over the free end of the wire which is in turn bent back over the ferrule. Flux is applied and the connection is dipped into a pot of melted solder. The solder should never be hotter than necessary as heat is very detrimental to the wire. This connection is 85% efficient.

Fig. 1 and Figs. 3 to 15, Plate A, show various experimental types of ferrule end connections.

Aviator strand wire usually consists of either 7 or 19 wires stranded together and is used for stays. It is replaced whenever it has broken wires or shows signs of wear or corrosion. The "end wrap" end connection, Fig. 127, is used. This

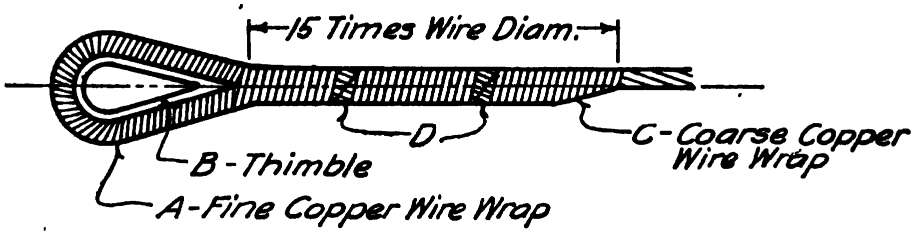


FIG. 127

is made up as follows: The strand is first bent to approximate shape and the loop wrapped with small copper wire A; the thimble B is then inserted and the strand drawn around it firmly. The length of the lap covered by the wrapping C is 15 times the diameter of the strand. Two openings D are left in this wrapping for the solder to run in. Flux is applied and the connection dipped in a pot of melted solder. This connection is 100% efficient.

Aviator cord wire is made by twisting 7 strands together forming a cord or rope, the strands being either 7 or 19 wire. The end connection made in this wire at the factory is usually the "end splice". Fig. 1, Plate B shows a thimble spliced in 7 by 19 aviator cord. Fig. 2 shows the splice after the serving is applied. Fig. 3 shows the result of a test to destruction; five strands have been broken at the last tuck in the splice. The splice usually fails at this point, and is only about 80% efficient. In repair a modified end wrap end connection is used; the only difference being that the wrapping A is omitted, otherwise it is made in the same manner as on strand wire.

D. BRAZING

Brazing is the uniting of two pieces of metal by a thin film of soft brass. It is practically the same as soldering except the brass or spelter takes the place of the solder. The common fluxes are borax and boracic acid. The parts to be brazed are brought into contact, dusted with borax or coated with some other flux, and the spelter is melted into the joint. The spelter will automatically run to the hottest part of the joint and no space need be provided for it.

E. WELDING

Welding is the uniting of metals by heat without using either flux or compression. The heat is ordinarily obtained from oxygen and acetylene gas and is usually about 6000°F. The pieces of metal are held together and the heat applied until the fusion takes place. If the pieces are large they should be heated all over to a red heat to avoid warping.

PLATE B

CHAPTER II.

COOPERATION WITH THE ARTILLERY

OUTLINE

1. The Artillery and Its Uses
   - A. The Characteristics of the Types of Artillery
     1. Gun
     2. Howitzer
     3. Mortar
   - B. Principal Types of Projectiles
     1. High Explosive
     2. Shrapnel
     3. Gas
   - C. The Duties of the Artillery
     1. Barrage
     2. Counter Battery
     3. Bombardment
        (Under each division)
        - a. Object
        - b. Projectiles Used
        - c. Artillery Used
        - d. Aviator's Duties
        - e. Occurrence
     4. Special Duties
        - a. Night Fire
        - b. Fleeting Opportunity Targets
     5. The Artillery Preparation for an Infantry Attack
        - a. During the Weeks and Months Previous to the Attack
        - b. When the Zone of Attack has been Selected
        - c. During the attack
        - d. When the Objective has been Attained
2. The Organization of the Artillery
   - A. The Allotment of Pieces and Objectives
     1. Divisional
     2. Army Corps
   - B. Principles of Organization
   - C. Organization of the Artillery Units
3. Methods of Fire (Ranging)
   - A. Terms Used in Ranging
   - B. The Accuracy of a Piece
   - C. Method of Reporting Shots
4. Methods of Fire (Continued)
   - A. Fire for Adjustment
   - B. Continuous Fire for Effect
   - C. Pre-Arranged Shoot
   - D. Impromptu Shoot

5. Procedure in Cooperating with the Artillery
   - A. General Suggestions as to Work of the Observer
   - B. Difficulties of Observation
   - C. Methods of Signalling
     1. Airplane to Ground
     2. Ground to Airplane
   - D. Organization and Routine for a Pre-Arranged Shoot
   - E. Report Forms and Reports

CHAPTER II.

COOPERATION WITH THE ARTILLERY

1. THE ARTILLERY AND ITS USES

A. THE CHARACTERISTICS OF THE TYPES OF ARTILLERY

Type	Comparative		Muzzle Vel. (m. p. s.)	Max. Range, Km.	Max. Angle	Path of Projectile	Targets
	Appearance	Mobility					
1. **Gun**	Longest, slender	Highest	500 to 800	27	20° (except Anti-Aircraft)	Flat	Vertical, aircraft, barb wire, men in open, long range work
2. **Howitzer**	Shorter, breech heavier	Lower (except field how.)	100 to 300	10	45°	Curved	Horizontal, reverse slope work
3. **Mortar**	Shortest, very heavy breech	Lowest	Max. 200	8	90°	Very Curved	Horizontal

B. PRINCIPAL TYPES OF PROJECTILES

Name	Case	Fuse	Contents	Action On Explosion	Targets
1. **High Explosive**	Thick	Percussion	Disruptive explosive as lyddite, T. N. T., amatol, etc.	Penetrates, disrupts	Material
2. **Shrapnel***	Thinner	Time and percussion	Propellant explosive, bullets, matrix	Nose blown off, bullets spray out	Aircraft, barb wire, men in open
3. **Gas**	Very thin	Percussion	Disruptive explosive and liquid	Shell bursts and liquid vaporizes	Men under cover

*The effect of shrapnel depends on:
1. Number of bullets
2. Energy of bullets on impact
3. Spread of bullets
4. Curve of trajectory
5. Position of the burst

For best results shrapnel must be fired from *guns* in order to obtain:
1. Sweeping effect due to flat trajectory,
2. High energy due to high remaining velocity

Other Types of Projectiles are:
a. Tank shells (armor piercing H. E.)
b. Liquid fire
c. H. E. shrapnel
d. Shrapnel gas

C. THE DUTIES OF THE ARTILLERY

Name	(a) Object	(b) Projectiles Used	(c) Artillery Used	(d) Aviator's Duties	(e) Occurrence
1. **Barrage**	1. Isolation 2. Neutralization 3. Sweeping 4. Defense	1. Gas, H. E. 2. H. E. & Shrapnel 3. Shrapnel 4. Gas and Shrapnel	Guns 75's and at times How. and guns 100	Location of batteries, troops, amm. etc.	During an attack
2. **Counter Battery**	1. Destruction	1. H. E.	Gun 100 up How. 155 " Mor. 220 "	Location. Control of fire and ammunition	All the time
	2. Neutralization	2. Shrapnel and gas	Guns 100 to 155		
3. **Bombardment**	1. Destruction of material	1. H. E.	Gun 155 up How. 155 " Mor. 220 "	Location and fire control	At all times
	2. Destruction of barb wire	2. Shrapnel	Guns 75 to 155		

4. Special duties

a. Night fire This type of work is usually carried out with 75's or some of the medium guns with shrapnel for any one of the following purposes:

1. To prevent reconstruction of works bombarded during the day
2. To prevent rest at rest camps and billets
3. To prevent bringing up supplies, etc.

b. Fleeting opportunity targets Targets (use shrapnel and sometimes H. E.) which last only for a short time; e.g., battery on the move, trench R. R. train with troops or supplies, troops in the open on the move, etc.

5. The artillery preparation for an infantry attack

a. During the weeks and months previous to the attack

1. Constant counter battery work
2. Bombardment to disorganize the defensive system—bridges, roads, command posts, observation posts, trench systems, etc.
3. Fire to prevent organization and supply—night fire, etc.
4. Destruction of all opportunity targets such as moving objects of all kinds, etc.

b. When the zone of attack has been selected

1. Destruction of the trenches and entire defensive system that is to be the objective
2. Destruction of all hostile artillery which would interfere with the attack
3. Destruction of wire in the path of the infantry

c. During the attack
1. Barrage fire
2. Counter battery work (neutralization)
3. Work on fleeting opportunity targets

d. When the objective has been attained
1. Prevention of reinforcements and counter attack
2. Prevention of hostile artillery interference with the consolidation of the position

2. THE ORGANIZATION OF THE ARTILLERY

A. THE ALLOTMENT OF PIECES AND OBJECTIVES

There are two main branches of the artillery—the Divisional and the Army Corps Artillery. The first includes the light or field artillery; the second is composed of the medium and heavy artillery.

Branch	Pieces	Objectives
1. Divisional		
a. Field guns	Guns 75 mm	a. Barrage in all attacks b. Destruction of barb wire c. Cantonments within range d. Night fire to prevent reconstruction
b. Howitzers (inc. mortars)	How. 155 mm Mor. 220 mm Mor. 270 mm	a. Bombardment within range b. Reverse slope work c. Fleeting opportunity targets
2. Army Corps		
a. Counter battery	Gun 100 mm 105 mm 120 mm 155 mm	a. Destruction of batteries b. Neutralization of batteries c. Night fire on cantonments and lines of supply
b. Heavy artillery	Gun 140 mm 240 mm 305 mm 340 mm How. 370 mm 400 mm 520 mm Mor. 270 mm 280 mm 293 mm	a. Heavy bombardment—batteries, forts, concrete works, deep dug-outs b. Long distance work—on cantonments, H. Q., supply and ammunition dumps.

B. PRINCIPLES OF ORGANIZATION

As the pieces of the Divisional Artillery have a short range they are assigned the immediate front, including our first line trenches and the enemy's first and sometimes his second line trenches; that is, they will cover very intensively the enemy's territory to a depth of about four kilometers.

The task of the Army Corps Artillery is to cover the region back of that covered by the Divisional Artillery. Further they will work upon objectives which require heavier projectiles than the Divisional Artillery is able to use even tho these objectives may be situated within the territory normally covered by the Divisional Artillery. Forts, batteries with heavy cover, and almost any concrete works will come under this type of work.

There are three principles that will determine the organization of the artillery.

1. The Divisional Artillery must be able to cover the immediate front intensively with a large number of pieces placed well forward.

2. The region covered by the Divisional Artillery must be covered twice—once by the Field Gun group and once by the Howitzers. This is due to the difference in the objectives for which the field guns and the howitzers and mortars are best suited.

3. The Army Corps Artillery will cover the region farther back, that is the enemy's rear. This region will be covered less intensively, as the region assigned to each piece will be much larger. This however does not mean that the Army Corps Artillery will be located behind the Divisional Artillery. The heavy howitzers, due to their short range and the fact that their objectives are situated well behind the enemy lines, must be put well to the front.

C. ORGANIZATION OF THE ARTILLERY UNITS

AA, AB, AC, DA, DB, DC, are battalions of Divisional Artillery Field Guns, allotted to cover the enemy zones A'A', A'B', A'C', D'A', D'B', D'C', respectively. (See Fig. 201)

BA, BB, CA, CB, are battalions of Divisional Artillery Howitzers, allotted to the zones A'A' to D'C' inclusive.

GA, GB, GC, are battalions of Army Corps Artillery allotted to cover the zones G'A', G'B', G'C', respectively.

Each battery is commanded by a Captain. Each battalion, or group, as AA, AB, etc., is commanded by a Major.

Headquarters of Commanding Officers: Lieutenant Colonels at A, B, C, D,; Colonels at E, F, G.

E', F', G', are aero squadrons and E'', F'', G'', are balloon companies under the Commanding Aeronautical Officer, K, assigned to work with the commands of Colonels E, F, G, respectively.

A special aero squadron, J', assigned to general H. Q.

A General at J commands the whole unit.

3. METHODS OF FIRE (RANGING)

A. TERMS USED IN RANGING

1. **The range of shot** is the straight line distance from the piece to the point where the shot strikes.

2. **The range of a piece** is the longest straight line distance that a given piece can place between it and a shot from that piece. This is usually referred to as the *maximum range*.

3. **The correction to the range** is the number of meters that a shot lands short or over the range correct line.

4. **The correction to the deflection** is the number of meters that a shot lands to the right or left of the Battery-Target (B-T) line.

5. **The time of flight** is the time in seconds that it takes a shot to travel from the piece to the point where it strikes.

6. **In salvo fire** all the pieces of the battery are aimed at the same point, and the pieces then fire at the target one at a time at intervals of five seconds. The appearance of a salvo about the target will be four bursts separated by intervals of five seconds. In ranging, the shots of a salvo must hit fairly close to one another. In case one piece is wild it will be corrected before further work is done with the salvo.

7. **The extreme right deflection** of a salvo is the correction to the deflection of the extreme right shot of a salvo.

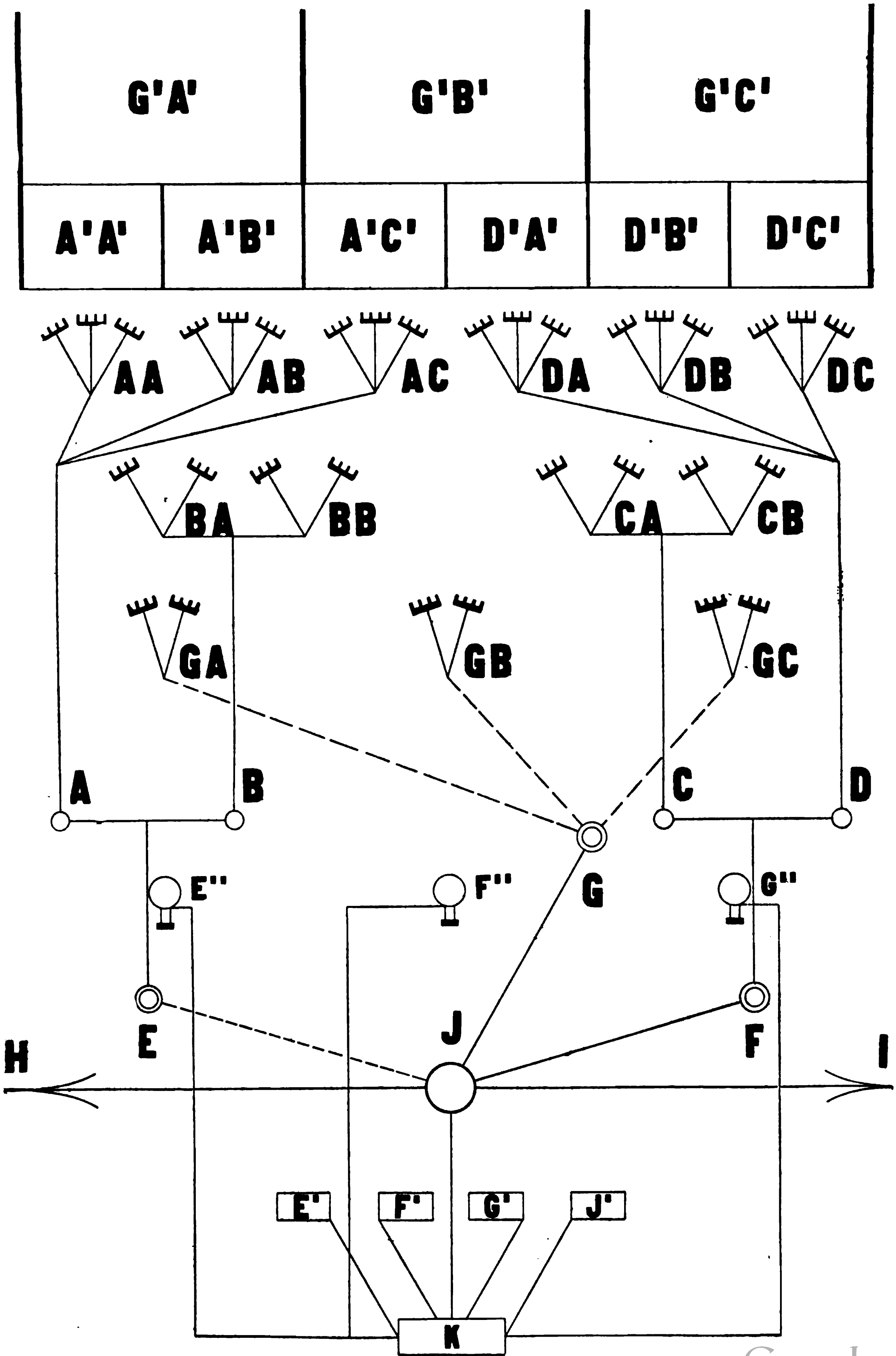


FIG. 201.—ORGANIZATION OF THE ARTILLERY UNITS

8. **The center of impact** for any group of shots is the average center of all the shots. It is the point which has the average correction to the deflection and the average correction to the range. In reporting on a salvo the aviator gives the *extreme right deflection* and the *range* of the *center of impact*. See Fig. 202.

9. **A bracketing salvo** is one in which half of the shots land over the range correct line and half short.

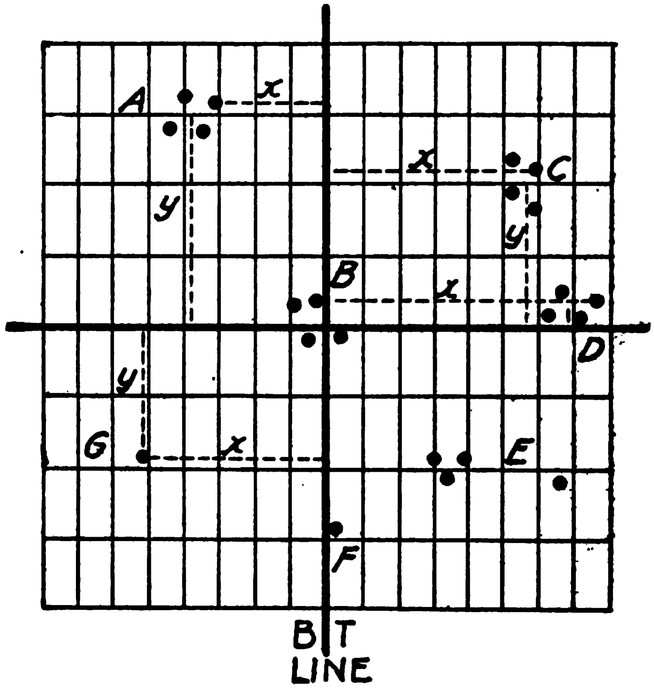


FIG. 202.—DIAGRAM SHOWING LOCATION OF SHOTS BY MEANS OF COORDINATES WITH REFERENCE TO THE BATTERY-TARGET LINE

For the salvos, x=extreme right deflection
y=range of the center of impact

A. Salvo; left 075, over 155.
B. Bracketing salvo. (Brackets the target, two over, two short)
C. Salvo; right 155, over 101.
D. Salvo; right 202, range correct.
E. Salvo in which one piece is shooting "wild". Such a piece must be corrected before ranging by salvo is continued.
F. Single shot; deflection correct, short 155.
G. Single shot; left 125, short 101.

B. THE ACCURACY OF A PIECE

The accuracy of a piece is measured by the size of its 100% zone. The 100% zone is the region where all the shots fired from a rigid piece (data kept constant) would fall. In general the 100% zone is an ellipse with the longer axis pointing in the direction of the piece. The zone for a gun is an elongated ellipse whereas that of a howitzer is more nearly circular. This shows that the gun is much more accurate in deflection (line) than in range. On the other hand the howitzer is as inaccurate in line as in range.

Ranging a piece means moving the center of the 100% zone over onto the target. When this is accomplished, fire to destroy the target follows.

The reasons for the existence of the 100% zone are:

1. **The unsteadiness of the piece.** Although the recoil mechanism of the piece may be very good, it is not perfect. Some movement of the piece occurs which causes the next shot fired with the same data to fall in a slightly different place.

2. **Wear on the piece.** This will include the wear on the piece during the firing which may be appreciable in the case of the larger pieces, also the previous wear on the piece. Both contribute to the inaccuracy of shooting.

3. **Irregularities in projectiles and ammunition.** This will include variations in the weight, polish, explosive power, etc.

4. **Irregularities in atmosphere.** This includes density, winds, eddies, humidity, pressure, etc.

5. **Irregularities in fire.** If the piece is not fired at regular intervals the projectile with its explosive will be heated more or less depending on the length of time it remains in the piece. An explosive has more force when heated. Unless the firing is regular, serious irregularities in the range will result.

C. METHOD OF REPORTING SHOTS

In reporting on shots the following rules must be observed by the aviator.

1. **General rules**

a. All messages must be preceded by the battery call given twice.

b. The correction to the deflection will be given first, then the correction to the range.

c. All distances will be reported in meters.

d. All reports on distances will consist of three figures, e.g., 075, 025, 125.

e. No set of figures representing a distance may end in a zero; send 055 for 50 m., 101 for 100 m., 202 for 200 m., etc.

2. **Rules for the correction to the deflection**

a. The deflection will be reported as either left, right, or correct.

b. The amount of the correction to the deflection will be estimated in multiples of 25 meters.

3. **Rules for the correction to the range**

a. The range will be reported as short, over, or correct.

b. The amount of the correction to the range will be estimated in multiples of 50 meters.

The code for the designation of the target and necessary information to be sent to the battery is confidential and will be given to the cadet in class.

4. METHODS OF FIRE (CONTINUED)

A. THE FIRE FOR ADJUSTMENT

The object of the fire for adjustment is to range the piece or battery. Thus the battery will fire and the aviator will report where the shots landed and then the battery will correct and fire again. This will continue until the battery is ranged. The deflection must be much more accurately corrected than the range.

Fire for adjustment is divided into: 1, preliminary adjustment; 2, final adjustment.

1. **Preliminary adjustment** The object of the preliminary adjustment is to correct the line or deflection. There is the additional effort

made to correct the range. The work is carried out by means of salvos. The aviator will report on each salvo, giving the extreme right deflection and the range of the center of impact. This work will stop when a bracketing salvo is obtained. The aviator will report the bracketing salvo as having hit the target.

2. **Final adjustment** The preliminary adjustment has corrected the deflection completely but as a rule the range needs further adjustment. This is carried out by the battery firing groups of three salvos (twelve shots) and the aviator making his report after each group of twelve shots and calling for the next group. In this work the aviator will report only the number of shots over and the number short, e.g., 8 over, 4 short, as what he is trying to do is to correct the range. This continues until the battery is satisfied and signals to the aviator to take up the next stage—continuous fire for effect. In this work, as in all the work, the aviator must report only what he sees. In case some of the shots fail, only those which appear will be reported upon; e.g., 7 over, 4 short. The shots may be lost due to their falling in places where observation is impossible or to the mis-fire of the piece.

B. CONTINUOUS FIRE FOR EFFECT

The object of the continuous fire for effect is either to destroy the target or to neutralize it. In this part of the fire the aviator ceases to tell the battery when to fire and the battery fires as rapidly as possible on the target. The aviator makes no reports on this fire except in two cases.

1. **In case the fire drifts off the target** due to movement of pieces, change in temperature of pieces, etc. Then the aviator will report this fact to the battery by giving either

   a. the range and, if necessary, the deflection of the center of impact, or

   b. the number of shots over and number short for a certain number of shots which are fired successively. This will be at least three salvos.

2. **In case the target is hit and destroyed** he will at once signal to the battery "result has been attained". The battery will then signal further instructions. The aviator will always inform the battery when he starts for home.

C. THE PRE-ARRANGED SHOOT

In the pre-arranged shoot the aviator is given all the necessary information about the battery and target before he takes the air. As to the battery, this information will be its range, time of flight, rapidity with which it can deliver fire, its location on the map, the identification panel it will use, and finally the program that it wishes to follow.

The information of the target will consist of its number or squared map location, photographs of the target taken from the air and ruled off to aid in the spotting of shots, and the amount of work which is to be done on the target.

On the other hand the battery knows which aviator is to direct the fire for it, the wave length he will use, and the time at which he will appear overhead. When he leaves for the battery this latter information is telephoned.

This kind of a shoot is the most successful and is made in the majority of cases.

D. THE IMPROMPTU SHOOT

The impromptu shoot will occur when the aviator is out on some work, such as artillery patrol or work on some particular target and finds a target which needs immediate attention. This might be any one of the targets which are classed as fleeting opportunity targets, or some particularly active enemy battery.

In this case it is necessary for the aviator to call the particular battery which can cover the target in question. For this purpose he carries with him a zone map on which are marked the arcs of fire of the various batteries. After determining the battery which can reach the target he gets into communication with it. Once communication is established the impromptu shoot is conducted in practically the same manner as the pre-arranged shoot.

5. PROCEDURE IN COOPERATING WITH THE ARTILLERY

A. GENERAL SUGGESTIONS AS TO WORK OF THE OBSERVER

As the aviator is to serve as the "eyes of the artillery" it is necessary that he be familiar with the artillery which he is to direct. Part of this knowledge can be obtained from books but much must be obtained from actual contact. "Observers should utilize every opportunity of visiting the batteries allotted to them. On non-flying days squadron and balloon company commanders should arrange to send observers to the batteries with which they work, in order to watch the procedure during a shoot so that they may get some idea of the difficulties and delay with which the artillery have to compete."

The observer must necessarily be mentally keen and alert; he must be persevering and have a clear-cut understanding of the problems connected with his work. He has a mission to perform and is, therefore, acting under orders. His duties are essentially two-fold: 1, location and surveillance of targets; 2, observation of fire effects. He must have a thorough knowledge of the artillery map. He must become expert in judgment of distance and direction. He must gain the confidence of his battery by accurate and painstaking work.

B. DIFFICULTIES OF OBSERVATION

1. **Physical**
   - a. Speed of airplane
   - b. Atmospheric conditions, (clouds, mist, haze, etc.)
   - c. Conditions on the earth's surface—difficult country, snow, shell action, burning buildings, dust
2. **Imposed**
   - a. Enemy planes
   - b. Anti-aircraft guns
   - c. Camouflage—dummy guns, etc.
   - d. Trajectories of shells from numerous batteries
3. **Observation will be aided by**
   - a. Photography—its careful interpretation (paths, snow, horses, etc.)
   - b. Moving objects, gun flashes
   - c. Ruses, false attacks*, sudden returns to suspected regions
   - d. Balloons
   - e. Ground observation posts
   - f. Sound ranging
   - g. Cross bearings

*During the great battles around Verdun, the French launched a false attack thereby causing the Germans to open fire with all their batteries. Observers were thus enabled to locate the positions of the batteries. During the following days these batteries were incessantly pounded and a large per cent destroyed so that the actual attack later was successful.

C. METHODS OF SIGNALLING

1. Airplane to ground

a. Wireless is used almost exclusively. If the wireless is out of order, plane will return to landing ground and another be sent up.

b. Other methods that may be used at times are: dropped written messages, searchlight or lamp-flash signals, fusee (Very's lights) signals.

2. Ground to airplane

a. Ground panels of white cloth, 4x4 m. and 4x½ m. If snow covers the ground, black cloth will be used.

b. Panneaus, using Morse code.

c. Wireless receiving sets have as yet been used only on a few planes with transmitting sets at receiving stations near important H. Q.

D. ORGANIZATION AND ROUTINE FOR A PRE-ARRANGED SHOOT

1. Cooperating planes Careful organization and strict discipline are necessary to reduce the chances of confusion to a minimum.

a. Identity of planes Planes may be identified by the "call" adopted by each receiving station, the use of varying wave-lengths, and the loudness of emission.

b. Zone of operation Due to wireless limitations, i.e., the interference of messages one with another, the number of planes operating on the front for observation is restricted to one plane for each 1000 meters. In some instances chronographs (watches with colored dials), have been used to enable neighboring planes to send messages at alternate specified intervals, but this interferes with the continuity of observation. It is important that planes keep out of neighboring zones when signalling, and that they do not come closer than two kilometers to their own receiving stations. Messages sent when directly above the antennae interfere seriously with other messages. Technical matters concerning wireless are prescribed in each Army Corps by the Chief of the Radio Service concerned.

c. Method of designating location of target Target locations will be given by coordinates on the artillery or squared map, as 88-97, or possibly in three figures, as 695-486. In order to prevent the enemy from knowing the meaning of a message, letters may be substituted for certain of the figures. In the event of a pre-arranged shoot, the target may be designated by a number, as N9. In case of a hostile battery, the right gun (as viewed from our line) is chosen as the center of the target.

d. Position of plane when observing The plane should be approximately over the target when observations are made. Observations may be made at angles up to 45°.

e. Position of plane when sending Plane should be headed directly towards receiving station when sending wireless messages. *Don't send messages when turning or when headed in opposite direction for wireless reasons.* (See Fig. 203)

2. Battery and receiving station

a. Identification Each receiving station is provided with identification panels, which enable the observer to distinguish his own receiving station. The squared map location of these panels is known to the observer.

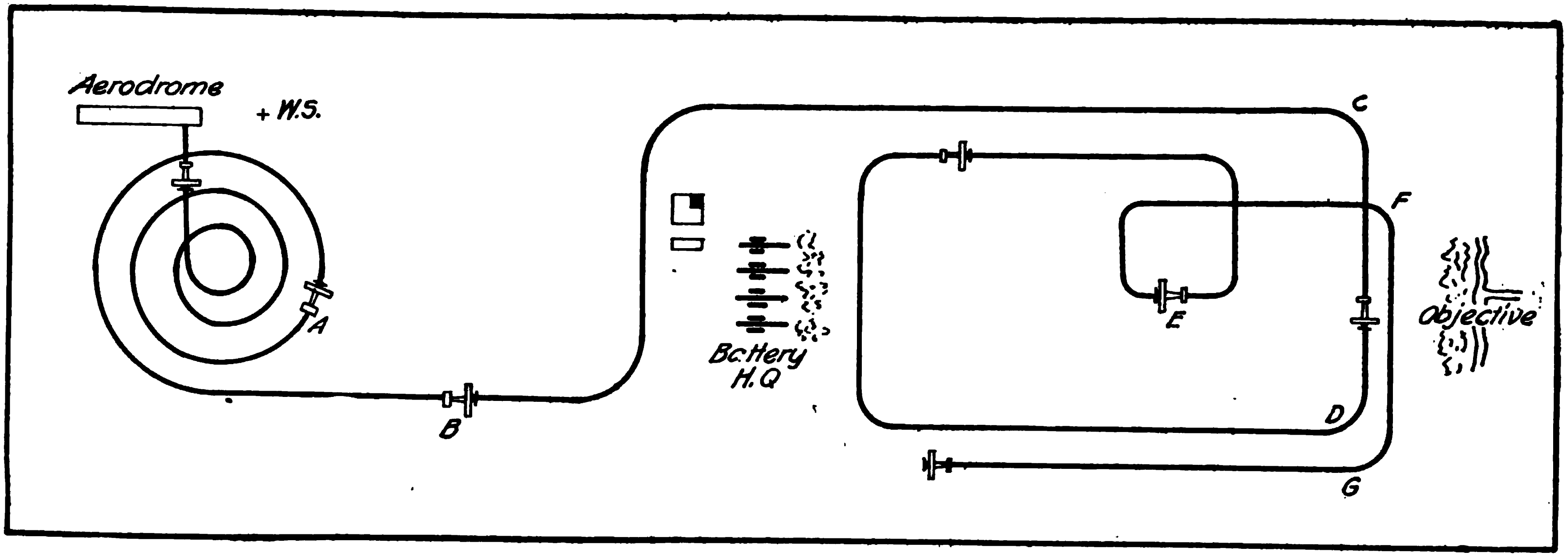


FIG. 203.—POSITION OF AIRPLANE DURING VARIOUS STAGES OF A PRE-ARRANGED SHOOT, SUGGESTING POINTS TO BE KEPT IN MIND.

(Diagram is not drawn to scale)

A. After leaving the aerodrome, the observer when at a height of about 500 feet lets out the aerial and puts in the safety plug, then calls the wireless station and tests his wireless. *B.* Calls the Battery as he approaches. *C.* Locates the target. *D.* Sends message to the Battery as he flies toward it. *E.* Suggestion of position when giving the "fire" signal. Plane must necessarily make a number of turns. Observer should be near the target in position to observe when the shell hits. *F.* Observes deflection and range. *G.* Sends corrections.

b. Receipt of messages All information by wireless is received at a special receiving station. Information as to targets and corrections is then transmitted to Battery Officer usually by telephone, then by megaphone or otherwise to men at the battery.

c. Signals to plane Ground panels should be placed where the observer expects to find them, either behind the second gun in a battery of four guns or nearer the receiving station.

d. Laying of pieces The observer must remember that some time is required to correct data and to change from one target to another and should make necessary allowance. After ranging has begun, however, the observer should expect prompt firing after he gives subsequent signals. The Battery Commander will deliver regular, accurate, and rapid fire. Time is important, as observation by plane is limited to three hours at a time and liable to interruptions from atmospheric conditions, engine trouble, gasoline supply, aerial combat, etc. The piece should fire in ten seconds from the time the signal is received. The observer knows the time of flight of the projectile and using a stop watch will be prepared to observe the shell burst. If battery does not respond within 30 seconds after "fire" signal, they must wait until the observer again signals to fire.

3. **Routine** Observer leaves the aerodrome and when at a height of about 500 feet, he lets out the aerial and puts in the safety plug, and then calls up the wireless operator at the aerodrome to test his apparatus. If the wireless is working properly, he flies toward his battery, calling repeatedly as he approaches. After communication is established with his battery, he then flies out over the target and proceeds with the work. Fig. 203 illustrates the position of the plane at various stages of the shoot.

When shoot has been completed, he sends the proper signal before leaving. Before returning to landing ground, he takes out safety plug and winds in aerial. After landing, he makes proper records and talks over the shoot with the Battery Commander.

E. REPORT FORMS AND REPORTS

Reports must be accurate. Daily records will be made. Especially in the case of hostile batteries detailed reports must be kept, including the history of the battery day by day, when engaged, when active, together with photographs taken. Destruction of enemy batteries should be continually in progress except during and immediately following an infantry attack. (Usually from 250 to 300 rounds from 8.2 or 9-inch howitzers or 500 rounds from 6-inch howitzers are required to destroy a battery). The following are sample forms of reports:

A card index record of hostile batteries is maintained. The face of the card contains a record of the coordinates and a photograph of the region. The reverse side of the card has the following form:

CARD INDEX RECORD OF HOSTILE BATTERY

Date seen active	No. of pieces	Targets	Adjustments		Results
			Calibre	Shots fired	

A form of report of summary of work done includes the following:

SUMMARY OF WORK DONE

Enemy Batteries Discovered

No.	Coordinates	No. of pieces	In action or not	Hour	Their objective (if possible)	Were they under bombardment

Fire Adjustments

No.	Battery whose fire was adjusted	Objective	Difficulties

No. of successful adjustments....................

Causes of failures....................

Photographs taken (region)....................

Airplanes met: Allied....................

Enemy....................

Sundries....................

Squadron No. .... The day of....................

Pilot .... Hr. of start.................... Hr. of return....................

Observer ....

CHAPTER III.

ENGINES

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CHAPTER III.
ENGINES

1. FUNDAMENTAL PRINCIPLES

The function of an airplane engine is to rotate a propeller against air resistance, and in performing this operation the expansive force of a combustible mixture of gasoline vapor and air is caused to act against the face of a piston within a cylinder so as to produce motion, this "reciprocating" motion being transmitted through a connecting-rod and transformed into "rotary" motion at the crankshaft which carries the propeller. The action within the cylinder is not unlike the explosion of gun-powder in a cannon, in which the pressure created by the sudden evolution of heat drives the ball out with great force. In other respects, the action of an engine is quite similar to the operation performed by a man turning a grindstone; the stone corresponds to the fly-wheel or propeller, the handle corresponds to the crank on the crankshaft, the man's arm acts as connecting-rod, and the force exerted by him represents the expanding gas. Thus the heat generated by the combustion of fuel (gasoline) is converted into mechanical energy, or power.

A. FOUR-STROKE CYCLE

A *Cycle,* in gasoline engine operation, constitutes a complete series of events. Four-stroke operation requires four strokes of the piston to complete a cycle, and in that case there is an explosion or working impulse only once in two revolutions of the crankshaft. The operation of a four-cycle engine may be summarized as follows, with reference to Fig. 301:

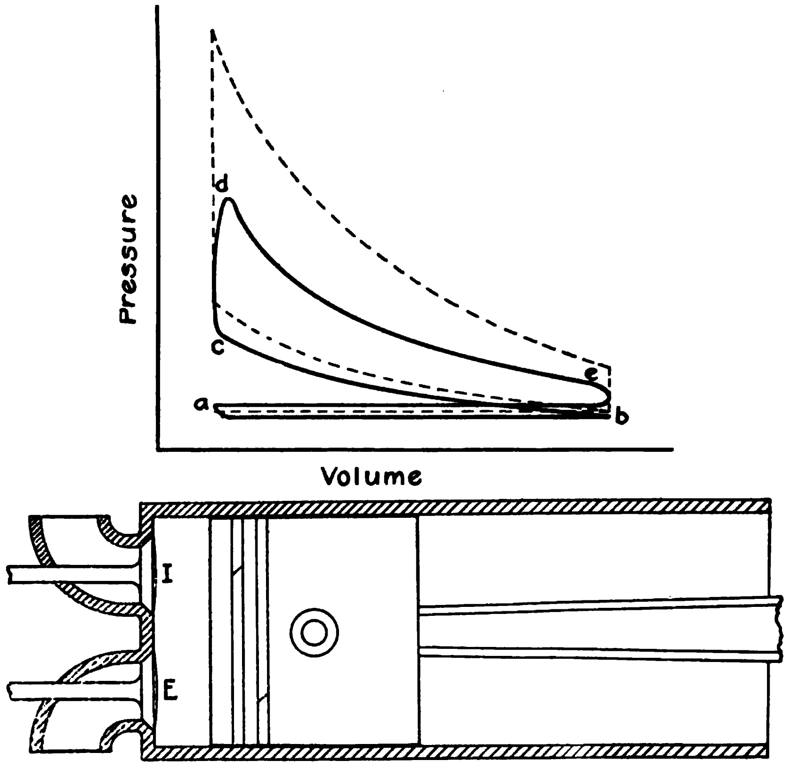


FIG. 301.—ILLUSTRATING FOUR-STROKE CYCLE OPERATION

1. **Suction stroke** (a-b) The piston moves away from the cylinder head, the intake valve I is opened, and a charge is drawn into the cylinder from the carburetor. (Note: The illustration shows the cylinder horizontal so that the movement of the piston may be more easily followed on the pressure diagram.) The suction pressure is below atmospheric, and it is the "pressure head", or difference of pressure, that causes the fresh charge to flow in.

2. **Compression stroke** (b-c) With both valves closed, the piston moves back and compresses the charge into the clearance space, and *Ignition* takes place near the end of the stroke.

3. **Expansion stroke** (d-e) After the charge is "fired", the pressure rises rapidly and forces the piston out on the power stroke.

4. **Exhaust stroke** (e-a) The exhaust valve, E, opens near the end of the expansion stroke, the pressure decreases, and on the return stroke the piston drives out most of the remaining burned gas. Owing to resistance to flow through the valve, the pressure within the cylinder during the exhaust stroke is somewhat above atmospheric.

Since the pressure in the crankcase of a four-stroke cycle engine is always approximately atmospheric, the net pressure tending to move the piston is the difference between the absolute pressure in the cylinder and atmospheric pressure underneath the piston. Let P_w be the average pressure above atmospheric during the expansion stroke, P_e the average pressure above atmospheric during the exhaust stroke, P_s the average pressure *below* atmospheric during the suction stroke, and P_c the average pressure above atmospheric during the compression stroke. It is obvious that P_w is a "forward" pressure, and that the "back" pressure of the other three strokes tending to slow down the engine is overcome only at the expense of a part of P_w, or energy stored up in the rotating parts of the engine during the expansion stroke. What is left after the losses have been deducted is called the *Mean Effective Pressure.* Algebraically, $M.E.P. = P_w - P_e - P_s - P_c$.

B. DEFINITIONS

1. **Work,** by definition, is the product of force times distance, and the common unit of work is the *foot-pound.* The distance through which the piston reciprocates in any engine is a definite measurable quantity, called the *Stroke.* But the force exerted upon the piston by an expanding gas doing work is variable, and can only be determined by means of a *Pressure Diagram* taken while the work is being done. A pressure diagram shows the actual pressure within the engine cylinder at any point of the cycle. The net area of the diagram is proportional to the work done.

2. **Power** is defined as the "rate of doing work"; i.e., work divided by time. *Indicated Power* is the power developed by action of the gaseous charge within the engine cylinder; it is the net power delivered to the face of the piston. Indicated power depends upon the weight of charge burned, and the efficiency with which the heat of combustion is converted into mechanical energy (thermal efficiency).

The *Delivered Power* at the propeller is always 10 to 20 per cent less than the indicated power of the engine, because of frictional losses in engine bearings and power used to drive the camshaft, magneto, water and oil pumps, etc. The percentage of the indicated power which represents the amount actually delivered to the propeller is called the *Mechanical Efficiency.* In other words, mechanical efficiency is the ratio of delivered power divided by indicated power.

3. **A Horsepower** is the equivalent of 33,000 foot-pounds of work per minute, or 1,980,000 ft. lb. per hour. A heat unit, or B.T.U., which is the amount of heat necessary to raise the temperature of 1 pound of water 1 degree Fahrenheit, is equivalent to 778 ft. lb. of mechanical energy. One horsepower-hour is therefore equivalent to 2545 B.T.U.

If the M.E.P. is known, it is a simple matter to calculate the indicated horsepower of an engine from a well-known formula, which is derived as follows:

Let: P=M.E.P. (lb. per sq. in.)
a=area of piston face, which is πr^2 or $\frac{1}{4}\pi d^2$ (sq. in.)
L=length of piston stroke (feet)
N=number of explosions per minute.

The effective force acting against the piston = P a (pounds); the distance through which the force acts = L (feet). The work done by one charge is, then, P a L (foot-pounds); and since the cylinder is charged N times per minute, the work done by the gas per minute is P a L N foot-pounds, whence

$$\text{I.H.P.} = \frac{P\,L\,a\,N}{33{,}000}$$

The "lower loop" of the pressure diagram is a measure of the power lost in overcoming the resistance of the valve openings and gas passages; in other words, it represents the "pump work" required to force gas into and out of the cylinder in the very short time available in gasoline engine operation.

4. **Charging of the cylinder** The space between the piston and the cylinder head when the engine is on top dead-center is called the *Clearance Volume*. This volume is determined by the amount of compression that can be used, and is usually about 25 or 30 percent of the stroke volume, or *Piston Displacement*. Only the piston displacement is available for filling with fresh charge, because the clearance volume cannot be "scavenged". The dead gas at exhaust pressure remaining in the clearance space at the beginning of the suction stroke must expand to below atmospheric pressure before actual suction of the fresh charge can begin. This delay reduces the volume available for charging, because of the increased volume occupied by inert gas expanded down to the suction pressure. Furthermore, the fresh gas in the cylinder at the end of the suction stroke is in a rarefied condition due to the low pressure, and is consequently lighter than an equal volume of gas would be at atmospheric pressure. Finally, the high temperature attained by the gas within the cylinder during suction causes it to expand and exclude some that would otherwise follow in, thus affecting the actual weight of charge inhaled. The efficiency with which the cylinder is charged with fresh gas by the displacement of the piston during normal operation is called *Volumetric Efficiency*. This is equal to the weight of charge actually drawn in divided by the weight that would fill the volume of piston displacement at atmospheric pressure and atmospheric temperature. Anything that rarefies or reduces the pressure of the gas entering the cylinder, or which increases its temperature, lowers the volumetric efficiency, and in turn the M.E.P. and the horsepower of the engine.

C. TWO-STROKE CYCLE

The two-stroke engine, while possessing certain advantages that make it the ideal type of motor for certain classes of work, has not yet attained the state of perfection and reliability so requisite in airplane service and therefore is not used to any large extent. The principal causes of its deficiency lie in the method of operation.

Referring to Fig. 302, the cycle starts with the cylinder containing a fresh charge. Compression, ignition and combustion, and expansion occur as in the other cycle. But near the end of the expansion stroke, the piston uncovers exhaust port E in the side of the cylinder, allowing the burned gas to escape and the pressure within the cylinder to drop. Immediately afterwards, a fresh charge under sufficient pressure is admitted through an intake port I in such a way as

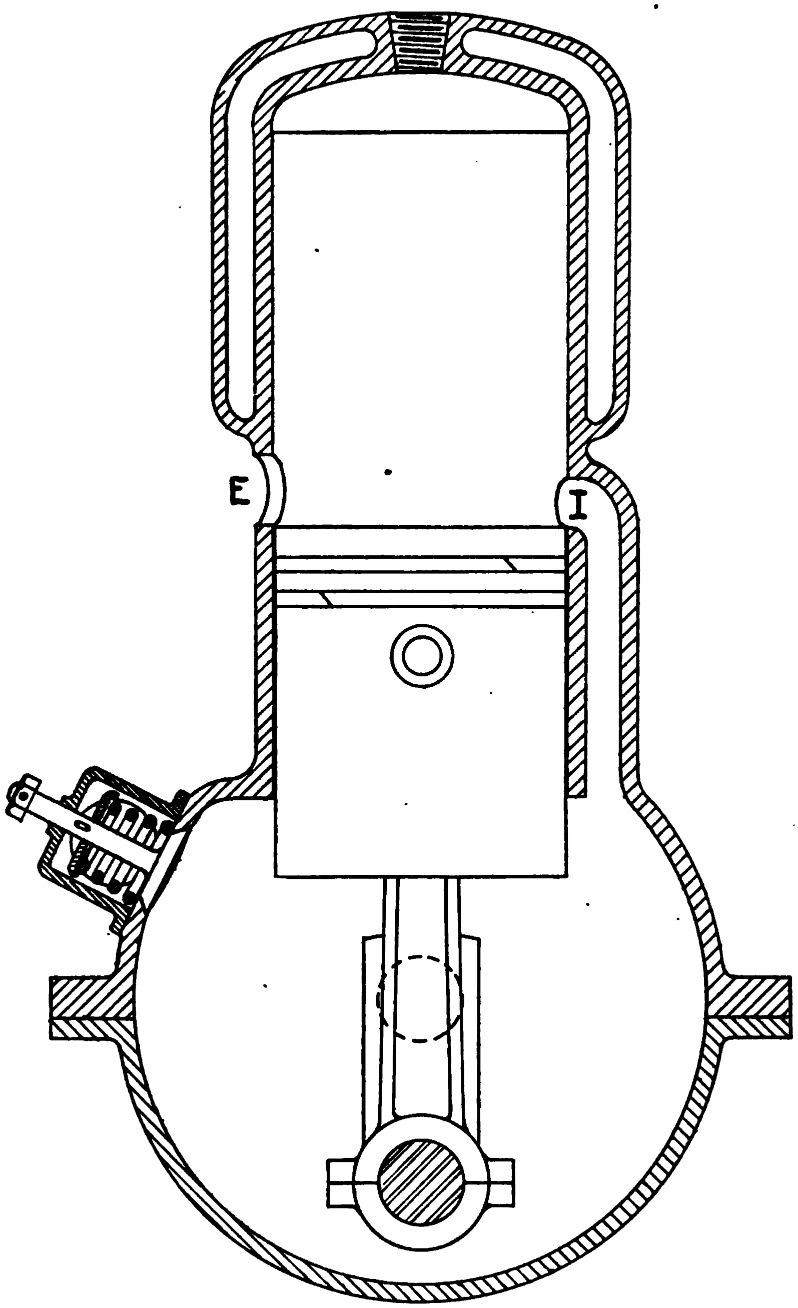


FIG. 302.—TWO-STROKE CYCLE ENGINE WITH CRANKCASE COMPRESSION

to further scavenge or clean out the dead gas (a baffle plate on the face of the piston deflects the incoming gas upward). After the piston covers the ports on the return stroke, compression begins, and the cycle is repeated.

Engines operated on the two-stroke cycle principle commonly utilize "crankcase compression", wherein the piston on its regular compression stroke sucks the mixture from the carburetor into the crankcase through an automatic intake valve, and during the expansion stroke this charge is compressed in the crankcase to sufficient pressure so that when the intake port is uncovered by the piston (shortly after the exhaust port is opened) the fresh gas at higher pressure rushes into the cylinder and sweeps out much of the remaining burned gas. The baffle on the face of the piston greatly assists this scavenging action, and prevents the fresh charge from passing directly across to the exhaust port.

It is obvious that exhaust and intake must take place while the ports are uncovered, that is, during a small part of the piston stroke. To bring about transfer of the mixture and displacement of the burned gases requires precompression of the full charge to 5 to 10 pounds pressure, and this work of precompression is lost as far as useful work is concerned. A pressure diagram taken on the crankcase would represent the work done on the gas in preparing it for entrance to the working cylinder, and the M.E.P. of this diagram must be subtracted from that of the power diagram in order to get the true M.E.P. of the cycle. In order to avoid waste of fuel, the main bearings of the crankshaft must be kept in close adjustment to prevent leakage from the crankcase.

Scavenging is never as perfect in a two-cycle engine as in a four, because in the latter the piston shoves out the products of combustion, while in the two-cycle engine the whole cylinder volume is full of hot gas at the time the fresh gas rushes in. Some of this inert gas will be driven out by displacement, but much of it will mix with the new charge, diluting and heating it to such an extent as to seriously reduce the power capacity of the engine. Although it has a power stroke every revolution, a two-cycle engine can develop only 1.4 to 1.6 times as much power as a four-stroke engine of equal size and running at the same speed; and at the same time the fuel and oil consumption of the former is 30 to 60 per cent greater. And while a two-stroke engine is limited to less than 1500 revolutions per minute, a four-stroke engine may develop its maximum power at a speed as high as 2500 R.P.M., so that if comparison is not restricted to the same speed of rotation the high-speed four-stroke engine is fully as light per horsepower, and its efficiency and fuel economy are much better.

Another serious disadvantage inherent to two-cycle operation is the fact that the engine will not throttle down well, because the amount of unscavenged burned gas increases as the fresh charge is decreased, and the effect of this increasing dilution is very detrimental to efficiency and reliability. The charge becomes weaker and weaker, and finally non-explosive.

The main advantages of a two-cycle engine are simplicity and cheapness. There are very few working parts, and no valves or valve-operating mechanism to give trouble. The engine will run equally well in either direction by simply providing for sufficient movement of the spark-advance lever both sides of the normal retarded (top center) position. There is a working stroke from each cylinder every revolution, which tends to give more uniform torque or turning effort than would result from less frequent application of power impulses; but since four-cycle airplane engines can revolve at much higher speed than is possible with two-stroke operation, this does not necessarily count as of any consequence.

2. CARBURETION

A. REQUIREMENTS FOR MAXIMUM ECONOMY

Gasoline will burn efficiently in an engine cylinder only when the following conditions are fulfilled:

1. **The proportions of gasoline and air must be correct** for every variable condition met with in engine operation, such as variations in compression, due to throttling or to atmospheric changes. Ordinarily there should be between 10 and 16 parts of air to one part of gasoline vapor, by weight. If there is a larger proportion of the gasoline, the mixture is said to be too "rich" in quality; if too little of the gasoline vapor is present, the quality is designated as "lean". In the case of a rich mixture, there is not enough air present to support complete combustion of the gasoline, and unconsumed fuel will be decomposed into soot by the action of the intense heat, which will either deposit in the cylinder and foul up the engine or pass out through the exhaust in the form of black smoke. Too lean a mixture does not necessarily mean incomplete combustion, but invariably results in slow burning of the fuel and loss of power. If the burning is slow enough, there may be flame still present in the cylinder when the intake valve opens, and a "back-fire" follows.

2. **The gasoline must be completely vaporized,** or gasified, in order to make possible a perfectly homogeneous mixture, uniform distribution to all cylinders, and rapid and complete combustion of the fuel. Gasoline vaporizes quite readily at ordinary summer temperatures, but will not vaporize in sufficient quantities to supply an airplane engine unless it is first broken up into a fine spray and the vaporization accelerated by the artificial application of heat. Whenever vaporization takes place, there is an absorption of heat during the process that tends to cool off the surrounding medium. The intake manifold must be kept warm enough to prevent condensation on the way to the cylinders. Liquid particles of gasoline, if present in the swiftly moving column of gaseous mixture, will be thrown out by their own inertia wherever there is a bend or branch in the pipe, so that the end cylinders are apt to get a proportionately larger amount of gasoline while the intermediate cylinders are starved, with the result that the power of the engine is lowered, fuel is wasted, and the end cylinders foul up rapidly and overheat. When little drops of gasoline are present in the cylinder at the time of combustion, only the surface of any drop is in contact with air, and the inner part of the drop is entirely excluded from chemical union with oxygen. The intense heat, however, liberates the hydrogen and "carbonizes" the unconsumed residue, which deposits in the cylinder or on the valves in the form of carbon. Whenever vaporization is poor, as in cold weather or when starting a cold engine, more than the normal amount of gasoline will be required to make the mixture combustible, because it is partly in the liquid form and much goes through unconsumed.

B. SINGLE JET CARBURETORS

The process of mixing gasoline vapor and air is called "carburetion", and the instrument used on gasoline engines to supply proper mixtures of gasoline vapor and air is called a "carburetor". The basic principle upon which most carburetors are founded consists of a single jet or nozzle located in a fixed air passage and supplied with gasoline from a vessel in which the level is always at or a trifle below the opening at the jet. The air passage is connected to the engine so that suction, when the intake valve is open, induces a flow of air and a spray of gasoline simultaneously, the relative proportions depending upon the suction and the size of the spray nozzle. The amount of mixture fed to the engine is regulated by a butterfly valve, or throttle, located above the jet.

The deficiency of a simple arrangement of that sort is that an adjustment for one speed would not be correct for any other speed, because with variations in suction the gasoline-flow changes more than the air-flow changes. This gives increased richness with increase in speed; or, vice versa, if properly adjusted for high speed the mixture becomes altogether too lean at low speed.

There are two principal schemes in use to automatically maintain proper proportions in a single-jet carburetor:

1. **An auxiliary air valve** The "throttle" by which the speed of an engine is controlled is always located between the spray nozzle and the intake manifold. When the amount of throttle opening is increased, the suction at the mixing chamber becomes greater. By admitting part of the air supply above the jet, through an air valve provided for that purpose, less air and less gasoline will be drawn from below, although the total amount of air going to the engine remains approximately the same. By properly proportioning the opening of the auxiliary air valve to the speed of the engine, the tendency for increased richness previously mentioned can be overcome in a more or less satisfactory manner. The auxiliary air valve may be controlled by a light spring, properly adjusted as to tension, or it may be linked with the throttle-operating mechanism so that its action is regular and positive under all conditions. The latter is by far the better, because a spring-controlled valve will not proportion the mixture satisfactorily over a very wide range, it has a tendency to "flutter" during operation, and in time dirt or grease will collect and interfere with proper action of the valve.

2. **A movable needle valve** Jets or spray nozzles are often provided with adjustable needle valves for varying the size of opening to give the required amount of gasoline. With a needle valve under automatic or mechanical control, there is no need for an auxiliary air valve, the needle being arranged to slightly decrease the size of the jet with increased throttle opening. In some carburetors, however, the mixture is controlled by a combination of auxiliary air and a movable needle valve (Schebler).

C. MULTIPLE JET CARBURETORS

In general, multiple jet carburetors may be likened to a series of small, single-jet carburetors, arranged to be brought into action consecutively to increase the speed of the engine. Fig. 303 illustrates the principle. The jets are in separate air passages over which the throttle fits. In the illustration the throttle is shown as a plain slide, for simplicity, but it might be a cylindrical throttle if slotted to open the air passages in succession. For slow speed operation, the velocity of the air past the spray nozzle is much higher than it would be in a single-jet carburetor of equal capacity, and the nozzle itself is small, which tend to produce better vaporization and mixing at low speeds. Furthermore, the possibility of adjusting the mixture accurately for a number of throttle positions makes certain more nearly correct mixtures over the entire range.

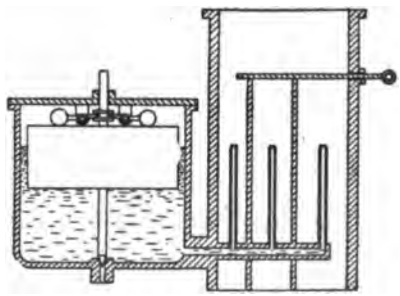


FIG. 303.—ILLUSTRATING MULTIPLE-JET PRINCIPLE

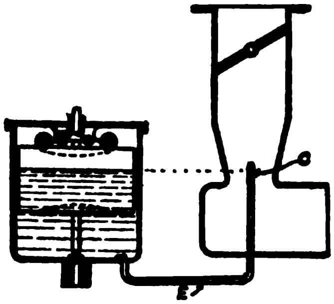


FIG. 304.—SIMPLE SINGLE JET ARRANGEMENT WITH NOZZLE CONNECTED DIRECTLY TO FLOAT CHAMBER

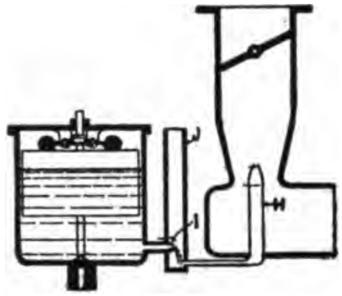
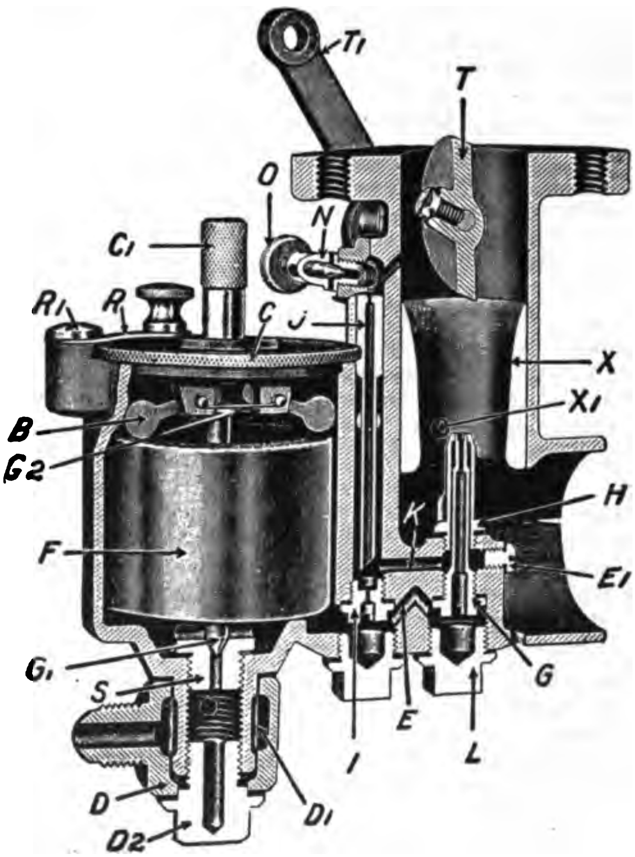


FIG. 305.—ARRANGEMENT OF COMPENSATING SYSTEM IN ZENITH CARBURETOR

Model "O"



F—float;
G_1—float valve;
I—compensator;
G—main jet;
H—compensating jet;
X—Choke;
O-N—idling adjustment;
T—throttle valve.

FIG. 306.—SECTIONAL VIEW OF ZENITH CARBURETOR

D. · THE ZENITH PRINCIPLE

The Zenith compound-nozzle carburetor, which appears to be a standard on airplanes today, utilizes a principle entirely different from those previously described. The simple jet (Fig. 304) with its characteristic deficiency is used as a basis, and around it is built a "compensating" jet which makes up for the deficiency of the first by its tendency to produce exactly the opposite results as regards variation in mixture proportions with variable speed or suction. The compensating jet, which is illustrated in Fig. 305, is not connected directly to the constant-level source of supply (float-chamber), but is connected to an open well, J, into which the gasoline feeds by gravity through a small hole, or "compensator", I. Since the well is open and under atmospheric pressure at all times, increased suction at the jet has no effect on the rate of flow through the compensator into the well, hence the flow is constant and depends only on the size of the opening I. The primary jet, calibrated to give *almost* enough gasoline at high speed, will give much too little at low speed, while the constant flow from the compensating jet is quite sufficient to make up the deficiency at low speed and is proportionately very little at high speed. Thus a substantially constant proportion is maintained by the two together.

1. Construction of the Zenith Referring to the sectional drawing of a Zenith carburetor, Fig. 306, the arrangement of the various parts may be seen. The float-chamber is a common type, located at one side of the mixing chamber. A removable fine-mesh screen is inserted at the union which connects the float-chamber with the pipe from the main gasoline tank. The compensator and the primary jet are screwed into place through plugged holes at the bottom of the carburetor. The plugs also serve as little pockets or wells into which dirt or water may collect, and should be cleaned occasionally. The compensating jet is screwed in from above, and probably never need be removed, since the *compensator* determines the flow and the size of the jet has practically no effect if large enough to handle the limited supply from the well.

The "choke-tube", which gives the Venturi or stream-line shape to the mixing chamber, increases the suction and the velocity of the air at the jets, thereby giving better spraying and vaporization, especially at low speeds where it is most difficult to effect proper carburetion. The passage must not be restricted too much, however, because of the throttling effect which affects the volumetric efficiency of the engine at full speed and reduces the maximum power.

The "idling-tube" through which gasoline is sucked directly into the air passage above the butterfly throttle-valve when the throttle is nearly closed, greatly assists in running the engine slowly when the suction, and the velocity of the air past the jets, are not sufficient to spray the gasoline. There is a needle-valve adjustment on the priming-tube by which a slight inleakage of air is permitted in order to reduce the suction enough to give the correct amount of gasoline. The priming-tube goes out of action entirely as soon as the throttle opens enough to induce spray from the jets.

The Zenith carburetor is usually equipped with a "strangler-valve" at the air intake, which may be used to partially restrict the flow of air and increase the suction on the jets for starting. In some other carburetors, a needle valve is arranged to increase the size of jet opening temporarily so that more gasoline will flow to enrichen the mixture. The latter scheme has the disadvantage that spraying is not as good with the opening enlarged, and the mechanism for moving the needle valve is not as simple.

There are two possible ways of supplying heat for vaporization. One is to preheat the air by passing it through a jacket or stove around the exhaust pipe of the engine. This method is often used in connection with Zenith carburetors, and the carburetor itself is then provided with a sleeve-valve or shutter whereby cold air may be admitted to keep down the temperature and prevent excessive heating. More heat than is necessary to produce complete vaporization would result in reduced volumetric efficiency and loss of power. The other way to furnish heat for vaporization is by circulating hot cooling-water or hot oil through a jacket around the carburetor and the intake manifold, thus at the same time cooling off the water or the oil, which is advantageous.

2. **Care of the Zenith carburetor** The Zenith carburetor is of the non-adjustable type, there being no external adjustments, except that on the idling-tube and a screw to limit the amount of throttle closure. The only way to change the "setting" of the carburetor is by removing the main jet, the compensator, or the choke-tube, and inserting different sizes. Jets and compensators are numbered according to their inside diameter in hundredths of a millimeter. Chokes are numbered in millimeters of smallest diameter.

Great care should be used to prevent dirt or lint from getting into the jets. If a carburetor suddenly develops indications of a lean mixture, it is more than likely that one of the holes has become clogged. In removing the obstruction, care should be taken not to enlarge the opening. Water in the gasoline sometimes gives trouble from skipping and irregular operation by collecting below the jets, but it may be drained off by removing the plug underneath after first shutting off the gasoline.

Flooding of the carburetor may be due to imperfect seating of the float-valve, or to a leaky float. The former may be caused by careless handling, or by collection of foreign matter between the valve and its seat. A leaky float can not always be repaired satisfactorily. Before making any attempt to effect a repair on a metal float, it will usually be necessary to make a second perforation in order to thoroughly dry out the inside. In sealing up the holes, solder must be used very sparingly, so that it will not weight down the float appreciably. Cork floats may be dried and shellaced.

Flooding of the carburetor might frequently happen during flight by tilting. Some carburetors are built to obviate this to a large extent by placing the float concentric with the mixing chamber (Schebler). There are also apt to be indications of flooding immediately after an engine is stopped, because of unvaporized gasoline running down the sides of the intake manifold momentarily. This condition is not as likely to obtain when the engine and pipes are thoroughly warmed up.

E. THE EFFECTS OF ALTITUDE

High altitude is characterized by low barometric pressure and low temperature. The atmospheric pressure at the earth's surface, due to the weight of air several miles high, is in the neighborhood of 15 pounds per square inch, but for every 1,000 feet elevation there is a decrease of approximately 0.5 lb. per sq. in. The rarefied condition of the air makes it impossible for the engine to inhale so much, and the weight of the mixture and the compression are consequently less. The power of the motor decreases at about the same rate as the air pressure. The mixture tends to vary in quality, and to prevent excessive richness at high altitudes there is usually provided an auxiliary air port between the carburetor and the intake manifold. Sometimes provision is made whereby the compression may be kept high for altitude work by simply removing large washers or spacers from beneath the cylinder flanges before flight, which decreases the clearance volume.

The temperature decreases at the rate of about 1 degree for every 300 feet rise. At an altitude of 20,000 feet the temperature is usually below zero, which makes vaporization of the gasoline difficult. There is danger of freezing the water in the cooling system, and if any water is present in the gasoline it will freeze in the pipes or the jets. There is always danger of moisture condensing out of the air in the gasoline tank when the temperature is reduced. Furthermore, extremely low temperature introduces excessive strains in metal parts of the machine, and may even produce "crystallization" and fracture. The lowered "boiling-point" must also be considered.

F. DUPLEX CARBURETORS

Engines of very high power require so much gasoline that the jet in a single carburetor would have to be too big for successful spraying. For that reason, it is common practice to use double carburetors on all but the very small engines. Two mixing chambers are cast side-by-side, and the jets in each are supplied from a single float-chamber. It is well to use a separate carburetor, or a separate mixing chamber, for every three or four cylinders, and care must be taken to synchronize the throttles to work in unison.

3. IGNITION

A. ELEMENTARY PRINCIPLES

Electrical current flows through a wire much the same as water flows in a pipe. The amount flowing depends upon the pressure and the resistance to flow. In measuring electrical quantities, the amount of current is expressed in *Amperes*, the pressure is measured in *Volts*, and the resistance is expressed in *Ohms*. The "jump spark" system of electrical ignition is always employed on airplane motors. The electrical resistance of the gap at a spark-plug is so great that an extremely high voltage is necessary to force the current across. The flame or spark which accompanies the flow of current across the gap sets fire to the compressed mixture in the cylinder, providing the spark is properly "timed".

B. SOURCES OF ELECTRICAL ENERGY

The source of current may be a "battery", in which electricity is stored and ready for use at any time. Common dry-cells, such as are used with "buzzers", give off current by virtue of chemical action within the cells, but the capacity of a dry-cell is so little that it is not suitable for prolonged use. So-called "storage batteries", in which the action is electrolytic, have much greater capacity, and can be re-charged when exhausted. Electrical energy can be pumped into a storage battery from a dynamo, and used when wanted, just the same as water is pumped into a reservoir on top of a building for use in case of fire. The switch in an electrical circuit corresponds to the valve in a water system. Storage batteries have not been used much in airplanes because of the constant danger of spilling and losing the liquid "electrolyte" (sulphuric acid), but with the increasing demand for self-starters on airplane engines it is probable that electrical systems will be perfected for this work. To start an engine by electrical means, it is necessary to make use of a storage battery; but once an engine is running, the current for ignition and lighting can be supplied by a dynamo.

An electrical generator, or dynamo, acts like a pump, and builds up a certain pressure or voltage which is more or less dependent upon the speed of rotation. If the dynamo is properly connected to a storage battery, it will pump electricity into the battery. A dynamo can also be used for ignition purposes. When current flows continuously in one direction, it is said to be *Direct Current*. Current that flows momentarily in one direction, then in the other, surging back and forth like a pendulum, is called *Alternating Current*. A "magneto" is a special type of alternating current dynamo used for ignition purposes. There are "low tension" and "high tension" magnetos, both identically the same in

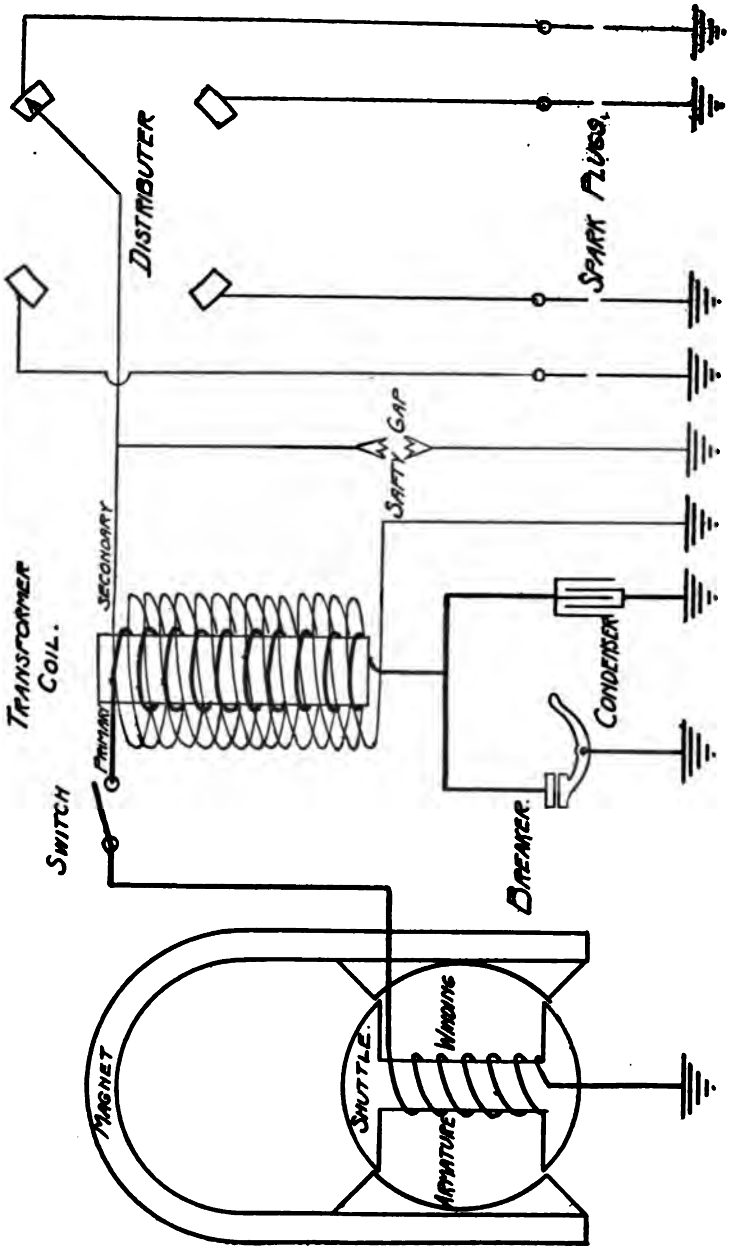


FIG. 307.—JUMP-SPARK LOW-TENSION MAGNETO IGNITION SYSTEM

principle but differing in constructive details. High-tension magnetos are almost invariably used, but for the sake of simplicity the low-tension type will be explained, and then the essential differences pointed out.

C. IGNITION CIRCUITS

The jump-spark system requires a high-tension current at the spark-plug. This gives rise to "primary" and "secondary" circuits in the ignition system. The primary circuit carries a low-voltage current, which is transformed or "stepped-up" to a high voltage in the secondary by means of an induction coil or transformer. This coil consists of a few turns of heavy wire, forming a part of the primary circuit, together with several thousand turns of very fine wire, wrapped around but insulated from the primary, and connected with the secondary circuit. A soft-iron core completes the transformer.

In addition to the primary transformer coil the primary circuit consists of an armature winding, an interrupter or contact breaker, a condenser, and a short-circuiting switch for cutting out the ignition. The secondary circuit includes, besides the transformer coil, the safety spark-gap, and a distributor for connecting in the different spark-plugs in proper sequence. (See Figs. 307, 308 and 309.)

D. MAGNETIC FLUX

When electrical current is caused to flow through a coil of wire around a soft-iron core, a magnetic field is established and the core is given magnetic properties. One end or "pole" of the magnet would point towards the North if free to turn, while the other pole would be attracted simultaneously towards the South. The "flux", or lines of magnetic force, can easily be traced by sprinkling iron filings over a piece of paper in the neighborhood of the electro-magnet. These lines of force practically disappear when the circuit is broken so that the current stops flowing, i.e., the magnetic flux collapses. If the core consists of hardened steel, however, a *permanent* magnet is formed. In an ordinary dynamo, the magnetic field is maintained by field coils wound on iron lugs, but in a magneto permanent magnets are employed.

E. THE ARMATURE

If a closed coil of wire is moved through a magnetic field, so that there is a change in the flux interlinking the coil, a current is induced in the wire. Then if the coil is moved across the field so that the direction of flux through the coil reverses, the flow of current is reversed. The armature of a low-tension magneto consists of a coil of wire rotating between the poles of a horse-shoe magnet and cutting lines of magnetic flux in such a way as to produce an alternating current in the primary circuit. The voltage depends upon the intensity of flux, the number of coils cutting the flux, and the speed of cutting. Both the current and the voltage increase to a maximum, and then decrease to zero and build up to a maximum in the opposite direction, a reversal occuring twice per revolution. The current wave lags behind the voltage because of "inductance". Magnetos are ordinarily arranged to "spark" in the secondary when the current generated in the primary is maximum and the breaker in "advanced" position. A retarded spark, then, is necessarily weaker in case only the breaker-box is moved, but in some magnetos special provision is made to have the spark of equal intensity for all positions (Dixie).

F. THE PRIMARY CIRCUIT

The current generated in the armature windings of a low-tension magneto is carried outside to the primary coil of the transformer. This current establishes a magnetic field around the secondary coil. When the breaker in the primary

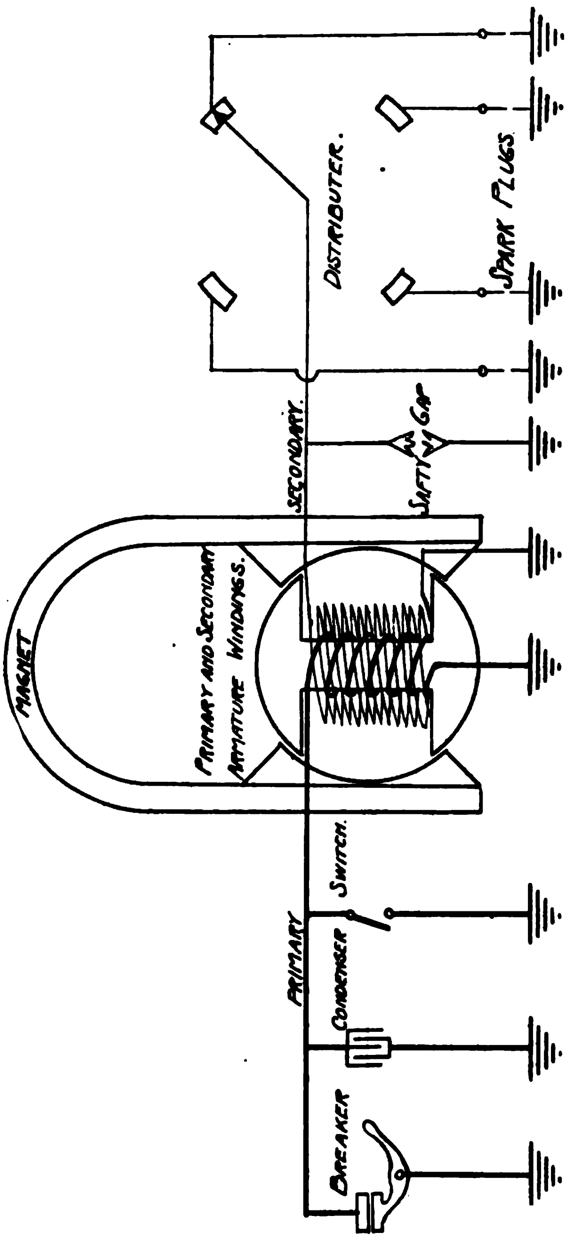


FIG. 308.—HIGH-TENSION MAGNETO IGNITION SYSTEM

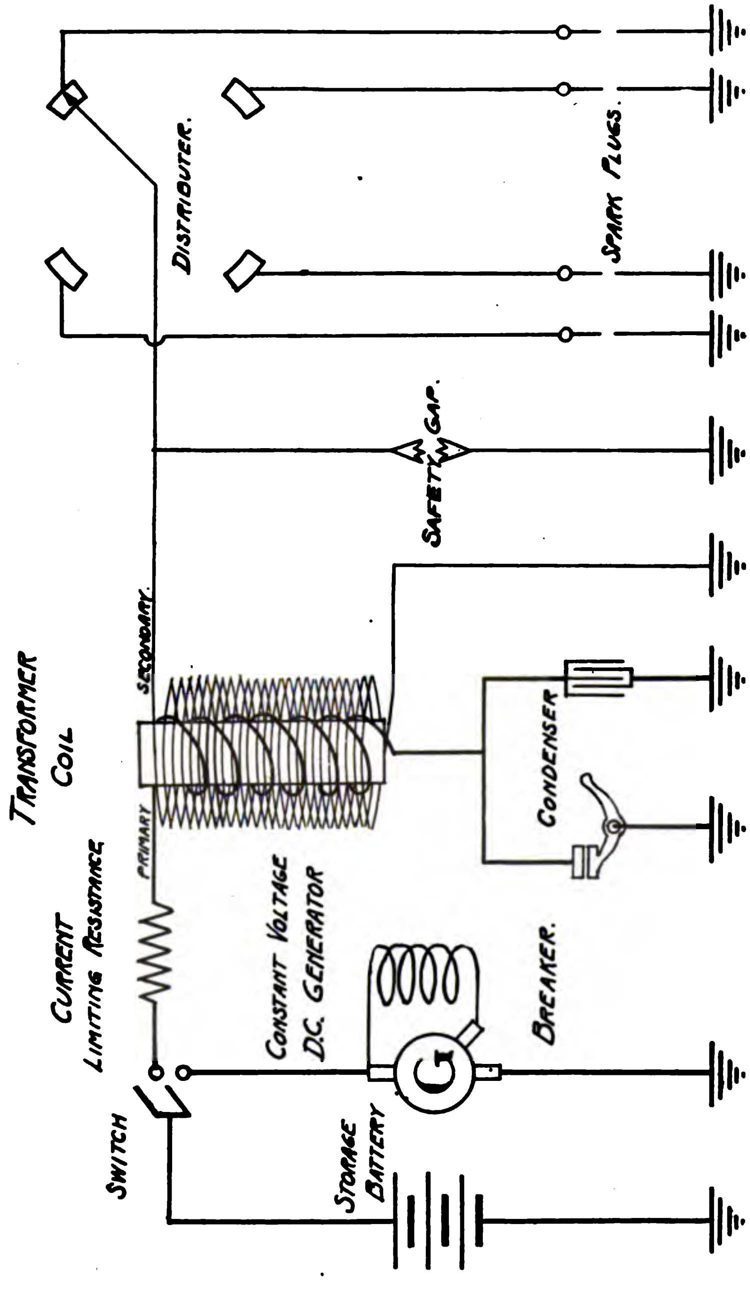


Fig. 309.—Jump-Spark Battery Generator Ignition System

circuit is opened, the current stops flowing and the flux about the coil collapses. In collapsing, the lines of force move with extreme rapidity, and in so doing they "cut" the large number of turns of wire in the secondary coil, which induces an extremely high voltage impulse. The high voltage is sufficient to break down the air gap and cause a current to flow across the gap at the spark-plug.

G. THE CONDENSER

The condenser plays an important part when the primary circuit is interrupted. It consists of several thin metallic plates (tin foil) carefully insulated from one another by mica or waxed paper. Alternate plates connect to one side of the interrupter, the other plates connect to the other side, thereby forming a "parallel" connection. When a "break" occurs, the current tends to keep on flowing because of its inertia, which causes a hot spark between the breaker points if the condenser is not functioning properly. The condenser acts like a shock absorber, absorbing the current abruptly, thereby preventing destructive sparking at the breaker points and at the same time increasing the intensity of the secondary spark by causing more rapid collapse of the flux.

H. SHORT-CIRCUITING SWITCH

Magneto ignition is usually discontinued by short-circuiting the breaker, so that the opening of the points does not interrupt the flow of current in the primary. Thus no high-tension voltage is generated in the secondary because the flux about the coil does not collapse.

I. THE CONTACT BREAKER

The device that interrupts the primary circuit at regular intervals consists of a movable contact point operated by cams, together with a stationary point, all mounted in a housing called the *Breaker-box*. The breaker-box may be stationary around one end of the armature shaft, and the cams integral with the shaft. The spark is advanced by simply moving the breaker-box opposite to the direction of rotation of the cams. One end of the armature coil is grounded while the other end connects to one of the breaker points. The other side of the contact-breaker is connected to the primary coil of the transformer, and the circuit then completed through the ground. In some magnetos the cams remain stationary, and the breaker is fixed rigidly and rotates with the armature. The action is identical to that of fixed breaker and rotating cam.

J. THE SECONDARY CIRCUIT

Current is generated whether a coil of wire crosses a magnetic field or a magnetic field moves past a stationary coil. The action of a transformer corresponds to the latter principle, the flux collapsing across the secondary coils with extreme rapidity and inducing an enormous voltage in the secondary circuit. This voltage is, of course, only momentary, but it is quite sufficient to break down the resistance of the spark-plug gap and produce the desired spark.

K. THE DISTRIBUTOR

The function of the distributor is to make connection with each spark-plug of the engine in proper sequence at the time a spark should occur. It consists of a hard-rubber disk, usually, with as many insulated contact-points as there are cylinders. The contacts are equally spaced in the path of a rotating brush, which turns at a predetermined speed and "distributes" the high-tension current just as the breaker points separate.

L. SPARK-PLUGS

The essential elements of a spark-plug are simply two stationary conductors or electrodes, insulated from each other and separated by a short air-gap about the thickness of a dime. One electrode usually forms the threaded outer shell of the plug, and grounds directly to the cylinder, while the central electrode is insulated by porcelain or mica, both of which have heat-resisting properties. The high-tension cables from the distributor connect to the insulated electrodes of the spark-plug.

M. THE SAFETY SPARK-GAP

If a spark-plug should be disconnected when the magneto is in operation the pressure or voltage in the secondary circuit would tend to become excessive. The safety spark-gap in an ignition system is analogous to the safety valve on a steam boiler. It is simply a ¼ to ½ inch gap, with one side grounded and the other terminal connected to the secondary circuit between the secondary coil and the distributor. It acts as a safe outlet for the induced charge before the voltage can become great enough to break through the insulation of the coils, or damage the condenser by excessive "inductive kick" in the primary.

N. HIGH-TENSION MAGNETOS

A low-tension magneto delivers current at a very low voltage, which requires the use of a spark transformer as a connecting link between the magneto and the spark-plug. In a high-tension magneto, the transformer is integral with the armature, so that high voltage is generated directly. The spark from a high-tension magneto is probably of longer duration than one produced in a high-tension system by a low-tension magneto, because of the voltage induced in the secondary by virtue of the continual flux change in the armature core produced by rotation after the contacts separate.

The armature may either revolve or be stationary. In the latter type, the rotor consists of iron lugs so arranged that every 90 or 180 degrees (depending upon whether it is a "four-spark" or a "two-spark" magneto), the flux flowing through the armature core from the N-pole of the magnet to the S-pole is suddenly reversed. Magnetos provided with stationary armatures are said to be of the "inductor" type. When the rotor comprises iron segments in the form of a sleeve around the armature, the machine is called a *Sleeve Inductor Type Magneto.* One in which the iron rotor operates in conjunction with an external armature core is called *Polar Inductor Type Magneto.* The Dixie is representative of the polar inductor type.

Magnetos in which the armature rotates, as in the Berling and the Bosch, are called *Rotating Armature Type Magnetos.* These require a "collector ring" and brush to take off the secondary current. The brush connects to the rotating arm of the distributor.

O. CONNECTIONS

In all types of magnetos, the primary current flows through the breaker-box, and since this current is of low voltage it is obvious that the contacts of the interrupter must be kept smooth and bright. Poor contact when the points come together, due to rust, grease or corrosion, will cause a large decrease in primary current. This, in turn, affects the voltage induced in the secondary and poor ignition results. All permanent connections in the primary circuit should be soldered, and the breaker points should be smoothed up and adjusted when necessary.

Poor contacts in the secondary circuit are not of much consequence except for heating effect, because the high voltage will jump across any slight obstruction. This very fact, however, is frequently a cause of ignition trouble when foreign matter accumulates either on the spark-plugs or on the distributor and forms a path of low resistance where leakage of current readily occurs. Distributors with little carbon brushes are very apt to foul up in this way, the carbon dust being spread along the path of the rotating arm where it acts as an electrical conductor from one segment to the next. This causes trouble because of the fact that a spark passes more readily in a cylinder that is not under compression.

The spark-gap type of distributor and brush, in which a metal brush is used and so arranged that there is a small air gap between it and the distributor segment, obviates the trouble from "tracking" experienced with the ordinary type of distributor.

4. CLASSIFICATION OF AIRPLANE ENGINES

A. FOUR-STROKE VS. TWO-STROKE

The comparative advantages and disadvantages of four-stroke and two-stroke cycle engines for airplane service were discussed under Part I. There are two-cycle motors in use, the Roberts being a notable example, but in the present stage of development the two-cycle engine is easily outclassed by the more efficient and flexible four-cycle type.

B. AIR-COOLED VS. WATER-COOLED

Air-cooled engines are necessarily of low power. Air cooling, at its best, is far less efficient than water cooling, because of the comparatively low specific heat and the low specific weight of air. With inefficient cooling, cylinders must be smaller in order to prevent overheating. Furthermore, compression in air-cooled engines must be lower in order to avoid pre-ignition. These factors limit the power of a cylinder. Only certain cylinder arrangements will permit of air cooling, because all of the cylinders must be swept by the current of air with equal intensity. The radial cylinder arrangement, in which the cylinders are distributed around a circular crankcase like spokes around the hub of a wheel, is best suited to air cooling, but only a limited number of cylinders can be so arranged. Air-cooled engines are not built in units much larger than 100 horse-power, and are used only for short flights in very light scout and pursuit planes.

C. CLASSIFICATION ACCORDING TO CYLINDER ARRANGEMENT

1. Vertical type Motors of the vertical type have four or six cylinders in line, and are not ordinarily built in sizes much larger than 150 horsepower. More than six cylinders in line is not a practical arrangement, because the additional cylinders would require not only an increase in the length of the crankcase, crankshaft, camshaft, etc., but also greater thickness and weight of the whole length to insure rigidity. Thus the increase in power would not be proportional to the increase in weight, and the resulting weight-power ratio (weight per horsepower) would be too great. The length would also be objectionable in an airplane. For school purposes, and elsewhere where engines of small power are suitable, the vertical type of motor is ideal, because it is less expensive than the more complicated types, it is more economical of fuel and oil, and it is easier to overhaul and adjust. It offers less "head resistance" than any of the other types, so at high speeds of flight less of the power of the engine is wasted in pushing itself through the air. This is a considerable item, when it is realized that the power absorbed in this direction increases with the cube of the velocity. Engines are usually enclosed in streamline housings to minimize air resistance, and a narrow housing naturally offers less resistance to high velocity than one of wider construction. (See Fig. 310.)

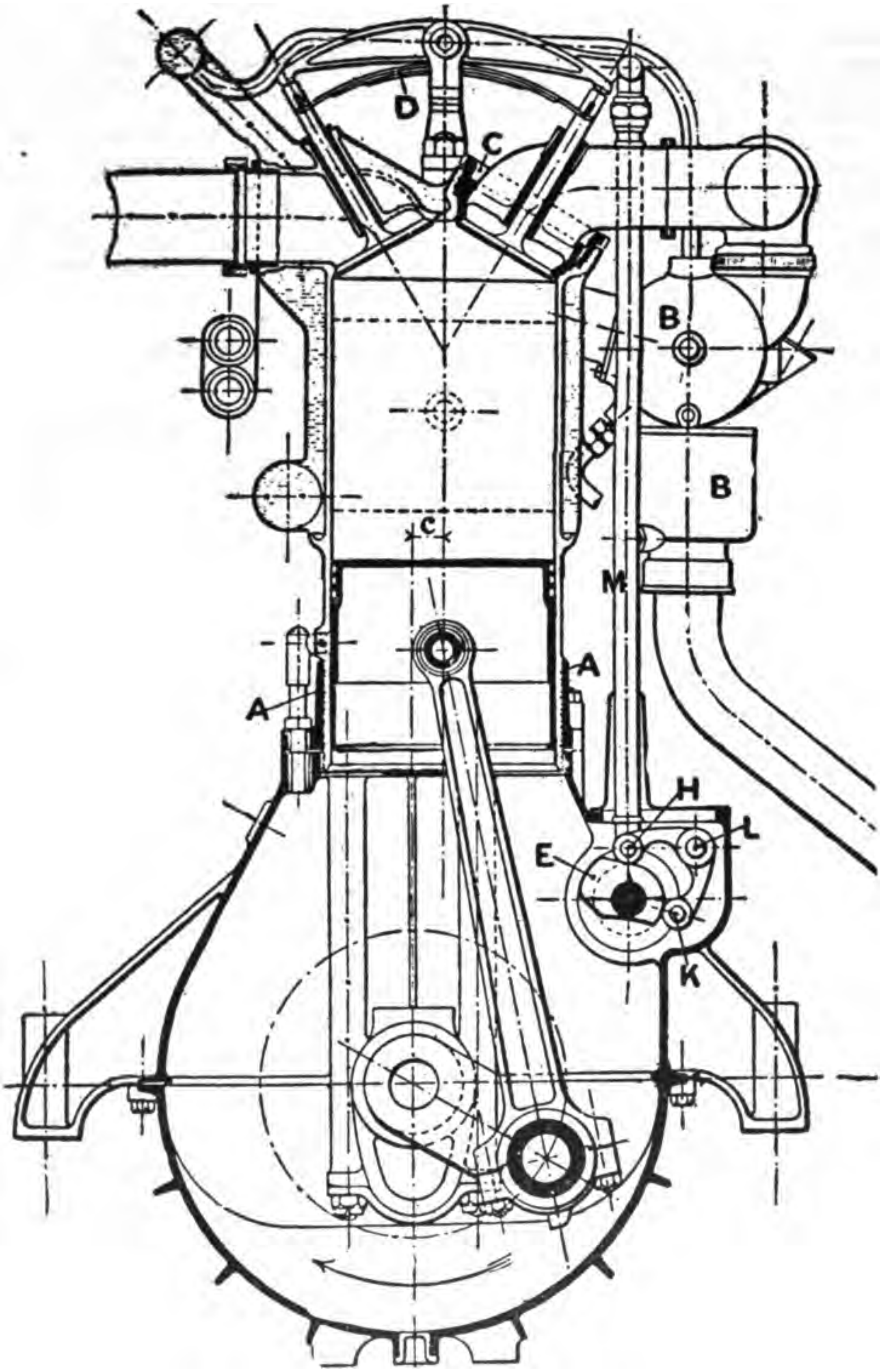


Fig. 310.—Austro-Daimler Aeroplane Engine

This engine has given wonderful service in the present war. It is very similar to the Mercedes-Daimler. At BB can be seen the two water jacketed, annular float feed single spray, nozzle type carburetors, identical in construction and adjustment, and each supplying three cylinders. The interchangeable, cone seated valves below C are each about one-half the cylinder bore in throat diameter and are inclined thirty degrees to the vertical. The exhaust valve seating and stem guides are formed in the combustion head casting and are also water cooled. The inlet valve on the right is in a separate casing fixed in one position by the removable hollow flange nut C. If this cage is removed, the exhaust valve on the left may be withdrawn. A single laminated spring D clamped at the center on the fulcrum post supporting the rocker arms keeps the valves seated. A single push rod positively operates both valves through the use of two cams in conjunction with a bell crank lever. At H the tubular push rod M is pin-connected to the bell-crank HLK, which is pivoted at L. The arms, however, are not coplaner as LH is located behind LK. Cam E actuates roller K, and as it revolves clockwise its plus part strikes K, M descends, and the inlet valve is opened. A similar cam behind E acts on H, the plus part raises M, and thus opens the exhaust valve. Relative proportions may be seen as the diameter of the cylinder is 4.78 inches for the 90 horsepower engine illustrated.—From *The Wisconsin Engineer.*

2. V-type eight and twelve By far the larger number of airplane motors in use today are of the V-type. Cylinders are arranged in two rows, each of four or six cylinders in line, and the two rows placed in V formation. The angle between the V will usually be 60 degrees for a 12-cylinder engine, and 90 degrees for an 8-cylinder, in order to have the explosions occur at regular intervals. Take an 8-cylinder engine, for example, and remember that there must be eight explosions in two revolutions of the crankshaft (720 degrees of crank travel). If equally spaced, the explosions will occur 90 degrees apart. The connecting-rods of any two opposite cylinders are necessarily attached to the same crankpin, and ignition in either of these cylinders must take place as the crankpin approaches the center-line of the cylinder (the amount of ignition advance ahead of center). Therefore, if ignition in the two cylinders is to occur 90 degrees apart, or any multiple of 90, the center-lines of the two cylinders must make an angle of 90 degrees. By similar reasoning it may be shown that the cylinders of a 12-cylinder engine should be set at 60 degrees. The Liberty aviation engine, however, as well as some foreign makes, has cylinders set closer in order to make the engine narrower to decrease head resistance. The period between explosions in such an engine running at 1,700 R.P.M. is so short that one cannot detect the slight irregularity due to the unconventional angle of the cylinders; and it is claimed that the difference can hardly be detected at speeds as low as 500 R.P.M. Another disadvantage of the unconventional arrangement with magneto ignition is that a separate magneto is required for each row of cylinders.

Engines of this class are not unlike the V-type automobile engines in general appearance, but are of far more expensive materials of construction and refined workmanship. The multi-cylinder types produce more frequent working impulses, hence a more uniform flow of power into the crankshaft and less vibration. Until recently, the highest powered motors developed for airplane propulsion were of the 12-cylinder high-speed type. 400 horsepower is not an unusual size, and it is claimed that one engine of this class actually developed over 600 H.P. under test. (See Fig. 311.)

3. Horizontal, opposed-cylinder type These motors, of which the Ashmusen is one of the few survivors, differ from the V-type only by having the cylinders set at an angle of 180 degrees (horizontally). The main advantage lies in the fact that the inertia forces on one side are counterbalanced by equal and opposite inertia forces on the other side, thus making a well-balanced and smooth-running engine. The principal difficulty appears to be the impossibility of uniformly cooling and lubricating the cylinders.

4. Y and broad-arrow types A notable endeavor to increase power capacity and decrease weight per horsepower simultaneously is apparent in the recently developed motors built by the Sunbeam Company in England. They are merely outgrowths of the V-type, made necessary by the constantly increasing demand for more powerful machines. In the Y-type, two rows of four or six cylinders are in standard V formation, and a third row is suspended vertically below, making either a 12- or an 18-cylinder engine. The broad-arrow type differs only in that the third row is placed vertically upright between the two inclined rows, and that oil is carried in the crank chamber.

The lower cylinders of the Y project a short distance into the crankcase, and oil is drained away as fast as it tends to accumulate. The shaft is mounted on ball-bearings, and the arrangement of connecting-rods is similar to the Gnome construction. One rod has a bearing on the crankpin, and

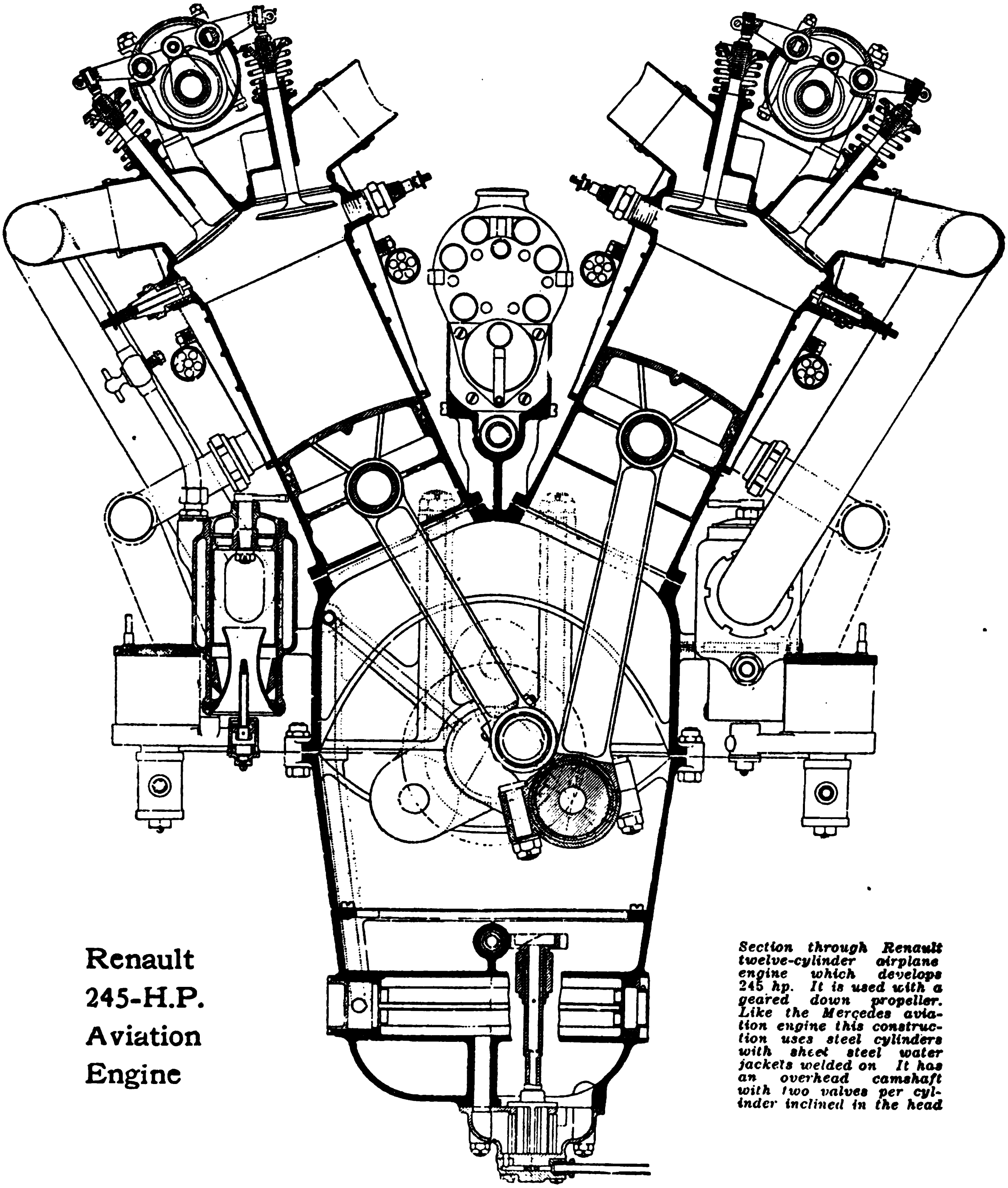


FIG. 311.—SECTIONAL VIEW OF MODERN V-TYPE AIRPLANE ENGINE USED IN FRANCE

the other two rods are pinned to this "master" rod. Details of newly developed motors are guarded with more or less secrecy in times of war, and very little information about these two types is available. It is perfectly obvious, however, that engines of this type may be built to develop over 600 H.P., and a few more months of development may bring out engines with four or five rows of cylinders, each additional row making possible higher power and a lower weight-power ratio.

5. **Radial, stationary cylinder type** In radial engines, the cylinders are grouped in a single plane around a circular crankcase, like spokes in a wheel, either completely around as in the "star" arrangement (Anzani), or the cylinders may all be above the horizontal plane in "fan" form (Masson). In either case, the connecting-rods work jointly upon a single crank throw, one rod serving as a master rod to which the other connecting-rods are attached by individual wrist-pins. By virtue of the shortness of the crankcase, crankshaft and camshaft, and the elimination of a number of intermediate bearings and their supporting webs which would be necessary with the usual tandem construction, the radial form is inherently lighter than any other. It is also adapted to air cooling, which is also conducive to lightness. But in actual service air-cooled radial motors with stationary cylinders will overheat and become distorted to such an extent as to render them useless except for very short flights. The blast of air impinging directly on the front side of a cylinder cools the front side more efficiently than it does the back side, and the temperature difference warps the thin-walled cylinders. There is also the disadvantage that a radial engine must overcome considerable "head resistance" at high speeds of flight, which absorbs a large percentage of the power output of the engine. Because of the shortness of the motor, the mass cannot be distributed fore and aft to any extent and must hang out over the end, which tends to make the airplane "nose heavy." There is also difficulty in lubricating the cylinders uniformly in the star arrangement, which perhaps accounts for the fan form previously mentioned.

6. **Rotary engines** Radial engines in which the cylinders revolve are better suited to air cooling than the stationary radial type, and have practically displaced that type of motor. The circulation of air set up by the motion of the cylinders results in more uniform cooling, and the flywheel effect of the revolving cylinders and the absence of reciprocating motion lead to a smoothness of operation not ordinarily possessed by any other type of gasoline engine. Centrifugal force keeps down the speed of rotation to about 1,200 R.P.M., however, and the power is further limited by low compression necessitated by air cooling, and by the limited number of cylinders that can be arranged around the crankcase. (See Fig. 312.)

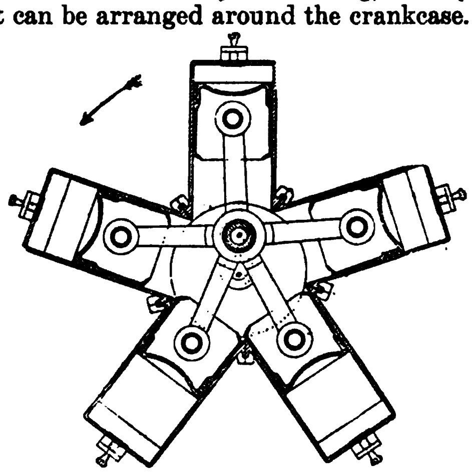


FIG. 312.—GENERAL SCHEME OF ROTARY ENGINES

Radial engines of the four-cycle type must have an odd number of cylinders in order to have firing balance. The cylinders fire alternately so as to distribute the explosions over two revolutions. It can be easily shown that an even number of cylinders, symmetrically arranged, would not fire with regular sequence, and would therefore lack smoothness of running while at the same time the sound would be far from pleasing.

The most decisive disadvantage of a rotary engine is that it is impractical for flights of more than 2 or 3 hours duration, primarily because of overheating, and also because of the excessive fuel and oil consumption. An economical stationary engine will not use more than 0.55 pound of gasoline per horsepower-hour (about ¾ pint), while a rotary engine usually consumes nearly twice that amount. Rotary engines, as a rule, use castor oil for lubricating purposes; and due to the fact that ample lubrication must be provided at all times, and because, on account of centrifugal force, the oil is necessarily wasted instead of being circulated over and over again, the amount of oil used in a rotary engine exceeds that of a stationary water-cooled engine by 5 to 8 times. The water-cooled engine uses about 0.03 pounds of oil per horsepower-hour, while the rotary engine requires about 0.18 pounds per horsepower-hour.

To illustrate by an example, suppose it is required to determine which of the two above-mentioned types would be more suitable for a flight of three hours in a 100 H.P. machine, if the rotary engine weighs 240 pounds and the stationary engine weighs (with cooling water) 425 pounds. From the economy data given in the preceding paragraph, the water-cooled engine would require 165 pounds of gasoline and 9 pounds of oil, making a total weight of 599 pounds, fully equipped for the flight. The rotary engine, on the other hand, would require about 330 pounds of gasoline and 54 pounds of oil, which added to the weight of the engine itself makes the aggregate weight 624 pounds. Another similar example is presented graphically in Fig. 313, which shows that a heavy economical engine is "lighter in the long run" than a rotary.

The poor fuel economy of rotary engines may be partially attributed to low compression, which results in a very low M.E.P. Then approximately 10 per cent of the power developed by the gas is used in turning the cylinders over against air resistance (not head-resistance), which detracts from fuel economy since fuel consumption is based on rated or delivered power. In the single-valve Gnome engine, which will be described in detail later, the early release of the expanding gas, made necessary by the unique method of operation, lowers the M.E.P. and power developed from a given weight of fuel.

Other disadvantages of the rotary type of motor might include such things as difficulty in making adjustments, frequent fouling of spark-plugs by lubricating oil and carbon, need of overhauling after 15 to 25 hours of service, large head-resistance, difficulty in shooting past a revolving engine, gyroscopic effect, impossibility of using a muffler, a tendency for exhaust gas and oil to sweep back towards the pilot, smoke obstructs his view, etc.

5. TYPES OF ROTARY MOTORS

A. CLERGET

Modern rotary engines invariably operate on the four-stroke cycle principle and are usually constructed with either 7 or 9 cylinders. The Clerget is representative of the type in which the intake and the exhaust valves are located in the cylinder head and both mechanically operated. The valve mechanisms are driven independently by two eccentrics, which is a distinctive

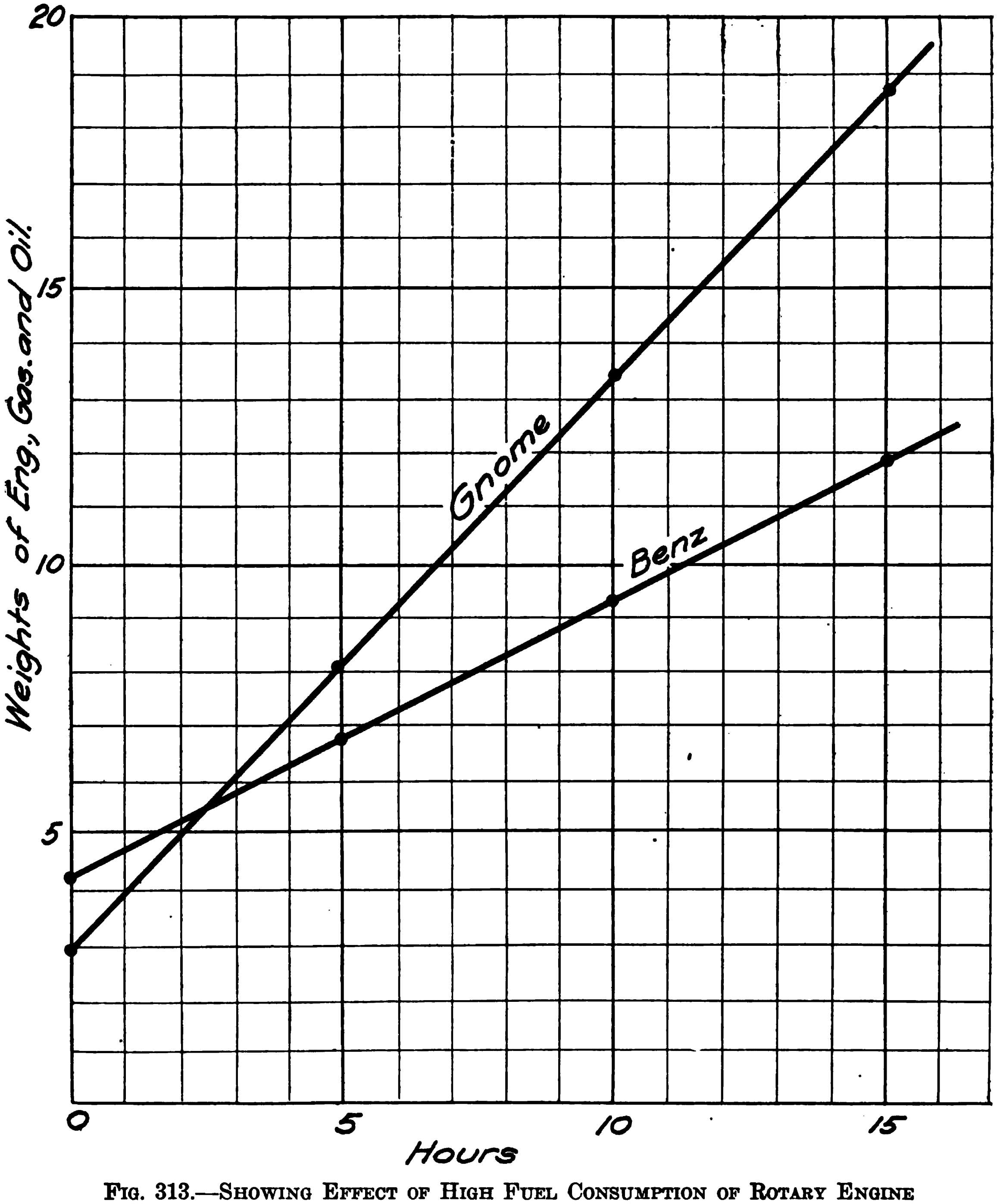


Fig. 313.—Showing Effect of High Fuel Consumption of Rotary Engine

feature of this motor. The 7-cylinder model, with bore of 120 mm. and stroke of 160 mm., is rated at 90 H.P. and weighs 280 pounds. The 9-cylinder model, having the same size cylinders, weighs 350 pounds and is rated at 120 H.P. The engine operates upon a single crank, and the hollow shaft serves as an induction tube. Ignition is by two high-tension magnetos. The pistons are of aluminum alloy. Clerget motors are used largely in Sopwith planes.

B. LE RHONE

This engine is being manufactured in sizes varying from 60 to 150 H.P. as follows:

Rated H.P. at 1200 R.P.M.	60	80	110	150
Number of cylinders	7	9	9	9
Bore, mm.	105	105	112	124
Stroke, mm.	140	140	170	180
Weight, pounds	199	240	308	360

The steel cylinders have cast-iron liners, and are screwed into a steel crankcase. There are two valves per cylinder, seating in the cylinder head. Induction is via crankshaft to crankcase and via external copper pipe from crankcase to cylinder head. Forced lubrication is employed. It is stated that these engines consume 0.72 pints of fuel and 0.1 pint of oil per B.H.P.-hour. Le Rhone engines are employed in Nieuport scouts.

C. GNOME

The main difference between the original Gnome and the Clerget or the Rhone lies in the scheme whereby the gaseous mixture is taken into the cylinders. The intake valve for each cylinder is located in the head of the piston, and is of the automatic type. The exhaust valve is in the cylinder head, and mechanically operated by pushrod and rocker-arm mechanism. The engine operates as follows:

The exhaust valve closes 13 degrees past top center, and as the piston is drawn away from the cylinder head a slight vacuum in the combustion chamber opens the intake valve and sucks in fresh mixture from the crankcase. At the end of the suction stroke, the intake valve automatically closes and compression begins. Ignition takes place 26 degrees before top center, this advance being necessary to secure maximum pressure within the cylinder early on the power stroke. The exhaust valve opens when the piston has gone only three-quarters of its stroke, or about 65 degrees before bottom center.

The head of the piston is bored out to receive the two pieces that make up the piston-pin bosses and the valve seat respectively. A leaf spring, with a hole through the center for the valve stem, is attached at the ends to small weighted levers calculated to give balance against centrifugal force. This is naturally a delicate mechanism, and one that readily gives trouble. The valve is removable through the cylinder head by the use of special tools, after first dismounting the exhaust valve and its seat.

D. "MONOSOUPAPE" GNOME

The Gnome engine described in the preceding paragraphs has practically gone out of existence. The Rhone, manufactured by the Gnome Company since the beginning of the war, is a very successful type; but at the present time there seems to be a great demand for the latest type Gnome, which has but one valve and is of extremely light construction. The 9-cylinder model, as manufactured in this country and abroad, is rated at 100 H.P. at 1200 R.P.M., and weighs but 2.7 pounds per horsepower. The finished cylinder, machined from a solid bar of forged steel, is about 1/16-inch thick and weighs only 5½ pounds; the finished distribution-case to which the cylinders are attached weighs but 15½ pounds; the "mother" rod, that odd looking integral piece to which are secured the other eight connecting-rods, weighs 5½ pounds. The entire engine calls for extremely choice alloy steels and fine workmanship.

The construction of the 7-cylinder 80-horsepower engine is practically the same as that of the 9-cylinder type. The bore and stroke are the same, viz., 110 mm. and 150 mm., respectively. The cylinders, valves, etc., of both types are interchangeable.

The crankcase of the engine is made in two halves, fastened together by bolts, the two halves clasping the cylinders in a groove at their base. The cylinders are prevented from turning in the crankcase by keys. Each cylinder is drilled near the bottom with a number of circular ports connecting the interior of the crankcase with the cylinder. The ports are uncovered by the piston near the bottom of the stroke, permitting a passage from the crankcase to the cylinder. The exhaust valve and seating is fixed at the extreme outer end of each cylinder by means of a castellated ring nut. The weight of this valve is so adjusted that its centrifugal action, when the engine is rotating, is equal to that of the tappet-rod and lever; and thus the use of counterbalance weights, such as are fitted to the rocking levers of the ordinary Gnome engine, is avoided. The exhaust valves are operated by long push-rods from the cam-box situated in front of the crankcase, the cams operating these rods through tappet-rollers.

The pistons are of cast-iron, and each has a portion of the trailing edge cut away to prevent interference. A thin brass "obturator" ring, of L-section, is fitted onto the head of the piston, and is kept pressed out against the cylinder wall by an auxiliary steel expansion ring. The gas pressure above the piston forces the thin brass ring against the cylinder walls and prevents leakage, even with the cylinder slightly distorted. The obturator-ring gap goes on the leading edge of the piston because the gases have a greater tendency to escape along the trailing edge. The clearance between cylinders and pistons is 5 or 6 thousandths of an inch.

The connecting-rods are of nickel steel, H-section. One of the rods, called the "master rod" (sometimes called "mother rod"), is mounted on ball-bearings on the crankpin, the outer ball-races being fitted into L-section rings integral with the rod. These rings are bored to receive the hollow steel wrist-pins upon which the other connecting-rods oscillate. Obviously the auxiliary rods are somewhat shorter than the master rod, but the difference does not appear to have any noticeable influence on the running of the motor.

The crankshaft is of built-up construction to enable mounting the master rod onto the crankpin. The 7- and 9-cylinder models use a single-throw shaft, but in the 14-cylinder model, which has two sets of cylinders, there are two throws at 180 degrees. The shaft is stationary, being held thus by a key and two bearer-plates at the rear end extension. The revolving part of the engine is mounted on large ball-bearings, and a ball thrust-bearing transmits the push or pull of the propeller, through the stationary shaft and its supports, to the plane.

The smaller part of the crankshaft can be dismantled from the front of the engine after the front cover or cam-box has been removed. This part of the shaft acts as a bearing for the cam-sleeve and the cover holds the cam-follower guides. The propeller hub is bolted to a nose-piece attached to the cam-box. The main part of the crankshaft has a long extension to the rear whereby the engine is supported in bearers attached to the airplane. The shaft is hollow for lightness and to admit air to the crankcase. It also carries the gasoline and oil pipes, the former terminating in several minute holes just inside the crankcase for the purpose of spraying the gasoline to break it up as much as possible. This spray is pointed downwards in the direction of flow of mixture towards the opening ports. The amount of air admitted to the crankcase is not sufficient to render the resulting mixture combustible. This is an important improvement, because a great deal of trouble from backfire was experienced in former rotary engines that took a combustible mixture into the crankcase.

The cam-block has a bearing on the stationary crankshaft, and is driven by satellite gearing. A fixed timing gear keyed to the shaft meshes with a planet or satellite gear of the same size pivoted to the revolving cam housing. A smaller integral planetary gear meshes with the cam-sleeve gear, the latter being twice the size of the former, which gives the half-speed motion to the cams. If one attempts to trace out the direction of rotation from a sketch, it almost appears as if the cams must go backwards; but as a matter of fact the cylinders and the satellite gears are revolving and the apparent "backward" motion of the cams is only relative, and is really the retarding action of the two-to-one gearing.

The thrust-box on the opposite side of the crankcase from the valve-operating mechanism carries a distributor, and a gear for driving the magneto and the oil pump. The magneto and the pump are mounted on the stationary bearer-plate by which the engine is supported. The distributor has an insulated brass segment for each cylinder, connected to the spark-plug by a bare wire. The high-tension current is led to the distributor through a stationary contact brush.

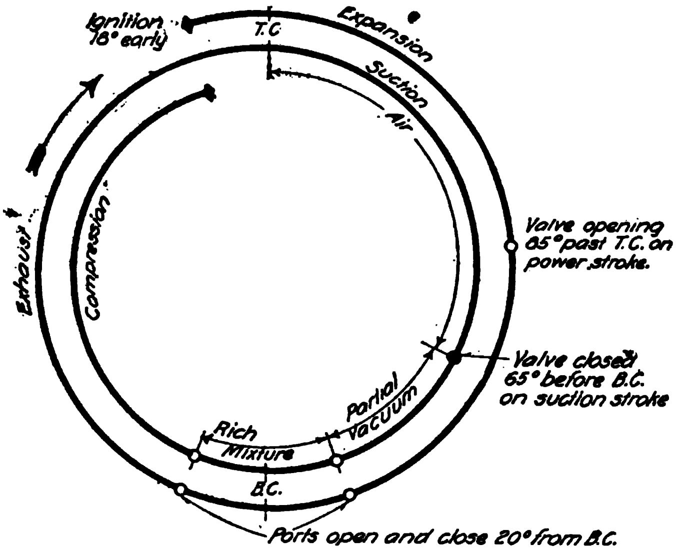


FIG. 314.—TIMING DIAGRAM OF "MONOSOUPAPE" GNOME

The engine works on a four-stroke cycle principle, as follows: Consider a cylinder in which the piston is on the compression stroke and follow the engine through two revolutions. (See timing diagram, Fig. 314)

1. **Ignition,** which is "fixed", is set to take place about 18 degrees before top dead-center, i.e., before the cylinder reaches the upright position.

2. **Working stroke** From top center, the piston recedes from the cylinder head on the expansion or power stroke. When the cylinder has turned through 85 degrees from top center (piston in mid-stroke), the valve in the head starts to open and the expanding gas is gradually released. The working stroke continues, however, until approximately 20 degrees before bottom center, the presumption being that the pressure within the cylinder

has become just equal to crankcase pressure (approximately atmospheric) at the time the ports are uncovered. The early opening of the valve is a contributory cause of the low M.E.P. obtained with this engine, but is necessary in order to avoid a pressure difference at the end of the stroke which would be sufficient to eject burned gases into the crankcase through the ports.

3. **Exhaust stroke** During the entire up-stroke of the piston, burned gas not previously discharged is pushed out of the cylinder. This scavenging action is assisted to a slight extent by centrifugal force acting on the gas.

4. **Induction stroke** The valve does *not* close at the end of the exhaust stroke, but remains open for 120 degrees of the down-stroke (three-quarters of the piston travel) to admit air. After the valve is closed, the descending piston reduces the pressure within the cylinder, and this partial vacuum causes transfer of the rich mixture from the crankcase when the piston uncovers the ports. The rich gas mixes with the air previously taken into the cylinder, and is thereby rendered combustible.

5. **Compression stroke** The ports are covered 20 degrees after bottom center, and compression then begins.

Ignition is by means of a high-tension Dixie magneto, mounted on the forward bearer plate and driven by gearing from the revolving crankcase. The spark is delivered from the magneto to a stationary contact-point bearing against the main distributor. An uncovered brass wire connects each distributor segment with the spark-plug of the corresponding cylinder. The distributor turns with the crankcase, and therefore makes contact for each cylinder every revolution, but the magneto is timed to spark for each cylinder only once in two revolutions when the spark is needed.

Lubrication is by means of a double plunger pump, and the oilway system is similar to that of the 80-H.P. Gnome engine. There are two leads from the pump, which supplies oil at about 5 pounds pressure, and each pipe has a branch connection to a pulsator glass in front of the pilot. The oil is conducted by one lead through the stationary hollow crankshaft to the cam-sleeve bearing and the timing gears at the front of the engine. Holes through the cams permit the oil to pass out to the cam-rollers, which pick it up and throw it into the hollow tappet. Centrifugal force carries the oil to the outer ends of the push rods, lubricating the tappet guides and all joints of the push-rods and rocker-arms, after which it is wasted. A branch connection at the rear end feeds a small amount of oil to the thrust bearing and the rear main bearing, after which the oil works out along the crankcase to the cylinder walls.

The second lead also enters the hollow crankshaft, but has its outlet at the crankpin. This oil is conducted through holes in the master rod to the various wrist-pin bearings of the other connecting-rods. From the wrist-pin bearing the oil passes through holes and out along the rod to the piston-pin bearing. Overflow from this bearing is collected in circular troughs at the sides of the bearing, and led to the piston ring and cylinder wall through holes drilled in the webs of the piston. Centrifugal force continues to carry the oil outward, and some carbonizes in the combustion chamber while the remainder passes out with the exhaust, impinging on and lubricating the valve stem. Castor oil is used, and once used it is wasted.

The speed is controlled through a limited range by simply manipulating the gasoline shut-off valve.

The characteristics of the "Monosoupape" engine, as compared with the ordinary Gnome engine, are:

a. Absence of inlet valves.
b. Solid piston heads.
c. No carburetor.
d. Non-explosive mixture in the crankcase.

The inlet valve on the older Gnome, besides adding weight to the rotating mass, was a constant source of trouble. Being inaccessible, accurate adjustments could not be made readily, and adjustments were often affected by heat and oil. Introduction of the gasoline spray directly into the crankcase does away with the carburetor and makes possible operation of the engine in any position. By limiting the amount of air admitted to the crankcase, the mixture is kept too rich to ignite until it gets into the cylinder and is mixed with the proper amount of air, and therefore "back-firing" is entirely avoided.

It should be noted in connection with rotary engines that the "reciprocating motion" of the pistons is purely relative to the cylinders, since both cylinders and pistons revolve about fixed centers. The path of the cylinders is eccentric to the path of the pistons by an amount equal to the "throw" of the crankshaft, or one-half of the apparent stroke of the piston. (See Fig. 312, page 325)

6. ESSENTIAL REQUIREMENTS AND ALLIED FACTORS

The three principal requirements of an airplane engine may be briefly summed up as follows:

1. Low weight-power ratio, which means lightness in proportion to power delivered.
2. Economy of fuel and oil, so as to obtain the maximum possible radius of action with a given quantity.
3. Absolute reliability, since no repairs can be made during flight.

In the demand for low weight per horsepower, the requirement of low fuel and oil consumption per horsepower-hour is included, since for practical purposes it is necessary to carry enough fuel for a running time of several hours. For long continuous flights, an inherently light engine may easily prove inferior to one of heavier construction, providing the latter has a better fuel efficiency. This matter has already been discussed in connection with rotary engines.

Hand in hand with reliability goes the demand for durability. An airplane engine runs almost continuously under full load, and deficient operation, however slight, can not be tolerated. A decrease in speed of only a few revolutions below normal is often quite sufficient to bring about a forced landing, which, should it occur at an inopportune moment, might be attended with disastrous consequences.

A. FACTORS THAT AFFECT POWER AND WEIGHT

Referring to the formula for indicated power, it becomes evident that the power transmitted to the piston by the working medium will depend upon the M.E.P., the piston displacement, and the speed of the engine. The power that is actually delivered to the propeller will also depend upon the mechanical efficiency of the engine.

Obviously the larger the volume of piston displacement per cylinder, the greater will be the power capacity of the engine. The diameter of a cylinder is limited in high-speed engines by cooling difficulties and inertia of the reciprocating parts, while the stroke is fixed by the allowable piston speed.

Rotative speeds of different airplane engines vary from 1,200 to 2,500 revolutions per minute. Propellers work most efficiently at 1,200 to 1,400 R.P.M., and engines that have propellers attached directly to an extension of the crankshaft must necessarily operate at speeds best suited for propeller efficiency. Higher speed engines, when properly designed and constructed, develop more power for the same displacement and engine weight; but the propellers used with such engines must be "geared down", and are larger to absorb the increased power. The maximum value of engine speed is limited largely by the inertia stresses of the reciprocating parts of the engine, and obviously these stresses have to be considered in conjunction with those resulting from the gas pressure. The whipping action of a connecting-rod tends to bend the rod every time its direction of motion is reversed, and this introduces large bending-moment stresses. Small unbalanced centrifugal forces in a rotating crankshaft are quite sufficient to bend the shaft at high rotative speeds and cause vibration, friction, and excessive wear in the shaft bearings. With high speeds, cooling and lubrication become more difficult because of the greater amount of heat liberated to the cylinder walls in a given time by the burning gas, and the increased velocity between rubbing surfaces. The rapidity with which valves must be opened and closed also limits the practical speed. Needless to say, the wear and tear of an engine running continuously at even ordinary propeller speed is not favorable to smoothness nor reliability of running, and it is taxing the ingenuity of designers and manufacturers to produce engines that will stand up in service for sufficiently long periods to be practical in modern warfare. The life of an airplane engine is short, and frequent overhauling is necessary; but in spite of adverse limitations, the tendency seems to be towards higher engine speeds and geared-down propellers.

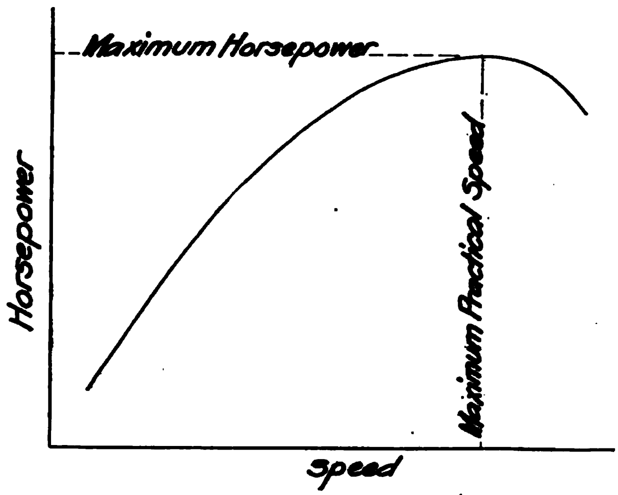


FIG. 315.—USUAL FORM OF POWER CURVE

Fig. 315 shows a typical horsepower-speed curve of an airplane engine. Note that as the speed increases the power increases less and less rapidly, and that finally a speed is reached at which the power is maximum. This curvature is explained by the fact that at high speeds the M.E.P. is reduced by lowered volumetric efficiency and insufficient time for proper completion of combustion. The practical operating speed is always somewhat less than the maximum shown by the curve, because near the peak it requires a large increase in speed to get but little increase in power, and the additional wear and tear more than offsets the gain.

There is no question about the desirability of increasing the M.E.P. factor. High compression and more complete expansion tend to increase the efficiency of combustion; but there are certain limiting conditions beyond which it is impractical to go. Compression of a gas is accompanied by a rise in temperature, and the limit of compression is reached when the heat of compression causes spontaneous pre-ignition of the combustible mixture. The usual compression for mixtures of gasoline vapor and air is about 90 pounds per square inch, although aircraft engines are being used with compression pressures as high as 130 pounds per square inch. Small cylinders and efficient cooling make high compressions possible.

The time necessary for complete combustion in an engine cylinder depends upon the character of the hydrocarbon fuel, the proportion of fuel to air, the amount of compression, the initial temperature, the homogeneity of the mixture, the cooling effect of the surfaces in contact, and various other things. This relative slowness of burning after ignition requires what is commonly known as "spark advance", which means making ignition occur some time previous to the end of the compression stroke, the amount of advance depending largely upon the speed of the engine.

The theoretical temperature of combustion is never even closely approached in an internal combustion engine. The maximum temperature permissible depends upon the ability of the lubricating oil to withstand heat and function properly. Pre-ignition is also a limiting factor. To keep the temperature from becoming excessive, it is always necessary to artificially cool the cylinders, either by forced air circulation or by water. Water is much more efficient for the purpose, because of its higher specific heat and greater density. The heat removed by the cooling medium represents a direct loss in heat efficiency, but as just explained, cooling is a necessary evil without which the engine could not run. Another source of heat loss equally as considerate is the hot exhaust gas, which leaves the cylinder before complete expansion and at a very high temperature. At least 75 or 80 per cent of original heat-energy of the fuel is wasted in making it practical to transform the other 20 or 25 per cent into mechanical work. *Thermal Efficiency* is the ratio of the heat transformed into work divided by the original heat content of the fuel used. True thermal efficiency would be that based on the indicated power, but frequently it is more convenient to use the rated power, which is approximately the delivered power in any case. A pound of gasoline has a thermal value of about 20,000 B.T.U.

There are a number of other items that directly affect the M.E.P. within the cylinder, and these logically divide themselves into two classes:

1. Those that decrease the weight of the cylinder charge.
2. Improper treatment of fuel charges.

1. Causes of decreased weight of charge It will be at once apparent that all of the causes of reduced volumetric efficiency simultaneously reduce the M.E.P. by diminishing the weight of charge. Some of the causes of lowered volumetric efficiency are as follows:

a. Resistance to flow of gases into or out of the cylinder, due to small or crooked intake passages and small valve openings, requires a greater difference of pressure to overcome the inertia of the gases and induce flow at high velocity, which during suction rarefies the gas within the cylinder and results in a smaller weight of charge. This would be indicated on the pressure diagram by a low suction line. With a high exhaust line, the dead gas in the clearance space at the end of the stroke must expand before suction can begin, which shortens the period of suction. Mufflers also increase back-pressure.

b. Heating by hot clearance gases and cylinder walls expands the incoming mixture and decreases its specific weight.

c. Improperly set valves affect volumetric efficiency. Too early closure of exhaust valve, for example, shuts in burned gas that would otherwise escape and make room for fresh mixture. If this valve closes too late, on the other hand, the suction immediately preceding would draw some inert gas back into the cylinder. The exhaust valve should close at the time the pressure within the cylinder reaches atmospheric, somewhat after the beginning of the suction stroke, in order to allow maximum scavenging effect. The intake valve should open almost immediately after the exhaust closes, a brief interval intervening in some cases to allow for slight inaccuracies in setting and adjustments. It is equally important that for best volumetric efficiency the intake valve should close when the pressure within the cylinder reaches atmospheric on the compression stroke. Until that time, gas will continue to flow in because of the difference of pressure; but if the valve remained open any longer there would be expulsion of combustible gas and reduced compression. The point of exhaust-valve opening has no effect on volumetric efficiency, and is considered under Class 2. (See diagram, Fig. 316.)

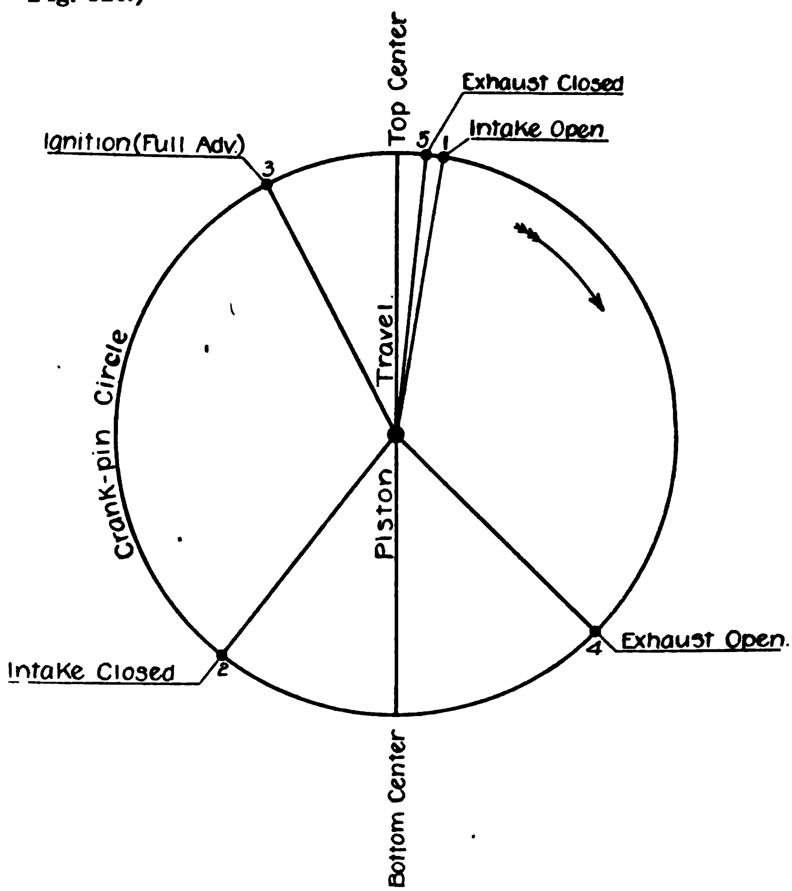


FIG. 316.—TYPICAL VALVE-TIMING DIAGRAM

d. Improper valve clearance, if too much, decreases the valve lift and shortens the period of valve opening. In addition to increasing the resistance to flow, the valve timing is affected, which in turn affects the volumetric efficiency as explained in the preceding paragraph. Too little valve clearance results in early valve opening and late closing. The clearance should be on the order of a few thousandths of an inch, and account must always be taken of the fact that expansion of the engine in heating up affects the clearance adjustment. The purpose of clearance is to permit free expansion and contraction between the cylinder and valve-actuating mechanism.

e. Worm cams result in improper valve action, giving very much the same effect as too much valve clearance. The only remedy is a new camshaft.

f. Weak valve springs will not close the valves quickly, and at high speeds this is a source of considerable loss in power. Stiff springs, on the other hand, increase the resistance to opening and reduce the mechanical efficiency of the engine. Four-valve construction makes lighter valves and lighter springs possible, besides offering larger openings. The spring on an automatic suction valve, as used with crankcase compression in a two-cycle engine, offers resistance to flow and reduces volumetric efficiency.

g. Too high a speed, requiring large differences of pressure to inhale or exhaust the gases in the allotted time, results in low volumetric efficiency. The amount of valve lift cannot ordinarily be as great at high speed because of the inertia of the valve.

Changes in atmospheric conditions, as, for example, decreased barometric pressure at high altitudes, affect the weight of charge taken into an engine cylinder and therefore affect the M.E.P. But the volumetric efficiency is not necessarily affected by atmospheric changes, for obviously it would not be consistent to brand an engine deficient when its power is reduced by some purely external agency.

2. Improper treatment of fuel charges Under this class may be mentioned the following causes of reduced M.E.P.:

a. Leaks, causing loss of compression and waste of fuel, may be due to a variety of causes. A little carbon on the valve seat may prevent the valve from closing tightly, or the valve may become permanently warped from excessive heat. Worn cylinders, scored cylinders, and broken or worn piston-rings, are often contributory causes of leakage.

b. Incomplete vaporization or improper mixture of gasoline and air due to faulty carburetor adjustment or inleakage of air at a manifold joint, results in inefficient combustion.

c. Improper ignition To obtain high M.E.P. with high engine speeds, it becomes necessary to use the highest grade of spark-plugs, to have a good spark at each, and to ignite the compressed charge at more than one point. Two-point ignition is common practice in airplane engines. It is also essential that the proper "spark advance" be given. Too early ignition is evidenced by "knocking" and loss of power; late ignition is followed by retarded combustion, loss of power, and overheating. The point of maximum pressure should occur soon after the piston starts out on the working stroke. Retarded combustion always tends to overheat an engine because of the additional surface exposed to flame when the piston is further down on its stroke.

d. Insufficient compression pressure, as previously explained, affects the efficiency of combustion and the M. E. P.

e. Too early release of the burned gases, thus shortening the period of full expansion and throwing away energy that might have been utilized.

f. Poor form of combustion chamber, or clearance space, as has been proved by numerous experiments, causes slow burning, greater heat loss during combustion, and consequently low M.E.P.

The factors heretofore mentioned affect the power applied to the face of the piston by the expanding gas. Mechanical losses within the engine merely subtract from the indicated power, and in that way affect only the power delivered to the propeller. Friction between the piston and the cylinder wall, and in the crankshaft bearings, together with the power required to drive the camshaft and auxiliary parts of the engine, make up most of the mechanical losses. Some power is lost in turning the crankshaft at high velocity within the crankcase against air resistance, and in the case of geared-down propellers there is some loss in the gearing. A short connecting-rod increases the side-thrust against the cylinder wall, and causes greater friction and more rapid wear. Tight bearings, or bearings not properly lubricated, also decrease the mechanical efficiency. A shaft that is not accurately balanced, or one that is not perfectly straight, throws itself out against the bearings at high speeds and causes excessive vibration, and consequently increased friction and wear. Heavy reciprocating parts, the inertia of which must be overcome and reversed twice every revolution, cause vibration and stress in the connecting parts at high speeds of rotation, and heavy pressure on the bearings. Stiff valve springs, which are necessary on high speed engines for closing the valves quickly, increase the power required to drive the camshaft. The use of two or more magnetos and oil pumps adds materially to the mechanical operation losses.

Lubrication of an airplane engine must at all times be positive and uniform. Only high pressure, forced circulation of large quantities of oil, will permit continuous operation of an engine at full speed for several hours at a time. Oil is supplied from a pump at a pressure of 50 or 60 pounds per square inch, perhaps, and the bearing surfaces are thus actually held apart by the thin film of oil maintained between them. The oil is often circulated from one bearing to the next, and for that reason bearings must have sufficient and uniform clearance, and the oil must be of proper viscosity. A tight bearing will exclude the oil, or throttle the pressure in such a way as to prevent the proper amount from flowing on to other parts of the engine. Too much looseness will have the same effect, because the oil will simply take the path of least resistance and leak out around the sides of the bearing. A thick oil, because of its high viscosity, will not flow freely, while an oil that is too thin will not maintain a film between the bearing surfaces under high bearing pressures even though it flows in copious quantities. An oil that appears heavy and viscuous when cold usually thins down very materially when heated up to the operating temperature, and it is always important that the oil retain enough "body" when hot so that the oil film will not be destroyed.

3. **The weight factor** It is perfectly obvious that an airplane engine must be as light as possible, in order to have greater load-carrying capacity, or higher speed and better climbing ability. To move swiftly with reference to the earth in the face of an opposing wind requires a very high speed relative to the sustaining medium and consequently a powerful motor. The horsepower available for climbing is the power output minus the power consumed in horizontal flight, and the latter varies directly as the weight of the machine. A light motor is therefore essential, which is the reason why the gasoline engine monopolizes the aviation field.

Lightness is attained largely by designing for maximum M.E.P. at the maximum feasible speed, and by the intelligent use of materials of selected kinds and cross-sections. Alloy steels, properly heat-treated, are nearly five times as strong as ordinary cast steel, and are used for crankshafts, connecting-rods, and other highly stressed parts. Aluminum alloy and sheet metal are used for parts that need not possess much strength, such as water-jackets, crankcases, pumps, and manifolds. Cylinders are often of cast aluminum alloy, but need to be lined with an iron or steel shell to give the necessary strength and wearing qualities. Pistons for airplane motors are almost invariably made of aluminum composition, known variously as Magnalite, Lynite, etc. Copper, forming about 8 per cent, is usually the alloying material, although zinc is used to a slight extent and in some cases nickel is a constituent. Aluminum is advantageous mainly because of its lightness and superior heat-conductivity, although the fact that it will not rust is important, and it makes a satisfactory bearing for piston-pins without being bushed. The main difficulty that has limited its usefulness is in properly providing for differences of expansion, since the coefficient of expansion is so high. It expands twice as much as iron or steel for a given temperature change, which practically precludes its use for large block castings. Fortunately, in using steel liners with cast aluminum outer walls, the latter are in contact with the cooling water while the steel sleeve is in direct contact with the hot gases, which practically equalizes the expansion. When aluminum is used for cylinder heads, it becomes necessary to provide iron valve-seats, because aluminum is too soft and malleable to stand up under the constant hammering of a valve. There are three ways of providing iron seats, namely: (1) casting an iron ring integral with the aluminum cylinder head; (2) threading the iron ring and screwing it into place; or (3) using a separate valve-cage, which has the valve seat and the stem guide integral. Passages for oil through aluminum castings need to be lined with steel tubes, to prevent high-pressure oil from breaking through porous places. Threads in aluminum are apt to cut out or shear unless a permanent steel insert is provided. Added to these complications is the cost of the material itself, which is very expensive. This, however, is a matter of secondary importance in military airplane construction.

Next in importance to the kind of material is the form or shape of the section. Connecting-rods are usually of I- or H-section, and sometimes tubular. Crankshafts, camshafts, wrist-pins, and other round pieces are made hollow. Such shapes get the most strength out of a given weight of metal by distributing the metal away from the center of gravity where it can do the most good. Pistons and crankcases are webbed for stiffness and strength instead of using thick, heavy walls. In the case of V-type engines, forked connecting-rods are sometimes used to minimize the length and weight of the engine, although they are more costly and difficult to manufacture. Bearing caps are now tied directly to the cylinders by through bolts, thus making the stress direct and eliminating most of the strain from the walls of the crankcase.

The arrangement of cylinders also affects the weight-power ratio. With cylinders arranged "in line", a piece of crankcase, crankshaft, camshaft, etc., must accompany each cylinder, while with the same cylinders arranged radially a short crankcase, a short crankshaft, and a short camshaft serve all together. Arrangement of cylinders radially, then, is conducive to lightness.

Air cooling, while not as efficient as water cooling, has the advantage of lightness, and lends itself fairly well to the cooling of radially-disposed cylinders, especially if the cylinders revolve. But air cooling is not generally employed in stationary cylinder engines, since uniformity in cooling can be obtained only by exposing all cylinders equally to a strong blast of air. The radiator, pump, and water necessary for a water-cooling system adds but little to the weight of the engine, and this little additional weight is fully compensated for by increased power, efficiency, and reliability.

B. FUEL AND OIL ECONOMY

Fuel economy is dependent first of all upon high compression. By forcing the particles of gasoline vapor and air into more intimate contact, and at the same time raising the temperature of the mixture closer to the ignition temperature by the heat of compression, the charge burns more rapidly and exerts a greater force against the piston after ignition takes place. The proper proportioning of the mixture and complete vaporization of the gasoline also improve the fuel economy. It is equally important that the ignition be of sufficient intensity and properly timed, and that the charge taken into the cylinder be in every way properly treated so that the maximum M.E.P. results from the combustion.

In the matter of oil economy, it is essential that the oil have a high "flash point" to prevent deterioration in so far as possible, in order that the oil may be re-circulated continuously. Cooling of the oil is desirable, and in some engines this is accomplished by passing the oil around the intake manifold, where it assists in vaporizing the gasoline.

C. RELIABILITY

In this connection it should be noted that only the best of materials and the most careful workmanship are tolerated, and that before an engine is accepted as a standard for military service it must fulfill very exacting requirements, and it must stand up under far more severe tests than would ever be imposed upon it in actual service. Experience has shown that the life of a certain type of engine is limited to approximately so many hours, and accurate service records are kept for every engine in the field. It is false economy to drive an engine to the limit, rather than give it the inevitable overhauling before it is badly crippled.

Dual ignition increases the reliability of the ignition apparatus, which is one of the most vital parts of the engine. It also adds to the power and to the fuel economy in high speed motors.

Various indicating instruments and devices, with which most machines are now equipped, add to the safety of flying. Reliability is further insured by taking definite precautions in looking over the machine before a flight, straining all gasoline and oil put into the tanks to minimize the danger of dirt working into the carburetor or into the engine bearings, going over the wiring and the piping regularly to make sure that both are secure and not wearing through at any point, cleaning the spark-plugs and distributor frequently, and other details that will be apparent from the section on "Engine Troubles".

D. DESIRABLE QUALITIES

In addition to the essential requirements mentioned above, certain additional features are advantageous and desirable for increased safety and better performance. These will be enumerated and discussed separately.

1. **Low air resistance** The importance of low air resistance becomes more marked with increase in speed of flight, as the power absorbed in this direction varies as the cube of the velocity. A motor that presents a large projected surface to the direction of motion is undesirable for high-speed service. Contrary to earlier practice, it is now customary to enclose the whole power plant in a stream-line housing, or fuselage, to minimize air resistance.

2. **Controllability or flexibility** Although there is not the same need for this as with engines employed on automobiles, it is none the less a desirable quality since at low speeds of rotation the propulsive or tractive effort of the propeller is insufficient to move the machine along the ground,

and hence the pilot will be able to start up without assistance should circumstances necessitate his so doing. Further, as the engine is not required to develop its full power in horizontal flight and when alighting, the ability to vary the speed during descent is certainly preferable to the crude method of switching the ignition off and on.

3. **Freedom from vibration** The necessity for elimination of vibration as far as possible will be obvious when the slender nature of the supports upon which the engine is carried is realized, especially as vibration of a dangerous character may be set up in the various parts of the machine. It is also worthy of note that an engine permitted to vibrate in that way can not deliver as much power as if more rigidly supported.

4. **Accessibility** is, if possible, of even more importance in aero engines than in those used in automobiles, because the nature of the service being so severe and exacting requires very frequent inspection and overhauling of the power plant.

5. **Silence** is desirable in any machine used for pleasure or sporting purposes, but when on military reconnaissance duties it becomes of increasing importance to be able to manœuvre without giving audible warning of approach, especially at night.

6. **Cleanliness** is in the nature of a refinement, but it is none the less necessary since a dirty appearance is generally caused by leaks, and leaks not only cause waste but render the risk from fire very much greater. Oil soaked wood or fabric deteriorates rapidly, weakening the structure and rendering its use dangerous.

E. DEMANDS DEPENDENT UPON WEIGHT EFFICIENCY AND FUEL EFFICIENCY

There is probably no form of prime mover in existence that is more highly stressed or that has a more strenuous life than the aeroplane motor, and there is undoubtedly no engine that has greater claims on reliability. The demands are for extremely light economical engines, such that probably as much as 90 per cent of the factors which determine the most successful machine are governed directly or indirectly by the weight efficiency and fuel efficiency of the engine. By the former is meant, of course, the number of pounds of weight for every horsepower developed.

Among the essential features of all successful aeroplanes are the following:

1. **Ability to ascend rapidly** is of paramount importance in warfare, where a machine's capabilities of evading destruction depend to a large extent on how quickly it can get out of range of projectiles. It must also be efficient in climbing in order to rise successfully from a small field surrounded by tall trees, as might be necessitated by a forced landing during a cross-country flight. The rate of climb varies directly as the power developed and indirectly as the weight to be lifted, so climbing ability depends to a large extent on the weight efficiency of the engine.

2. **A combination of fast and slow flying speeds** is highly desirable, but this is only possible by the adoption of an extremely light and powerful engine. If the machine is designed for very high speed, a slow speed is only possible by the aggregate weight being very light.

3. **Safeness of handling in winds,** with or without engine in operation, is more characteristic of lightly loaded machines. Aeroplanes have been built that will carry as much as 15 to 20 pounds per square foot of supporting surface, but the average loading on the planes today is generally in

the neighborhood of 4 or 5 pounds per square foot. A heavily loaded machine depends to a great extent on high speed of flight in order to maintain it in the air, and should the speed fall the control becomes sluggish and will not answer quickly, and only by nosing down promptly to increase the speed can the pilot prevent floundering. The life of the pilot of a heavily-loaded machine is more dependent upon the good behavior of the engine than is the life of the pilot of a lightly-loaded machine, and the latter could probably go on flying in search of a good alighting ground with two or three cylinders not firing at all.

4. **Ability to remain in the air for long periods** depends chiefly on the oil and gasoline consumption of the engine, and without efficiency in this respect the extremely light power-plant is practically useless, as flights of only a few minutes duration are not likely to be of much use in serious warfare.

7. ENGINE TROUBLES

In answer to the question that is foremost in the minds of most embryo pilots who are confronted with the seemingly impossible task of getting thoroughly familiar with all the details of engine operation in a relatively short time, there are four possible reasons why a military aviator needs to be expert in detecting engine troubles:

First, no repairs can be made during flight. This makes it imperative that all adjustments be attended to beforehand, and it is a safe rule never to pin too much faith upon your mechanic. Confidence is a most effective nerve tonic, and only by absolute belief in the reliability of the power that responds to his touch can a pilot render the most efficient service.

Second, a pilot must be capable of diagnosing any troubles that might develop on cross-country flights, in order to make rapid and practical repairs if possible.

Third, if impossible to make repairs with the material at hand, he must send an intelligent message for parts.

Fourth, whenever troubles appear during flight, he should upon return explain to his mechanicians the nature of the trouble, and perhaps the remedy.

A. ESSENTIAL CONDITIONS

The following conditions must be fulfilled if the engine is to deliver its maximum power:

1. **The mixture** must be of the correct strength, and its components properly mixed.

2. **There must be sufficient compression** to bring the particles of gasoline vapor and air into intimate contact, and to raise the temperature of the mixture to make it readily explosive.

3. **Means for igniting the explosive mixture** at the right time, i.e., just before the end of the compression stroke, must be provided.

4. **Proper lubrication and cooling.**

B. CARBURETION TROUBLES

1. **Mixture too lean** is characterized by lack of power, especially at low speeds, when the "pick-up" will be uncertain and there will be an occasional popping-back through the carburetor. Backfiring of this sort is dangerous, and should be avoided. Continued operation on a very lean mixture will result in overheating of the exhaust valve, because of the slowness with which the mixture burns.

Indications of a lean mixture may be apparent when an engine is cold, or in winter weather, on account of incomplete vaporization. The gasoline pipe might become clogged, or the valve might be only partially opened, thus preventing free flow to the carburetor. Similarly, insufficient pressure in the gasoline tank of a pressure-feed system, or a clogged vent in a gravity system, may be the cause of too little gasoline in the float-chamber. Jets partially closed by dirt or lint, or water in the gasoline, may cause an engine to suddenly develop signs of a lean mixture during flight. Tilting, if so that the mouth of the jet is raised much above the level of gasoline in the float-chamber, tends to reduce the proportion of gasoline in the mixture. Inleakage of air at the manifold joints, or past a badly-worn intake valve-stem guide, will affect the suction at the jets, and decrease the amount of spray.

Water-vapor occasionally condenses out of the air inside of the gasoline tank, due to sudden or extreme cold outside, and running down the sides of the tank it collects at the bottom and feeds into the carburetor. (See "The Effects of Altitude", end of Part 2.) In cold weather, water may freeze in the line and stop the flow of gasoline.

2. **Mixture too rich** is characterized by black smoke at the exhaust, loss of power, overheating, and rapid fouling of the cylinders and spark-plugs. A rich mixture may be produced by choking the air intake, as with the strangler valve. The same effect would be produced if some foreign object, like waste, was sucked against the air opening during operation. Jets of too large size will give excessively rich mixtures. Flooding has the same effect, and may be caused by improper seating of the float-valve, by a leaky float, or by tilting of the jet downward during flight. In the case of incomplete vaporization, where it is necessary to increase the flow of gasoline to make up for the unvaporized portion, the inertia of the heavy liquid particles throws them outwards wherever there is a change in the direction of flow, and this action "loads up" the end cylinders.

C. COMPRESSION

The necessity for high compression has already been explained. Loss of compression affects the power and the fuel economy adversely, hence it is important to avoid leaks. The compression may be tested roughly by turning the engine over by hand, with the ignition *off*. It should be absolutely uniform in all cylinders to give smooth running and least vibration. Loss of compression may be due to:

1. **Leakage at the valves** Particles of carbon lodge between the exhaust valve and its seat, and eventually the whole edge of the valve becomes covered with carbon. Continued leakage overheats the valve and warps it, and leakage is usually so rapid in case of a warped valve that the explosion is very weak. Lack of valve clearance will prevent a valve from closing tight. The valve stem frequently gets dirty or sticky, and the excessive friction retards the action of the valve spring to such an extent as to cause late valve closure at high speeds, which of course would not be apparent at all when turning the engine over by hand. Broken or overheated springs have a similar effect, and it is always best to carry spare springs on a long flight.

2. **Leakage at spark-plug gaskets,** which is not an infrequent occurrence, is most aggravating at slow speeds.

3. **Leakage at the pistons** Too thin oil, or lack of oil, is a common cause of piston leakage and loss of compression. The thrust on the cylinder wall, due to the shortness of the connecting-rod (angularity), wears

the cylinder out of round in time, and there is no remedy except to re-grind the cylinder or replace it with a new one. Piston-rings expand as they wear, and the joint opens up. A plain joint under such conditions allows leakage, and for that reason specially designed rings are sometimes used in which the joint overlaps so that leakage cannot occur at that point. In fitting a piston ring, a small amount of clearance is allowed at the joint when the engine is cold, so that expansion due to heat will not force the ends together and break the ring. Broken rings not only leak, but sometimes score the cylinders. Scored cylinders are more likely to result from dirt or insufficient lubrication, however. It is not uncommon to find a cracked piston the cause of lost compression and leakage.

Too high compression results in pre-ignition. Compression may easily be increased by carbon accumulating in the combustion chamber, and when coupled with the fact that cooling is not as efficient under such conditions, it is easily understood why carbon causes knocking. Unusually hot weather will also cause pre-ignition, as well as overheating.

D. IGNITION TROUBLES

The most common of ignition troubles is a defective spark-plug. Only the very best plugs will stand up for any length of time at the high temperature and the rapid functioning to which they are subjected in an aeronautical motor. Porcelains crack and allow oil and carbon to work through and short-circuit the plug. The points burn away and cause irregular action at low speeds. Carbon and oil deposit all over the insulation if not cleaned frequently, or a piece of carbon or a drop of oil sometimes lodges between the points, which completes the circuit and no spark takes place. The presence of a drop of oil might be the effect instead of the cause, however, for after a cylinder has been out of action for a time it will be found that the combustion chamber is wet with oil that has worked up past the piston, and the spark-plug is quite apt to collect oil under such conditions.

Upon feeling just below the water-jackets, an inactive cylinder will be decidedly cooler than those that are firing regularly. In case the exhausts are separate and accessible, a cylinder that is not firing may be located by exposing the hand or a stick directly in front and noting the relative weakness of the "puffs". A third test, which is always applicable, is to throttle down the engine and "short" each plug in succession by means of a screw-driver until one is found that shorting makes no apparent difference in the speed. Short-circuiting a good plug will immediately slow down the engine. After locating the missing cylinder, the plug should be taken out and examined. In case the plug is not at fault, examine the wiring for loose connections and worn insulation, and examine the distributor segment.

When a whole group of cylinders fail to get a spark, the trouble will most likely be either in the switch connections or in the magneto. A "ground" due to worn insulation in the wire leading from the magneto to the switch, or stray strands of wire short-circuiting the switch itself, will prevent ignition. Oil, dirt, or moisture on the distributor plate will cause irregular firing; wipe frequently with a clean cloth, and if corroded clean with a fine metal polish.

Pitted or burned breaker points make poor contact, and should be carefully smoothed up by means of a thin file. The gap must be accurately adjusted by means of a gauge. The condenser is provided to prevent excessive sparking between the breaker points, which would burn the points and possibly fuse them together. Sparking is an indication of condenser trouble, which sometimes results from punctured insulation. The function of the safety spark-gap is to provide an outlet for the current before the voltage gets high enough to break through the insulation of the secondary coil and back to the condenser, so that condenser trouble is rare. The safety spark-gap also furnishes a means of determining whether magneto trouble is internal or not. A short-circuited condenser would shunt the breaker points, and prevent interruption of the primary circuit.

If an engine fails to stop when the switch is thrown to the "off" position, it is probable that the switch circuit is broken by a loose connection, either at the magneto or at the switch. The purpose of the switch is to "ground" the magneto to stop the engine, hence it is always advisable to make sure that the switch is functioning properly before moving the propeller for any other purpose than to start the engine.

The importance of correct spark-advance has already been mentioned. In case it is necessary to determine the amount of advance, first remove the spark-plugs to relieve compression and give access to the top of the piston. Turn the engine over until the breaker points are closing, and insert a thin cigarette paper between them. Continue to turn the engine in its direction of rotation, and at the same time pull gently on the cigarette paper until it can be pulled out. At that position of the engine the breaker points are just about to open to produce a spark in the particular cylinder for which the distributor segment is making contact. One can then determine the piston position by means of a steel scale through the spark-plug hole, or if the lower half of the crankcase is off the crank angle may be measured with a protractor.

E. LUBRICATION TROUBLES

In starting a cold engine, always run it slowly for several minutes and then open up the throttle gradually. This gives the oil time to get warmed up and circulating freely to all parts, and also avoids distortion and cracking from too rapid heating of the cylinders.

In airplane engines, where the pressure system is invariably used, it is very essential that the oil be of the correct grade and the bearings properly adjusted. If the oil is too heavy, it will not flow freely to all parts of the engine. Oil is more viscuous when cold than when warm, and the oil gauge on an airplane will invariably show decreasing pressure until the oil becomes thoroughly heated up. The pressure relief valve, which forms an important part of all pressure lubricating systems, is used to prevent excessive pressure on the system when the oil is cold or too thick. It will not give the same results with different grades of oil, unless readjusted. If for any reason it should get stuck open, the oil gauge would show little or no pressure as soon as the oil heated up. The same thing would happen if the pressure became high enough to burst an oil pipe. It is advisable to stop an engine immediately at the first indications of lack of oil pressure. This, however, should not be confused with the normal decrease in pressure previously mentioned. Loose bearings will cause low working pressure, and tight bearings will increase the pressure. It is important that the crankshaft bearings and the crankpin bearings be properly adjusted, because it is these adjustments that usually determine the amount of oil that reaches the cylinders. Too little oil will increase the friction and wear on the cylinder walls and cause overheating, while too much oil fouls the combustion chamber and the spark-plugs and causes bluish-white smoke at the exhaust. Bearings should have at least two or three thousandths of an inch clearance—no less.

Oil pumps may be either plunger type or gear type. In either case, a worn pump will not deliver as much oil as when new. Wear of this sort may be indicated by low gauge pressure. One must be guided largely by experience and good judgment as to how low the pressure may be allowed to go without endangering the engine.

A strainer, or screen, is usually provided over or within the oil-sump to collect dirt or grit and prevent it from getting into the pump or the bearings. This may need cleaning occasionally, in order that it may not retard the flow of oil back to the reservoir. If ordinary precautions are used, there is little danger of any of the oil pipes getting clogged. Copper tubes are easily jammed, however, and if knocked together the oil supply will be affected.

F. COOLING TROUBLES

Overheating may be caused by lack of water. When filling the radiator, be sure that the system is entirely filled. To make sure of this, run the engine for a few moments, and then see if the radiator is still full. The pump sometimes prevents the water from entering the cylinders, or air pockets may be present. Leakage should not be tolerated, however slight, because it is an easy matter to prevent it. During long flights, enough water may evaporate to decrease the efficiency of cooling materially. A thermometer is usually provided to warn the pilot when an engine is getting hot, but such an instrument in the radiator cap is not always reliable when the water level is low. The best place for a temperature indicator is in the outlet just above No. 1 cylinder.

Lack of circulation may also cause overheating. A centrifugal pump is the type universally used on water systems, and if it becomes broken or shears off its key, circulation becomes retarded. That might easily happen during freezing weather, when starting the engine. Occasionally the radiator or connections become clogged by scale, dirty water, pieces of rubber from the hose connections, etc.

Lack of cooling surface may be apparent in extremely hot weather, when the cooling will not be sufficient to prevent pre-ignition. Oil on the inside surfaces of the radiator acts as a partial heat insulator, thus cutting down the effectiveness of cooling. Scale formation on the tubes has a similar effect. It is good policy to flush out the radiator and the cylinder jackets occasionally, and never use rotten or frayed hose connections.

8. NOTES ON TIMING

Proper timing of the valves and ignition of a gasoline engine is very important. When one realizes that for a four-stroke cycle engine running at 1400 R.P.M. there is only 0.085 second available for a complete cycle, it is apparent that the valves must operate rapidly and all events occur at the proper time. In this small fraction of a second, the mechanism must draw a definite amount of liquid fuel from the source, vaporize it, mix it with the correct amount of air, distribute the mixture uniformly to the cylinders, entrap and compress it to a fairly definite pressure, ignite and burn it, expand the highly heated and high pressure gases, and expel the products of combustion. Failure to have any of these operations performed at the proper time results in a loss of power and a waste of fuel. An improperly timed engine, therefore, weighing as much as when properly timed, develops less power and consequently has a higher weight-power ratio.

A. DESIGNATION OF VALVE EVENTS

Valve events are measured from the nearest dead center, either in terms of piston travel or in degrees of crankshaft rotation. The point of *valve opening* is when the tappet first touches the valve stem and the valve begins to leave its seat. *Valve closure* is when the valve just touches the valve seat in closing. The interval during which the valve is off of its seat is called the *period of valve opening,* and is measured in degrees of crank travel.

Valve lift is the distance parallel to the stem between the valve and its seat when the valve is fully opened. This varies from ⅜ to ½ inch. It is governed by three things—the eccentricity of the cam or difference between the radius of the point of the cam measured from the center line of the camshaft and that of the round or neutral part of the cam, the relative lengths of the two arms of the rocker arm, and the valve clearance. In high speed engines there is not time enough available to utilize as much lift as would be desirable, which adds to the difficulty of high speed engine design.

B. VALVE CLEARANCE

Valve clearance is the distance (about five to thirty thousandths of an inch) between the end of the valve stem and the tappet on the end of the rocker arm, measured and set with the valve closed tight and the cam follower on the neutral part of the cam. It is necessary to have the valve clearance properly adjusted *before* timing valves. To set the clearances for the valves of any one cylinder, turn the engine over in the proper direction of rotation until the piston is near the end of the compression stroke, at which time both valves are closed and the cam followers are down. This position may be obtained with sufficient accuracy by turning the engine until the intake valve closes, and then turning a quarter to half of a revolution farther. The adjustment can then be made on each valve by loosening the lock nut that holds the tappet screw, and turning the screw until a thickness gauge of the proper size can just be inserted. Repeat for all cylinders.

C. DIRECTION OF ROTATION

If the direction of rotation of an engine is not known, one can determine it very easily by observing the occurrence of the valve events in any one cylinder. Bear in mind that exhaust valve closure and intake valve opening occur almost simultaneously just after top center on the suction stroke. If the engine is turned in the wrong direction, the intake valve will close and the exhaust valve will open at about the same time, whereas these two events normally occur at widely different points in the cycle.

D. GRINDING VALVES

If the valves are in need of grinding, this should be done *before* setting the valve clearance. Different engines require somewhat different preliminary procedure to gain access to the valves. If the valves are in valve cages, or if the cylinder heads are detachable, the cylinders need not be removed. In any case, it is necessary to free the valve springs, which may be done by depressing the spring and taking out the key that holds the retainer to the valve stem. Intake valves seldom need grinding; but the exhaust valves, exposed to hot gases and carbon, soon become pitted or warped in service and require frequent attention to keep them from leaking badly.

Valve grinding paste consists of powdered emery or other abrasive material mixed with grease to hold it together. A coarse grade may be used first, but the grinding should never be considered complete until a fine grade of paste has been applied. To grind a valve, apply the paste uniformly around the bevelled edge of the valve, and with a screw driver or valve grinding tool twist the valve back and forth against the valve seat several times, and at the same time press the valve firmly but not too hard against the seat. It is good practice to lift the valve occasionally and turn it to a new position, in order to avoid cutting deep grooves. Several applications of the paste may be necessary if the valve is badly pitted. If the valve is found to be warped, it should be discarded for a new valve, not only to save time but also to avoid grinding away an excessive amount of the valve seat.

The valve should be inspected frequently during the grinding process, so that it will not be ground more than necessary. First wipe off the paste and clean the valve with gasoline. The seating edge of the valve will then appear shiny. If there are any dark spots present, the valve should be ground until these are removed. But always apply the paste uniformly all of the way around, and clean off all traces of the abrasive substance before assembly.

E. PRINCIPLES OF VALVE TIMING

The general scheme to be followed in timing the valves of an engine consists in placing the piston or the crank throw for any one cylinder in the position recommended by the maker for some particular valve event to take place, and then turning the camshaft in the proper direction by hand, independently, until the exact position is reached where that event does take place. The camshaft should be connected to the crankshaft in that position, by meshing the driving gears. When one event is timed, the others must be correct if the camshaft is properly designed and constructed.

The event by which an engine is usually timed is the closing of the exhaust valve, for the reason that it is most important to have this event accurately fixed. A slight error in exhaust closure would have more effect on the power of the engine than the same error on any of the other valve events. The exhaust valve should close when the pressure within the cylinder just reaches atmospheric pressure shortly after the suction stroke begins, in order to get rid of as much burned gas as possible. Burned gas takes up space in the cylinder, and dilutes the fresh charge. If the exhaust valve should close too late, the suction would draw back burned gas (or air), with about the same effect.

F. SETTING THE ENGINE

Some V-type engines are difficult to set by the crankshaft method, while on some engines there is no hole in the top of the cylinder suitable for accurate measurement of the piston position. The Curtiss OX engine, for example, should be timed by setting the piston 1/16 inch past top center, measuring through the spark-plug hole. First turn the engine in the proper direction of rotation until the piston of some particular cylinder (say No. 1) is exactly on top center, as indicated by a wire or measuring device held against the face of the piston and parallel to the center line of the cylinder. Then continue to turn the engine in the same direction until the piston has travelled the proper distance from this position, as specified on the manufacturers' test card. Extremely accurate measurements must be made, because an error of a hundredth of an inch causes an appreciable error in the setting.

A vertical engine, like the Hall-Scott, may be timed by the use of a protractor applied to the milled surface of the upper half of the crankcase. This requires removal of the lower half, of course, but there is no alternative on the Hall-Scott engine because the spark plugs are in the side of the combustion space and there is no hole through the top of the cylinder parallel to the center line. The crank throw by which the engine is to be set (say No. 1 cylinder) should be placed 10 degrees past top center, as measured by the protractor. Then, with the camshaft gear removed, turn the camshaft in its proper direction of rotation until the exhaust valve just touches its seat, then replace the gear. On Model A5a a screw adjustment makes it possible to shift the gear relative to the shaft, so that the gears may be meshed properly should they fail to do so in the positions set. On Model A5 this may be accomplished by shifting the upper half of the vertical drive shaft relative to the lower.

Many engines have timing marks on the propeller hub, placed there by the manufacturer. One of these marks, lined up with a mark on the crankcase, indicates top dead center for No. 1 cylinder. With this position prevailing, and the piston in No. 1 cylinder just starting on the suction stroke, a mark on the camshaft gear should be in line with one on the bottom of the camshaft gear housing. On Model A5 Hall-Scott the marks on the flanges of the upper and lower halves of the vertical driving shaft should be in line and to the front.

The timing should always be checked by turning the engine over until the exhaust valve just seats, and then measuring the piston position or the crank angle to see if it is correct.

G. PRINCIPLES OF IGNITION TIMING

There are two distinct processes involved when timing a magneto ignition system. First, the internal mechanism of the magneto must be arranged so that the breaker points separate when the distributor brush is in contact with a segment, both in advanced and retarded positions. Second, the spark generated by the magneto must be timed to occur at the right point in the engine cycle, near the end of the compression stroke (No. 1 cylinder is most convenient). It is also necessary to have the breaker points properly adjusted, and to have the wires from the distributor to the spark plugs connected in accordance with the firing order of the cylinders.

H. TIMING THE DISTRIBUTOR

Adjust the breaker points so that they open the proper amount specified by the manufacturer. A thickness gauge should be used for this purpose. Turn the breaker box to the advanced position (opposite to the direction of rotation of the magneto), then turn the armature shaft or rotor in its proper direction of rotation until the breaker points just start to separate and note whether the distributor brush makes contact with a segment. Retard the spark, turn the shaft until the points are just opening again, and note if the distributor brush still makes contact with the same segment. If contact is not made in both the advanced and retarded positions, the distributor gear must be re-meshed so that the proper condition will obtain.

I. FIRING ORDER

Before wiring the magneto to the engine, it is necessary to know the firing order of the cylinders. Determine this by turning the engine in its direction of rotation and noting the order in which a particular valve event occurs.

J. SETTING THE ENGINE

The engine should be set in much the same way as for timing valves, except that it should be in the proper position for ignition near the end of the compression stroke (say in No. 1 cylinder). The crank angle, or the piston position, for either advanced or retarded spark, will be specified by the manufacturer. The breaker box should be placed in the position specified, and the magneto shaft turned in the normal direction until the distributor brush is on the segment corresponding to the cylinder that is ready for ignition, and the breaker points just beginning to separate. A thin cigarette paper between the points will indicate when the points are separating. Having thus set the engine in the proper firing position, and the magneto ready to deliver a spark to the proper cylinder, the gears should be meshed and the timing checked.

K. WIRING UP

When the wires are in a casing or manifold, it is necessary to trace them out before connecting up. Do this by means of a dry cell and electric bell or lamp, and tag each wire at both ends after testing. From the known direction of rotation of the distributor arm, and the firing order of the engine, each successive segment of the distributor should be connected to a spark plug in the order in which the various cylinders fire, beginning with the segment and the cylinder used in timing the ignition.

L. DOUBLE IGNITION

When there are two independent ignition systems on an engine, it is absolutely necessary for efficiency that they be synchronized. That is, the breaker points in the two magnetos should separate simultaneously. The slightest variation is sufficient to make one spark occur too late to be of any use except as a reliability factor. Extreme care should be used in setting and checking, and in connecting up the advance-and-retard mechanism.

CHAPTER IV.

GUNNERY

OUTLINE

1. Nomenclature of the Lewis Gun
   - A. Body Group
   - B. Barrel Group
   - C. Piston Group
   - D. Magazine
   - E. Accessories

2. Stripping and Assembling—Lewis Gun
   - A. Stripping
   - B. Assembling
   - C. Rules to Observe when Stripping or Assembling

3. Mechanism of the Lewis Gun
   - A. Backward Movement
   - B. Forward Movement

4. Drill and Immediate Action—Lewis Gun

5. Stoppages and Jams—Lewis Gun
   - A. Defects Prevented by Proper Cleaning and Oiling
   - B. Defects Prevented by Inspecting and Testing Magazines
   - C. Defective Ammunition Eliminated by Testing and Inspecting
   - D. Defects Prevented by Inspection of Parts
   - E. Principal Causes of the Lewis Gun Stopping
     1. Empty Magazine
     2. "Stoppages"
     3. "Jams"
   - F. Definitions
   - G. Sequence of "Immediate Action"

6. Care of the Lewis Gun
   - A. Cleaning and Oiling
   - B. Points to be Observed before Flight
   - C. Points to be Observed during Flight
   - D. Points to be Observed after Flight

7. Standard Tests of Stripping—Lewis Gun
   - A. Increase Return Spring Tension
   - B. Decrease Return Spring Tension
   - C. Change Cartridge Guide
   - D. Change Bolt
   - E. Change Ejector
   - F. Change Pinion Casing Complete

8. Range Practice—Lewis Gun
    - A. Practices
        1. Practice No. I Drill
        2. Practice No. II Grouping
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    - B. Range Discipline
        1. Duties of Cadets
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9. Nomenclature of the Marlin Aircraft Gun

10. Stripping and Assembling—Marlin Aircraft Gun
    - A. Stripping
    - B. Assembling
    - C. Stripping and Assembling Group Parts of the Marlin Aircraft Gun
    - D. Points to be Carefully Observed when Stripping or Assembling the Marlin Aircraft Gun

11. Mechanism of the Marlin Aircraft Gun
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12. Drill—Marlin Aircraft Gun
    - A. Loading
    - B. Firing
    - C. Unloading

13. Stoppages and Jams—Marlin Aircraft Gun
    - A. Defects Prevented by Proper Cleaning and Oiling
    - B. Defects Prevented by Proper Inspection of Parts
    - C. Defects Prevented by Proper Assembly of Gun
    - D. Defects Prevented by Proper Adjustment of Gun
    - E. Defective Ammunition Eliminated by Testing and Inspecting
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    - G. Stoppages and Jams.
        1. Position I
        2. Position II
        3. Position III
    - H. Uncontrolled Automatic Fire
    - I. Reports of Stoppages and Jams.

14. Care of the Marlin Aircraft Gun
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    - D. Points to be Observed After Flight

15. Aerial Sights
    - A. Purpose
    - B. Types
    - C. Ring Sights
    - D. Principles Governing the Use of Ring Sights on a Fixed Gun
    - E. Use of Ring Foresight with Bead Backsight on a Fixed Gun
    - F. The Norman Wind-Vane Foresight
    - G. Use of Norman Wind-Vane Foresight with Ring Backsight on a Movable Gun
    - H. Compensation for Depression and Elevation of Movable Gun
    - I. Practice with the Model Aiming Airplane

CHAPTER IV.

GUNNERY

1. NOMENCLATURE OF THE LEWIS GUN

The following is a list of the principal parts of the Lewis Automatic Machine gun, 1916 model. Cadets should be able to identify each part named and give its function.

A. BODY GROUP

1.	**Spade grip**	**Plate 6, 92**
	a. Spade grip cap	
2.	**Body cover or Feed cover**	Plate 4, 13
	a. Cartridge guide (1915 model) or Cartridge guide spring	4, 40
	b. Right stop pawl or Stop pawl	4, 28
	c. Left stop pawl or Rebound pawl	4, 29
	d. Stop pawls spring or Magazine pawls spring	4, 27
	e. Tangent sight or Backsight	4, 11
3.	**Feed arm or Feed operating arm**	Plate 4, 34
	a. Feed arm latch or Feed operating arm latch	4, 66
	b. Feed arm pawl or Feed pawl	4, 35
	c. Feed arm pawl spring or Feed pawl spring	4, 36
	d. Feed arm pawl spring stud or Feed pawl spring stud	4, Q
	e. Tail of the Feed arm with stud	4, 34
4.	**Pistol grip or Guard**	Plate 3,
	a. Plunger or Sear spring box	3, 42
	b. Trigger spring or Sear spring	3, 41
	c. Trigger	3, 30
	d. Sear	3, 91
	e. Spade grip catch	3, 7
	f. Spade grip catch spring	
5.	**Ejector cover**	Plate 4, 44
6.	**Ejector**	4, 21
7.	**Body locking pin or Receiver lock pin**	Plate 3, 68
8.	**Pinion casing or Gear casing**	3, 61
	a. Pinion pawl or Gear stop	3, 46
	b. Pinion pawl spring or Gear stop spring	3, 49
	c. Tension screw or Collet pin	3, 56
	d. Pinion or Gear	3, 52
	e. Return spring casing or Mainspring casing	3, 53
	f. Return spring or Mainspring	3, 55
	g. Hub or Mainspring collet	3, 57
9.	**Body or Receiver**	Plate 3, 26
	a. Pinion casing hinge pin or Gear casing hinge pin	3, 65
	b. Right and left safety catch or Right and left safety	3, 62

c. Ejection opening
d. Magazine post — 3, 63
1. Magazine post center key or Center key
e. Ejector seating
f. Boltway
1. Longitudinal guideways
2. Locking recesses
g. Piston way

B. BARREL GROUP — Plate 2,

1. **Gas regulator key** — Plate 2, 81

2. **Gas regulator or Gas regulator cup** — 2, 84

3. **Clamp ring** — 2, 85
a. Clamp ring screw — 2, 88
b. Fore sight or Front sight — 2, 86
c. Clamp ring positioning stud — 2, 87

4. **Radiator casing** — Plate 2,
a. Front radiator casing — 2, 90
b. Rear radiator casing — 2, 74
1. Gas regulator key positioning stud or Regulator key stud
c. Rear locking piece — 2, 71

5. **Gas cylinder** — 2, 77

6. **Gas chamber** — 2, 82

7. **Barrel mouth piece** — 2, 89

8. **Barrel** — 2, 76
a. Gas port
b. Barrel register

9. **Barrel band or Gas chamber band** — 2, 83

10. **Radiator** — 2, 78

C. PISTON GROUP — Plate 2,

1. **Cocking handle or Charging handle** — 2, 38

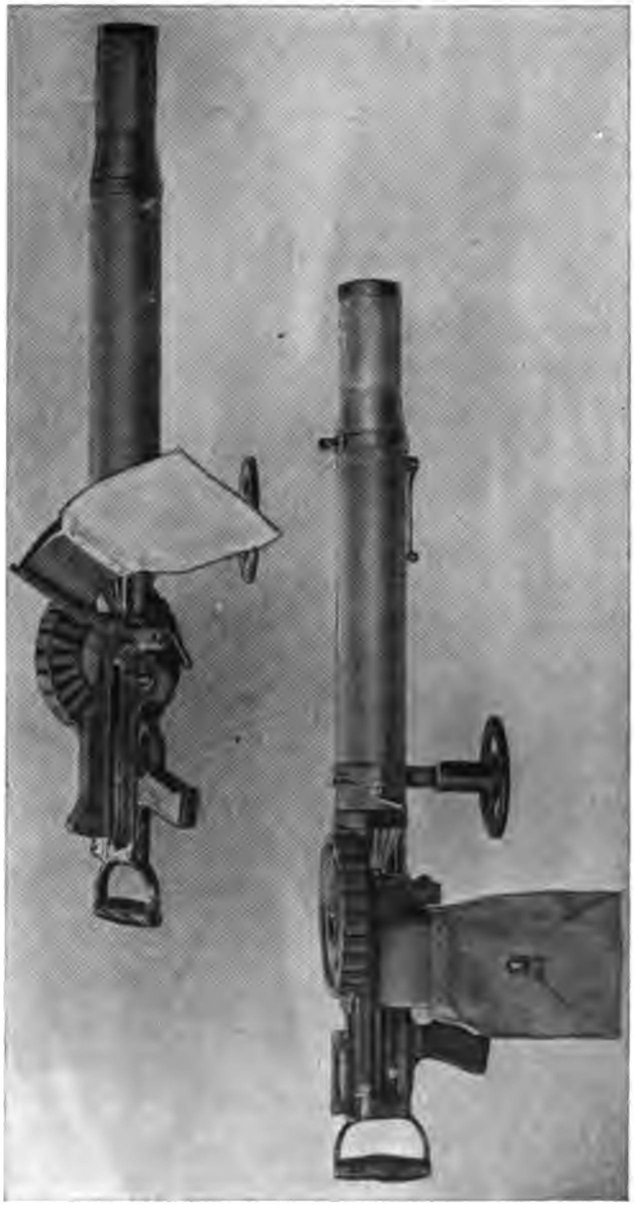
2. **Piston rod or Piston** — 2, 79
a. Rack — 2, 72
b. Bent or Cocking notch
c. Striker post
d. Striker — 2, 50
e. Striker fixing pin — 2, 47
f. Cocking handle slot or Charging handle slot

3. **Bolt** — Plate 4, 37
a. Extractors — 4, 45
b. Camway groove or Cam slot
c. Resistance lugs or Locking lugs

4. **Feed arm actuating stud or Feed operating stud** — Plate 4, 31
a. Boss
b. Guide lugs

D. MAGAZINE — Plate 5

1. **Magazine pan** — 5, 43
   a. Outer circumference
2. **Separating pegs or Interior separators** — 5, 70
3. **Magazine catch** — 5, 62
4. **Magazine center block or Magazine center** — 5, 58
5. **Magazine catch spring**



THE LEWIS AUTOMATIC MACHINE GUN

PLATES DESCRIPTIVE OF LEWIS GUN PARTS

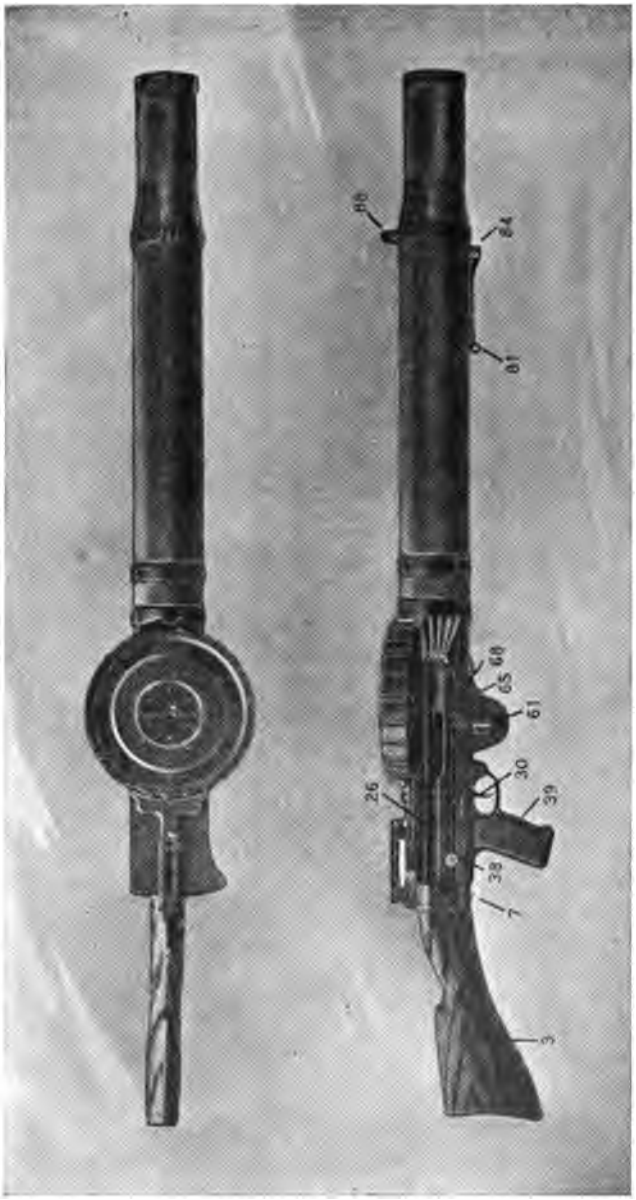


PLATE 1.—THE LEWIS GROUND GUN WITH MAGAZINE AND RIFLE BUTTSTOCK

Plate 2.—Gun parts: Barrel group, and Piston Rod

Plate 3.—Gun parts: Body, Return spring, and Trigger Mechanism

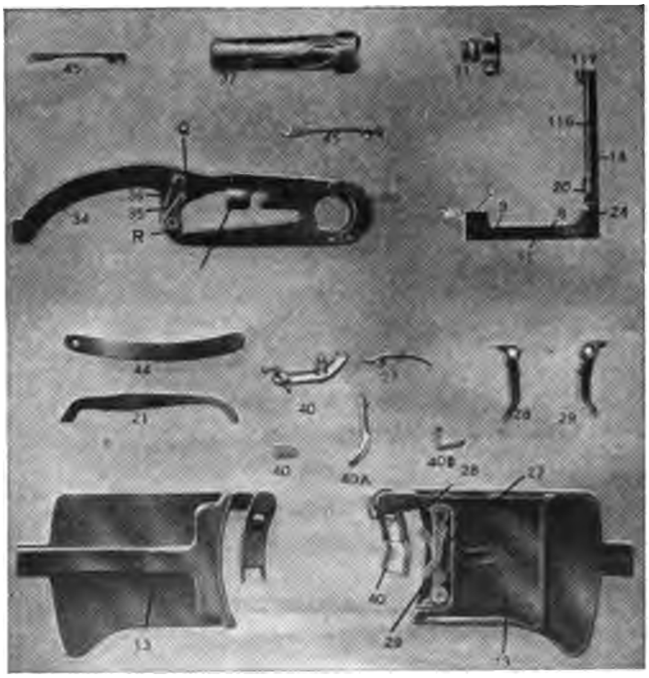


Plate 4.—Feed Mechanism, Bolt, Extractors, and Ejector

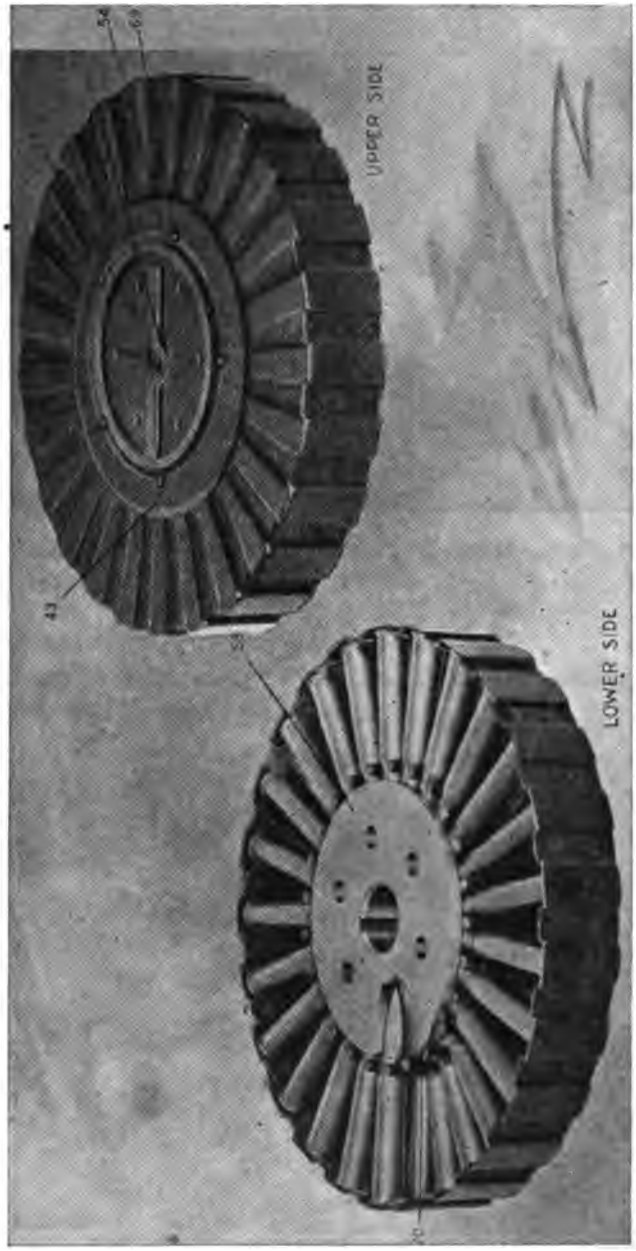


PLATE 5.—MAGAZINE COMPLETE

ACCESSORIES

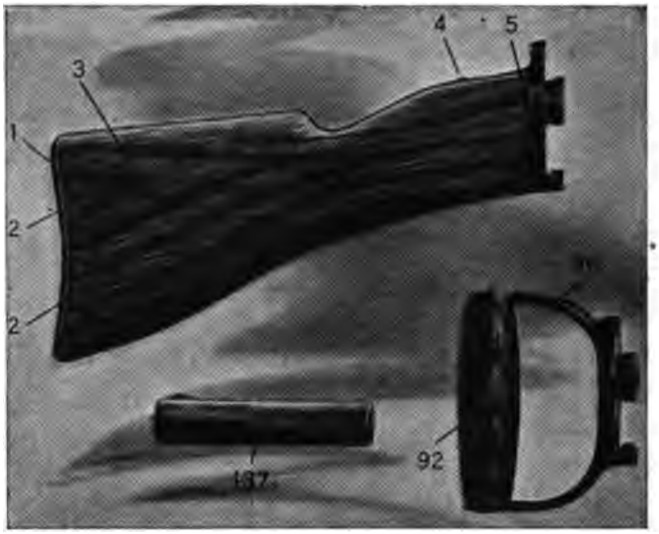


PLATE 6.—RIFLE BUTTSTOCK, LOADING HANDLE, AND SPADE GRIP

PLATE 7.—DEFLECTOR BAG COMPLETE

PLATE 8.—MOUNTING YOKE AND STANDARD

E. ACCESSORIES

1.	**Loading handle**	Plate 6, 137
2.	**Spanner wrench**	2, 136
3.	**Spring balance**	
4.	**Oil can**	
5.	**Barrel cleaning rod with wire gauze**	
6.	**Gas cylinder cleaning rod with mop and wire brush**	
7.	**Mounting yoke and standard**	Plate 8,
8.	**Deflector bag**	Plate 7,

2. STRIPPING AND ASSEMBLING—LEWIS GUN

With the exception of the gas chamber and the barrel mouthpiece for which a spanner wrench has to be used, and the clamp ring screw which is removed with the gas regulator key, the Lewis gun can be stripped by means of the nose of a bullet.

A. STRIPPING

1. **Remove spade grip**
2. **Remove body cover**
   a. Remove cartridge guide
   b. Remove stop pawls spring
   c. Remove stop pawls
3. **Push feed arm latch forward and remove feed arm**
   a. Remove feed pawl and feed pawl spring
4. **Remove pistol grip**
5. **Remove pinion casing**
   a. Release tension of return spring
   b. Remove tension screw
   c. Remove pinion from pinion casing
   d. Force return spring casing out of pinion
   e. Remove hub

6. Draw back cocking handle to fullest extent, remove it, and take out piston rod and bolt

a. Remove bolt from striker post
b. Remove one extractor
c. Unscrew feed arm actuating stud

7. Remove ejector cover

8. Remove ejector

9. Remove body locking pin and unscrew body

10. Remove gas regulator key

11. Remove gas regulator

12. Unscrew clamp ring screw and remove front radiator casing

13. Remove clamp ring

14. Remove rear radiator casing

15. Unscrew gas cylinder

16. Unscrew gas chamber

17. Unscrew barrel mouthpiece

B. ASSEMBLING

The gun is assembled by reversing the operations given above for stripping.

C. RULES TO OBSERVE WHEN STRIPPING OR ASSEMBLING.

1. Be sure that magazine is removed and that the gun is free of all fired or unfired cartridges before beginning to strip.

2. Care should be taken

a. That the feed arm is towards the right before removing and before replacing body cover.

b. That the bolt is at the rear of its travel before attempting to remove or replace the ejector.

c. That the feed arm is at the extreme left before attempting to insert the piston rod and bolt into the body.

d. That the feed arm actuating stud is screwed into the bolt as far as it will go, and that the striker post is in the rear of the camway groove before inserting piston rod and bolt into body.

e. That the cocking handle is securely in place in its guide slot.

3. MECHANISM OF THE LEWIS GUN

A. BACKWARD MOVEMENT

1. Action of the Gases

On the cartridge being primed, the powder is turned into gas which forces the bullet up the barrel. Four inches from the muzzle, part of the gases enter through the gas port into the gas chamber and, passing through the large hole in the gas regulator, enter the gas cylinder. Here they strike against the cupped head of the piston rod and drive it to the rear.

In the case of the ground gun, the remainder of the gases leave the barrel mouthpiece and spreading out evenly, strike against the inner surface of the front radiator casing, driving the air out and causing a suction, which draws in cool air from the rear along the radiator fins. By this means the barrel is kept cool.

2. Action of the Piston Rod and Return Spring

During the first $1\frac{1}{8}''$ of the backward travel of the piston rod, the striker post travels along the straight portion of the camway groove, and the teeth of the rack being engaged with the teeth of the pinion, the winding up of the return spring commences. This $1\frac{1}{8}''$ travel is the safety device to insure that the gas pressure on the face of the bolt has dispersed before the bolt is unlocked.

3. Action of the Bolt and Extraction

The right side of the striker post now bears against the right side of the curved portion of the camway groove, causing the bolt to rotate $\frac{1}{8}$th of a turn to the left. This action unlocks the bolt by withdrawing the resistance lugs from the locking recesses. The striker post now bears against rear end of the bolt and from this point the piston rod and bolt come back together. As the bolt comes back, the extractors bring with them the empty case from the chamber.

4. Action of the Ejector

The left guide lug of the feed arm actuating stud now strikes the tail of the ejector which, working on its pivot, causes the head to enter the recess in the bolt, and travel across the face of the bolt. It strikes against the base of the empty cartridge and knocks it out through the ejection opening on the right side of the body.

5. Action of the Sear

The piston rod and bolt continue their backward movement and if the trigger is released, the nose of the sear will engage with the bent of the piston rod as the latter commences to go forward. The return spring is now fully wound up.

6. Action of the Feed Arm and Pawls

As the bolt comes back, the boss of the feed arm actuating stud working in the curved channel in the tail of the feed arm, causes the feed arm to move from right to left. The feed pawl, being engaged behind a corrugation of the magazine, rotates the magazine clockwise one corrugation. The feed pawl spring stud bearing away from the right stop pawl, allows it to come into action. This prevents the magazine from rotating more than one corrugation. The left stop pawl is depressed by a corrugation of the magazine and engages behind it. This prevents the magazine from rotating counter-clockwise.

7. Action of the Magazine

As the magazine rotates, the cartridge which is held in the magazine by the outer circumference and the separating pegs, is forced down into the feed way by means of the cartridge guide assisted by the slope of the centre block. It is now in position in the slot on the top of the body ready to be pushed forward by the bolt in the forward movement.

B. FORWARD MOVEMENT

Note: During the forward movement, the magazine does not rotate.

1. Release of the Sear

When the trigger is pressed, the nose of the sear will become disengaged from the bent of the piston rod. The return spring will carry the piston rod forward, and the striker post bearing on the left side of the curved portion of the camway groove, and the bolt being unable to rotate owing to the resistance lugs being engaged in the longitudinal guideways, the bolt is carried forward also.

2. Forcing of the Cartridge into the Chamber

As the piston rod and bolt move forward, the top extractor strikes the lower edge of the rim of the cartridge and forces it into the chamber, where the extractors spring over and grip the rim.

3. Action of the Ejector

As the bolt moves forward, it strikes the head of the ejector and forces the tail into the boltway, ready for the backward movement.

4. Action of the Bolt

The resistance lugs are now opposite the locking recesses. The left side of the striker post still bearing against the left side of the curved portion of the camway groove, causes the bolt to rotate ⅛th of a turn to the right and the resistance lugs enter the locking recesses so locking the bolt. When the gun is fired, the resistance lugs being engaged in the locking recesses, take the shock of discharge.

5. Priming the Cartridge

As the striker post travels along the straight portion of the camway groove, the striker passes through the hole in the face of the bolt and so primes cartridge.

6. Action of the Feed Arm and Pawls

During the forward movement of the bolt, the boss on the feed arm actuating stud working in the curved channel in the tail of the feed arm, moves the feed arm from left to right. The feed pawl rides over a corrugation of the magazine and engages behind it ready for the backward movement. The feed pawl spring stud bears against the right stop pawl and forces it out of action. The left stop pawl remains stationary and prevents the magazine from rotating counter-clockwise.

4. DRILL AND IMMEDIATE ACTION—LEWIS GUN

The object of "Drill" is to instruct cadets in the art of handling the Lewis Gun in the air and to teach them the combined use of eye, brain, and fingers, which is so essential to good aerial gunnery.

IMPORTANT

a. Keep away from muzzle
b. See that gun is unloaded
c. See that no live rounds are among the dummies.

Cadet to be seated on tripod, with six magazines placed flat on the floor on his left. The movements of Drill are as follows:

1. Hold the magazine firmly with both hands, with fingers under the center block and thumbs on top. Tilt front part downwards to give *stream line* effect. Keep thumbs away from magazine catch. Keeping the magazine in this position lift it up and place it on the magazine post.
2. With hands still in the same position, attempt to lift magazine off post by giving a direct pull upwards, in order to see if magazine catch is holding.
3. Grasp spade grip with *right* hand; with left hand pull back cocking handle to fullest extent.
4. Grasp pistol grip *firmly* with *left* hand.
5. Lay sight on to target (in barracks room a chalk mark on the wall is sufficient for a target); press the trigger.
6. Apply "Immediate Action" *with eye on the target* by rotating magazine sharply clockwise with left hand.

7. Grasp magazine as in 1, with thumb of right hand release magazine catch, lift off magazine and place it on floor to the right still keeping the *stream line* effect as in 1.

8. Repeat these same operations with all the magazines.

9. After removing the last magazine, cadet executes (a) "Lock Gun", (b) "Unlock Gun", and (c) "Unload".

a. Lock gun To lock gun, pull cocking handle to rear, raise safety, press trigger.

b. Unlock gun To unlock gun, pull cocking handle back, depress safety.

c. Unload To unload pull cocking handle to rear twice holding the pistol grip with the *right hand* and keeping the trigger pressed all the time. During these operations the gun must be kept sighted on the target.

5. STOPPAGES AND JAMS—LEWIS GUN

The Lewis Gun stops firing when in action because of defective mechanism or defective ammunition. It must be borne in mind that three-quarters of the difficulties which *may* occur are due to careless cleaning and inattention to small details. If magazines and ammunition are thoroughly inspected, if the return spring tension is properly adjusted, and if the gun is carefully cleaned, well oiled, and correctly assembled, it will seldom stop when in action.

A. DEFECTS PREVENTED BY PROPER CLEANING AND OILING

1. Clogged gas port
2. Excessive friction in gas cylinder
3. Excessive friction in working parts
4. Hard extractions due to grit or rust in chamber
5. Defective extractors due to brass dust under extractor hooks

B. DEFECTS PREVENTED BY INSPECTING AND TESTING MAGAZINES

1. Damaged magazine
2. Dented magazine
3. Empty space in magazine

C. DEFECTIVE AMMUNITION ELIMINATED BY TESTING AND INSPECTING

1. Bulged rounds
2. Thick rims, deep set caps, split cartridge cases
3. Hard extractions (partially eliminated)

D. DEFECTS PREVENTED BY INSPECTION OF PARTS

1. Defective feed mechanism
2. Damaged striker

Note: By firing 20 rounds into the ground the feed mechanism and striker will be known to be in good condition initially. They are not likely to become defective while firing a few hundred rounds.

E. PRINCIPAL CAUSES OF THE LEWIS GUN STOPPING

1. Empty magazine
2. "Stoppages"
   a. Insufficient charge
   b. Weak cartridge guide
   c. Worn striker post or camway groove

Note: Striker post becomes worn, camway groove becomes burred, resulting in excessive friction.

3. "Jams"
    a. Broken cartridge guide
    b. Broken return spring
    c. Broken extractor (s)
    d. Broken ejector
    e. Full or loose deflector bag

F. DEFINITIONS

1. A "stoppage" can be remedied by applying "Immediate Action"
2. A "jam" cannot be remedied by applying "Immediate Action"

G. SEQUENCE OF "IMMEDIATE ACTION"

1. If the Lewis gun stops, try to rotate the magazine clockwise with the left hand, keeping the eye on the target.

2. If the magazine rotates it is empty, and should be replaced with a filled one.

3. If the magazine does not rotate, pull back on cocking handle, aim, press trigger.

4. If the gun fires, the trouble was a "stoppage".

5. If the gun does not fire, apply "Immediate Action" again.

6. If the gun still does not fire the trouble is due to a jam.

7. Remove the magazine and proceed to determine the cause of the jam.

a. Examine the ejection opening. An empty case in the boltway indicates a broken ejector or a full or loose deflector bag. An empty case in the chamber indicates defective extractors. If the ejection opening is clear and a live round is under the cartridge guide, either the cartridge guide is broken or the top extractor has broken, resulting in an "under run".

b. If the cocking handle comes back with no resistance when applying the first "Immediate Action" the defect is a broken return spring.

Note: If the gun fires after applying "Immediate Action" twice, the trouble was a stoppage.

6. CARE OF THE LEWIS GUN

The reliability of the Lewis Gun depends upon the care and the attention accorded it. It is of the greatest importance that the cadet knows how to clean and oil the Lewis Gun properly, how to inspect the gun for defects, and how to adjust the gun for firing.

A. CLEANING AND OILING

1. **Time of cleaning**
    a. After every firing
    b. Before every firing
    c. At end of each week

2. **Kind of cleaning**
    a. After every firing
        1. If more than 500 rounds have been fired, thorough cleaning
        2. If less than 500 rounds have been fired, partial cleaning

    b. Before every firing, partial cleaning

    c. At end of each week, thorough cleaning and inspection of parts by officer in charge of guns

3. Definitions

a. Partial cleaning Strip body group and gas regulator. Clean working parts, barrel, and gas cylinder. Do not use boiling water.

b. Thorough cleaning Strip body group and barrel group, last part to be stripped being gas chamber. Clean working parts, barrel, gas cylinder, and other parts of barrel group. Use boiling water as specified later.

4. Kind of oil specified: Light Havoline Oil

5. Procedure in cleaning

a. Strip gun part by part, last part to be removed being gas regulator.

b. Clean each part as it is stripped, first with an oily rag, then with a dry rag.

c. Lay cleaned parts on clean end of table where they cannot become dirty.

d. Having cleaned working parts, clean barrel.

1. Push cleaning rod through barrel from muzzle end.
2. Put oil on flannellette. Work oil well into flannellette. Thread flannellette through eye of cleaning rod. Wrap flannellette around end of cleaning rod.
3. Pull rod through barrel from chamber end with one stroke.
4. Repeat (1), (2), (3) with same piece of flannellette reversed.
5. Repeat (1), (2), (3) with dry flannellette.
   a. If over 500 rounds have been fired, 7 pints of boiling water should now be poured through barrel, and then barrel should be cleaned as in (1), (2), (3), (4), (5).
   b. If less than 500 rounds have been fired, oily flannellette and dry flannellette should be used alternately as in (1), (2), (3), (4), (5) above until barrel is clean.
6. An oily flannellette should then be drawn through barrel to leave a thin film of oil in bore.

Note: If any nickeling appears on the lands of the barrel, barrel should be sent to an armorer.

e. Clean gas cylinder.

1. Use wire brush with oil on it.
2. Use *dry* soiled mop.
3. Use *dry* clean mop.
4. If over 500 rounds have been fired, 7 pints boiling water should also be poured through gas cylinder and body.

6. Assembling and oiling Oil parts as they are assembled in following order

a. Gas regulator and gas regulator key (no oil). Large hole of gas regulator should be placed to rear.

b. Body.

c. Body locking pin (no oil).

d. Ejector and ejector seating (slightly).

e. Locking recesses (well).

f. Head of piston rod (well, on lateral surface of head, not on cup).

g. Rack (slightly).

h. Striker post (well).

Insert piston rod half way into body. Assemble bolt, oiling

i. Worm of feed arm actuating stud (slightly),

j. Camway groove (well),

k. Surface of bolt (slightly).

Put bolt on striker post, push in on bolt, insert cocking handle correctly, push cocking handle forward.

l. Pinion casing complete, having slightly oiled edges of coiled return spring in return spring casing before inserting latter into pinion.

m. Oil parts on top of pistol grip (slightly), assemble pistol grip to body.

n. Feed pawl where it pivots on stud (slightly).

o. Curved channel in tail of feed arm (slightly).

p. Around magazine post and underneath feed arm (well). Assemble feed arm to body.

q. Around stop pawls studs (slightly).

r. Stop pawls (slightly).

s. Ribs of body cover (slightly).

t. Projections on sides of body cover.

u. Assemble body cover to body.

v. Assemble spade grip.

Note: Always remove both extractors when cleaning the bolt in order to clean the face of the bolt and prevent the accumulation of brass dust under the hooks on the extractors. It must also be borne in mind that the Lewis gun depends upon a sharp backward movement to unlock the bolt. If a slow movement results, energy of the gases will be overcome in rotating the bolt, hence a stoppage occurs. For this reason, all working parts must work with as little friction as possible.

B. POINTS TO BE OBSERVED BEFORE FLIGHT

1. The gun must be stripped as far as the gas regulator and cleaned and oiled. Remove the oil from the barrel bore and see that there is no obstruction in it, that it is dry, and that the chamber is dry.

2. See that the large hole of the gas regulator is to the rear, which is indicated by placing the "L" on the gas regulator to the rear.

3. See that the cocking handle is in correctly.

4. See that the return spring is at the correct working tension, about 11 lbs.

Note: If the tension is too low the rack will strike the spade grip too hard on the backward stroke which would probably result in breakage of working parts. If the tension is too high, the piston rod will not be moved back far enough to feed the next cartridge.

a. To measure return spring tension, engage hook of spring balance with cocking handle, pull back ring of spring balance and read the tension just as the cocking handle starts to rear.

5. See that the cartridge guide is in the proper position, i.e., acting as a spring.

6. See that the sights are fixed firmly and are upright.

7. Place an empty magazine on the gun and work the cocking handle to see that the feed mechanism is operating correctly.

8. Fire 20 rounds into the ground.

9. See that the deflector bag is on correctly. See that it is hammered up tight and the bottom of the bag securely fastened.

10. See that the mounting yoke latch is on the right hand side. See that the pin is pushed in from the rear and the handle turned down.

C. POINTS TO BE OBSERVED DURING FLIGHT

1. Immediately upon leaving the ground place a filled magazine on magazine post and cock the gun.
2. It is a good plan to work the moving portions backward and forward about 15 to 20 times every ten minutes in order to free the recoiling portions from congealed oil in case they are getting clogged. The magazine must first be removed.
3. During a temporary cessation of fire, a partially emptied magazine should be replaced with a filled one.

D. POINTS TO BE OBSERVED AFTER FLIGHT

1. Before landing on airdrome, remove magazine. If live round is in the feed way, lock gun, and on landing fire off round into the ground having previously warned mechanics that you are going to do so.
2. When landed, have gun taken to gun shop and cleaned as laid down above. (See par. A)
3. Magazines must be emptied, examined and tested before being refilled.
   a. Testing magazines
      1. Place each on a loading handle and spin to ensure free rotation.
      2. Place on magazine post and rotate slowly to test for diameter.
      3. Examine separating pegs to insure that none are broken or loose.
      4. Examine aluminum center to insure that aluminum lip is not bent.
      5. Test magazine catch to insure its working freely.
   b. To fill a magazine
      1. Place the magazine bottom upwards on a flat surface.
      2. Insert the loading handle and rotate the center block, placing the cartridges horizontally in succession between the separating pegs in such a way that the lip of the bullet groove engages them and leads them to place.
      3. Care should be taken not to leave an empty space; an empty space will cause the gun to cease firing when in action.

      Note: When no loading handle is available, the nose of a bullet may be used as a substitute; it is a help to place a cartridge vertically in one of the holes of the center block of the magazine.
4. Ammunition must be tested.
   a. The testing of ammunition is most important as the passing of one defective round through carelessness may cause very serious results when in the air.
   b. Each round must be carefully examined for deep set caps, split or damaged cases.
   c. The best test to employ is to drop each round into the breech of a new Lewis gun barrel in order to see that the cartridge enters freely, and by removing the striker from the striker post each round can be passed through the gun and tested for thick rims.

   Note: Great care must be taken to insure that the striker *has* been removed.
5. Return spring must be left at correct working tension before gun is put away, for if it is left at too great a tension it is liable to break during cold weather.

6. Guns must not be left lying about with the magazine on, since magazine is specially liable to damage.

7. Spare parts must be given proper attention.

a. Spares should be checked over at least once a week, and inspected by the officer in charge of guns.

b. After checking they should be wrapped in greased paper and returned to the receptacles provided.

c. On no account should they be left lying loose in the large boxes.

d. Every gunner should assure himself that the spare parts provided fit his gun properly; e. g., feed arm actuating studs may not be interchangeable.

e. In view of the fact that some little time is always needed to get a machine away from the ground, it will, as a rule, not be necessary to keep guns mounted on machines, or standing in arm racks. They should be kept in their boxes until wanted for use.

8. Weekly inspection of guns is necessary.

a. Guns and magazines, like spares, should be inspected by the officer in charge of guns at least once a week.

b. Every gun should be stripped and the parts be laid out for inspection. Consequently the gas cylinder must be removed; the only other occasion upon which this should be done is when the gun has fired a total of over 500 rounds.

7. STANDARD TESTS OF STRIPPING—LEWIS GUN

The following tests are designed to make the student skillful in adjusting the return spring tension and in replacing broken parts of the Lewis Gun. Continued practice of the pre-arranged actions will soon enable the student to perform these important operations quickly and automatically.

In these tests only wooden bullets or dummy cartridges of a distinctive shape should be used. Necessary spares and a dummy cartridge should be on table beside mounted gun equipped with deflector bag. Cadet must begin each test anew if he makes an error.

It is assumed that initially the cocking handle is forward and that the gun is free of cartridges in all of these tests.

A. INCREASE RETURN SPRING TENSION

1. Remove magazine
2. Remove spade grip
3. Holding pinion casing in place, release pistol grip
4. Pull cocking handle back
5. Drop pinion casing, disengaging pinion from rack
6. Push cocking handle forward
7. Mesh pinion with rack
8. Push pistol grip forward
9. Measure return spring tension
10. Replace spade grip
11. Replace magazine
12. Pull back charging handle (C. H.)
13. Aim
14. Press trigger

B. DECREASE RETURN SPRING TENSION

1. Remove magazine
2. Remove spade grip
3. Holding pinion casing in place, release pistol grip
4. Drop pinion casing, disengaging pinion from rack

5. Pull cocking handle back
6. Mesh pinion with rack
7. Push pistol grip forward (Cocking handle will snap forward)
8. Measure return spring tension
9. Replace spade grip
10. Replace magazine
11. Pull back C. H.
12. Aim
13. Press trigger

C. CHANGE CARTRIDGE GUIDE

1. Remove magazine
2. Remove cartridge guide
3. Insert new cartridge guide
4. Put on filled magazine
5. Pull back C. H.
6. Aim
7. Press trigger

D. CHANGE BOLT

1. Remove magazine
2. Remove spade grip
3. Holding pinion casing in place, release pistol grip
4. Drop pinion casing
5. Pull back C. H.
6. Remove C. H.
7. Withdraw piston rod far enough so that bolt can be removed
8. Put new bolt on striker post
9. Push forward on bolt
10. Insert C. H.
11. Push C. H. forward
12. Mesh pinion with rack
13. Push pistol grip forward
14. Replace spade grip
15. Put on filled magazine
16. Pull back C. H.
17. Aim
18. Press trigger

E. CHANGE EJECTOR

1. Remove magazine
2. Remove spade grip
3. Remove body cover
4. Pull back C. H.
5. Put feed arm to right
6. Remove ejector cover
7. Remove ejector
8. Slip in new ejector
9. Replace ejector cover
10. Put feed arm to left
11. Ease C. H. forward
12. Replace body cover
13. Replace spade grip
14. Put on filled magazine
15. Pull back C. H.
16. Aim
17. Press trigger

F. CHANGE PINION CASING COMPLETE

1. Remove magazine
2. Remove deflector bag
3. Remove spade grip
4. Holding pinion casing in place, release pistol grip
5. Remove pinion casing complete
6. Replace new pinion casing complete, having return spring at correct tension
7. Mesh pinion with rack
8. Push pistol grip forward
9. Replace spade grip
10. Replace deflector bag
11. Put on filled magazine
12. Pull back C. H.
13. Aim
14. Press trigger

8. RANGE PRACTICE—LEWIS GUN

A. PRACTICES

The purpose of range practice is to teach the cadet "Drill", to hold the gun properly, to sight accurately, and to group his shots correctly.

There are three practices; Drill, Grouping, and Application.

1. **Practice No. I, drill**

   Range, 25 yards
   Six magazines, each with one round
   Six-inch group to be obtained
   Follow instructions for "Drill"

2. **Practice No. II, grouping**

   Range, 25 yards
   Three magazines each with ten rounds
   Three six-inch groups to be obtained
   Aim respectively at first, second, and third marks from left of target

3. **Practice No. III, application**

   Range, 25 yards
   Three magazines; one with ten rounds, two with twenty rounds each
   Five six-inch groups to be obtained
   Fire as follows

   1. Ten rounds in first magazine at first mark from left of target
   2. Ten rounds from second magazine at second mark from left of target
   3. Ten rounds from second magazine at third mark from left of target
   4. Ten rounds from third magazine at fourth mark from left of target
   5. Ten rounds from third magazine at fifth mark from left of target

B. RANGE DISCIPLINE

1. **Duties of cadets**

Number I cadet is in charge of the squad and is responsible for the actions of each cadet in the squad. He transmits all instructions from the officer in charge to his squad, and assumes the duties of each cadet in the squad when the latter is firing.

Number II cadet records the number of the gun and number of rounds fired by each cadet, scores all shots, and notes all stoppages.

Number III cadet superintends the filling of magazines and inspection of ammunition. He sees that all magazines together with any live rounds, are returned to the munitions room. He sorts any live rounds from the empty cases, and puts the latter into a proper receptacle.

Number IV cadet takes charge of the gun.

Number V cadet takes charge of the target.

Number VI cadet prepares the cleaning materials for use and superintends the cleaning of the gun. He runs an oily rag through the barrel of the gun at the immediate close of range practice before returning to the cleaning room.

2. **Procedure**

The procedure of range practice shall be as follows:

The targets having been set, the guns are mounted on the tripods, muzzles down. When the first whistle is blown by the officer in charge each gunner takes his seat and performs his practice, all the other men of each squad remaining behind their gun. At the conclusion of the practice, each gunner unloads and leaves his gun with muzzle down. At the second whistle all gunners leave their seats. At the third whistle the targets may be examined.

No disobedience of these orders will be tolerated.

9. NOMENCLATURE OF MARLIN AIRCRAFT GUN

A. LOCK CONTAINER

1. Lock container screws
2. Hammer screw
3. Hammer
   a. Sear and trigger notch
4. Hammer spring
5. Hammer spring guide
6. Sear and trigger pin
7. Trigger
8. Sear with sear spring

B. TRIGGER SPRING

C. RECEIVER PLUG

D. BOLT PIN RETAINER

E. BOLT PIN

F. BOLT

1. Cam slot
2. Firing pin
3. Firing pin spring
4. Firing pin retaining pin
5. Shell extractor
6. Shell extractor spring
7. Shell extractor retaining pin
8. Triangular fin

G. SIDE PLATE REAR SCREW

H. SIDE PLATE FRONT SCREWS (2)

I. LEFT SIDE PLATE

1. Feedway
2. Bullet guide

J. TRIP

1. Nose
2. Arm
3. Head

K. RIGHT SIDE PLATE

1. Charging slide and handle
2. Charging slide retaining lug
3. Charging slide guide
4. Charging slide spring
5. Inspection opening
6. Beltway
7. Inspection opening cover
8. Inspection opening cover cartridge guide
9. Inspection opening cover retaining spring
10. Feed lever
11. Ratchet lever
12. Ratchet lever pawl
13. Feed throw-off

L. BOTTOM PLATE

1. Feed wheel
2. Feed wheel supports (2)
3. Cartridge stop
4. Feed wheel dog
5. Feed wheel dog spring
6. Feed wheel shafts (2)
7. Feed wheel shafts spring
8. Belt support
9. Cartridge extractor cam
10. Cartridge extractor cam seating
11. Cartridge extractor cam spring
12. Carrier stop
    a. Carrier stop screw
    b. Carrier stop spring
13. Rear mounting bracket

M. CARRIER PIN

N. CARRIER

1. Carrier dog
2. Carrier dog pin
3. Carrier dog plunger
4. Carrier dog spring
5. Carrier dog spring guide

O. GAS CYLINDER

1. Gas cylinder bracket
2. Gas cylinder block
   a. Positioning lugs
3. Gas adjuster
4. Channel

P. BARREL

1. Gas port
2. Shell extractor clearance slot
3. Bullet guide

Q. SLIDE

1. Cartridge extractor
2. Cartridge guides (right and left)
3. Cartridge extractor spring
4. Carrier cam notch
5. Slide cam groove
6. Feed lugs (front and rear)
7. Piston rod lock pin and spring

R. ACTION SPRING GUIDE AND BELT GUIDE

S. ACTION SPRING

T. PISTON ROD

1. Piston
2. Balance block

U. BUFFER BLOCK AND SPRINGS

1. Buffer block pin

V. RECEIVER

1. Receiver plug lock-latches (2)
2. Receiver plug lock-latch spring catch
3. Ejection opening
4. Hammer way
5. Trip way
6. Barrel lock pin and spring
7. Bolt way
   a. Locking recess
   b. Ejector
   c. Ejector spring
   d. Ejector plunger
   e. Cartridge retainer
   f. Chamber guide

W. TOOLS

1. Gas adjuster wrench
2. Combination barrel and action spring tool

10. STRIPPING AND ASSEMBLING—MARLIN AIRCRAFT GUN

A. STRIPPING

1. Remove lock container
2. Remove trigger spring
3. Remove receiver plug
4. Draw back charging slide
5. Remove bolt pin retainer, bolt pin, and bolt.
6. Release charging slide
7. Remove left side plate
8. Remove trip
9. Remove right side plate
10. Remove bottom plate
11. Remove carrier pin and carrier
12. Remove gas cylinder
13. Remove barrel
14. Remove slide
15. Remove action spring guide and action spring
16. Remove piston rod from slide
17. Remove buffer block

B. ASSEMBLING

The gun is assembled by reversing the operations given above for stripping.

C. STRIPPING AND ASSEMBLING GROUP PARTS OF THE MARLIN AIRCRAFT GUN

1. To strip the lock container

a. Release hammer by pressing trigger
b. Remove hammer screw, holding fingers on hammer
c. Remove hammer, hammer spring, and hammer spring guide
d. Remove sear and trigger pin
e. Remove sear and trigger

2. To assemble the lock container

a. Replace sear and trigger
b. Replace sear and trigger pin

c. Put hammer spring on hammer spring guide; start hammer spring guide into position; place hammer against hammer spring guide (sear and trigger notch to rear); push hammer into position; insert hammer screw

d. Screw hammer screw into position

e. Press trigger to raise hammer spring guide into position; cock hammer

3. To remove feed wheel from bottom plate

a. With drift, push in on front feed wheel shaft, lifting front end of feed wheel slightly

b. With drift, push in on rear feed wheel shaft, lifting rear end of feed wheel slightly

The feed wheel shafts are now held in against the action of the feed wheel shafts spring by the feed wheel supports

c. Lift up feed wheel with right hand keeping both ends of feed wheel covered with left hand so as to catch feed wheel shafts as they are forced out.

d. Remove feed wheel shafts and feed wheel shafts spring

4. To assemble feed wheel to bottom plate

a. Insert feed wheel shafts spring and feed wheel shafts into feed wheel

b. Place feed wheel between feed wheel supports, ratchet end to front

c. Compress feed wheel shafts until shoulders engage between the feed wheel supports

d. With drift push in on front feed wheel shaft, pushing down front end of feed wheel slightly until this shaft is engaged behind front feed wheel support

e. With drift push in on rear feed wheel shaft, pushing down rear end of feed wheel slightly until this shaft is engaged in front of the rear feed wheel support

f. Push down on both ends of feed wheel evenly until feed wheel shafts spring into place

5. To remove firing pin from bolt

a. Holding bolt in left hand, press in on rear end of firing pin with index finger

b. With drift remove firing pin retaining pin

c. Let firing pin spring extend gently

6. To assemble firing pin to bolt

a. Holding bolt in left hand with rear fin up, press firing pin and firing pin spring into position, notch on firing pin up.

b. Replace firing pin retaining pin from right

7. To remove shell extractor from bolt

a. Holding bolt in left hand with shell extractor up, face of bolt to front, press down on rear of shell extractor with thumb

b. With drift remove shell extractor retaining pin by pushing from right

c. Shell extractor and shell extractor spring will fall off

8. To assemble shell extractor to bolt

a. Holding bolt in left hand with extractor seating up, face of bolt to front, press shell extractor spring and shell extractor into position

b. Replace shell extractor retaining pin from left

9. To remove action spring from slide

a. With slide vertical, piston resting on table, press down with left thumb on belt guide and push belt guide clear of cartridge extractor

b. Grasp belt guide with right hand, thumb on top, and allow action spring to extend gently

c. Withdraw action spring

10. To assemble action spring to slide

a. Hold slide vertical in left hand, cartridge extractor to left, piston pressing on table or floor

b. Insert action spring and action spring guide into piston from right

c. Place combination barrel and action spring tool on belt guide

d. Guiding action spring with left hand, compress action spring with right hand until belt guide comes into position

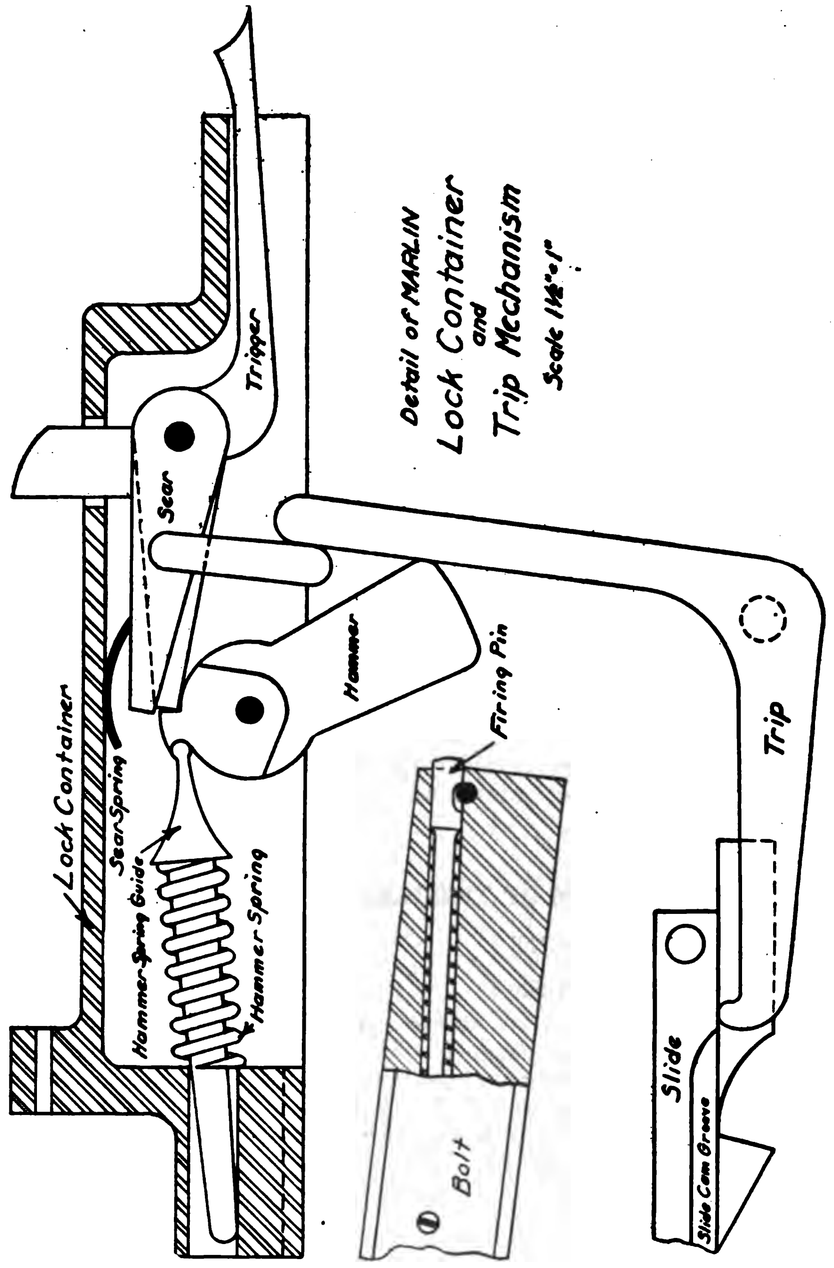

Detail of MARLIN
Lock Container
and
Trip Mechanism
Trigger
Sear
Hammer
Firing Pin
Lock Container
Sear Spring
Hammer-Spring Guide
Hammer-Spring
Trip
Slide
Slide Cam Groove
Bolt

PLATE 10

11. To remove piston rod from slide

a. Remove action spring from slide

b. Holding back piston rod lock pin with screw-driver, unscrew piston rod from slide

12. To assemble piston rod to slide

a. Screw piston rod into slide, holding back piston rod lock pin with screw-driver. Screw piston rod tight and then unscrew until piston rod lock pin engages in first notch.

D. POINTS TO BE CAREFULLY OBSERVED WHEN STRIPPING OR ASSEMBLING THE MARLIN AIRCRAFT GUN

1. Always cock the lock before removing it from gun.
2. When removing the lock container screws remove the front screws first because of the action of the trigger spring in forcing the rear of the lock container up
3. Always remove action spring guide and action spring from slide as soon as slide is removed from receiver
4. When assembling, never hammer or force a screw that does not start properly
5. When placing slide into receiver care must be exercised not to allow the belt guide to be too low to engage in the dove-tailed slot in receiver, as this will prevent cartridges from being fed properly against the cartridge stop by the feed wheel
6. When assembling right side plate to receiver, be sure that feed lever is at extreme forward position so that it lies between the front and rear feed lugs on the slide
7. Be very careful when screwing barrel into receiver to insure proper alignment of threads. Barrel should be screwed fully home, and locked.
8. When replacing lock container, hammer should be in cocked position
9. Replace rear lock container screws first
10. After assembling gun, always pull charging slide to rear and release it.

11. MECHANISM OF THE MARLIN AIRCRAFT GUN

A. BACKWARD MOVEMENT

1. Firing the First Shot

When the trigger is depressed it is disengaged from the sear and trigger notch of the hammer. The hammer spring guide, actuated by the hammer spring and bearing against a grooved notch in the hammer, forces it forward. The hammer strikes the rear end of the firing pin, forcing the front end through the striker way, priming the cartridge. (See plate 10)

POSITION OF CARRIER DURING FIRST PART OF FORWARD MOVEMENT.

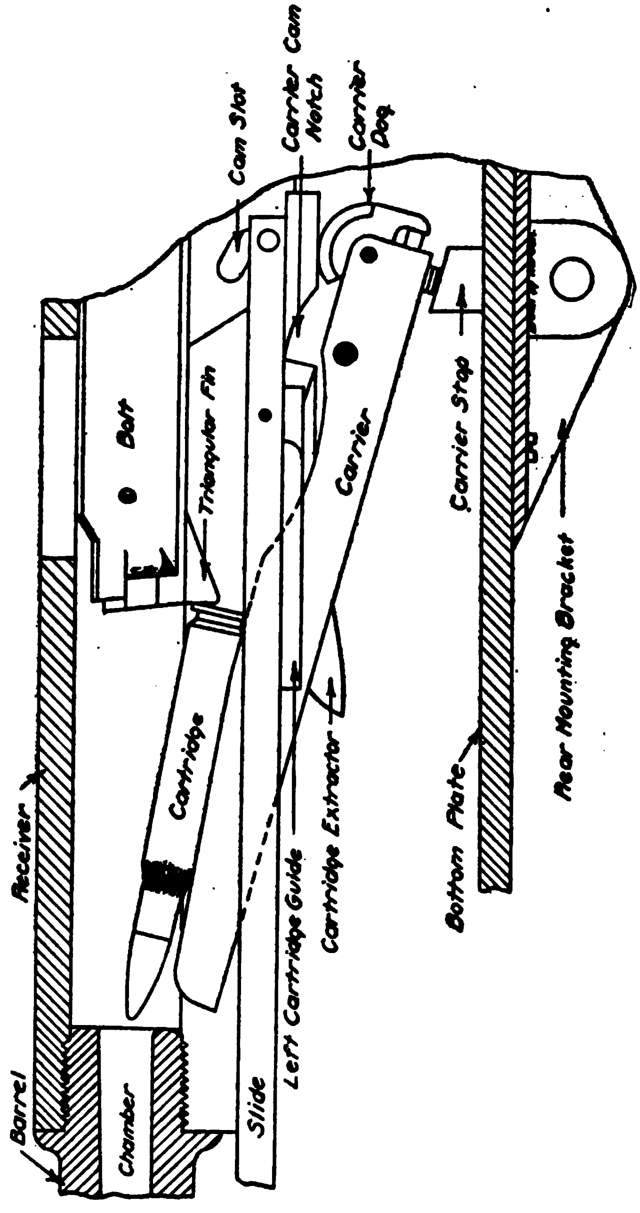


PLATE 11

2. Action of the Gases

When the bullet passes the gas port, a portion of the powder gases escape through the gas port down the gas channel into the gas cylinder and impinge against the head of the piston, forcing it with the slide to the rear, compressing the action spring.

3. Backward Action of the Slide and Bolt

As the slide moves to the rear, the bolt pin, acting in the cam slot in the rear guide fin of the bolt, raises the rear end of the bolt out of the locking recess in the receiver. The nose of the trip, under pressure of the sear spring at its head, rides up into the slide cam groove; thus the nose of the sear is lowered ready to engage in the sear and trigger notch of the hammer. The bolt moving to the rear pushes back the hammer and rides beneath it, compressing the hammer spring. As the slide passes to the rear, the rear end of the slide flanges strikes the front end of the carrier dog, forces it back compressing the carrier dog spring, and rides above it. The carrier dog spring then forces the carrier dog into the carrier cam notch of the slide.

4. Backward Action of the Shell Extractor and the Cartridge Extractor

As the bolt moves to the rear, a shell is withdrawn from the chamber by the shell extractor and is carried to the rear until its base strikes the stud on the ejector, when it is thrown out through the ejection opening. The ejector spring and plunger cushion the blow on the ejector. In the meantime the cartridge extractor has withdrawn the next cartridge from the belt and carried it back on the carrier, guided by the cartridge guides and the inspection opening cover cartridge guide. The backward motion of the slide is arrested by the buffer block and springs.

5. First Action of the Feed Lever

As the slide moves backward the front feed lug forces the feed lever to the rear. The ratchet lever is thereby raised until the ratchet lever pawl rides over the next tooth of the feed wheel and engages behind it. The feed wheel dog prevents counter-clockwise rotation of the feed wheel.

B. FORWARD MOVEMENT

1. Action of the Carrier

The force of the gases now being expended, the action spring begins to extend, forcing the slide forward. As the slide moves forward, the carrier dog riding in the carrier cam notch on the bottom of the slide flanges, and acting as an integral part of the carrier, depresses the rear end, and it being pivoted, elevates the front end of the carrier. Thus the carrier disengages the cartridge from the cartridge extractor and carries it up against the guide shoulders below the boltway. The upward motion is limited by the carrier stop upon which the rear end of the carrier strikes. The carrier stop spring acting on the rear end of the carrier, forces the front end of the carrier down as soon as the slide moves clear of the carrier dog. The cartridge, being pushed forward by the bolt, is then supported at its rear end by the cartridge retainer and the sides of the receiver. (See plate 11)

2. Second Action of the Feed Lever

As the slide moves forward, the rear feed lug forces the feed lever forward. The ratchet lever is thereby forced down, rotating the feed wheel one tooth clockwise (from gunner) thus bringing the next cartridge into position in the feedway against the cartridge stop. At the same time the feed wheel dog rides over the next tooth of the feed wheel and engages behind it.

3. Forward Action of the Slide and Bolt

As the bolt moves forward, the hammer is forced down by the hammer spring guide, actuated by the hammer spring, until the nose of the sear engages in the sear and trigger notch in the hammer.

The triangular fin, on the front of the bolt, strikes the rim of the cartridge, supported by the cartridge retainer in front of the bolt, and forces it into the chamber; the nose of the bullet is guided into the chamber by the chamber guide.

After the bolt reaches its forward position, the bolt pin, riding in the cam slot of the rear guide fin of the bolt, draws the rear end of the bolt down into the locking recess in the receiver, thus locking the breech. After the breech is locked, the nose of the trip rides out of the slide cam groove. This causes the head of the trip to move forward, and working against the arm of the sear, disengages the nose of the sear from the sear and trigger notch in the hammer. Thereupon the hammer moves slightly forward and is held back only by the nose of the trigger which then engages in the sear and trigger notch in the hammer.

4. Forward Action of the Shell Extractor and the Cartridge Extractor

As the bolt reaches its forward position, the shell extractor springs over and grips the rim of the cartridge in the chamber.

As the slide nears its forward position, the cartridge extractor strikes the base of the next cartridge in the belt, and is forced down against the cartridge extractor cam thus causing the cartridge extractor claw to grip the rim of the cartridge.

The forward motion of the slide is limited by the piston rod balance block striking the rear end of the gas cylinder block.

12. DRILL—MARLIN AIRCRAFT GUN

Drill consists in
A. Loading
B. Firing
C. Unloading

A. LOADING

Insert belt in the feedway from left until first cartridge is engaged in feed wheel. Draw charging slide to rear and release. Draw charging slide again to rear and release. The gun is then ready for automatic fire.

B. FIRING

The gun is fired only by synchronized gear trigger trippers which actuate, according to the type of gear, either the tail end of the trigger or the vertical projection to be seen above the lock container. After the first shot the gun is automatically fed.

C. UNLOADING

Draw charging slide to full cock, ejecting live round from chamber. Push forward on feed throw off and withdraw the belt, then allow charging slide to go forward quickly. The live round in the chamber may then either be fired by depressing the trigger or ejected by drawing the charging slide to rear. As a safety precaution this action is repeated.

13. STOPPAGES AND JAMS—MARLIN AIRCRAFT GUN

If the Marlin Aircraft gun is properly cleaned, oiled, inspected, assembled, and adjusted many defects in operation may be prevented.

A. DEFECTS PREVENTED BY PROPER CLEANING AND OILING

1. Excessive friction caused by too little oil or too much oil (congealing)
2. Clogged gas port

B. DEFECTS PREVENTED BY PROPER INSPECTION OF PARTS

1. Excessive friction due to burrs
2. Worn or broken parts

C. DEFECTS PREVENTED BY PROPER ASSEMBLY OF GUN

1. Belt guide too low to engage properly in dove-tailed slot in receiver, which will prevent cartridge from being fed properly against cartridge stop.
2. Barrel improperly assembled to receiver, resulting in lack of alignment between shell extractor and shell extractor clearance slot; also between gas port and gas channel.
3. Feed lever not between feed lugs, which will be detected when applying "Immediate Action" after assembly.
4. Improperly assembled lock container which will prevent gun from firing.

D. DEFECTS PREVENTED BY PROPER ADJUSTMENT OF GUN

1. Defective trip: To test the trip

a. Use the *no trip gauge* to determine if the sear is engaged before the breech is locked. Draw charging slide to the rear, hold the *no trip gauge* against the gas cylinder block (fillet to rear), and release charging slide quickly. The trigger should not be engaged. If it is, it means there would be a premature priming of the cartridge. If it is engaged, the head and nose of the trip are too close and must be separated a short distance.

b. Use the *trip gauge* to determine if the sear is disengaged by the trip after the breech is locked. Draw charging slide to center notch, hold the *trip gauge* against the gas cylinder block (fillet to rear), and release charging slide quickly. The trigger should now be engaged, otherwise the gun would not fire. In case the trigger is not engaged, the head and nose of the trip are too far apart and must be bent closer.

c. After any change is made in the trip, the *no trip gauge* must be used followed by the *trip gauge,* until both fulfill their purpose.

2. Gas adjuster unscrewed too far.

E. DEFECTIVE AMMUNITION ELIMINATED BY TESTING AND INSPECTING

1. Deep set caps, high primers, split cases, thick rims (eliminated by inspection).
2. Bulged rounds, (eliminated by dropping rounds into a new gun barrel).

F. DEFECTS PREVENTED BY PROPER LOADING OF BELTS

1. Empty space in belt
2. Rounds out of line in belt

G. STOPPAGES AND JAMS

The principal causes of the Marlin Aircraft Gun stopping when in action are divided into three positions.

1. **Position I** Bolt forward and breech locked, or charging slide is held by slide shoulder.

"Immediate Action". Draw charging slide to rear, release, and carry on.

a. If automatic fire occurs, the stoppage was due to an insufficient charge resulting in very little backward action.

b. If one shot is fired and gun stops, examine for
1. Excessive friction
2. Incorrectly adjusted gun

c. If gun does not fire after applying "Immediate Action' at least twice, examine for
1. Defective trip mechanism
2. Defective lock container mechanism
3. Defective feed wheel mechanism
4. Defective firing pin; bolt must be changed. To change bolt
   1. Remove belt
   2. Remove receiver plug
   3. Draw charging slide to rear
   4. Remove bolt pin retainer and bolt pin
   5. Insert drift from front end of lock container under hammer spring guide. This will hold hammer up while changing bolt.
   6. Remove bolt
   7. Replace new bolt
   8. Remove drift
   9. Replace bolt pin and bolt pin retainer
   10. Release charging slide
   11. Replace receiver plug
   12. Apply "Immediate Action"

2. **Position II** Bolt not more than one-third of the way back, or charging slide is free for a distance of about 1½ inches. Apply "Immediate Action".

a. If automatic fire occurs the stoppage was due to an insufficient charge resulting in enough backward action to withdraw cartridge from belt but not enough to operate carrier.

b. If automatic fire does not occur, examine for
1. Cartridge in feed wheel jammed against cartridge stop.
2. Defective cartridge extractor mechanism
3. Obstruction in chamber such as a primer or a piece of a shell.

3. **Position III** Bolt in back of Position II, or charging slide is free for a distance greater than 1½ inches.

Apply "Immediate Action".

a. If automatic fire does not occur, examine the ejection opening.
1. If there is an empty case in chamber, the jam is due to a broken shell extractor or broken shell extractor spring.
2. If there is an empty case in the boltway and a cartridge jammed beneath it, the jam is due to a broken ejector stud.
3. If there is a cartridge on the carrier which is just visible in the ejection opening, the jam is due to a solid cartridge retainer.

4. If there is a cartridge in the boltway projecting partially into the chamber, the jam is due to a ruptured case remaining in the chamber.

5. If the slide cannot be moved, the bolt pin is partially out.

6. Examine also for

a. Defective carrier dog mechanism

b. Defective chamber cartridge guide.

H. UNCONTROLLED AUTOMATIC FIRE

Pull back charging slide and lock it.

1. Cause: defective trigger mechanism

I. REPORTS OF STOPPAGES AND JAMS

Whenever the gun is used in the air, gunner must report all stoppages and jams, position of bolt, "Immediate Action" applied, and whether the trouble was remedied and how.

14. CARE OF THE MARLIN AIRCRAFT GUN

A. CLEANING

The gun muts be completely stripped and thoroughly cleaned after every firing in the same manner as the Lewis Gun. All working parts should be slightly oiled except the face of the bolt and the piston which should not be oiled. The slide should be well oiled.

B. POINTS TO BE OBSERVED BEFORE FLIGHT

1. The gun must be completely stripped, cleaned, inspected, oiled, and assembled. Remove the oil from the barrel bore and see that there is no obstruction in it, that it is dry and that the chamber is dry.

2. Screw gas adjuster fully home.

3. See that mounting pins and bolts are securely fastened

4. Securely fasten feed box and deflector box

5. Securely fasten trigger motor

6. Fill and "time" C. C. gear

7. Harmonize ring sights

8. Fire a burst of twenty

9. Unload gun, then reload so that there is a cartridge gripped by the cartridge extractor but none in the chamber. Finish loading when out of the airdrome.

C. POINTS TO BE OBSERVED DURING FLIGHT

1. Reservoir handle must be kept up.

2. On cold days or at high altitudes, fire burst of ten every ten minutes.

3. After each burst, determine if breech is closed by pulling on charging slide.

D. POINTS TO BE OBSERVED AFTER FLIGHT

1. Unload gun

2. Have gun taken to gun shop and thoroughly cleaned and inspected.

a. Replace any damaged part, and "time" it with the mechanism.

b. Leave a thin film of oil in bore of barrel

c. If gun is not used regularly, barrel should be cleaned every day for ten days.

3. Test the trip

4. Give a detailed account of guns' behavior in the air to armorer.

5. Test ammunition as directed for the Lewis Gun, except that rounds should not be run through the Marlin Aircraft Gun.

6. Fill belts.

a. Belts should be clean and reasonably stiff; do not use belts after the pockets have become so large that the cartridges fit into them loosely.

b. When filling belts, use the belt loading machine and examine for

1. Empty space in belt
2. Rounds out of line in belt

15. AERIAL SIGHTS

A. PURPOSE

The purpose of special sights for aerial gunnery is to compensate automatically for gunner's speed and for enemy's speed so that gunner sights directly on target (which usually is the enemy pilot).

B. TYPES

1. **For a fixed gun**—The Marlin Aircraft Gun.
   a. Ring foresight with fixed bead back sight
   b. Ring backsight with fixed bead foresight
   c. Aldis optical sight

2. **For a movable gun**—The Lewis Aerial Gun.
   a. Ring backsight with a Norman Wind-Vane foresight
   b. Aldis optical sight with special mountings and gears

C. RING SIGHTS

1. **Description** Two concentric rings (the outer ring being of definite diameter) mounted on a post and sometimes connected by four radial wires (See Fig. 401)

2. **Purpose** To compensate for the enemy's speed. (See Fig. 402)

3. **Factors determining the diameter of ring**
   a. The enemy's speed
   b. The distance between gunner's eye and ring sight
   c. Velocity of bullet

4. **Common sizes of ring sights**
   a. For a fixed gun with fixed bead backsight
      1. Enemy's speed, 100 miles per hour
      2. Distance from gunner's eye to ring sight, 38 in.
      3. Diameter of ring, 5 inches

   b. For a movable gun with Norman Wind-Vane foresight
      1. Enemy's speed, 80 miles per hour, 1⅞ in. diameter
      2. Enemy's speed, 100 miles per hour, 2 5/16 in. diameter
      3. For both of these sizes, distance from gunner's eye to ring sight is 19 inches
      4. Enemy's speed 110 miles per hour, 2¼ inches; distance from gunner's eye, 18 inches

5. **The independence of range**

D. PRINCIPLES GOVERNING USE OF RING SIGHTS ON A FIXED GUN WHEN USED EITHER

1. **As a backsight with fixed bead foresight**

2. **As a foresight with fixed bead backsight**

   a. Align the eye so that the bead appears to be in the center of the ring sight.

   b. The eye must be held at the distance in back of the ring sight for which the ring sight was designed.

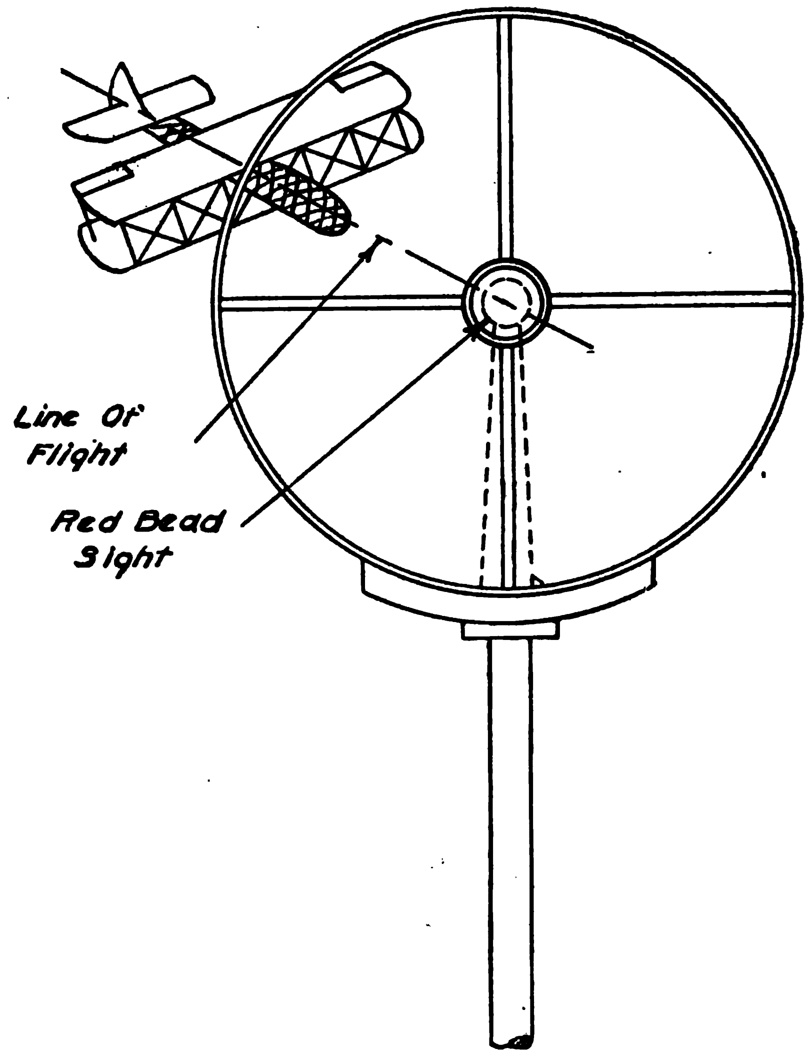


FIG. 401.—AERIAL RING SIGHT

c. The enemy airplane must be placed in the ring so that it is flying *towards the center* of the ring. (See Fig. 403)

d. An enemy airplane flying at right angles to the line of fire, at the speed for which the ring is designed, must be placed on the outer ring with the pilot cutting the ring.

e. An enemy airplane approaching the line of fire obliquely must be placed in a position suggested by its foreshortening. The more the body of the airplane is foreshortened, the nearer it must be placed to the vertical diameter of the ring sight.

E. USE OF RING FORESIGHT WITH BEAD BACKSIGHT ON A FIXED GUN

1. Under conditions for which the ring sight is designed.
2. At variable speeds.
3. As a range finder.

F. THE NORMAN WIND-VANE FORESIGHT

1. **Description** A bead sight connected by levers to a wind vane which, when the airplane is moving, is blown back in opposite direction to the line of flight thus causing bead sight to place itself ahead of gun. (See Fig. 404)

2. **Purpose of Wind-Vane foresight** To compensate for gunner's speed (See Fig. 405)

3. **Factors determining the dimensions of Wind-Vane foresight**
   a. Speed of Gunner
   b. Distance between the wind-vane foresight and ring backsight
   c. Velocity of bullet

4. **Common sizes of Wind-Vane foresights**
   a. Speed of gunner, 80 miles per hour
   b. Speed of gunner, 100 miles per hour
   c. Both of these foresights are to be set 18 inches ahead of ring backsights

G. USE OF NORMAN WIND-VANE FORESIGHT WITH RING BACKSIGHT ON A MOVABLE GUN

1. Wind-Vane foresight compensates for gunner's speed. (See Fig. 406)
2. Ring backsight compensates for enemy's speed
3. Gun is placed according to instructions regarding ring sights (See par. D above)

H. COMPENSATION FOR DEPRESSION AND ELEVATION OF MOVABLE GUN

1. If gun is depressed, bead on Norman Wind-Vane sight will rise through wind pressing on upper surface of the Vane B, Fig. 404.
2. If gun is elevated, bead on Norman Wind-Vane sight will fall
3. (1) and (2) apply when gun is pointed in direction of flight. When gun is pointed in opposite direction to flight, reverse is true.

I. PRACTICE WITH THE MODEL AIMING AIRPLANE, USING A DUMMY GUN EQUIPPED WITH RING BACKSIGHT AND FIXED BEAD FORESIGHT

1. Aim by lining up the center of the ring backsight, the bead foresight, and the ball on the aiming rod of the airplane. Note the position of the airplane in the ring back sight.
2. With the aiming rod removed from the Model Aiming Airplane, aim the gun by following the instructions for aiming with the ring and bead sight, (See par. D above). Check the aim by inserting the aiming rod into the Model Aiming Airplane, and noting the distance the ball of the aiming rod departs from an imaginary line extending from the center of the ring through the bead of the foresight. This distance indicates the error.

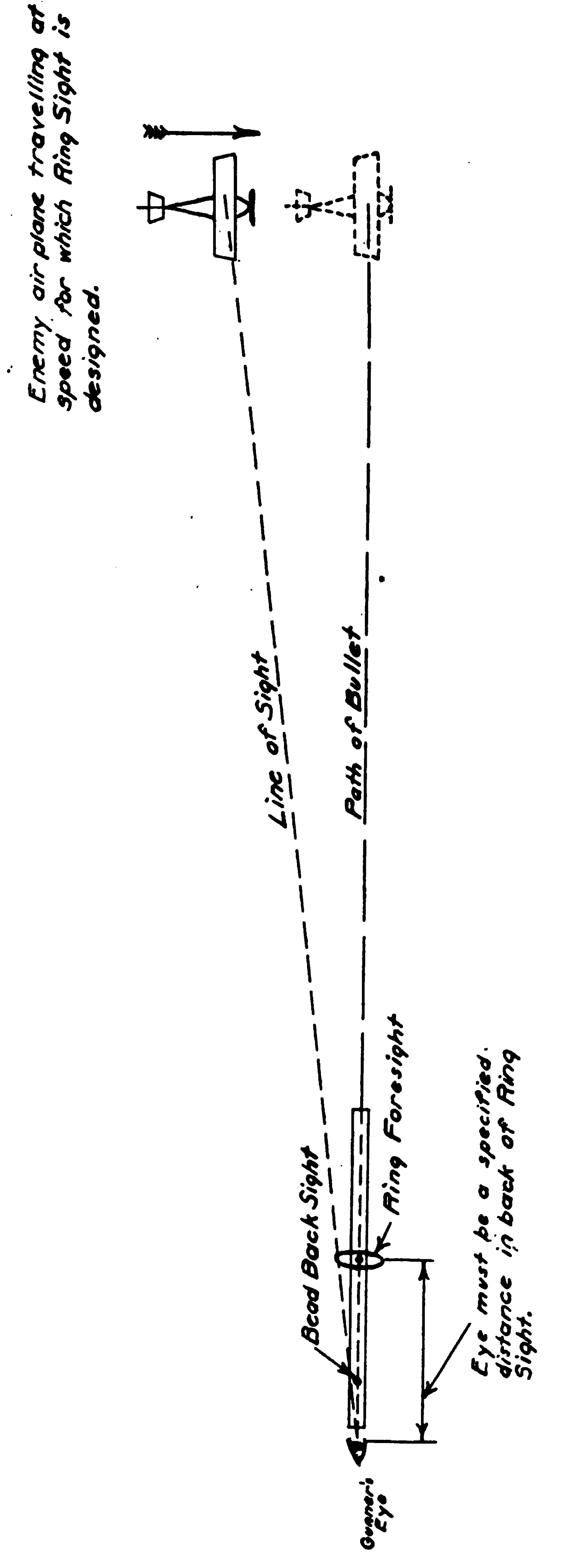


FIG. 402.—DIAGRAM SHOWING HOW RING SIGHT COMPENSATES FOR ENEMY'S SPEED. GUN IS ASSUMED TO BE FIXED

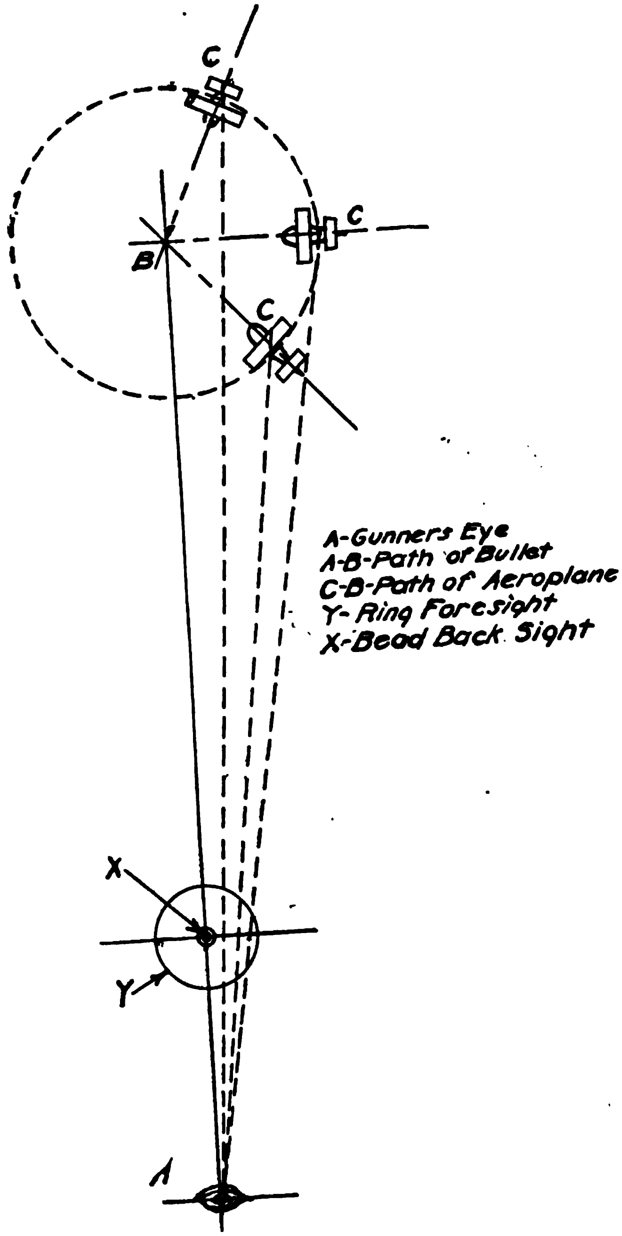


Fig. 403.—Diagram of Sighting

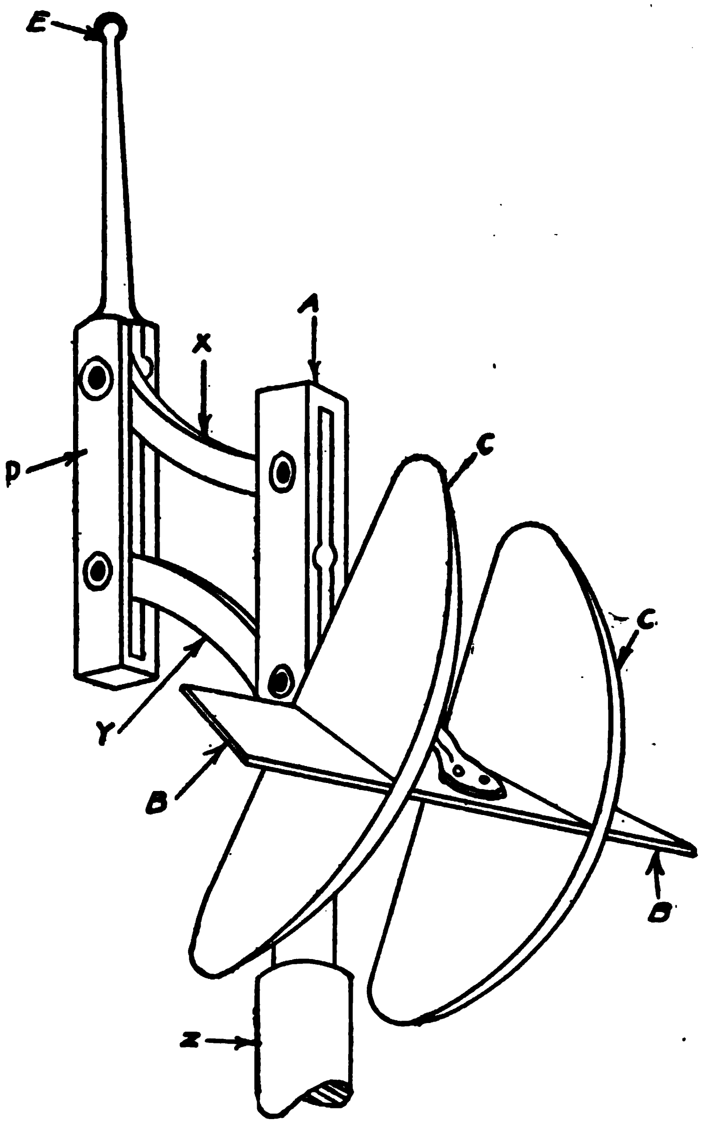


FIG. 404.—NORMAN WIND-VANE FORESIGHT

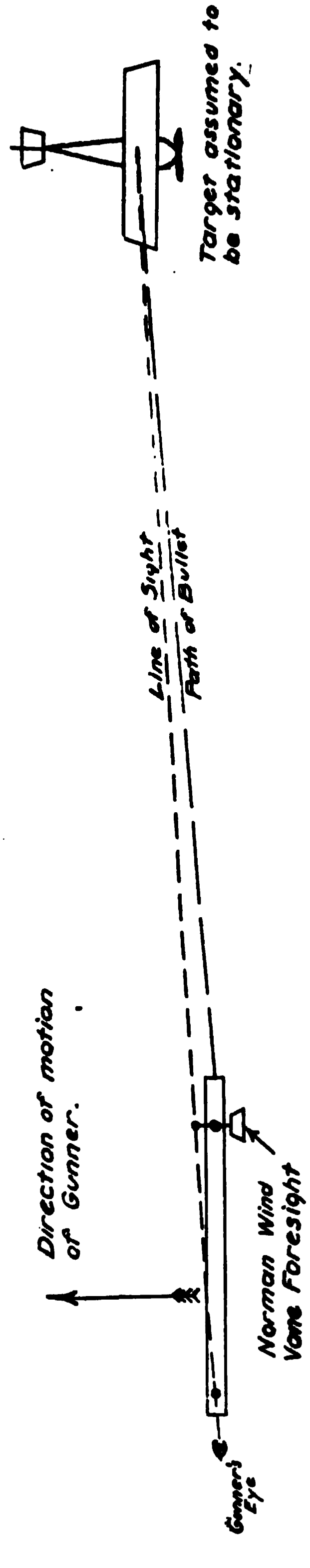


Diagram showing how Norman Wind Vane Foresight compensates for Gunner's speed.

FIG. 405

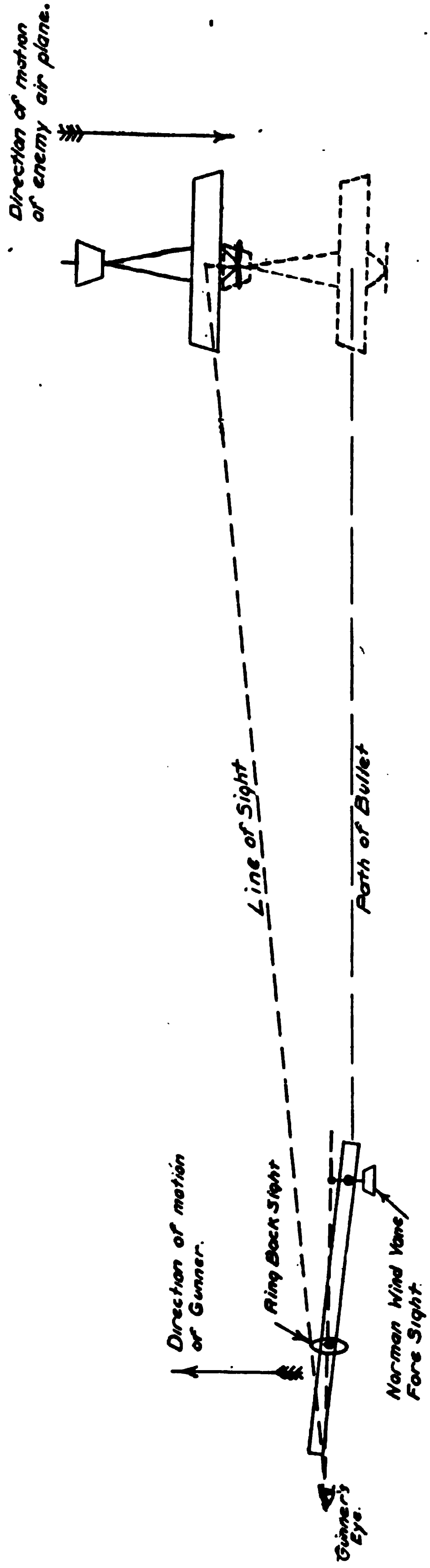


Diagram showing how Ring Back Sight and Norman Wind Vane Foresight compensate automatically for speed of both Gunner and Enemy.

FIG. 406

CHAPTER V.

INSTRUMENTS

OUTLINE

1. Instruments for Determining Direction
    - A. Gyroscopic Compass
    - B. Magnetic Compass
        1. Description
        2. Variation
        3. Deviation
        4. Computation of Compass Course
        5. Errors of Compass
    - C. Drift Meter
2. Instruments for Determining Altitude
    - A. Altimeter
        1. Description
        2. Errors and Corrections
    - B. Barograph
3. Instruments for Determining Speed Through the Air
    - A. Air Speed Indicator
    - B. Tachometer
4. Instruments for indicating Stability
    - A. Inclinometer
    - B. Angle of Incidence Meter
    - C. Banking Indicator
5. Instruments for Determining Ground Speed
    - A. First Method
    - B. Second Method
    - C. Third Method
6. Special Instruments used in Testing
    - A. Climbing Meter
    - B. Statoscope
7. Miscellaneous Instruments and their Specifications
    Oil Gauge, oil-pressure gauge, gasoline supply gauge, gasoline-flow indicator, and radiator temperature indicator.

CHAPTER V.

INSTRUMENTS

1. INSTRUMENTS FOR DETERMINING DIRECTION

A. GYROSCOPIC COMPASS

The gyroscopic compass works on the principle of the gyroscope. It consists of a comparatively heavy fly-wheel whose axis is mounted as the diameter of a circular rim, which in turn is mounted in gimbals so that when the wheel is rotated rapidly by electrical energy the axis will always point in the same direction regardless of the movements of the airplane in which the compass is mounted. The axis of the wheel acts as the reference line, always constant in direction, which is the essential feature of any direction instrument. There is also a circular scale by means of which the direction of the airplane with respect to the reference line is determined.

The direction of the axis of the rapidly rotating wheel will not be changed by any motion of the base, but there is a force which will slowly pull the wheel into a position of rotation parallel to the earth's rotation. Thus for use as a compass, the axis at starting should lie in a north and south vertical plane.

The gyroscopic compass is the most satisfactory compass yet devised, but owing to its weight, bulk, and cost is not used to any extent.

B. MAGNETIC COMPASS

1. Description The magnetic compass consists of: a glass-covered hemispherical *bowl*; a circular *card* with a central jeweled cap resting lightly on an iridium-pointed pin fixed perpendicular to the bottom of the bowl; *magnetic needles* fixed parallel to each other on the lower surface of the card; a pointer or *lubber line*; and a corrugated expansion chamber at the bottom of the bowl which allows for changes in the volume of the colorless liquid which fills up the bowl. The liquid is a mixture of alcohol and water. The card is of mica, and its upper surface is marked in degrees in a clockwise direction. The plane of the card remaining always horizontal, its point of support should be so low that its edge will not touch the glass top when the compass is tilted through a considerable angle, otherwise it will be necessary to mount the entire instrument in gimbals to keep it level. The lubber line is simply a pointer on the bowl adjacent to the edge of the card. The compass is mounted so that a line joining the center of card to the lubber line either coincides with or is parallel to the longitudinal axis of the airplane.

2. Variation True north is the direction along the arc of a great circle towards the north pole of the earth. Magnetic north is the direction of the pointing of the magnetic needles when mounted as described (the needles *do not* point towards the north magnetic pole). The angular difference between true north and magnetic north is called *variation*. The variation at a place can be read from a map showing isogonic lines, i.e., lines passing through the points of equal variation. In the United States the variation ranges from about 25° E to about 20° W. In Belgium and France the variation is from 11° W. to 14° W.

3. Deviation When a mass of soft iron is brought near the magnetic compass, the card is observed to move from its normal position. This angular change is called *deviation*. The engine and other metal fittings of an airplane cause disturbances of this kind. The amount of the deviation will depend on the position of the engine, etc., with respect to the compass. It varies for different pointings of the airplane. To determine the amount of the deviation, the airplane is placed with its axis pointing in a number of directions of magnetic azimuth (0°, 45°, 90°, etc.) and the deviations recorded in a deviation table. This operation is known as "swinging the ship".

4. Computation of the compass course The order of procedure in computing a compass course is as follows:

a. Find the map course On the map draw a line AN from the starting point A towards true north, and also the intended line of flight AB. The angle measured (with a protractor) clockwise from AN to AB is the *map course* or azimuth of AB, or azimuth of B as seen from A.

b. Correct for variation Find the magnetic variation at the starting point from an isogonic chart. If the variation is west, add it to the map course; if east, subtract it. This gives the *magnetic course*.

c. Correct for drift due to wind Draw a line AW (wind from A to W) on a convenient scale to represent the estimated velocity of the wind at the flying level. With W as the center and a radius equal to the intended airplane speed, using the same scale as before, strike an arc cutting the line AB at point C. Through A draw a line AD parallel to WC. Then CAD is the angle of drift; the machine will be headed always parallel to AD; AC represents in magnitude and direction the ground speed of the airplane; and the angle NAD is the corrected magnetic course.

d. Correct for deviation The amount of the deviation is found by interpolating from a table of deviations. Add the deviation if it is west, and subtract if it is east. The result is the *Compass Course*. It is essential that the deviation correction be applied last. The above steps may be put in the following formula:

Compass Course = Map Course ± Variation ± Drift ± Deviation

As a rule the return course does not differ from the outward course by just 180°, therefore it must be computed independently.

5. Errors of magnetic compass When flying in a straight line in fair weather, the compass can be depended on to give the proper direction; but on the other hand, if the machine turns about quickly, the compass may become very unreliable. Especially, if the machine while flying from south to north turns to the right, the compass card will almost invariably turn faster than the airplane. That is, the card will turn to the right, and will tell the pilot that he is turning to the left, which is not true. If, starting from that point, he turns to the left, the card will not seem to turn at all, and after a turn of 90°, even though the machine at that moment is directed toward the west, the compass will report it pointing towards the north. The principal cause of this error is the inclination the compass card assumes under the influence of centrifugal force or inertia on turning. This error is called "the northerly-turn error".

At a certain speed of the engine, the vibrations are sufficient to produce turns in the compass card up to 90°. This speed should be known and avoided when using the compass.

C. DRIFT METER

The drift meter in its simplest form is an open tube mounted vertically in the airplane and free to move about its vertical axis. Inside the tube as a diameter there is a wire and on the outside a pointer which moves around a graduated arc. When the wire is in the longitudinal axis of the airplane, the pointer indicates zero on the arc.

The instrument is used by turning the tube until the wire is parallel to the "stream lines" of objects seen on the ground. The reading of the scale then gives the drift angle due to the wind. The drift meter and the compass can be synchronized so that as the wire of the former is turned through the necessary angle, the lubber line of the latter will be turned through the same angle. In this way drift is eliminated from the calculations.

2. INSTRUMENTS FOR DETERMINING ALTITUDE

The barometer is an instrument for measuring the pressure of the air. The atmospheric pressure as indicated by the barometer is a measure of the altitude of the instrument above sea level. Barometers of two kinds are used in aviation work, namely, the Altimeter and the Barograph.

A. ALTIMETER

1. **Description** The altimeter consists of a stout metal case containing a small metal box with a thin corrugated top from which the air has been partially exhausted, a series of levers for magnifying the motion of the top of the box, and a pointer at the end of the lever system which moves around a dial on the outside face of the case. The varying pressure of the atmosphere acting upon the top of the vacuum box causes a movement which is transmitted through the levers to the pointer which indicates on the dial the altitude in feet. The dial plate can be rotated until the zero is opposite the pointer, as required at the beginning of a flight. All altimeters should register up to at least 8000 meters or 26,300 ft.

2. **Corrections** There are four sources of inaccuracy in the readings of an altimeter. These are (1) lag, (2) temperature, (3) change in ground elevation, and (4) change in surface pressure.

By "lag" is meant the slowness of the instrument in responding to rapid changes in altitude. An altimeter may be regarded as fairly satisfactory if, after an ascent and descent of 20,000 feet at the rate of 1000 feet per minute, the error on account of lag does not exceed 150 feet. The extent of this defect depends on the quality of the metal used in the construction of the vacuum box. By the use of hard steel boxes, lag may be practically eliminated.

The readings of an altimeter may be affected by its own temperature. The error due to this cause is slight. In an instrument tested recently, the error was found to be 2.18 feet per 1° F. change in temperature. The principal source of inaccuracy in the altimeter is the variability of the temperature of the air. The difference in pressure between any two levels depends on the temperature of the intervening layer of air. The scale of an altimeter is usually graduated for a uniform temperature of 50° F., and when the average temperature of the layer of air between the ground and the altimeter is other than 50° F. a correction must be made. For a temperature of -27° F. at the level of the instrument, the correction to be *subtracted* varies from 15% at 1000 ft. to 10% at 20,000 ft.; for -9° F., the correction varies from 11% to 7% at the same levels; for 9° F., from 8% to 3%; and for 27° F., from 4% to 0%.

The change which takes place in the elevation of the surface may be obtained from a map and the necessary correction made.

On returning from a long flight, the aviator may find the reading of his altimeter to differ from the initial reading due to changes which are constantly taking place in the pressure of the atmosphere. However, ordinarily the error due to this cause will rarely exceed 100 feet and may be neglected.

B. BAROGRAPH

A barograph is a recording altimeter. The pointer of the altimeter is replaced by a pen arm which records altitudes on a chart wound round a drum actuated by clockwork. In this way a record of the altitude at every instant of flight is obtained which may be studied later on the ground.

3. INSTRUMENTS FOR DETERMINING SPEED THROUGH THE AIR

A. AIR SPEED INDICATOR

The air speed indicator, or buoyancy meter, is a box with two chambers separated by a diaphragm whose motions are magnified by levers and communicated to a pointer which moves around a dial. A tube from one chamber opens into the wind (dynamic opening), and one from the other chamber opens into still air (static opening). Both openings are contained in a cone-shaped head which is fastened to one of the forward struts with the dynamic opening parallel to the longitudinal axis of the airplane. This instrument measures wind pressures, so that as the density of the air decreases with altitude, the scale reading is too low, due to the fact that the dial is calibrated at a density which normally exists comparatively close to the ground. The true air speed may be obtained from the formula,

$$\text{True air speed} = \frac{\text{Indicated speed}}{\sqrt{\text{Density}}}$$

The values of the density to be used in the above formula are as follows:

Altitude above sea level	Percentage of standard density
800 Feet	1.000
3000 "	.932
5000 "	.874
8000 "	.792
10000 "	.740
13000 "	.673
15000 "	.630
18000 "	.571
20000 "	.533

B. TACHOMETER

The engine tachometer or revolution counter is of two types. The type ordinarily used is similar to the spedometer on an automobile and may indicate either revolutions or velocity. The recording instrument on the instrument board is connected with the engine by means of a flexible shaft.

The second type makes use of the principle of the electric generator and ammeter.

4. INSTRUMENTS FOR INDICATING STABILITY

A. INCLINOMETER

The inclinometer is either simply a spirit level, or a wheel weighted like a locomotive driver and having its motions damped by paddles immersed in a liquid. In either case inclinations with respect to gravity are measured. There may be two inclinometers in an airplane, one mounted longitudinally and the other laterally. Accelerations of the airplane cause errors in inclinometers of these types.

B. ANGLE OF INCIDENCE METER

The angle of incidence meter consists of a cylindrical dial box with a central shaft, and, fixed perpendicular to the shaft, a very light tail piece with supporting fin. This tail piece can move up and down. For velocities necessary to flight, it lies along the direction in which the air is moving. The ratio between the angular motions of the tail and the dial hand is the same as that between the angular motions of the hour and the minute hands of a watch. As the instrument is mounted in a position away from propeller influence and consequently at a distance from the pilot, the dial numbers (0 to 15) must be large.

This instrument is independent of gravity and gives the pilot the true angle between the chord of the planes and the direction of the air in which he is flying.

C. BANKING INDICATOR

The banking indicator is simply an inclinometer mounted laterally. If of the wheel type, an arrangement for causing an electric contact and the lighting of a colored light can be provided for the purpose of showing dangerous angles.

5. INSTRUMENTS FOR DETERMINING GROUND SPEED

A. FIRST METHOD

If the aviator is familiar with the ground over which he is flying and knows the distance between two well defined objects, he can note from his *clock* the time it takes him to fly the known distance, and can compute his ground speed.

B. SECOND METHOD

The aviator first determines his elevation above the ground using his altimeter and the contours on his map, and then flying horizontally as indicated by his inclinometer he sights along a line of sight fastened to the side of his plane at a fixed angle with the horizontal axis of the plane at a definite object on the ground ahead and notes the time it takes to fly directly over the object. If the line of sight makes an angle of 45° with the horizontal, the distance traversed is the same as the elevation; and for other angles there is a definite relation between the distance and the elevation. Knowing the distance and the time, the ground speed is easily computed.

C. THIRD METHOD

Lieut. Crocco of the French Aviation Corps has recently invented a stadia device which, used in connection with the altimeter and clock, makes the computation of ground speed a very simple matter. For a detailed description and illustrations of this instrument, the student is referred to the Jan. 9, 1918, issue of *Aeronautics.*

6. SPECIAL INSTRUMENTS USED IN TESTING

A. CLIMBING METER

The climbing meter consists of a bottle with a tube of small bore opening into the air, and a U-tube partly filled with liquid and opening into the air and into the bottle. There is a reading scale on the arm of the U-tube which opens into the air. While climbing the density and pressure of the air inside the bottle is greater than that on the outside, and this is shown by the elevation of the liquid in the outer arm. When the liquid stands highest in the outer arm, the best climbing angle is being used.

B. STATOSCOPE

The statoscope is an instrument used in testing airplanes to indicate to the pilot changes in altitude which are too small to be read on the altimeter.

It is very similar to the climbing meter and differs from it only in the shape and position of the glass tube attached to the outside of the bottle. The tube is bent to the arc of a circle of large radius and is mounted horizontally on the bottle with the convex side down—just opposite to the mounting of a spirit level tube. Inside the tube there is a drop of liquid, and one end of the tube enters the bottle and gives bottle-pressure and the other end is open to the air and gives air pressure. For horizontal flight, gravity holds the drop of liquid to the bottom of the tube, but for slight changes of altitude the drop is forced to one side or the other depending on whether the bottle-pressure is greater or less than air-pressure.

7. MISCELLANEOUS INSTRUMENTS AND THEIR SPECIFICATIONS

The *oil gauge* should indicate definitely the amount of oil in the crank case, and the *oil-pressure gauge* should indicate the pressure in the oil system and that the flow is undisturbed.

The *gasoline-supply indicator* should preferably be of the mechanical type, the *gasoline-flow indicator* should show that gasoline is being supplied to the service tanks, and the *gasoline feed system pressure indicator* must be reliable under vibrations and changes of temperature.

The *radiator temperature indicator* should clearly indicate the best operating temperatures, and be readily inserted in the radiator.

CHAPTER VI.

MAP READING

OUTLINE

1. Classification
   - A. Plane Maps
   - B. Topographic Maps
2. Scales
   - A. Reading Scales
     1. Used on U. S. Maps
     2. Used on French Maps
     3. Units of Measurement
   - B. Working Scales
     1. Kinds of Working Scales
     2. Construction of Working Scales
3. Peace Maps and War Maps
4. Sketches
   - A. Line Sketches
   - B. Area Sketches
     1. Place Sketch
     2. Position Sketch
     3. Outpost Sketch
5. Orientation
6. Map Symbols and Abbreviations
7. Contours
   - A. Definition
   - B. Method of Showing
   - C. Characteristics
   - D. Slope Board and Slope Scale
   - E. Profiles from Contour Maps
8. Landscape Sketches
9. Photographic Maps
10. The "Squared" Map
    - A. English Map
    - B. French Map
11. Map Reading Proper
12. Practical Applications of Map Reading

CHAPTER VI.

MAP READING

The following notes prepared for the course in Map Reading are largely presented as map making since a thorough knowledge of the methods of making maps and sketches is essential for a proper study of maps.

1. CLASSIFICATION

A. PLANE MAPS

A plane map is one that shows all the ground features in their true relation to each other to some scale but does not distinguish variations in elevation. Plane maps for war purposes are made usually from sketches or from photographs.

B. TOPOGRAPHIC MAPS

A topographic map has all the information that is shown on a plane map and in addition shows relative elevations. A topographic map is made from data obtained with surveying instruments, so that all distances, directions, and elevations are quite accurate. In war times information of a military nature obtained from sketches or from photographs is added to the topographic maps made in times of peace.

2. SCALES

A. READING SCALES

Reading scales are shown on a completed map in one of three ways: (1) by the Representative Fraction (R. F.) where the numerator indicates the number of units on the map which corresponds to the number of like units on the ground as indicated by the denominator; (2) by words and figures, for example, 3 inches=1 mile; and (3) graphically, that is a line of definite length is drawn at the bottom of the map and divided into the miles and fractions thereof that it represents.

1. Scales used on U. S. maps The scales in use in the United States for topographic maps are 1/250,000 with an associated contour interval of 20 ft., 1/125,000 with a contour interval of 20 ft., and 1/62,500 with a contour interval of 10 ft. The last is frequently spoken of as a one-inch-to-the-mile map because of its close approximation.

2. Scales used on French maps The scales of the maps used in France and the use to which each is put are as follows:

SCALE	NAME
1/600,000	General Reference Map
1/250,000	Emergency Map
1/200,000	Trip Map
1/100,000	Strategical Map
1/80,000	Traffic Map
1/50,000	Zone Map
1/40,000	Tactical Map
1/20,000	Artillery Map
1/20,000	Trench Map
1/5,000	Detail Map

The intention of the American Forces is to eliminate the 1/250,000 and the 1/100,000 and to use the 1/200,000 and the 1/80,000, respectively, in their stead. Also the 1/50,000 map is to be gradually replaced by the 1/40,000.

The General Reference map is for office purposes, and because of its small scale enables a large area to be shown on a small map.

The Emergency map on account of the small scale to which it is drawn is the aviator's reference map and is his personal property. The enemy's trench lines should be drawn on this map, and the location and relative accuracy of all anti-aircraft guns should be indicated. Pilots and observers should compare their maps frequently to make sure that they contain all the available information.

The Strategical map gives more detail than the Emergency map as it is made to a little more than twice the scale of the latter. One map sheet covers a distance of about 25 miles back of the enemy's lines and most reconnaissances do not extend beyond this distance.

The Traffic map is used to show traffic routes, railways, bridges, roads, canals, water supply, communication lines, etc.

The Zone map is used for artillery work and is divided into the zones effectively covered by each battery. The zones are colored to agree with a small designated circle indicating battery headquarters.

The Tactical map has more detail than the Strategical map. All houses of any size, roads including the fourth class, small orchards, and small streams are shown. One map sheet covers a distance of about 13 miles, so that one map sheet would be sufficient for all ordinary tactical reconnaissances.

The Artillery map shows considerable detail, such as small groups of two or three trees, so that gun emplacements, etc., can be located accurately. One map sheet covers a distance of about six miles so that a machine on artillery reconnaissance would ordinarily have to use only one map of this scale. On the Artillery map the entire trench system of the enemy should be drawn.

The Trench map is a larger scale map and upon it are shown the enemy's defenses in the intrenched area.

The Detail map is used to reproduce to scale battery targets and small portions of the enemy's trench system for accurate work.

3. **Units of measurement** In order to have uniformity in calculations the following approximate conversion factors between the English and the Metric systems of measurements are given as being sufficiently accurate for all practical purposes:

1 inch = 2.54 centimeters (cm.)	1 centimeter (cm.) = 0.4 inch
1 yard = 0.9 meter (m.)	1 meter (m.) = 1.1 yards
1 mile = 1.6 kilometers (km.)	1 kilometer (km.) = 0.62 miles

B. WORKING SCALES

Working scales are the scales actually used in the construction of military sketches. However, working scales never appear upon the completed map.

1. **Kinds of working scales** Working scales are of three kinds: (a) a stride scale, if the sketcher is walking; (b) a time scale, if the sketcher is on horseback or in an airplane; and (c) a revolution scale, if the sketcher is riding in a vehicle where the revolutions of the wheels are counted.

2. Construction of working scales

a. Example of stride scale Given:—sketcher's stride = 60 ins. and scale of sketch = 3 ins. to the mile.

Then 1056 strides = 1 mi. on ground = 3 ins. on sketch
And 1000 " = 2.84 ins. on sketch

A line 2.84 ins. is laid off and divided into five equal divisions each representing 200 strides. The first of these divisions may be further subdivided.

b. Example of time scale Given:—speed of airplane = 150 km. per hour and scale of map = 1/200,000.

Then 60 min. of time = 150 km. on ground = 75 cm. on map
And 20 " " " = 50 km. " " = 25 cm. " "

A line 25 cm. is laid off and marked 20 minutes and subdivided to show map distances for shorter intervals of time.
The revolution scale is calculated and constructed in a similar manner.

3. PEACE MAPS AND WAR MAPS

When any section of a country becomes the scene of war operations, it is necessary for army commanders to have war map of this area. These maps differ from peace maps in that they have additional information of a purely military nature, such as the cultivation of fields along the roads and the location and character of all fences so that a commander can determine what resistance he will have to moving the various arms of his army outside of the road. For constructing war maps, accurate topographic maps of the territory which have been made in times of peace are used as a foundation, and information of a military nature is secured by means of sketches and photographs and added to them.

4. SKETCHES

A. LINE SKETCHES

The *Road Sketch* is the only subdivision of the Line Sketch. The United States Regulations prescribe that road sketches shall be on a scale of 3 inches to the mile, with a contour interval of 20 ft. A road sketch is one of some particular route or direction over which the sketcher travels obtaining his direction by means of a pocket compass or simply by means of deflection angles obtained by sighting ahead along the road with the map oriented. Distances along the road are laid off on the sketch by the use of a working scale. All information to the right or left of the road for a distance of three or four hundred yards is shown. Contours are drawn in to show differences of elevation by the use of a slope board and slope scale in a manner to be described later.

B. AREA SKETCHES

The United States Regulations prescribe that area sketches shall be made to a scale of six inches to the mile with a contour interval of 10 feet. Area sketches are of three kinds, namely, Place, Position, and Outpost.

1. Place sketch A place sketch is one made by the sketcher located at a single point of observation and as close to the enemy as possible. Distances are estimated and directions are taken by sighting along a pencil or other improvised straight-edge to locate the position of desired details. This map is made under the most adverse conditions and requires much knowledge and skill in handling the sketching outfit. The average man gains such skill and knowledge only by practice.

2. Position sketch A position sketch is one made by a sketcher who travels over or has access to all the area to be placed on the sketch. It shows all the details that would be given on several road sketches combined and any military information concerning good positions for guns and troops in camp.

3. Outpost sketch An outpost sketch is one made of the ground along the firing line or friendly outpost and extends as close to the hostile line as possible. The sketch, by necessity, is made from observation in the rear along the line. Points are located as far as possible by schemes of intersection, or by estimation of the distance away along a line of sight.

When area sketches are made of fortifications, a scale of twelve inches to the mile is used with a contour interval of 5 feet.

5. ORIENTATION

By orientation is meant the placing of the map in its true relation to the ground it represents so that this area, if compressed to the size of the map, would be represented point by point as shown on the map. In short, this is obtaining the north and south direction of the map and placing it parallel to the same direction on the ground. In general, maps have true north and south lines printed on them. These lines are called meridians. In some instances, sketches also have the true meridian given, but more often only the magnetic meridian is shown. The sketch is oriented by turning the sketch until the magnetic meridian is parallel to the needle of the compass.

A second method of orienting a map or sketch is to locate on the map the position of the observer and also the position of some point which can be seen. When a line connecting these two points coincides in direction with the line on the ground between these points, the map is oriented.

Resection is the opposite of intersection and the most important use made of it is in locating one's self on a map. Orient the map by means of the compass and then choose two landmarks which can be identified on the map. Through these points on the map draw lines parallel to the lines of sight to the objects on the ground. The observer is at the intersection of the two lines.

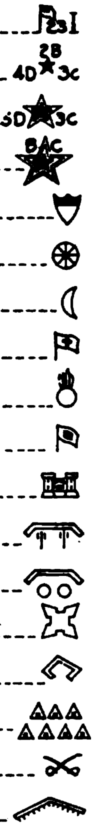
6. MAP SYMBOLS AND ABBREVIATIONS

The symbols and abbreviations included in these notes are more or less standard, and a knowledge of them will be of assistance in reading any map. Any symbols in use other than those shown can be readily understood if it is remembered that a symbol is usually a profile or a plan of the object it represents. The student should study these symbols and abbreviations carefully. A comparison of the symbols used by the British, French, and Americans should be made. The French symbols should be memorized as they are the ones that will appear on the maps used by the Americans in France. (The British and French symbols may be found on the back cover of book.)

7. CONTOURS

A. DEFINITION

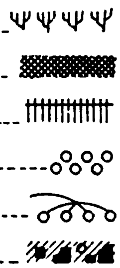
Differences in elevation are represented on a map by means of lines called *Contours*. These lines are obtained by cutting the surface by several horizontal planes spaced an equal distance apart. In other words, contours are light lines drawn through the plotted position of points that have the same elevation, at regular vertical intervals, to show differences of elevation.



Regimental Headquarters
Brigade Headquarters
Division Headquarters
Corps Headquarters
Adjutant General
Quarter-master
Commissary
Medical Corps
Ordnance
Signal Corps
Engineer Corps
Gun Battery
Mortar Battery
Fort } True plan to be shown if known
Redoubt }
Camp
Battle
Trench

OBSTACLES

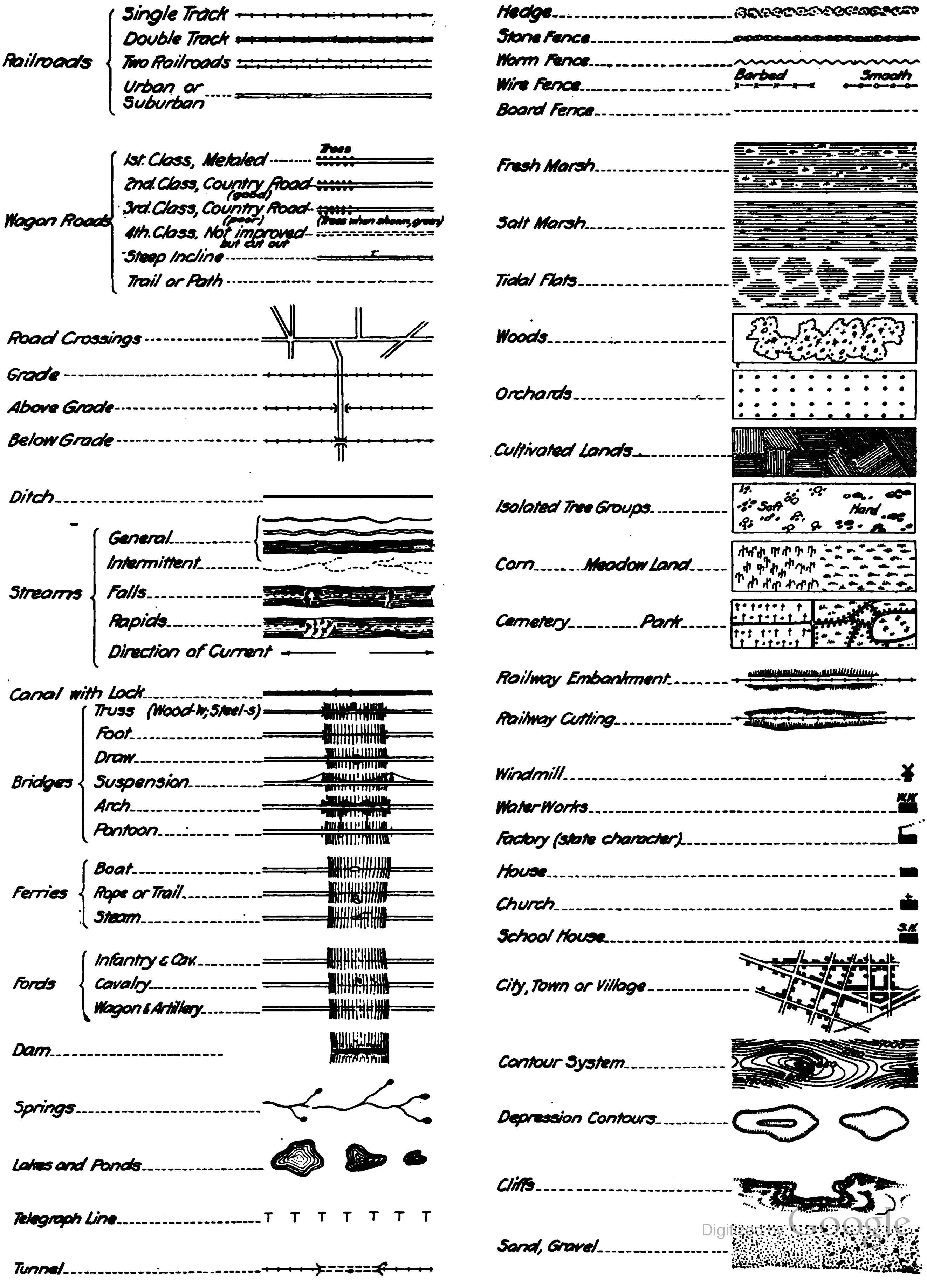
Note: When color is used execute these in red



Abatis
Wire Entanglement
Palisades
Contact Mines
Controlled Mines
Demolitions

ABBREVIATIONS

Arroyo	A.
Abutment	abut.
Blacksmith Shop	B.S.
Bottom	bot.
Branch	Br.
Bridge	br.
Cape	C.
Cemetery	cem.
Concrete	con.
Covered	cov.
Creek	Cr.
Culvert	cul.
Deep	d.
East	E.
Estuary	Est.
Fordable	f.
Fort	Ft.
General Store	G.S.
Girder	gir.
Gristmill	G.M.
Iron	i.
Island	I.
Junction	Jc.
King-post	k.p.
Lake	L.
Latitude	Lat.
Landing	Ldg.
Life-saving Station	L.S.S.
Lighthouse	L.H.
Arch	Ar.
Brick	b.
Longitude	Long.
Mountain	Mt.
Mountains	Mts.
North	N.
Not fordable	n.f.
Pier	P.
Plank	pk.
Post Office	P.O.
Point	Pt.
Queen-post	q.p.
River	R.
Roundhouse	R.H.
Railroad	R.R.
South	S.
Steel	s.
Schoolhouse	S.H.
Sawmill	S.M.
Station	Sta.
Stone	st.
Stream	str.
Tollgate	T.G.
Trestle	Tres.
Truss	tr.
Water Tank	W.T.
Water Works	W.W.
West	W.
Wood	w.
Wide	wd.


Railroads
Single Track
Double Track
Two Railroads
Urban or Suburban
Wagon Roads
1st. Class, Metaled
Trees
2nd. Class, Country Road (good)
3rd. Class, Country Road (poor)
(Trees when shown, green)
4th. Class, Not improved but cut out
Steep Incline
Trail or Path
Road Crossings
Grade
Above Grade
Below Grade
Ditch
Streams
General
Intermittent
Falls
Rapids
Direction of Current
Canal with Lock
Bridges
Truss (Wood-W; Steel-S)
Foot
Draw
Suspension
Arch
Pontoon
Ferries
Boat
Rope or Trail
Steam
Fords
Infantry & Cav.
Cavalry
Wagon & Artillery
Dam
Springs
Lakes and Ponds
Telegraph Line
T T T T T T T
Tunnel
Hedge
Stone Fence
Worm Fence
Wire Fence
Barbed
Smooth
Board Fence
Fresh Marsh
Salt Marsh
Tidal Flats
Woods
Orchards
Cultivated Lands
Isolated Tree Groups
Soft
Hard
Corn
Meadow Land
Cemetery
Park
Railway Embankment
Railway Cutting
Windmill
Water Works
W.W.
Factory (state character)
House
Church
School House
S.H.
City, Town or Village
Contour System
Depression Contours
Cliffs
Sand, Gravel

B. METHOD OF SHOWING

On the ground the contours are imaginary lines. This may be best illustrated by considering an island in the center of a body of water (See Figs. 601 and 602). Imagine the surface of the water to be raised a distance of ten feet. The shore line thus formed would represent a contour drawn through all points whose elevation was ten feet above the elevation of the points on the contour represented by the first shore line. Successive contours representing equal increases in elevation can be secured in a similar manner. These contours when projected down onto a single plane would represent a contour map (See Fig. 603). The vertical distance between the successive elevations is known as the *contour* or *vertical interval,* which is abbreviated to V. I. The distance measured on the map between two successive contours is called the *map distance,* which is abbreviated to M. D.

C. CHARACTERISTICS

1. All points on any contour have the same elevation above datum.
2. Contours always close or run off the map.
3. A contour line never splits.
4. Contours of different elevations do not cross or run into each other, except in the case of overhanging cliffs.
5. Contours run up valleys and cross at right angles in a V shape. (See Fig. 607)
6. Contours run down ridges and cross at right angles in a U shape. (See Fig. 607)
7. On a uniform slope, contours are equally spaced.
8. The spacing of contours indicates the slope of the ground.
9. A hilltop is represented by several concentric closed contours. (See Fig. 604)
10. Contours do not cross a road or railroad, but break and continue on the other side.
11. Usually every fourth or fifth contour is numbered according to the vertical interval used.

D. SLOPE BOARD AND SLOPE SCALE

A simple device for measuring the degree of slopes is constructed by fastening a string to the back of the sketching board near one edge and attaching to it a weight so as to form a plumb line. An arc drawn as large as the board will permit, with the point of suspension as the center, is marked in degrees. The zero of the scale is immediately under the line formed by the string when it hangs perpendicular to the top edge of the board. By sighting along the top edge of the board parallel to any slope, the slope of the ground will be measured by the arc through which the plumb line swings.

Knowing the slope of the ground, the contours can be spaced by the use of a *slope scale.* This scale is constructed by computing the map distance between contours for the scale to which the map is being made and the vertical interval used. These computations are based upon the mathematical fact that a slope of 1° gives an increase in elevation of 1 ft. in a horizontal distance of 57.3 ft. If a vertical interval of 20 ft. is to be used, this increase in elevation is secured when a horizontal distance of 1146 ft. is traveled. To a scale of 3 inches to the mile, this distance would be represented by a line .65 of an inch in length. A 2° slope would reach an increase in elevation of 20 ft. in one half this distance, and would be represented to the same scale by a line .33 of an inch in length. These values are laid off on a strip of cardboard and marked with the corresponding degrees of slope, thus making a slope scale.

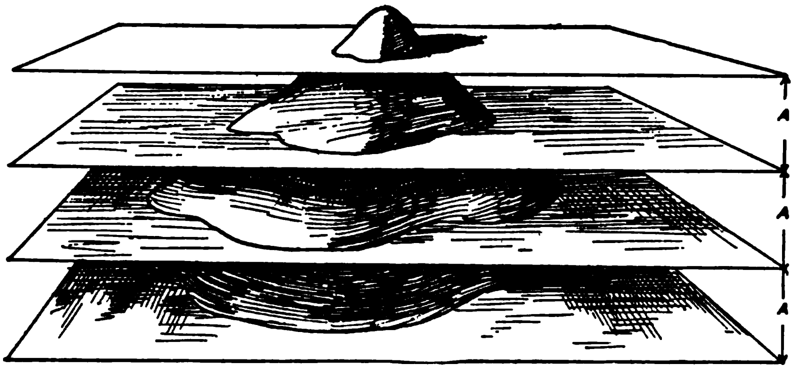


Fig. 601

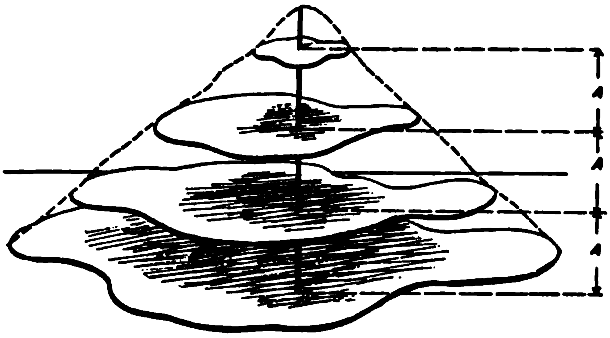


Fig. 602

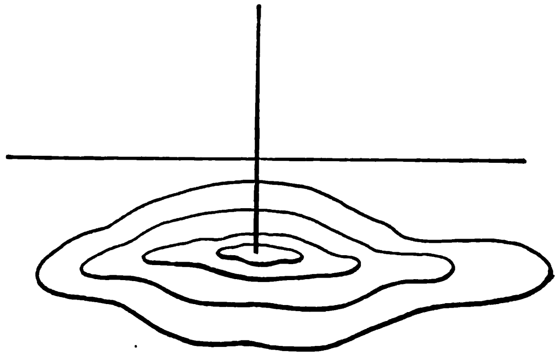


Fig. 603

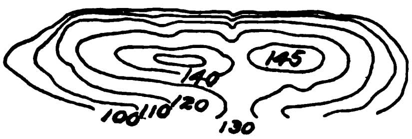


Fig. 604

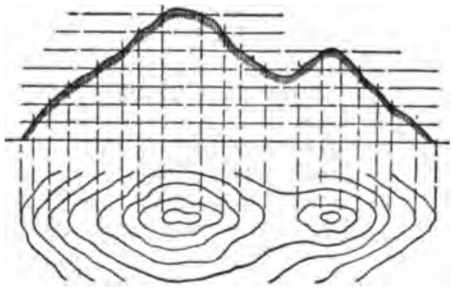


Fig. 605

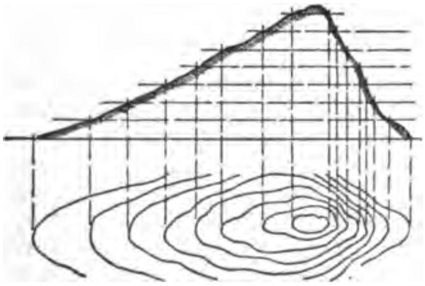


Fig. 606

Fig. 607

A formula developed for computing the spacing of contours for any slope is

$$G.\ D.\ (\text{ground distance}) = \frac{V.\ I. \times 57.3}{\text{Degree of Slope}}$$

The formula can be used with either the English or the Metric units if it is remembered that the ground distance obtained is in the same units as the vertical interval. After the ground distance is obtained, the map distance between successive contours is secured by introducing the scale of the map.

E. PROFILES FROM CONTOUR MAPS

In military work it is often desired to secure a profile of the ground between two points. This is done by drawing a line across the contour map between the two points, and projecting the intersections between this line and the contours onto successive horizontal lines spaced to the same scale as the scale of the map. (See Figs. 605 and 606) Profiles constructed in this manner are useful for visibility problems, which will be discussed later.

8. LANDSCAPE SKETCHES

At the Fort Sill school of artillery, a method of sketching targets by *landscape sketches* is being taught. For this purpose a standard sketch pad 8¼x5½ inches is divided by vertical lines into ten ¾-inch strips the long way of the pad. In the center of the pad, horizontal lines are drawn between which all the sketching is done. At the top of the sheet, three horizontal lines are drawn and marked T, RN, and DEF, respectively. Upon these lines target, range, and deflection are given.

The sketch is made from one position as in place sketching, and frequently an observation balloon is used for this purpose. The position of an object on the sketch is located in direction by the angular deflection measured in mils from the reference point, and the distance is estimated. A mil is 1/6400 of a circle, or approximately 3 minutes of arc. The reference point selected must be clearly defined. The ¾-inch strips give arcs of 50 mils if the pad is held 15 inches from the eye when sighting. This can be done by knotting a string 15 inches from the pad and holding it in the teeth at the knot. By lining up the reference point with a vertical line near the center of the pad and sighting along the top edge of the pad to some other object, the angle of deflection is graphically measured. The sketch is oriented when completed by turning it so that the reference line points to the reference point and drawing a magnetic meridian parallel to the compass needle.

9. PHOTOGRAPHIC MAPS

The use of photography for securing information for constructing war maps is quite general in the present war. The majority of the information secured in this manner is used in making plane maps, but it can be superimposed upon a topographical map of the same area made in peace times to make a war map. It is practically impossible for the camera to be perpendicular to the earth's surface when every picture is taken. For that reason considerable distortion results and before a photograph can be transferred detail by detail to a map it is necessary to correct this distortion. This is done by taking a photograph of the completed negative with the camera placed at the same angle to the negative that the camera was to the ground when the first picture was taken. A special instrument has been constructed which will transfer, item by item, all information on a photograph to any given scale map when the photograph shows everything in its true relation. A camera can be used also to construct topographical maps. A special Theodolite camera is used for this purpose.

10. THE "SQUARED" MAP

A. ENGLISH MAP

For the purpose of reporting quickly and accurately the location of any thing of military importance, the artillery map is divided into squared sections and the position of objects is given by co-ordinates. The area of operations is divided into standard areas, 36,000 yards from east to west and 22,000 yards from north to south. This is divided into six strips, 6,000 yards wide, from west to east and into four strips from north to south. The first and last of these four are 5,000 yards wide and the second and third are 6,000 yards wide. Beginning at the northwest subdivision, they are lettered from capital A to capital X from west to east. These lettered areas are divided into thirty or thirty-six squares 1,000 yards on a side, depending upon whether the lettered area is 6,000 by 5,000 yards or is 6,000 yards square. These squares are numbered from 1 to 30 or 36, beginning at the northwest square and numbering from west to east. Each numbered square is divided into four equal parts and lettered small a, b, c, and d, beginning in the northwest corner and lettering from west to east. To locate any target in these smallest areas an origin is taken at the southwest corner and the number of tenths to the east is given first and those to the north from this origin are given next. Thus a point in one of the smallest squares would be described as G19c54.

B. FRENCH MAP

The French system of designating points on their maps is by metric co-ordinates. An initial point was chosen to the south and west of the battle area. Through this point are drawn a north and south line and an east and west line. These lines are the axes of the co-ordinate system. The area is then divided into squares one kilometer on a side by two series of parallel lines; one series is parallel to the north and south axis, and the other series is parallel to the east and west axis. These lines are numbered from the initial point to the east and to the north. Only the ten-kilometer lines are marked with the full number; the intermediate or kilometer lines are numbered from 1 to 9. Each kilometer square is subdivided by *imaginary lines* into squares 100 meters on a side, thus making 100 meters the unit of measurement of the system. A point on the map is designated by the coordinates of the nearest corner of the 100-meter square in which the point is situated. The *west to east coordinate* is given first. For example, the designation 2165—2943 locates a point which is 2165 100-meter units east of the initial point and 2943 100-meter units north of that point.

11. MAP READING PROPER

A map is a more or less complete picture of a large area drawn on a small scale and its purpose is to convey to one who has not seen the mapped area an idea as to the relative positions of the works of man, such as towns, highways, railways, etc., and the natural objects such as streams, hills, ridges, and general relief. To read a map is to familiarize one's self with the data shown and to form a mental picture of the area in question. In forming a mental picture of the area covered on any map the first thing to study is the location and appearance of the villages, towns and cities. Each of these will cover a certain relative area and have a certain shape on the map. By the number of roads and railroads running into each and the different shapes that they form they can be distinguished readily from each other. If a proper study is made it should be impossible for an aviator to fly over any of these towns without knowing which one it was. A study of the lakes and rivers is important as they form good landmarks on dull days, as they will shine up to you when other features on the ground can not be distinguished. Streams look black from the air and are sometimes very useful to follow. Flooded areas should be shaded in blue on your maps as they serve the same purpose as lakes. In the case of tactical work and forced landings, a knowledge of the relief is essential. The relief disappears almost entirely from seven to eight thousand feet except at sunrise and sunset when shadows are cast by the hills. The sun shadows thrown by objects such as trees or buildings are of great assistance in judging the configuration of the ground as these vary in length in proportion to the slope of the ground. Thus if you see a long shadow thrown by a tree and a short one by another tree of equal size you will know at once that the ground where the long shadow falls is sloping more than where the short one falls. Saddle hills form important landmarks and can be picked out on your map by the peculiar contour construction. Woods and forests are also good landmarks and are represented by standard symbols on the maps.

12. PRACTICAL APPLICATIONS OF MAP READING

The ability to readily form a mental picture of any area from a study of the map is valuable for all types of reconnaissance. Especially in tactical reconnaissance, landmarks are used almost entirely to fly by, and gun emplacements, troop movements, etc., are located on the map by finding the features on the ground as represented on the map. One should be able to pick out good landing places from a study of the map. This can be done by first determining if the slope is suitable from a study of the contours. Then see if there is any cultivation of the area which would interfere with landing. An apparently good landing place, picked out from the map, will often be found to be ditched when investigated and therefore unsuitable for this purpose. More landmarks such as a group of two or three trees are shown on a larger scale artillery map and are very useful in locating gun emplacements in artillery observation and in following an attack in cooperation with infantry.

The construction of profiles and a study of them for visibility problems is necessary for a commander of troops before any troop movement is undertaken. This will enable a commander to determine locations of likely ambush and positions where the enemy would be likely to unlimber their batteries, and how much of the area to either side of a road can be seen from the road.

CHAPTER VII.

METEOROLOGY

OUTLINE

1. The Atmosphere
   - A. Composition
   - B. Extent
   - C. Weight or Pressure
   - D. Density
   - E. Effect of Temperature
   - F. Effect of Pressure
2. Heat
   - A. Source of Heat
   - B. Effect of Sun's Heat
   - C. Effect of Altitude on the Temperature of the Air
3. Wind
   - A. Cause of Wind
   - B. Major Wind System
   - C. Minor Winds
   - D. Cyclonic Storms
   - E. Weather Maps
     1. Lows or Cyclones
     2. Highs or Anti-cyclones
     3. V-shaped Depressions
     4. Wedges
   - F. Wind Velocity
   - G. Variation in Direction and Velocity of Wind above the Surface
4. Clouds
   - A. Formation
   - B. Types of Clouds
   - C. Velocity of Clouds
5. Air Currents
   - A. Ascending Currents
   - B. Descending Currents
   - C. Surface Contour Currents
   - D. Gusts
   - E. Wind Eddies
   - F. Thunder Storm Currents
   - G. Line Squalls

CHAPTER VII.

METEOROLOGY

Meteorology may be defined as the study of atmospheric phenomena. It treats of the condition of the atmosphere, its changes of condition, and the causes of these changes.

1. THE ATMOSPHERE

A. COMPOSITION

The atmosphere is a gaseous mantle which envelops the earth and moves along with it. It is a mixture of dry air, water vapor, and dust. Dry air is composed of nitrogen, 78%; oxygen, 21%; and several minor gases, 1%. The oxygen is the part of the atmosphere which sustains life.

B. EXTENT

The atmosphere extends from 50 to 200 miles above the surface of the earth. However, that part of it which is dense enough or contains oxygen enough to support life is limited to about five or six miles.

C. WEIGHT OR PRESSURE

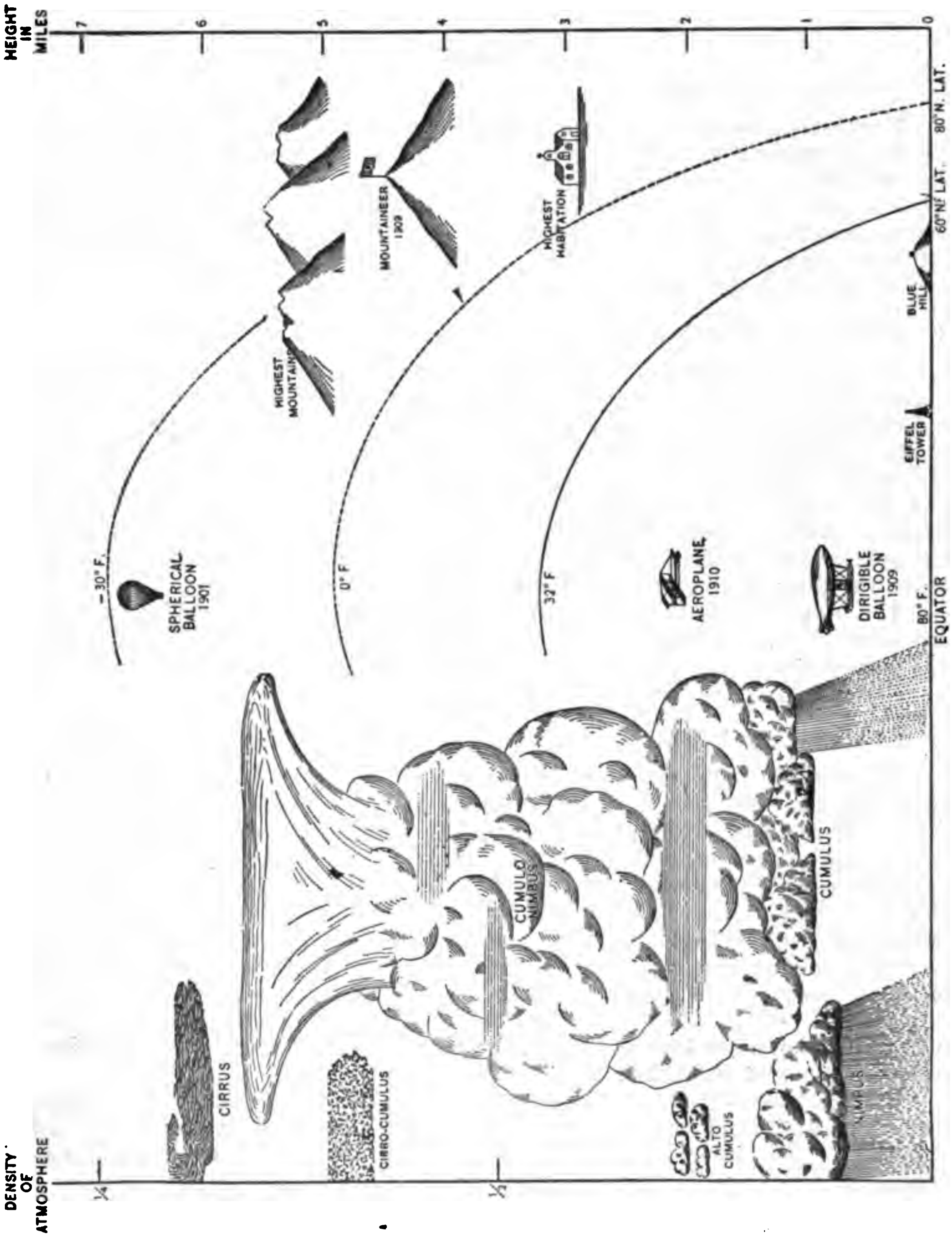
Although it is light and invisible, the air has perceptible weight, and at sea level at a temperature of 60° F. a column of air one square inch in section weighs 14.7 lbs., which is the equivalent of a column of mercury 30 inches high. This column of air weighing 14.7 lbs. will exert a pressure of 14.7 lbs. per square inch on whatever surface it may be resting. The column of air resting on the top of a mountain is less in height than a similar column at sea level, and, therefore, is of such diminished weight that the atmospheric pressure on the mountain top is less than it is at sea level. The pressure decreases 1 lb. per square inch for approximately each 2500 feet of ascent.

D. DENSITY

Pressure pushes the particles of the atmosphere together so that the air is denser or more compact near the sea than it is on mountain tops. At a height of about 3.6 miles there is as much air by weight above as there is below. As shown in Fig. 701, the density of the air at this point is ½, that is, the air at this level contains just ½ as much oxygen, etc., as the air at sea level, and hence it is difficult for one to breathe. The change in density will also affect the working of the airplane's engine. From Fig. 701 it is also seen that ¾ of the atmosphere, by weight, is within seven miles of sea level. At an altitude of ten miles the density of the air is just ⅛ of its density at sea level. As the density of the air decreases, the supporting power of the air is reduced in the same ratio; and, since the resistance to propulsion through the air against head winds increases faster than their density diminishes, it follows that an *airplane can not be operated efficiently higher than is necessary to overcome the irregular conditions at the earth's surface.*

E. EFFECT OF TEMPERATURE

A rise in the temperature expands the air and decreases its weight per unit volume. Warm air will rise in cooler air just as a cork held under water will rise when it is released.



Rotch and Palmer

Fig. 701

F. EFFECT OF PRESSURE

When air is compressed it becomes warmer and when it is expanded it becomes cooler. Thus ascending air is expanded and becomes cooler; and descending air is compressed and becomes warmer and drier.

2. HEAT

A. SOURCE OF HEAT

Practically all of the earth's heat is received from the sun. The rays of the sun in passing through the ether of space do not give off any heat due to the fact that there is nothing there to heat. It is only when the heat vibrations are interfered with by dust particles, water vapor, or the earth itself that any heat is absorbed. For this reason the ether of space above our atmosphere is extremely cold, and the upper layers of the atmosphere itself are so thin that very little heat is absorbed by them.

B. EFFECT OF SUN'S HEAT

When the heat vibrations from the sun strike any object, part of the heat is absorbed and part is reflected back into space. Some bodies reflect little heat and absorb nearly all the sun's rays which strike them. This is especially true of black objects. The blacker the soil, the more heat will it absorb; hence, a field dark from recent plowing will become warmer than an adjoining stubble field, and ground covered with vegetation will warm up less rapidly than bare ground. Water reflects about 40% of the heat waves which strike its surface. The aviator can make use of this knowledge in making a forced landing. The cooler the ground, the safer the landing.

The heat which is thus absorbed by the earth is then given off by radiation and conduction, and the air near the surface is heated. Then by convection this heated surface layer is mixed with the air above. So then the atmosphere is really heated at the bottom instead of at the top.

C. EFFECT OF ALTITUDE ON THE TEMPERATURE OF THE AIR

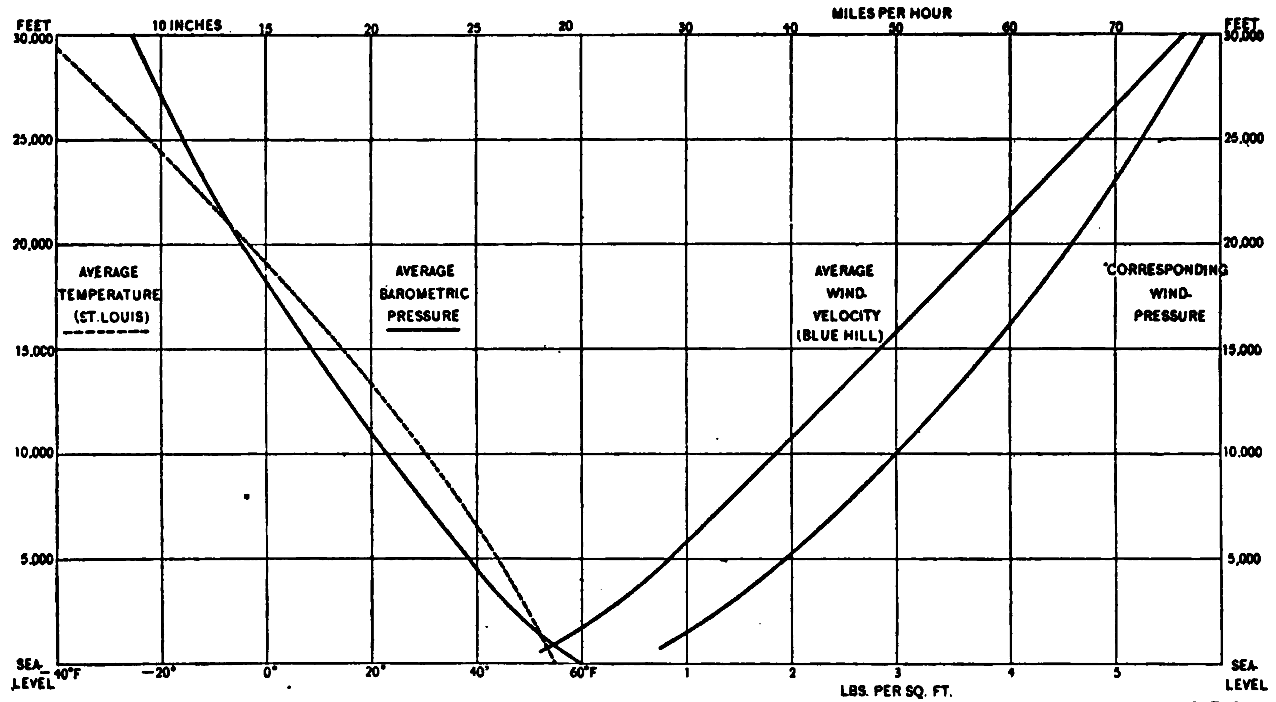
The average temperature at the surface of the earth is about 50° F. As we ascend into the air, there is a decrease in temperature which amounts to about 1° F. for each 300 feet of ascent. The temperature of the air decreases at this rate until a temperature of –67° F. is reached at an altitude of about seven miles where the temperature becomes stationary and even increases slightly. This warmer portion of the upper air is called the *stratosphere*. Near the ground the temperature may vary considerably in the course of a day, but the upper air alters its temperature much more slowly. At a height of six miles above the earth, a temperature much below zero constantly prevails, while at ten miles, –80° F. has been recorded in a sounding balloon. The dotted line in Fig. 702 shows the temperature of the air at different heights as determined by observations at St. Louis.

Owing to the decrease in temperature with altitude, the aviator must dress himself to withstand the cold experienced at high altitudes. Also the low temperature will affect to some extent the operation of his engine and machine gun.

3. WIND

A. CAUSE OF WIND

Wind is simply air in motion, usually in a horizontal direction. It is due primarily to the unequal heating of the earth's surface by the sun. The air at one place is heated more than it is at another, and consequently becomes



Rotch and Palmer

FIG. 702.—CHART SHOWING THE AVERAGE WIND VELOCITY, CORRESPONDING WIND PRESSURE, AVERAGE TEMPERATURE, AND AVERAGE BAROMETRIC PRESSURE AT DIFFERENT ELEVATIONS ABOVE SEA LEVEL

lighter. The lighter air is forced to rise by the pull of gravity on the cooler heavier air nearby, which rushes in to take the place of the lighter air, and in this way a circulation is set-up which we call *wind*.

B. MAJOR WIND SYSTEM

The circulation of the air around the earth results in the formation of seven belts or areas of varying atmospheric pressure. Three of these belts are areas of calms. The equatorial belt is called the "doldrums" and is a belt of low pressure in which air rises. In about latitude 35° in both hemispheres we have other belts of calms called the "horse latitudes". These are belts of high pressure in which the air is descending. When the air in these descending columns strikes the earth it divides into two parts: one of these is drawn toward the equator and forms the winds known as the "trade winds"; the other part is drawn toward the poles by the area of low pressure there and forms the belt of winds known as the "prevailing westerlies". The latter are the surface winds with which we have to deal in this latitude.

C. MINOR WINDS

Along the sea coast and the shores of large lakes there are minor wind circulations known as *land and sea breezes.* During the day the breeze is from the sea, and during the night from the land. These breezes are caused by the unequal absorption of heat by land and by water, and by the difference in the rate at which each gives off its heat.

In mountainous regions, the hilltops and slopes at night are cooled rapidly by radiation, and the cool heavy air flows down into the valleys, causing *mountain winds* which may attain considerable force during the night. The opposite circulation takes place in the day time.

D. CYCLONIC STORMS

If the surface of the earth were uniform throughout, so that all parts were capable of absorbing the same amount of heat, in our latitude we would have a surface wind from the southwest every day in the year; and at an altitude of less than a mile we would have a wind from the northwest, and at about three miles a wind from the southwest. However, owing to the non-uniformity of the surface composition, there are numerous irregularities and even reversals of wind direction. These are due to the so-called cyclonic storms which are indicated on our weather maps as "Lows".

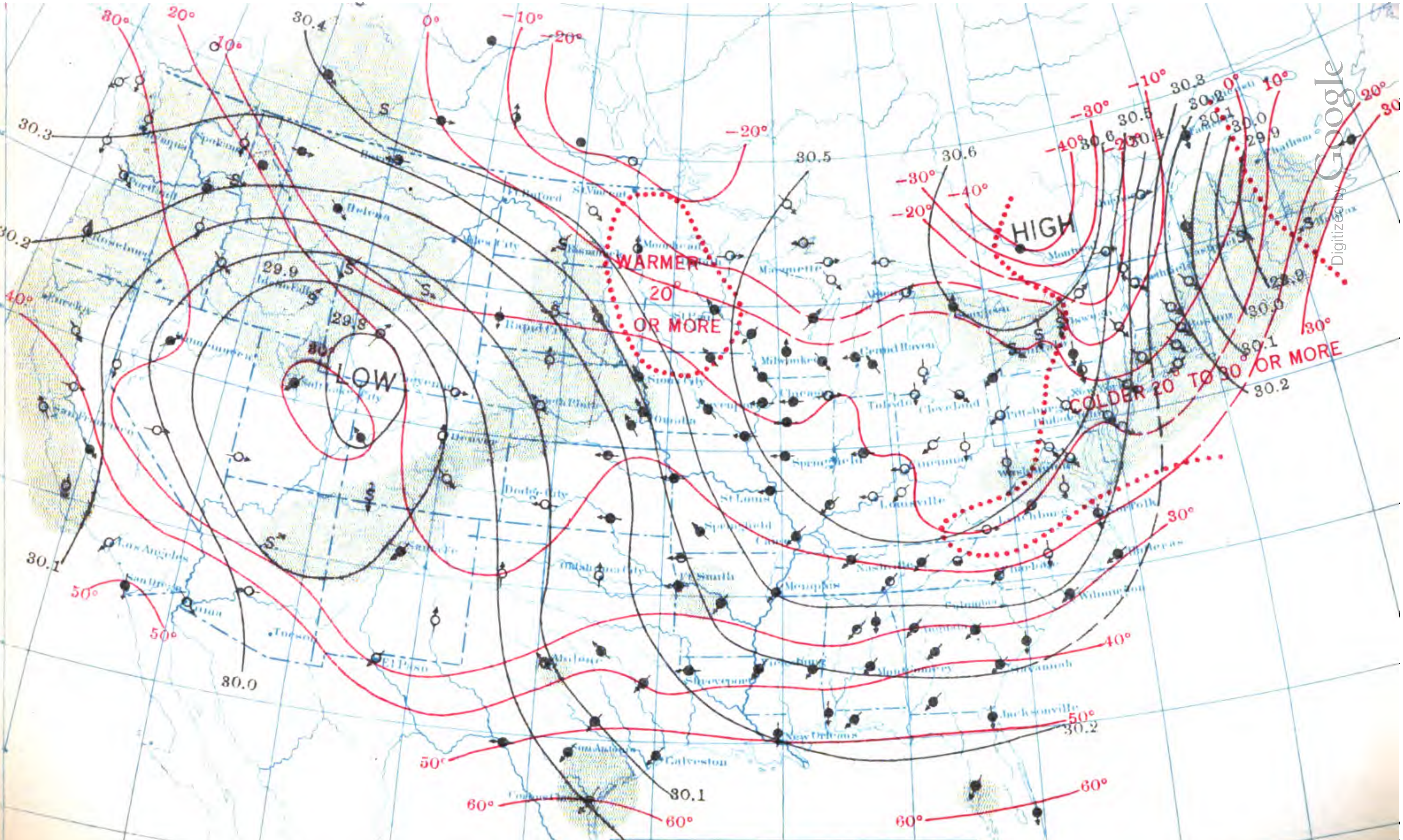
E. WEATHER MAPS

The accompanying weather maps with explanations should be carefully studied before proceeding further.

A study of the weather maps will enable one to forecast with considerable certainty the changes that will take place in the direction and velocity of the wind and in the clearness of the air with respect to clouds for the ensuing 24 hours.

Pressure is the basis upon which the weather is predicted. The pressure is indicated on the weather map by *isobars,* which are found in four formations, namely, Lows, Highs, V-shaped Depressions, and Wedges.

1. **Lows** The Lows charted on the weather map are technically known as cyclones, because they are areas of low pressure toward which the wind blows from all directions and in which rain frequently falls. A cyclone should be distinguished from that type of violent wind of small area known as a *tornado.* In a cyclonic area the wind blows *inward and in an anti-clockwise direction around the area of low pressure* which is itself



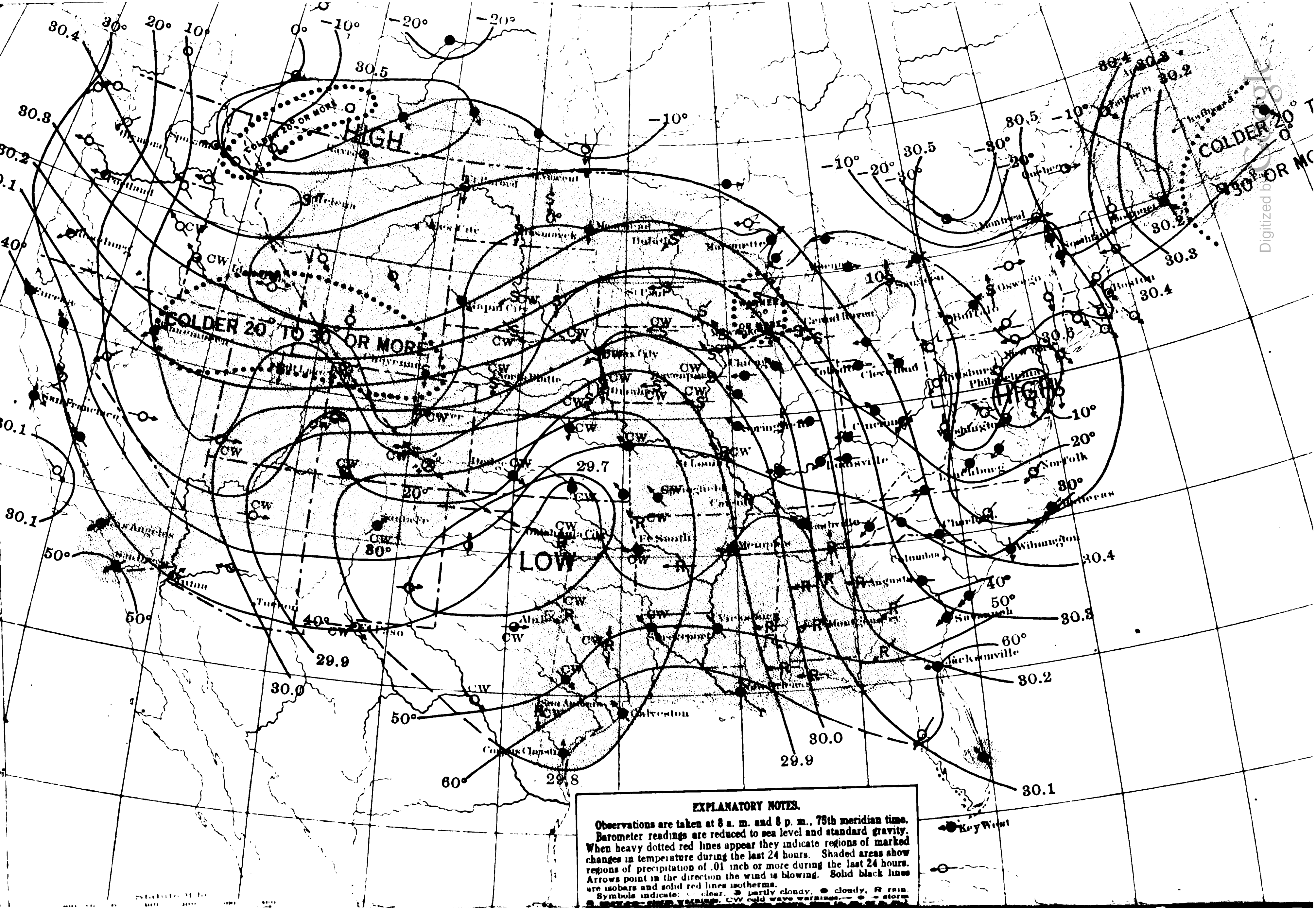
EXPLANATORY NOTES.

Observations are taken at 8 a. m. and 8 p. m., 75th meridian time. Barometer readings are reduced to sea level and standard gravity. When heavy dotted red lines appear they indicate regions of marked changes in temperature during the last 24 hours. Shaded areas show regions of precipitation of .01 inch or more during the last 24 hours. Arrows point in the direction the wind is flowing. Solid black lines are isobars and solid red lines isotherms.

Symbols indicate: ○ clear, ◐ partly cloudy, ● cloudy, R rain.

THE DAILY WEATHER MAP

WITH EXPLANATION



EXPLANATORY NOTES.

Observations are taken at 8 a. m. and 8 p. m., 75th meridian time. Barometer readings are reduced to sea level and standard gravity. When heavy dotted red lines appear they indicate regions of marked changes in temperature during the last 24 hours. Shaded areas show regions of precipitation of .01 inch or more during the last 24 hours. Arrows point in the direction the wind is blowing. Solid black lines are isobars and solid red lines isotherms.

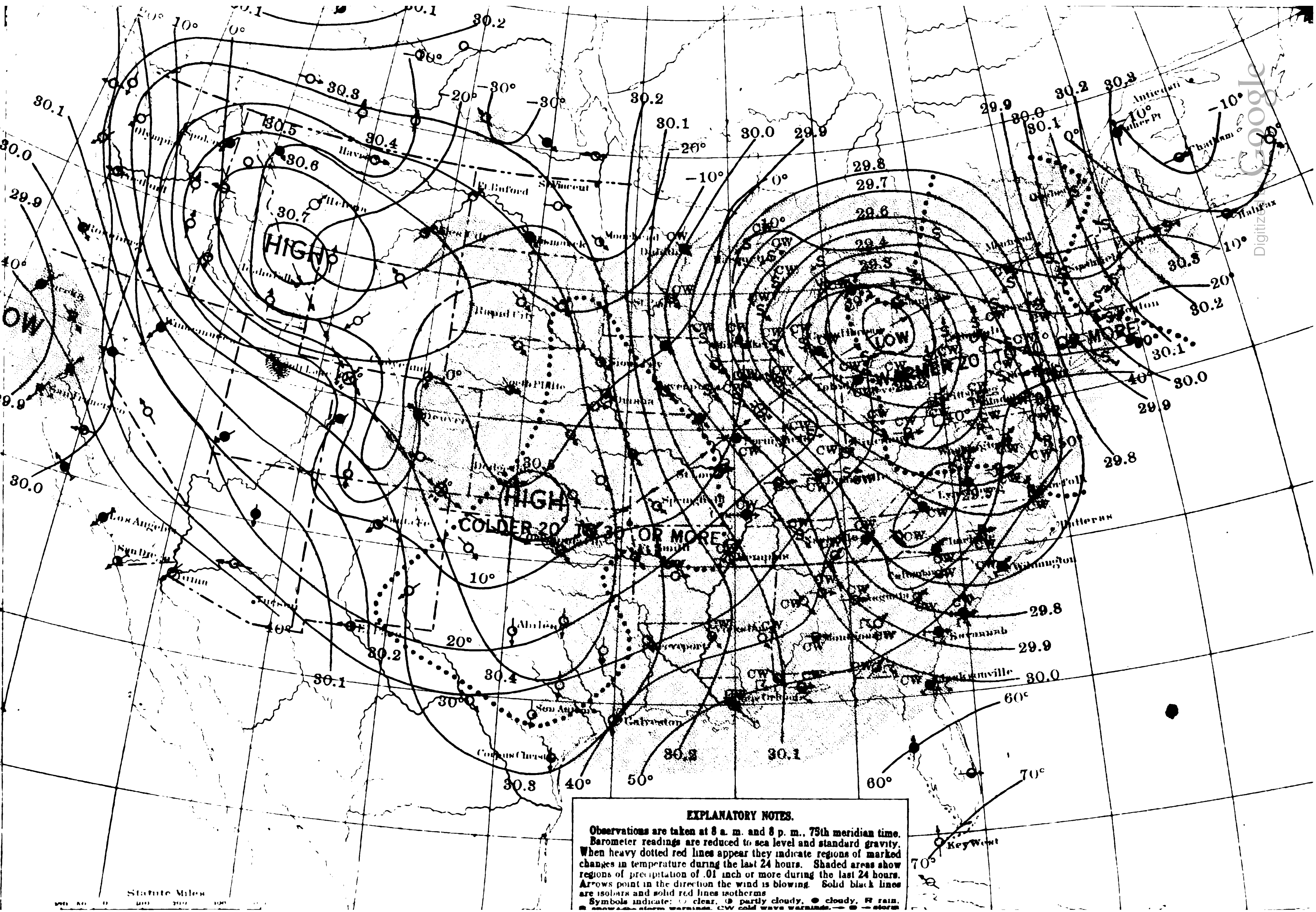
Symbols indicate: ○ clear, ◑ partly cloudy, ● cloudy, R rain, S snow, CW cold wave warnings, [illegible] storm warnings [illegible]

EXPLANATION OF THE WEATHER MAP.

The daily weather maps of the Weather Bureau are based on telegraphic reports of observations, taken at 8 a. m. and 8 p. m., seventy-fifth meridian time, from stations in the United States and Canada (see a. m. maps January 30 to February 2, 1908). The reports consist of observations of the barometer and thermometer, the velocity and direction of the wind, state of the weather, and amount of rain or snow. On the weather maps solid black lines, called isobars, are drawn through points that have the same atmospheric pressure, a line being drawn for each tenth of an inch. Solid red lines, called isotherms, are drawn through points that have the same temperature, a line being drawn for each ten degrees. Heavy dotted red lines are sometimes used to inclose areas where decided changes in temperature have occurred during the preceding twenty-four hours. The direction of the wind at each station is indicated by an arrow which flies with the wind. The state of the weather—clear, partly cloudy, cloudy, rain, or snow—is indicated by symbols. Shaded areas which appear on the maps issued at Washington and at several stations show regions within which precipitation in the form of rain or snow has occurred during the preceding twenty-four hours. The tabular data (not reproduced on the maps herewith) give details of maximum and minimum temperatures, twenty-four hour temperature changes, wind velocities, and amounts of precipitation during the preceding twenty-four hours. The text that appears on the printed maps gives forecasts for the several States, and summarizes general and special meteorological features that are also shown by the lines, symbols, and tabulated data.

The centers of areas of low barometric pressure are indicated on the maps by the word "LOW" and the centers of areas of high barometric pressure by the word "HIGH."

In the Northern Hemisphere winds blow spirally inward, counter-clockwise, toward and around the center of a LOW, while from the center of a HIGH they blow spirally outward in a direction similar to that described by the hands of a clock. On the front of a LOW, therefore, the winds are easterly, and in the rear, westerly. Southerly winds prevail to the west of a north and south line passing through the center of a HIGH and northerly winds to the east of that line.



EXPLANATORY NOTES.

Observations are taken at 8 a. m. and 8 p. m., 75th meridian time. Barometer readings are reduced to sea level and standard gravity. When heavy dotted red lines appear they indicate regions of marked changes in temperature during the last 24 hours. Shaded areas show regions of precipitation of .01 inch or more during the last 24 hours. Arrows point in the direction the wind is blowing. Solid black lines are isobars and solid red lines isotherms

Symbols indicate: ○ clear, ◐ partly cloudy, ● cloudy, R rain, S snow; storm warnings, CW cold wave warnings.

When a LOW is closely followed by a HIGH it is not easy to distinguish between the winds of the two systems. As before stated, the winds in the rear of the LOW are north to west and these winds are also appropriate to the east side of a HIGH, with the exception that when the HIGH is separated from the LOW by a considerable distance the winds of its eastern side are generally north to east, rather than north to west, as on the west side of a LOW.

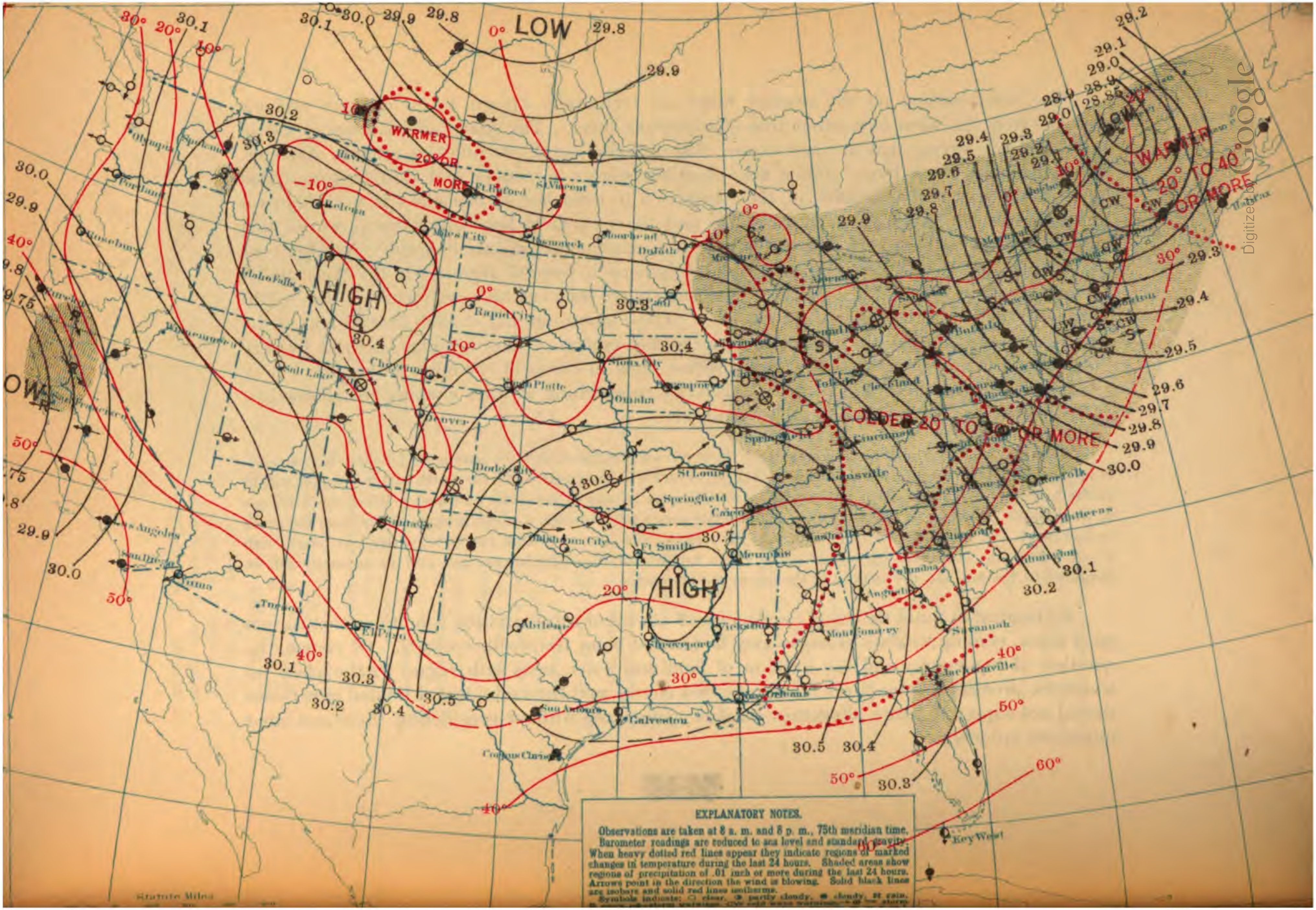
Separate and distinct from the circulation of winds around the centers of LOWS and HIGHS, the whole system of winds has a translatory movement of over 500 miles a day. The general course of LOWS and HIGHS in the United States is from west to east, the same as the prevailing winds. Lows usually move in an easterly or north of east direction and HIGHS in an easterly or south of east direction.

In general there are two rather well-defined storm tracks: The first passes from the Canadian Northwest across the Lake region and down the St. Lawrence Valley; and the other over the middle Rocky Mountain region to the Gulf States. After passing to the Gulf States, the LOWS almost invariably recurve up the Ohio Valley, leaving the country by way of the St. Lawrence Valley, or else cross the Gulf States and recurve up the Atlantic coast. Weather changes over the Canadian Northwest will appear from three to four days later over the Eastern States.

Highs.—The summer HIGHS make their appearance over the Canadian Northwest or over the north Pacific coast and northern Rocky Mountain region. In winter there are fewer of the North Pacific HIGHS and more of the Canadian HIGHS.

Lows.—Most of the LOWS that affect weather conditions in the United States enter the country from the Canadian Northwest; some, however, pass from the ocean over the North Pacific States; others over the South Pacific States; some develop over the Rocky Mountain region; some over the Gulf States; a few off the south Atlantic coast; and quite a number, particularly in summer, over the Central States. In the summer time the great majority of the LOWS first appear in the Canadian Northwest. Summer LOWS pursue, on the average, a more northerly course than those of the winter season and are also of less intensity and of slower movement.

There is more or less regularity in the sequence of HIGHS and LOWS; they are as fully the complements of each other as are hills and hollows and are generally traveling companions. Lows are usually associated with rising temperature and accompanied by cloudiness and rain or snow; while the HIGHS are usually associated with falling temperature and attended by fair weather.


LOW
HIGH
HIGH
LOW
WARMER 20° OR MORE
COLDER 20° TO 30° OR MORE
WARMER 20° TO 40° OR MORE
EXPLANATORY NOTES.
Observations are taken at 8 a. m. and 8 p. m., 75th meridian time. Barometer readings are reduced to sea level and standard gravity. When heavy dotted red lines appear they indicate regions of marked changes in temperature during the last 24 hours. Shaded areas show regions of precipitation of .01 inch or more during the last 24 hours. Arrows point in the direction the wind is blowing. Solid black lines are isobars and solid red lines isotherms.

The LOWS charted on the weather maps are technically known as cyclones, or cyclonic systems, from the wind circulation that characterizes them. The sphere of influence of one of these cyclonic storms may at times exceed that of a circle of 1,000 miles or more in diameter. Associated with these larger storms are secondary storms, tornadoes and thunderstorms, that form in the southern quadrants of the former. The influence of tornadoes is felt only over limited areas, but the high wind velocities and the extremely low barometric pressures that attend them make them very destructive and, as a consequence, greatly dreaded. Another type of storm is the West Indian hurricane which originates in tropical regions—in the West Indies between the parallels of 12° and 28°. They first move from east to west, recurve to the northward, and then pursue a northeasterly course. These storms are not of such limited area as the tornado and neither are they nearly as large as the cyclone. They are characterized by very low barometric pressure and high wind velocities, often in excess of 100 miles an hour.

The following indications of the character of approaching weather changes are afforded by local observations of the wind and the barometer:

When the wind sets in from points between the south and southeast and the barometer falls steadily, a storm is approaching from the west and northwest, and its center will pass near or to the north of the observer within twelve to twenty-four hours, with winds shifting to northwest by way of southwest and west. When the wind sets in from points between east and northeast, and the barometer falls steadily, a storm is approaching from the south or southwest, and its center will pass near or to the south of the observer within twelve to twenty-four hours, with winds shifting to northwest by way of north. The rapidity of the storm's approach and its intensity will be indicated by the rate and the amount of the fall in the barometer.

By bearing in mind the usual movements of LOWS and HIGHS and the conditions that accompany them, coming weather changes may be foretold from the weather charts. Of course, the question of topography and the location of land and water areas with regard to the place for which the prediction is made are most important factors, and the individual of limited experience should not expect to make altogether satisfactory forecasts without considering these and other important influences.

moving. When the diameter of an area of low pressure becomes unusually small, the pressure gradient is said to be "steep" and the weather changes are sudden and violent. In general, the closer the isobars, the higher the velocity of the wind.

2. **Highs** The Highs or anti-cyclones are the opposite of the lows. In them the wind is blowing *spirally outward in a clockwise direction.* While a high is passing over, the weather is usually excellent and the winds are never high. High pressure areas are erratic in behavior, moving slowly, sometimes standing for days, and follow no rule for direction.

3. **V-shaped depressions** Sometimes the isobars are shaped like the letter "V" with the low pressure inside the "V". This formation is known as a V-shaped Depression, and moves along with the area of low pressure. If the foot of the "V" points south, the wind is southerly in front and northerly behind the depression. The weather in front is very rainy. As the center passes there are squalls and heavy showers which are followed by a quick improvement in the weather.

4. **Wedges** Sometimes the isobars inclose an area of high pressure in the shape of a "V", usually with the foot of the "V" to the north. This formation is called a Wedge. The winds are light, northerly in front and southerly behind. While a wedge is passing over, a short period of extremely fine weather is experienced.

F. WIND VELOCITY

To assist in estimating the velocity of winds, the following table known as the Beaufort Scale is given:

Beaufort No.	General Description	Specifications of Scale	Velocity in Miles per hr.
0	Calm	Calm, smoke rises vertically	–1
1	Light Air	Direction of wind shown by smoke drift, but not by wind vanes.	1–3
2	Slight Breeze	Wind felt on face; leaves rustle	4–7
3	Gentle "	Wind extends light flag	8–12
4	Moderate "	Raises dust and loose paper	13–18
5	Fresh "	Small trees in leaf begin to sway	19–24
6	Strong "	Whistling heard in telegraph wires. Umbrellas used with difficulty	25–31
7	High Wind	Whole trees in motion; inconvenience felt when walking against wind	32–38
8	Gale	Breaks twigs off trees; generally impedes progress	39–46
9	Strong Gale	Chimney pots and slates removed	47–54
10	Whole "	Seldom experienced inland; trees uprooted	55–63
11	Storm	Very rarely experienced. Accompanied by widespread damage	64–75
12	Hurricane	....	75–up

The average wind velocity in the U. S. throughout the year at a height of 50 ft. above the ground is 11 miles per hour. Over the oceans the velocity of the wind is slightly greater than this.

G. VARIATION IN THE DIRECTION AND VELOCITY OF THE WIND ABOVE THE SURFACE

With a high barometric pressure at the ground and in clear weather, the wind velocity increases slowly with altitude; but with a low barometer and in cloudy weather, its velocity increases rapidly with altitude, especially near the strata of lower clouds.

The Blue Hill Meteorological Observatory at Milton, Mass., gives the following results of its observations of the wind velocity at different heights.

Height in Miles	0.5	1.2	2.5	4.7	5.0
Velocity in Summer (m.p.h.)	16	18	23	31	51
Velocity in Winter (m.p.h.)	19	32	47	108	119

Near the ground the wind is retarded owing to the friction of the air with the surface. The effect of friction does not extend beyond an altitude of about 2,000 feet above land, and from 300 to 500 feet above water. As a rule for winds other than north, a doubling of the wind velocity may be expected between the surface and 2,000 feet, excepting during a hot sunny day when a general mixing of the air by convection currents tends to equalize the different strata, and the velocity at the surface will not be much less than that of the wind above.

Not only does the wind change in velocity but it also changes in direction. With increased altitude the wind is veered on the surface wind—that is, more from the right as you face the wind. As a rule the average change in the wind direction from the surface to a height of 2,000 feet amounts to about 22°.

Above 2,000 feet, there may be five types of wind changes.

1. After the first increase up to 2,000 feet, the wind remains constant in velocity and direction up to great heights; this condition is *frequent in easterly winds* and is *occasionally found in westerly winds,* but is *rare with winds from north or south.*

2. After the first increase up to 2,000 feet, the wind falls off in velocity and is calm to great heights. This distribution is associated *entirely with easterly* winds, with an anti-cyclone to the north and a cyclone to the south.

3. After the initial increase, the wind falls off as in the last case, but above the calm there is a reversal of wind direction and the upper wind usually increases slowly with height. This happens with *easterly winds* when there is a low pressure area off the southwest.

4. The wind may continue to increase but at a slower rate than near the surface. The increase may continue to great heights, or after an increase for 8,000 or 10,000 feet, there may be a slight decrease followed again by an increase. This happens in the *westerly winds* on the south side of a Low, and may be found with winds from any direction, though perhaps less often with *easterly winds.*

5. After the initial increase, the wind direction changes very widely from that at the surface. This happens in the *southwest winds* of an approaching area of low pressure. The upper winds blow away from the center of the area of low pressure and may be veered 90° on the surface wind.

The changes of direction in types 3 and 5 may take place at any height up to 15,000 feet or so. In type 5, the change may be gradual or quick. When there is a quick change of direction with height, there is always a calm at the height at which the change occurs.

4. CLOUDS

The clouds may be used as drifting aerial buoys indicating to the observer on the ground the direction and velocity of the air currents at their respective heights.

A. FORMATION

The water vapor in the air is supplied by evaporation from the surface of oceans, lakes, rivers, etc. The air is said to be *saturated* when it contains all the water vapor it can possibly hold. If saturated air is warmed, it is no longer saturated, because its capacity for moisture increases as the temperature increases. On the other hand, if saturated air is cooled, it can no longer hold all its moisture, and some of the water vapor will condense into fog or cloud.

Fog is formed when the air over damp plains is chilled to the point of saturation. Fog consists of particles of water of such minute size that they float.

FIG. 703.—COMMON CIRRUS *Clayden*

During the summer many clouds are caused by the rise of damp warm air to such altitudes that the air is cooled to the point of saturation. The formation of clouds is chiefly due to the cooling which accompanies the expansion of the rising air. Another cause of cloud formation is the blowing of damp air over cold surfaces, such as the top of a mountain. Still another cause is the coming in contact of a warm and a cold current of air, one above the other. Clouds of this kind are common on days when the warm air is also very damp.

B. TYPES OF CLOUDS

The highest clouds are the *Cirrus* and the *Cirro-stratus,* which are at an average height of six miles and are composed of particles of ice and snow. Cirrus clouds are delicate, fibrous, and hair-like. Fig. 703 illustrates the most persistent and probably the most frequent form of the cirrus cloud, which is called common cirrus. It occurs in detached masses which have very variable forms but are wholly fibrous. This cloud when moving slowly indicates settled weather conditions and fine weather. Cirrus clouds moving rapidly from the southwest indicate a fall in the temperature, and moving rapidly from the northwest indicate a decided rise in the temperature within the next 24 hours.

When the cirrus clouds appear in a sheet or layer formation they are called *Cirro-stratus.* In the lower part of Fig. 704 are seen fluffy cirrus clouds which are several thousand feet above the cirro-stratus clouds in the upper part of the picture. This cloud is an indication of condensation in a calm atmosphere, and usually means the end of a period of good weather. About 80% of the time this cloud is followed by rain within 24 hours.

FIG. 704.—CIRRO-STRATUS *Clayden*

The clouds of intermediate height, that is from three to five miles, are called *Cirro-cumulus, Alto-cumulus,* and *Alto-stratus.*

In Fig. 705 cirrus clouds are in the upper part of the picture and cirro-cumulus in the lower part. This cloud forms at an altitude of above five miles during the hottest months of the year when the air is still and the evaporation is great—the same conditions which cause thunder storms.

The alto-cumulus form occurs at an altitude of from three to four miles. Fig. 706 illustrates this type. These clouds may either close up forming a uniform layer which is then called alto-stratus, or they may break up and gradually disappear. This cloud is usually seen in the afternoon. The alto-cumulus is char-

FIG. 705.—CIRRO-CUMULUS *Clayden*

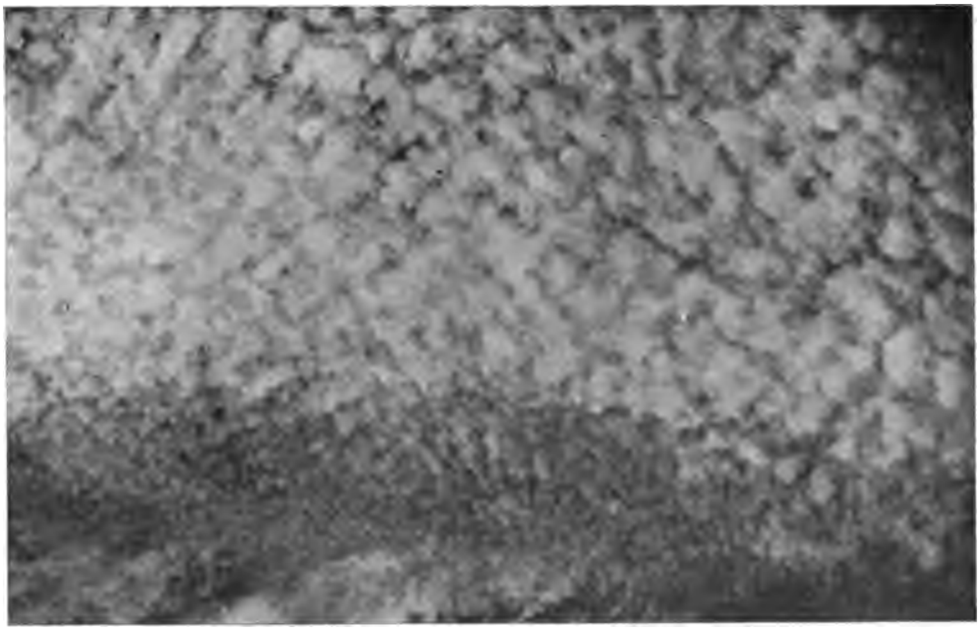


FIG. 706.—ALTO-CUMULUS *Clayden*

FIG. 707.—COMMON STRATUS *Clayden*

FIG. 708.—CUMULUS *Clayden*

acteristic of thunder weather, and is followed by rain within 24 hours, three times out of four.

The lowest of all the clouds, the *Stratus*, which are shown in Fig. 707, form at an altitude of from 1,500 to 2,500 feet. This cloud is without structure of any kind, and is the typical overcast-weather cloud. They often come so low as to lie upon the tops of hills in the form of mist or fog.

The lower clouds formed daily by ascending air currents are called *Cumulus, Cumulo-nimbus,* and *Nimbus*. Cumulus is the lumpy, piled-up, white cloud which looks like exploded cotton bales. They are detached masses of clouds with flat bases and rounded, dome-like summits. Fig. 708 shows this type of cloud. The average thickness of the cumulus clouds is about one mile; but when the uprush of air is very strong, as in thunder storms, their tops reach to the level of the cirrus clouds. They are then called Cumulo-nimbus. This cloud formation is well illustrated in Fig. 702. Cumulus clouds are convection clouds and are at the tops of rising columns of air. When entering and leaving such a column of air the aviator must be prepared for a change in the condition of the air and adjust his controls accordingly.

On hot oppressive mornings in summer, when the air is full of moisture, cumulus clouds form in all parts of the sky. In the afternoons of such days, these clouds grow larger and darker and develop into cumulo-nimbus or thunder clouds, which rise in rolling surging masses to great heights. These are always followed by rain, lightning, and thunder, and sometimes by hail. They are very dangerous clouds to enter as the air is full of whirls and eddies. The air currents here are frequently of sufficient force to carry rain drops at a low level upward to such a height that they freeze and become hail. Fig. 709 is a picture of a thunder cloud forming. Thunder storms may cover very large areas, but are sometimes only a mile across. They travel eastward in the prevailing westerly winds at the rate of from 20 to 50 miles an hour.

A nimbus cloud is any cloud from which rain is falling. It is a very low cloud, but may have a thickness of two miles. Rain seldom falls from clouds less than one-half mile thick.

Of all the cloud forms, the dark sheet of stratus and clouds of lenticular shape are most frequently followed by rain. In general, flat and flaky clouds, clouds forming and disappearing rapidly, and clouds changing to form at a higher level precede dry and colder weather.

C. VELOCITY OF CLOUDS

The average velocity of the cirriform clouds is 90 miles an hour in winter and 60 miles an hour in summer; but occasionally in winter cirrus clouds have been observed to have the enormous velocity of 230 miles an hour. On the average, the velocity of the air currents increase, from the lowest to the highest clouds, at the rate of about 3 miles an hour for each 1,000 feet of height; but near the ground the increase with height is greater.

5. AIR CURRENTS

A. ASCENDING CURRENTS

Since the air is heated by the radiation of the heat which the earth receives from the sun, it follows that ascending currents of air are more numerous and more vigorous in warm clear weather. These currents of air may rise with a velocity as high as 25 feet per second. On entering a column of ascending air the supporting power of the air is increased by the upward current and the airplane will start to climb. On leaving this column of air the conditions are reversed, the supporting power of the air is decreased, and the machine will glide downward till the velocity of flight is increased. Rising currents are more fre-

FIG. 709.—THUNDER-CLOUDS FORMING *Clayden*

quent during the middle of the day than in the morning and evening, and are rarely experienced during the night or in the daytime when the sky is entirely covered with clouds. Usually a cumulus cloud will be at the top of the ascending current, and the height to which the cloud extends is an indication of the velocity of the current of air beneath.

B. DESCENDING CURRENTS

The effect of a descending current upon an airplane is just the reverse of that of an ascending current. Such currents may be found over water during the day and over large areas of ground covered with trees or vegetation. Clear patches between clouds usually indicate descending currents.

C. SURFACE CONTOUR CURRENTS

In hilly country the wind follows somewhat closely the contour of the surface. The swift downward sweep of the air on the leeward side of a hill when the wind is strong may carry the airplane with it. Such currents of air should be entirely harmless so long as the aviator keeps his machine well above the surface and out of the treacherous eddies near the ground.

D. GUSTS

What the aviator most wants is steady air conditions, particularly so in a high wind. The condition of flight in still air and in steady moving air are nearly identical, the only difference being the motion of the airplane with respect to the ground. Owing to the irregularities in the surface of the earth, the wind at the surface is not at all uniform in velocity nor constant in direction, but moves in gusts which are troublesome. Wind gusts may be either from the front or the rear. If from the front, the result is an increase in the supporting power of the air and the machine will rise. On the other hand, a rear gust will decrease the supporting power of the air, and the machine will fall. A rear gust of 20 ft. per second will cause an unconstrained machine to drop 80 feet in 15 seconds. However, gusts rapidly disappear with altitude; hence, in general, the windier it is the higher the aviator should fly.

E. WIND EDDIES

In an eddy the air is moving in a loop, and hence the direction of the air at the top and at the bottom of an eddy are in opposite directions. The direction at the top is with the wind higher up, and at the bottom it is against it; and the stronger the wind the more rapid is the rotation of the eddy. Eddies are most pronounced on the leeward side of cliffs and steep mountains, but also occur to a lesser extent on the windward side of such places. For this reason aviators should avoid landing on the leeward side of hills or of large buildings.

F. THUNDER STORM CURRENTS

Thunder storm conditions are accompanied by rolling, dashing, and choppy winds. They are often of such violence, up, down, and sideways that an airplane in their grasp is in a very dangerous situation. These are without doubt the most dangerous currents that the aviator can encounter.

G. LINE SQUALLS

The most dangerous wind met with in England and France is the "line squall", so called because it advances with a line front like a tidal wave, usually lying southwest and northeast, and advancing from northwest to southeast. The squall is accompanied by thunder and lightning. It probably extends to considerable heights and it is not advisable for the aviator to try to climb above the storm. The signs of this wind are:

1. A sudden fall in the temperature.
2. A veer of the wind.
3. A rise of pressure.
4. A squall of rain, hail, or snow.

CHAPTER VIII.

SIGNALLING

OUTLINE

1. Airplane Radio Equipment
   - A. General
   - B. Description of Apparatus
     1. Transmitter
     2. Storage Battery
     3. Sending Keys
     4. Safety Switch
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     6. Aerial System
2. Use of Radio in Artillery Observation
   - A. Handling of the Radio Set
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     1. Wave-lengths
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     3. Directional Sending
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CHAPTER VIII.

SIGNALLING

1. AIRPLANE RADIO EQUIPMENT

A. GENERAL

The radio equipment of an airplane should possess the following properties: (1) simplicity; (2) ruggedness; (3) selectivity. The transmitting set used by the British possesses the first two qualities in a marked degree, this, however, at the expense of the third. The American and French types possess ruggedness and selectivity, but are not so simple, and therefore require more knowledge on the part of the pilot. An American set modeled after the British Sterling transmitter is being made and used for training purposes, hence the following discussion will apply particularly to this set, although the remarks on the handling of the set and on the prevention of interference will apply more or less rigidly to all aerial transmitter sets now in use.

The Signal Corps transmitting set, known as type SCR-65, consists of the following units: transmitter; storage battery; sending keys; safety switch; fairlead; aerial wire with reel and weight; connecting wires.

B. DESCRIPTION OF APPARATUS

1. **Transmitter** The transmitter consists of a spark-coil having an adjustable vibrator, a condenser, a spark gap, and a flat spiral sending helix, or oscillation transformer. The spark-coil, condenser, and spark gap are enclosed in a box 7 7/16 inches long, 6⅜ inches wide, and 3¼ inches deep, outside measurement. The top of the box is of hard rubber and forms a panel upon the outer side of which are mounted the sending helix and four binding posts which are marked respectively "antenna", "counterpoise", "key", and "battery". The outer turn of the sending helix is connected permanently to the "counterpoise" binding post. What is known as the "closed circuit" of the radio set is formed by connecting in series the spark gap, the condenser, and several turns of the helix. The connections to the helix are made by leading a heavily insulated wire from one electrode of the spark gap to the "counterpoise" binding post, connection being made on the under side of the panel, and by passing another heavily insulated conductor leading from one terminal of the condenser through an opening in the center of the panel, the outer end of the conductor being attached to some point on the helix by means of a clip. Hard rubber markers bearing numbers from 100 to 300 are placed at certain points on the helix and indicate the proper point of attachment of the closed circuit clip for the corresponding wave-length. The helix also forms a part of the open, or "radiating", circuit of the set. This circuit is formed by connecting the "counterpoise" binding post to the bonded wire stays of the machine, which constitute the "ground", and by connecting the "antenna" binding post to the fairlead by means of a heavily insulated wire. The "antenna" binding post is connected to the helix by means of a flexible insulated cord which ends in a clip. The position of this clip is determined by experiment, and after once being determined remains fixed. The purpose of the spark-coil is to change the low pressure direct current from the storage battery into high pressure pulsations in order to provide successive

re-charges of the condenser, which discharges through the helix and spark gap when the pressure becomes sufficiently great. To attain this, the secondary terminals of the spark-coil are connected to the spark gap electrodes. The primary terminals are connected to the "key" and "battery" binding posts. The transmitter and the storage battery are mounted on a tray which is placed in position on a shelf just back of the rear cockpit. This shelf is made accessible simply by moving the turtle-back a short distance to the rear.

2. **Storage battery** The storage battery differs from any four-cell, eight-volt automobile storage battery only in that the plates are smaller, and less current can be obtained. The battery will provide current for about five hours of continuous sending before a re-charge is necessary. When installed in a plane, the battery rests inside a deep box which is fastened to the tray upon which the transmitter is mounted.

3. **Sending keys** Three sending keys are provided in a two-seater machine, one in the forward cockpit and two in the rear cockpit. These keys are larger and much more rugged than the ordinary telegraph key, the heavy lever and large knob making sending with the gloved hand less difficult. All three keys are connected in parallel, so that the pilot may send with either hand, or that the observer may also send any necessary signal.

4. **Safety switch** The safety switch is located in the rear cockpit within easy reach of the pilot's right hand, and is for the purpose of completely disconnecting the battery from the transmitter. Two leads from the battery are connected to one side of the switch. From the other side, one lead goes directly to the spark-coil primary and a second lead goes to the right hand key in the rear cockpit, and from the key a lead goes to the spark-coil primary, thus completing the battery circuit.

5. **Fairlead** The fairlead is a metal bushing set into a bushing of ebonite, and is located directly below the aerial reel. The fairlead serves as a runway for the aerial wire, makes the electrical connection between the aerial and the transmitter, and also insulates the aerial from the machine. It is clamped to the lower longeron on the right hand side of the machine, and outside of the forward part of the pilot's cockpit.

6. **Aerial system** The aerial consists of a stranded bare wire. Except when the machine is in flight the aerial is wound on a fibre reel, the free end passing down through the fairlead and being attached to a lead weight of about two pounds. The weight is necessary for the proper action of the aerial during the process of reeling in and out, and also during flight. The reel is equipped with a brake in order to control the speed at which the aerial runs out. The length of the aerial depends upon the wave-length to be used. For example, for a 200-meter wave-length, the radiating circuit should be two hundred feet long. The wiring in the machine as far as the fairlead supplies a part of this and the aerial supplies the remainder. The aerial reel is fastened to the cowl at the right hand of the forward part of the pilot's cockpit, so that its position is directly above the fairlead.

2. USE OF RADIO IN ARTILLERY OBSERVATION

A. HANDLING OF THE RADIO SET

1. **Preparatory to flight** The responsibility for the proper working condition of the radio set rests with the Radio Officer of the squadron. It is his duty to see that the plane contains a transmitter and properly charged battery with all connections made, to adjust the vibrator of the spark-coil, make the proper settings of the helix clips, and to adjust the spark gap, securely tightening all lock nuts or screws as he does so. Also, he provides the

machine with a reel carrying an aerial of the proper length to correspond to the wave-length adjustment of the helix.

Before beginning a flight, the pilot should assure himself as to the proper condition of the radio equipment by proceeding as follows: (1) see that the plane contains a transmitter; (2) examine the aerial system to see that the reel works freely, that the wire passes readily through the fairlead, that the weight is securely fastened to the end of the aerial and is pulled up close to the fairlead, and that there are no broken strands in the aerial; (3) adjust sending keys both as to spring tension and length of beat, tightening lock nuts securely; (4) close safety switch, press the key and listen for the sound of the spark; (5) open safety switch. If any broken strands are noticed in the aerial, a new aerial should be asked for.

2. **During flight** When the machine has reached an elevation of five hundred feet or more, the aerial may be let out. It should not be allowed to run out rapidly and stop with a jerk, as the sudden stop will cause the wire to break. When the weight is lost, the aerial should be reeled in at once. The reeling in will be less difficult if the machine is flown in a zig-zag course in order to keep the wire stretched out behind the machine. When the aerial has been let out to its full length, the safety switch may be closed, and the set is ready for use. The central radio station of the squadron should be called first, and upon receipt of his acknowledgment, the battery station should be called.

In calling up ground stations in order that they may "tune in" your signals, the machine should not approach within two miles of the ground station while sending. When two stations are very close together, the tuning in becomes ineffective because of the intensity of the signals, and then when the two stations become separated by the proper distance, the receiving station must repeat the tuning in process before any signals can be heard.

When the tuning has been completed and both the central station and the battery station have answered their calls, the pilot may take his position above the target, ready to report the results of his observations. In reporting to the battery station, the sender should take pains to send "as plain as print". The signals should be spaced as carefully as possible, as they represent words in themselves, otherwise they would have no meaning. The receiving operator hears many signals in his receivers, and can follow any one sender only when the sending is firm, steady, and properly spaced. Care should be taken never to send while turning, but only when flying directly toward the receiving station. When the observations have been completed and the last signal has been sent, the safety switch should be opened and the aerial reeled in.

B. METHODS OF PREVENTING INTERFERENCE

The confusion of signals, commonly spoken of as interference, or "jambing", results from the large number of airplanes which often operate within a given region of the front. Four methods are used in the attempt to prevent this "jambing" at receiving stations: (1) use of different wave-lengths; (2) use of variously tuned sparks; (3) directional sending; (4) synchronized chronometers.

1. **Wave-lengths** The use of different wave-lengths, when tuning is carefully done, serves to eliminate jambing, provided the wave-lengths can be varied over a sufficiently wide range. Since the shortest practical wave-length for an airplane set is about one hundred meters, and the longest about three hundred meters, this method does not eliminate interference completely, and other means must be employed.

2. Tuned sparks Although the receiving operator often hears signals from a number of machines simultaneously, he is able to follow the signals from one machine and to disregard the others if the spark notes from the various machines differ in pitch. The tone of the spark depends upon the rapidity of vibration of the spark-coil vibrator. Hence the tone of the spark for each machine is fixed by the Radio Officer through a proper adjustment of the vibrator. From the standpoint of the receiving operator, the situation becomes that of reading signals from an open buzzer in a room where a number of other buzzers are in operation at the same time, except that the signals are much less intense and more outside interference is present.

3. Directional sending Directional sending is very important in the reduction of interference. Not only is it necessary that the sending operator avoid sending any unnecessary signals, that all information be transmitted in code as far as possible, and that the spacing of the letter groups be so distinct as to leave no doubt in the mind of the receiving operator as to what the signals are, but also it is very important that the machine be flying directly toward the receiving station when the sending is done. The strongest radiation from an aerial occurs in a direction perpendicular to the aerial. Hence on account of the backward drift of the aerial, an approaching machine presents the broadside of its aerial to the receiving station, and the signals will be of maximum strength for the given distance. Sending should never be done while the machine is turning, because the swinging of the aerial will cause the direction of the strong signals to be changing rapidly for a time. Such signals would be extremely difficult for a receiving operator to follow on account of their continual change in intensity. An additional reason for flying toward the receiving station when sending is that the battery station also possesses a "directional aerial". This aerial is erected in such a position that it responds to signals coming from the direction of the target much more strongly than to signals of the same strength coming in from other directions.

4. Synchronized watches Under exceptional circumstances, when "jambing" is very bad, pilots are supplied with synchronized chronometers, or very accurate watches, and each machine has a definite time assigned in which its sending must be done. This is an emergency measure, as it renders observation very slow on account of the necessity that machines take turns in sending down the results of their observations.

[redacted]AL SIGNS
[redacted]SH

- Any trench organized for fire
- Approximate line, reported by observers and not yet confirmed by photographs
- X X X X X Wire entanglements
- Ground cut up by artillery fire
- Enemy tracks
- Buried pipe line or cable
- Air line
- Supply depot
- Observation post
- Dugout
- Earthwork
- or M.G. Machine gun emplacement
- or T.M. Trench mortar emplacement
- L or L.P. Listening post
- Mine crater, unfortified
- Mine crater, fortified
- Organized shell holes
- Anti-aircraft gun
- Hutments
- Aerodrome
- Airship shed
- Balloon
- Barge
- F Fire
- H Railhead
- Mechanical transport, moving
- Mechanical transport, stationary
- Horse transport, moving
- Horse transport, stationary

- Infantry, moving in column of route
- Cavalry, moving in column of route
- Artillery, moving in column of route
- Post
- Patrol
- Holding line in action
- Gun emplacements
- 3 Battery of guns, inactive
- Single guns, inactive
- Battery of howitzers, active
- Single howitzers, active
- Doubtful battery, active
- Doubtful guns or howitzers, active
- Hedge, fence, or ditch
- 5'W 6'D Ditch, permanent water
- Woods
- Orchard
- Brushwood or undergrowth
- Faults in chalk country
- Embankment
- Cutting
- Church
- Wind mill
- Water mill
- Houses, standing
- Houses, ruined
- Fenced / Unfenced Roads, 1st class
- Roads, 2d class
- Roads, 3d class
- Railways, double
- Sta Railways, single
- Narrow gage railway
- Trench railway
- Ferry
- Railway over river
- Marsh

CONVENTIONAL SIGNS
FRENCH

German

- Trenches (with loopholes, without loopholes, Ob, Fire trench, Communicating trench, Abandoned trench)
- Trenches, from report
- Trenches, abandoned
- Batteries (to 4 pieces, Camouflaged)
- Anti-aircraft gun
- Camps, Wagon parks (Park), Munition depots
- Works
- X X X X X X Wire entanglements
- Abatis
- Shelters
- Screened gun pits
- O Ob, P.C. Observation, post commanders
- Shell or mine craters
- M, B Machine guns, bombthrowers
- C.R. Revolving cannon
- Standard gage, R. R.
- Narrow gage, R. R.

French

- Advanced line
- Infantry
- Cavalry squadron
- Cavalry regiment
- Field battery, occupied
- Field battery, prepared
- Aero squadron
- Aero park
- Balloon
- Automobile service

- National road
- Departmental road
- Road passable in dry weather
- Dirt road
- Path, cleared line
- Standard gage single track R.R.
- Standard gage double track R.R.
- Narrow gage R. R.
- Bridge, Foot bridge, Ford, Large stream
- Small stream
- Towpath, Canal
- Pond
- Spring
- Well
- Inundated land
- Wall
- Hedge
- Wooden fence, Iron wire fence
- Ditch
- Earth embankment or fill
- Ruins, Houses, Village
- Steeple
- Wayside cross
- Chapel
- Cemetery
- Wind mill
- Water mill
- Smokestack
- Vines
- Gardens and orchards
- Woods
- Fir or pine thicket
- Brush
- Isolated trees
- Marsh or swamp
- 166 Contours and elevations
- Sand dunes
- Quarry
- Steep slopes