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AIRPORT SURFACE TRAFFIC CONTROL CONCEPT FORMULATION STUDY

VOLUME I - EXECUTIVE SUMMARY

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16. Abstract

This four-volume report presents system concepts for use in semi-automated airport surface traffic control at all positions in the tower cab of the major airports. The control functions and data requirements of a Ramp Control System, a Ground Control System, and a Local Control System are presented. The concept development process has been based upon an extensive study of cab operations at O'Hare Airport. This effort has included extensive delay analysis, study of communication tapes, and personal observations of the widely-varying situations that are faced by tower controllers. Following the Operations Analysis effort, a detailed study of requirements was performed and is presented in Volume IV of this report. This requirements effort provided an estimate of the performance requirements of a surveillance sensor that would be required in a TAGS (Tower Automated Ground Surveillance) system for use in both good and poor visibility conditions. Detailed studies were made of the complex type of conflicts to be solved by both the Ground and Local Controllers and operational levels and densities were developed. One particular TAGS system concept (employing an ATCRBS Trilateration Surveillance Subsystem) is described in Volume I and an estimate is made of its deployment potential at major airports. Backup material on this concept in the form of a working paper is held by TSC. This working paper also includes synthetic digital display concepts for the three systems which have been summarized in Volume I.

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PREFACE

At tower-equipped airports, the controllers in the tower cab are responsible for those aspects of Airport Surface Traffic Control (ASTC) requiring centralized management: issuing clearances for aircraft to land, taxi, or take off; establishing routing patterns for arriving and departing aircraft on the runway/taxiway network so as to minimize delays; sequencing aircraft movements on runways and taxiways and at critical intersections to ensure safety; and controlling the movements of service or emergency vehicles on the airport surface. Because of the expertise of the controllers and pilots, the ASTC system has worked well most of the time. However, the unfortunate incidents at Chicago-O'Hare (20 December 1972) and Boston-Logan (31 July 1973) have pointed out certain deficiencies; e.g., the system's surveillance capability when visibility is poor.

Initiated by the Federal Aviation Administration (FAA), the ASTC program is in the process of implementing several near-term system improvements. However, it is expected that these improvements, while adequate for the 1970's, will not be adequate to meet the more stringent long-term requirements of the 1980's.

The approach which has been taken in the present study is to concentrate on the Nation's most active and, in one sense, most mature airport; i.e., Chicago-O'Hare. In performing the study at O'Hare, the cooperation of the Airport Traffic Control Tower, the City of Chicago Department of Aviation, and the FAA Great Lakes Region was essential to the success of the effort. Mr. Paul S. Rempfer, of the Transportation Systems Center (TSC), acted as technical monitor for the Government. In addition, Messrs. Rempfer and L. Stevenson, also of TSC, performed the theoretical analysis of local area capacity which is presented in Section 5.3.3.1 of Volume III.

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SECTION 1 - INTRODUCTION

At tower-equipped airports, the controllers in the tower cab are responsible for those aspects of Airport Surface Traffic Control (ASTC) requiring centralized management: issuing clearances for aircraft to land, taxi, or take off; establishing routing patterns for arriving and departing aircraft on the runway/taxiway network so as to minimize delays; sequencing aircraft movements on runways and taxiways and at critical intersections to ensure safety; and controlling the movements of service or emergency vehicles on the airport surface. While the Federal Aviation Administration (FAA) does not currently have formal control responsibility in the terminal ramp areas, it is also necessary for controllers at some major airports to provide advisory instructions for aircraft in these areas.

The tower controllers' surveillance function--determining the position and identity of vehicles of interest--is normally accomplished by visual observation supplemented by position reports obtained by voice radio communication with the pilots. Twelve airports also have Airport Surface Detection Equipment--the ASDE-2--which provides a primary radar-type display of the airport surface traffic situation. Nine of these twelve radars are in service and three are in caretaker status. Control instructions are sent from the controllers to the pilots via voice radio communication. Each pilot is responsible for the guidance of his own aircraft, within the overall framework set up by the controllers. Lights, signs, and markings are installed on runways and taxiways and at intersections to aid the pilot in traversing the runway/taxiway network. The pilot calls the appropriate tower controller via voice radio when he requires a clearance or guidance support.

Because of the expertise of the controllers and pilots, the ASTC System has worked well the vast majority of the time. However, unfortunate incidents such as those at Chicago-O'Hare (20 December 1972) and Boston-Logan

(31 July 1973) have pointed out deficiencies in the present ASTC System's surveillance capability under conditions of poor visibility. To overcome these deficiencies, certain ASDE-2 improvements have already been installed and others will be implemented over the next several years. A program is also underway to identify and acquire improved visual guidance aids for use by the pilots.

While these improvements will satisfy the ASTC System requirements of the 1970s, even greater improvements will be needed to meet the more stringent requirements of the 1980s that will result from:

- Increasing flight operations and/or a larger percentage of widebody jets.
- Increased airport surface traffic flow rates under poor visibility conditions, which will be an outgrowth of the forthcoming installation of Category II and III landing systems at many airports.
- Increased peak-hour aircraft landing rates at major airports due to the forthcoming installation of wake vortex detection and avoidance systems and automated metering and spacing techniques.

In order to examine all aspects of Airport Surface Traffic Control and to develop preliminary system concepts, the Transportation Systems Center (TSC) awarded this Concept Formulation Study to Computer Sciences Corporation in October, 1973. The Final Report of this contract is composed of four volumes as follows:

Volume I	Executive Summary
Volume II	Operations Analysis of O'Hare Airport - Part I
Volume III	Operations Analysis of O'Hare Airport - Part II
Volume IV	Estimation of Requirements

The first phase of this program consisted of an extensive Operations Analysis effort at O'Hare Airport, the busiest commercial airport in the world. This airport was selected since it would be representative of most of the problems to be solved by an advanced ASTC System. The Operations Analysis effort included a system Evaluation Analysis (Task 3) to determine the potential benefits obtainable from an improved ASTC System. The results of this phase are set forth in Volumes II and III of this report; a summary of the major findings is provided in Section 2 of this Executive Summary (Volume I).

The second major phase of this contract was directed toward establishing the overall functional requirements for a semiautomated ASTC System designated as TAGS (Tower Automated Ground Surveillance) System. The TAGS acronym defines the family of possible ASTC systems wherein the controllers are provided synthetic computer-driven displays indicating at least aircraft position on the airport facilities based upon a surveillance Data Acquisition Subsystem (DAS). Digitally processed ASDE radar and cooperative trilateration techniques using the existing Air Traffic Control Radar Beacon (ATCRBS) transponders represent possible DAS alternatives. The TAGS system will provide the functional capabilities which are required for all control areas of the airport and as such may be considered as consisting of a Ground Control System (GCS), a Local Control System (LCS), and a Ramp Control System (RCS). While a particular TAGS System could include various combinations of these three elements, it is our understanding that the initial TAGS Engineering Model to be developed by TSC will be one wherein automation is applied to the various tasks of the Ground and Local Controllers with no development planned for the RCS. The results of the Requirements Estimation effort are set forth in Volume IV of this report; an overview of this effort is given in Sections 4 and 6 of this Executive Summary.

The third phase of this program was directed toward the development of a TAGS concept employing ATCRBS Trilateration Surveillance techniques for use in both the GCS and LCS areas. In addition, to explore what could be done to aid ramp traffic, a Ramp Control System concept based on improved data exchange with airline users and use of empirical data rather than surveillance inputs was also developed. The results of this phase are summarized in Sections 4, 5, and 7 of this Executive Summary. Back-up material for the summary have been provided TSC as a Working Paper.

Deployment of the proposed TAGS system at major airports has been studied by MITRE[1]. Since the basic findings of our operations analysis at O'Hare are in general agreement with MITRE's findings at O'Hare, the results of that deployment analysis have been included in Section 8 of this volume.

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[1] Federal Aviation Administration, Systems Research and Development Service, Airport Surface Traffic Control Systems Deployment Analysis-Expanded, FAA-RD-75-51, Washington, D.C., June 1975.

SECTION 2 - OPERATIONS ANALYSIS OF O'HARE AIRPORT

The goals of this phase of the study were to define the basic operations at O'Hare, collect quantitative data describing the operations, and to identify problem areas.

2.1 O'HARE FACILITIES

A map of O'Hare is shown in Figure 2-1. The runways are generally operated as independent North side and South side operations. For example, the most popular configuration is one with arrivals onto 27R and departures off 32R for the North side and arrivals onto 32L and departures off 27L for the South side. Local Control at O'Hare consists of two controllers with the division of responsibility being between the North and South sides.

On both the North or South sides there are a variety of runway configurations which can be operated. These configurations affect the strategies employed by Local Control and the capacity of the runways. At O'Hare the configurations include (1) a single runway operated for both arrivals and departures (mixed operations) and (2) crossing runways with one runway operated primarily for arrivals and the other operated primarily for departures. Crossing runways are further classified as to where and how they cross in Table 2-1.

Ground Control at O'Hare also consists of two controllers. However, unlike Local Control, there is no geographic separation of taxiing traffic. North side and South side traffic must both use the Inner and Outer taxiways. To avoid handoffs between two Ground Controllers, the division of responsibility is between arrivals and departures. Therefore, once an arrival is handed off from Local Control to Ground Control no added voice communication frequency changes are required of the pilot.

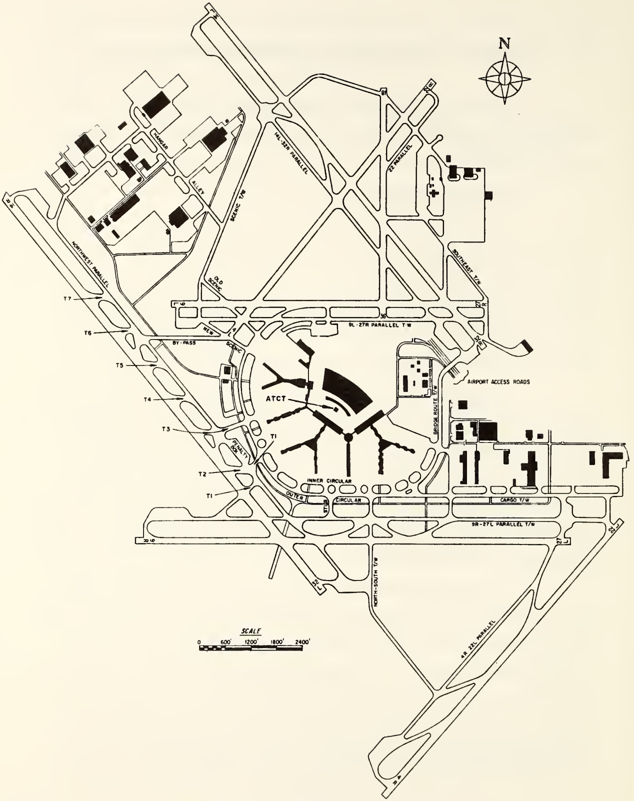


Figure 2-1. Current O'Hare Layout

The Ground Controller at O'Hare rarely controls traffic in the ramps. However, he is concerned with ramp traffic indirectly since ramp tie ups will affect traffic on the Inner and Outer taxiways. Such tie ups are not unusual at O'Hare due to the long narrow ramps between the concourses and the requirement for flow in only one direction at a time for large aircraft.

Table 2-1. Classification of Crossing Runway Configurations

Crossing Runway Configuration Classification	Arriving Aircraft Will Cross Departure Runway	Departing Aircraft Will Cross Arrival Runway	Examples (Arrival/Departure Runway)
Near-Near	While still in air or within 2000 ft from start of touchdown zone	Within 2000 ft from roll initiation	• 27R/32R • 9L/4L
Near-Far	Same as above	Roll to intersection > 2000 ft	• 32L/27L
Far-Far	Intersection beyond 2000 ft from start of touchdown zone <u>and</u> arrivals routinely cross departure runway prior to turn off	Same as above	• 14L/4L
Quasi-Independent	Arrivals routinely turn off prior to intersection <u>but</u> a missed approach initiated just prior to touchdown may pass over the departure runway	Not constrained	• 14R/27L • 14R/9R

2.2 FACILITIES UTILIZATION

The utilization of the taxiways depends upon the runways in operation. The utilization of the runways depends on the weather (winds and visibility conditions), demand (primary approach and departure directions), and noise abatement procedures. O'Hare operates in good weather (clear and calm) about 70 percent of the time. In these circumstances "dual approaches" are preferred. In the dual approach mode the approach headings are skewed toward each other and the departure headings are skewed away from each other (e.g., arrivals on 27R and 32L, departures on 32R and 27L).

In bad visibility O'Hare operates in a "parallel approach" mode; that is, approaches are made on parallel runways. An example of this operation is O'Hare's Category II configuration, single runway mixed operations on both 14R and 14L. Although O'Hare is rarely in Category II, the threat of extreme bad visibility generally brings the use of the 14s for arrivals, if not departures, in case the minimums should drop.

2.3 OPERATIONAL CHARACTERISTICS

The operational characteristics of O'Hare are summarized in Table 2-2. The Air Traffic Control Tower (ATCT) at O'Hare is centrally located providing excellent visibility. The O'Hare ASDE ground surveillance radar is located atop the ATCT. The basic radar has good coverage; however, the O'Hare ASDE BRITE display is about the poorest of all the ASDE BRITEs in use at the three airports which had ASDE BRITE displays at the time of the study and severely compromises ASDE use at O'Hare.

The airport has a quota of 135 operations/hour during the evening rush. All flights arriving or departing (including VFR) during that period must file to be assured of service. However, VFR "pop-ups" and delayed air carriers are handled when feasible and, therefore, the quota can be exceeded.

2.4 DATA COLLECTION EFFORT

Numerous data sources were used during the Operations Analysis effort. Daily traffic records maintained by the tower were reviewed. Data on aircraft movements within the ramp areas were collected by means of visual observations on over 350 aircraft. Extensive interviews were conducted with both controllers and pilots. The prime sources of quantitative data were ASDE film records and tape recordings of the various radio communication channels. From the ASDE film which presented at 2-second

Table 2-2. Significant Characteristics of O'Hare Airport

FACILITIES

6 Major Runways (2 CAT II) + 1 GA R/W

9 Ramp Areas (90 Gates) - Single Area

Area - 7700 acres (Landlocked)

Taxiways - 100,000 linear feet

Ramp Control Towers - UAL; AAL

Centrally located ATCT - 200' high with no significant blind spots

OPERATIONS

Quota - 135/hr at 1500-2000 hrs

Over 90 percent Air Carrier

Level - Yearly - >700,000 (1974)

Daily (0800-2100) Hourly Operations

	Winter	Summer
Average	120	135E
Peak	140	160E

ATC

5 Radio Positions - CD, IGC, OGC, LCN, LCS

ARTS III; ASDE

TCA Procedures/Group I

Flight Strips - Departures Only

Independent North-South Side Runway Operations intervals a picture of aircraft movements on the surface of O'Hare, a large amount of aircraft movement statistics were derived. The time spent by aircraft in the various phases of movement on the surface, as well as the duration and location of delays experienced by these aircraft, represents the raw inputs from which the aircraft flow analysis was made for the areas of responsibility handled by the Ground Controllers and the Local Controllers.

Major system variables which were studied included the influence of runway configuration on aircraft movements as well as the effect of weather on operations at O'Hare. Over 100 hours of data was collected and from these 14 one-hour runs were selected for detailed analysis. These runs included five wherein the visibility conditions were quite poor (one in Category II); the remaining nine were classified as good cab visibility although not necessarily VFR.

The ASDE films permitted the determination of hourly operation levels in terms of those arrivals and departures with respect to the pavement areas handled by the Ground Controllers and Local Controllers, respectively. Analysis of the utilization of the respective communication channels was performed and a detailed study made of the various categories of message types employed by the respective controllers. It should be noted that the delay analysis included only those time elements wherein an aircraft was forced to stop; since situations wherein slowdown or yield instructions given by the controller could not be observed from the ASDE film, these delays represent increases in the "service time" of aircraft which would not normally be experienced in a less dense environment.

2.5 MAJOR FINDINGS

The evaluation of the ASTC system can be made in terms of cost, fuel consumption, passenger inconvenience, and safety. The first three of these factors are directly relatable to delay. Table 2-3 gives the average hourly load on each control area and the delay in GOOD VISIBILITY CONDITIONS. It indicates that, although Ground Control is most heavily loaded, there is very little delay in the taxiways which is not attributable to ramp/gate limitations or runway limitations. In further examining this finding, consider the voice channel loading for Ground Control in Figure 2-2.

2.5.1 Ground Control

In Figure 2-2, average communication loading over an hour is plotted versus hourly ground operations. Analysis of each hour indicates that an hourly AVERAGE of 60 percent will guarantee (with 95 percent confidence) saturation of the channel (i.e., controller is talking continuously) for at least five minutes out of the hour. With a quota of 135 operations/hour split evenly between arrivals and departures it can be seen that it is rare for a Ground Controller to saturate in GOOD VISIBILITY. In fact, each controller is generally about 40 percent loaded. However, THIS CHANGES DRAMATICALLY AS CAB VISIBILITY BECOMES POOR even with ASDE in use. Target detection and identification on the O'Hare ASDE is poor and pilot position reports are heavily relied upon. Ground Control becomes a very busy position in bad weather and saturation of the voice channel is not unusual.

2.5.2 Local Control

Referring again to Table 2-3, the major delay contributor by far in GOOD VISIBILITY conditions is Local Control. To examine Local Control

Table 2-3. Summary of Overall Airport Findings

Average*Hourly Aircraft Load (density) - Based on 120 ops/hr (Busy Weekday Hours)

Ramp	4-5
Ground Control	7-16
Local Control	4-5
Total	15-26 (excluding LC Departure Q)

*Peak load can add 50 percent to average values shown. for short time intervals (five minutes) during the hour.

Average Delay - Good Visibility - 120 ops/hr

	Arrivals (seconds)	Departures (seconds)
Within Ramp Area	9	6
Penalty Box	36	0
Taxiways (Ramp Congestion)	20	0
Taxiways (Competing Traffic)	10	10
Runway Crossing	0	40
Departure Q and R/W "Holds"	0	396
Total		4.4 mins/ops

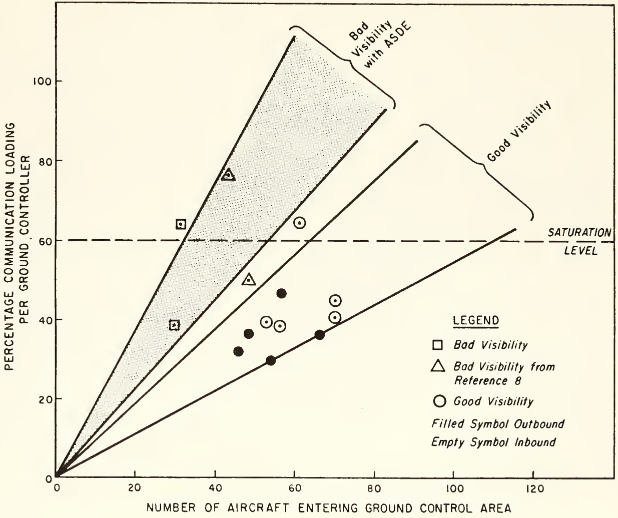


Figure 2-2. Ground Control Communication Saturation

communication loading consider Figure 2-3. The results are significantly different than for Ground Control. Even in poor visibility conditions it is rare for the Local Control channel to saturate. The number of aircraft under simultaneous control is lower than for Ground (see Table 2-3) and the operation is more regular with less peaking. The rationale for Local Control limitations lies elsewhere.

To explain the limitations of Local Control consider Figure 2-4, a time line plot of an ideal single mixed runway operation. IF all aircraft traveling on final approach were traveling at 120 knots and were spaced at 3 n. m. (i. e., 1.5 minutes) apart, IF all arrivals landed and departed the runway in 45 seconds, and IF all departures took 45 seconds from start of take off to lift off, then the runway could sustain a capacity of 80 operations (40 arrivals, 40 departures) an hour. However, THIS IS NOT THE CASE. Figure 2-5 shows a time line plot of an actual single mixed runway operation. The spaces between arrivals (inter-arrival separations) are irregular. The slopes of the arrival lines (arrival on times) and the departure lines (departure on times) are irregular. The release of departures is no longer automatic as in the ideal case. As each arrival sets down, Local Control must estimate the time-to-threshold for the next arrival and judge whether or not the current arrival will clear the runway soon enough to permit a departure before the next arrival reaches the threshold. With a dense arrival stream, the use of visual observation, and even with ARTS BRITE assistance, this is a difficult job.

Several problems demonstrate the demands of Local Control in such operations. Referring to Figure 2-5, departure 2 was released onto the runway to take off between arrivals 2 and 3. As it turned out, the inter-arrival space was too small and the departure was instructed to roll off the runway on a convenient taxiway. Shortly after departure 2 cleared the runway, arrival 3 came over the threshold. The departure should not have been cleared on. Inability to predict time-to-threshold was likely responsible for this undesirable situation.

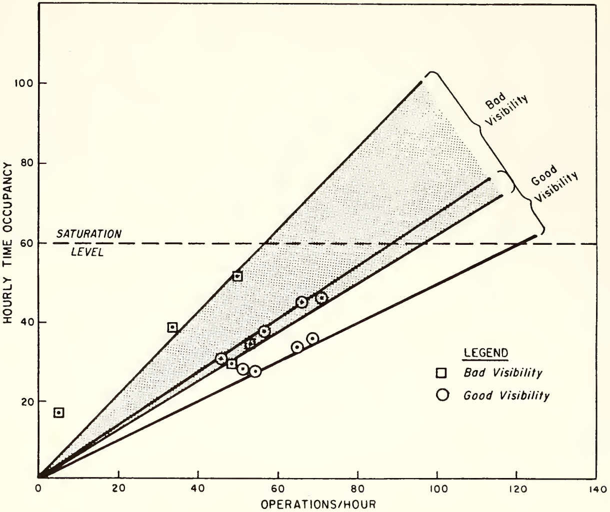


Figure 2-3. Local Control Communication Saturation

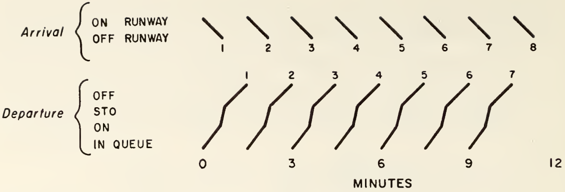


Figure 2-4. Time Line Plot of Ideal Single Runway Operation Saturated In Arrival and Departure Demand (80 Operations/Hour)

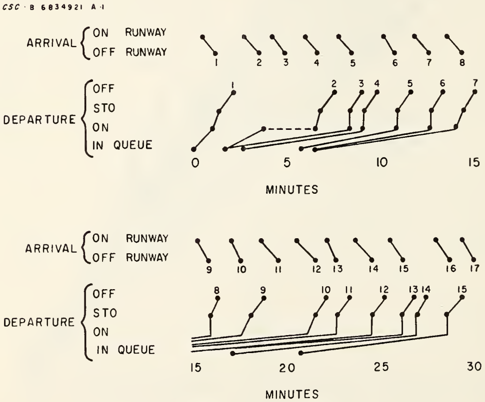


Figure 2-5. Time Line Plot of Actual Single Runway Operation Saturated In Arrival and Departure Demand in Good Visibility Conditions (64 Operations/Hour) (R/W - 27L)

The opposite condition occurs for departure 10. The space between arrivals 11 and 12 is adequate to permit a departure but departure 10 is held until the next slot. A departure release opportunity is missed reducing system capacity.

To assess the impact of missed departure release opportunities on the capacity of the runways, a set of release strategies were patterned after those used by Local Control for each runway configuration. Actual traffic statistics were then used to assess the ideal capacity of each configuration WERE THE STRATEGIES PERFECTLY EMPLOYED and to determine the actual capacities of the runways given the missed departure releases observed. The results are given in Table 2-4. The results indicate that, when the runways are (1) quasi-independent (arrivals cross the departure runway so rarely as to be non-existent) or (2) cross very near to the threshold and runup ends, ASTC equipments alone are expected to do little to improve these situations under good visibility conditions. These are clean configurations and are used over 50 percent of the time at O'Hare. However, the rest of the time O'Hare experiences a loss in departure capacity whose weighted average is six departures/hour. This represents nearly a 20 percent loss over the ideal. This loss is chiefly due to the controllers inability to predict the suitability of the short (60 to 90 seconds) inter-arrival spaces.

It should be pointed out that, to improve arrival capacity, Metering and Spacing will attempt to maximize the number of short inter-arrival spaces. Without assistance to Local Control, the impact of metering and spacing will be to constrict departures in favor of arrivals for the latter three runway configurations of Table 2-4.

In bad visibility the capacity loss gets worse due to lost visual information on the ground. The use of ASDE helps substantially but it does not cover the initial departure airspace and final approach airspace, and the ARTS coverage in these areas does not adequately replace the visual cues. The bad

Table 2-4. Actual Runway Capacities in Good Visibility Conditions Compared with Ideal Capacity

Runway Configuration	Hourly Departure Rate		Relative Usage Averaged Over All Weather Conditions (%)
	Actual	Ideal	
Near-Near Crossing	37	37	23
Quasi-Independent Crossing	36	36	29
Near-Far Crossing	31	36	20
Far-Far Crossing	27	35	18
Single Mixed	23	28	10

Note: Departure rates based on an arrival rate of 34 arrivals/hour

visibility operations were analyzed in a manner similar to that in good visibility. Operations with and without ASDE in operation were considered. Only the single mixed operation used in very poor visibility (14L and 14R) was analyzed. The results are given in Table 2-5. In performing the analysis a steady 34 arrivals/hour was assumed. The departures, therefore, represent estimated departures based upon the observed lost departure release opportunities for the short inter-arrival spaces. In practice, the arrival spacings can be widened to achieve a more balanced arrival/departure mix. The total operations, however, would likely remain as shown with a 30 percent loss without ASDE and a modest 13 percent loss (when compared with the 8 percent loss in good visibility) with ASDE.

Table 2-5. Effect of Bad Visibility on Single Runway Mixed Operations

		Ideal	Good Visibility	Bad Visibility With ASDE	Bad Visibility Without ASDE
Current Analysis	Arrivals	34	34	34	34
	Departures	28	23	20	9
	Total	62	57	54	43
	Percent of Ideal	-	92	87	69
Preliminary Analysis	Total	60	54	43	40
	Percent of Ideal	-	90	72	67

To summarize Local Control, departure capacity is lost for at least three runway configurations examined in good visibility. The average loss is six departures/hour representing almost a 20 percent loss. The loss is due to inadequate prediction of the suitability of each inter-arrival space for release of a departure. This loss is important in the face of substantial departure queue delays quoted in Table 2-3. In bad visibility conditions the capacity loss is worse, up to 30 percent without ASDE. The use of ASDE helps substantially in returning the capacity to within five percent of the good visibility operation.

2.5.3 Ramp Area

The significant findings within the ramp area are summarized in Table 2-6. With a mean turnaround time at the gate of approximately 45 minutes, the limited number of gates at O'Hare (approximately 90) can support 150 aircraft operations per hour, only slightly above the current quota. A significant difference exists between the service time of arrivals and departures within the ramp areas, with the latter being almost three times that of the former. Calculation of the average hourly density of a busy ramp area implies

Table 2-6. Ramp Area Findings (Sample - 350 A/C)

Gates	Mean Turnaround Time - 45 minutes Equivalent to capacity of 150 ops/hr
Service Time	75 seconds - Arrivals 200 seconds - Departures
Average Hourly Density	Q = 0.84 (22 ops/hr) - Single Area (implies "batch" operation)
Percent of A/C "Held"	8.5% - Arrivals 13.0% - Departures

that, in many cases, the departures must move on a "batch" or "platoon" basis because of the space limitations (single channel) within a given ramp area. At the operational levels observed of approximately 120 per hour, it was found that about 10 percent on the average of the ramp operations experienced delays within the ramp area. While the FAA has no formal responsibility for control within the ramp areas, the Clearance Delivery man and both of the Ground Controllers (Inbound and Outbound) do provide some advisory service and take into account the ramp area status in controlling aircraft in the taxiways. The excellent location of the tower provides almost 100 percent visual surveillance capability of all ramp areas; without the current location of the tower, ramp entry and exit under the current operational levels at O'Hare would be extremely hampered. As is seen in Table 2-3, activities within the ramp area impact on aircraft movements within the Ground Controllers area of responsibility. Aircraft which do not have gates available must be routed to the Penalty Box and arrival aircraft wishing to enter a particular ramp are often delayed due to departures in some part of the pushback process.

SECTION 3 - TAGS MOTIVATION

3.1 POTENTIAL PAYOFF AREAS

3.1.1 Cost of Delay

The impact of aircraft surface operations at a major terminal such as O'Hare may be expressed in terms of cost, fuel, passenger inconvenience, and safety. As part of the Operations Analysis effort, models were developed to translate the measured aircraft movement values and associated delays into yearly estimates of some of the above parameters. These parameters may be considered as areas of potential payoff achievable through improvements in Local Control's ability to detect departure release opportunities, reductions in Ground Control's voice channel loading (especially in bad visibility conditions), and developments in positive Ramp Control to permit efficient flow of ramp traffic.

Based upon the preliminary 1974 figures of slightly over 700,000 operations it is estimated that slightly over 100,000 hours are expended by active aircraft on the surface of O'Hare Airport excluding time spent at gates, hangar or cargo areas. Of this value about 40 percent represents delays in which aircraft were actually stopped and forced to wait for service. Time delays experienced by aircraft due to compliance with "yield" instructions or reductions in taxi speed by the pilot which could not be determined during data collection from the ASDE film are not included in the 40 percent. Therefore, potential delay savings may be obtained both from reduction in service times (i.e., the 60 percent) as well as from reduction of measureable delays. However, only measureable delay costs are considered in the following factors.

1. Operating Cost - While on the surface of O'Hare the aircraft (and associated crew) cost the airlines (and indirectly the paying public) an average of $11.23 per minute. This translates into an annual cost of delay of nearly 30 million dollars. Further, based upon an average aircraft utilization of 3000 hours per year, the delay represents an unavailability of about 14 aircraft to the air carriers.

2. Fuel - While on the surface of O'Hare the aircraft expend fuel at an average rate of 8.6 gallons per minute. This translates into over 20 million gallons of fuel used each year due to delays. This fuel would satisfy nearly 10 percent of the automobile gasoline needs of the District of Columbia or the State of Vermont.

3. Passenger Inconvenience - On the average, one minute of aircraft delay amounts to almost 1 man-hour of passenger delay. On a yearly basis, this translates into well over 2 million passenger man-hours spent delayed on the surface of O'Hare.

3.2 SYSTEM OBJECTIVES

General criteria for the TAGS System include: (1) to be as simple and low in cost as possible while addressing the basic objectives and (2) to be equally applicable to all airports requiring it, which could be quite a few. The basic system objectives fall into the three major areas of control as follows:

1. Local Control - To provide accurate and timely information to Local Control on the suitability of each inter-arrival space for a departure release. This assistance would offer benefits which could amount to a 20 percent increase in departure capacity for the more difficult to handle runway configurations with good visibility and a 30 percent increase for single mixed operations with bad cab visibility. Also, Local Control must be provided with positive assurance that the runway on which he is about to clear an operation is, in fact, clear of other vehicles. This latter requirement is critical to the basic safety of operation.

2. Ground Control - To provide the location and identity of each vehicle under control to Ground Control to reduce the excessive communications (work) load due to position reporting under bad visibility conditions. Table 3-1, the average content of voice communications for Ground Control, indicates that these position reports represent 85 percent of the increased channel loading experienced under bad cab visibility. The identity could also assist Ground Control in maintaining vehicle/identity correlation in good visibility.

3. Ramp Control - To provide a centralized system of ramp entry clearance to permit the most efficient use of those ramp areas which can only support one-way traffic flow. This implies operation in a batch or platoon mode (e.g., multiple "pushbacks" and taxiing aircraft within a ramp area).

The first two objectives are basically information presentation (surveillance) problems. In light of criteria (1), the initial TAGS concept will be surveillance only, without control automation. In addition, automation of control functions would make it much more difficult to maintain equipment commonality

Table 3-1. Contents of Arrival Ground Control Communications

Message Type	Average No. Per Operation	
	Good Visibility (86 Ops/Hr)	Bad Visibility (50 Ops/Hr)
Control Instructions	0.66	0.66
Sequence Instructions	0.20	0.14
Penalty Box/Holding Area Instructions and Advisories	0.04	0.00
Hold Instructions	0.22	0.41
Yield Instructions	0.23	0.11
Clearances to Pilots to Enter Ground Control System	✓ 0.78	0.60
Hold Instruction Combined With Clearance To Enter Ground Control System	0.04	0.06
Handoffs	0.01	0.05
Position Reports	✓ 0.08	1.56
Destination or Gate of Arrivals	✓ 0.50	0.63
Traffic Advisories	0.22	0.33
Taxi Requests to Move Aircraft Between Hangar and Terminal, Etc.	0.06	0.24
Gate Status Information	✓ 0.24	0.08
Communication Incidents	✓ 0.09	0.34
TOTALS	3.37	5.21

between airports. While the basic information needs at different airports may be the same, the control problems, especially for an automated Ground Control System, can be quite different.

The third problem is quite different from the first two. There is currently no centralized ramp control. The FAA is not responsible for the ramp area; there is no such control position. Staffing constraints and room in the cab make addition of a position undesirable. Such a system would have to be heavily automated and managed by the current complement of controllers, primarily Clearance Delivery. This automation would probably require the substantial tailoring of equipment to each airport. In addition, the participation of airline operations personnel would be required in the system and scheduling of pushbacks (a controversial item at best) would be involved.

3.3 TAGS CONCEPT OVERVIEW

The above considerations motivate the Tower Automated Ground Surveillance (TAGS) concept. TAGS is basically a surveillance system aimed at problems 1 and 2 above. Information retrieval, processing, formatting, and display are automated. Control functions remain in the hands of the controllers. It is a simple system (conceptually), addressing the basic problems and permitting inter-airport equipment commonality. In the remainder of the report TAGS is described in terms of subsystems covering its major areas; a Local Control System (LCS) and a Ground Control System (GCS). In addition, to provide an understanding of what could be offered in the ramps, a Ramp Control System (RCS) is also described. Because of the problems enumerated above, RCS is considered an option and is not intended as part of the initial TAGS development.

3.3.1 Ground Control System (GCS)

The average content of voice communications for Ground Control (arrival) is shown in Table 3-1 in good and bad visibility conditions. From this table the potential areas for channel loading reduction can be defined (as checked). As previously mentioned, the major area is position reports. A good synthetic display showing location and identity could nearly eliminate this category of message. It would also impact on the communication incidents (e. g., clarification communications associated with incorrect addressing of aircraft).

A second area is gate related. Arrival Ground currently receives gate assignments from the pilot by voice frequency at the time of taxi clearance request. In addition, gate availability--and, if unavailable, the hold required before it will be available--is transmitted at that time by the pilot. This is done in both good and bad visibility conditions. If TAGS could receive gate assignments and hold requirements directly from airline operations via a simple data entry device [Automatic Gate Status Equipment (AGSE)] and display this directly to Ground Control, then this category of communication could be substantially reduced--even in good visibility conditions. Furthermore, the current delay in contacting Ground Control while the pilot contacts his airline for the necessary information would be eliminated.

The last area is related to taxi clearance requests. Arrival Ground currently receives taxi requests from arrivals off the active runways. He must address the arrival at that time (which may be inconvenient) or tell the aircraft that he will get back to him (requiring an added communication). If TAGS could detect the arrival preparing to exit the runway and automatically cue Ground Control and provide him with the gate information, then Ground Control could address the aircraft at the best time for him and the initial call in communication load would be reduced. This procedure is currently used at O'Hare for departures with great success. Departures call in to Clearance Delivery (not Departure Ground) for taxi clearance, Clearance Delivery marks his location (i. e., gate) on the flight strip and posts the strip in the outbound strip board as a cue to Ground Control that taxi request has been made. No taxi request communication to Ground Control, therefore, is required.

3.3.2 Local Control System (LCS)

The information requirements of Local Control are most easily demonstrated by examining a runway in operation. Single mixed operation is used but the same basic information is required for all configurations. Table 3-2 illustrates the three major decisions for Local Control, the information required, the visibility conditions in which data acquisition problems occur, and the areas in which ASDE helps. In formulating the table it is assumed that time-to-threshold inferred from ARTS is not precise enough and that ARTS track initiation on departures is prohibitive with respect to time-since-takeoff and course. It is intended that TAGS provide direct, accurate and timely indication of all information in Table 3-2. As previously indicated, this will lead to improved capacity and increased safety of operation.

Table 3-2. Local Control Information Acquisition Problems

Critical Functions	Critical Information	Problems*	ASDE Aids
Clear the Subject Departure onto the Runway	Current arrival is down and braking	BV	x
	Time-to-threshold for next arrival	GV/BV	
	Time-since-takeoff for previous departure	BV	
	Course of previous departure relative to that intended for the subject departure	BV	
Clear the Subject Departure for Takeoff	Current arrival is in process of turning off	BV	x
	Subject departure is in position to take off	BV	x
	Time-since-takeoff for previous departure	BV	
	Course of previous departure relative to that intended for the subject departure	BV	
Clear the Next Arrival for Landing (or Direct a Missed Approach)	Time-to-threshold for next arrival	GV/BV	
	Subject departure has initiated takeoff	BV	x
	Time-to-lift off for subject departure	BV	x

*BV-During bad cab visibility conditions
GV-During good cab visibility conditions

SECTION 4 - OPERATIONAL DISPLAY CONCEPTS

4.1 INTRODUCTION

Preliminary display concepts have been developed for the three systems comprising TAGS, namely GCS, LCS, and RCS. The main features of these display concepts and their potential operational usage is summarized in this volume; additional backup material has been furnished to TSC in the third working paper of this study.

Synthetic digital displays are proposed for use in the cab. Each of the Ground and Local Controllers would have a separate display using a 16-inch CRT refreshed at a high rate (above 40 Hz). These displays would provide the controllers with a PPI-type picture of the airport facilities (runways, taxiways, etc.) as well as "list-type" information on aircraft for which the particular controller is responsible.

The GCS and LCS displays would represent taxiways by a single line and runways by lines representing the edges. This map representation would also include outlines of departure queue and Penalty Box areas as well as indications of ramp throat areas. This map representation would be at a lower brightness than that of the aircraft symbols and associated identification labels and leaders. A scale of approximately 1 in. = 1000 ft would be used for O'Hare.

Aircraft position with respect to this map would be indicated by a "V" symbol with the apex of the "V" representing the aircraft nose. Aircraft heading is represented by the axis of the "V". [Representation of the aircraft by an arrow (↑) was ruled out because of the possible confusion between its center line and the taxiway lines.] Two symbol sizes would be shown; "heavies" would be indicated by a 1/4 in. symbol (250 ft) while all other aircraft would be represented by a 1/8 in. (125 ft) "V". Aircraft symbols would be constrained to fall on taxiway lines or within runway edge lines except at certain areas of the map representation.

Associated with each aircraft symbol will be a single line flight identification label. While all aircraft will be displayed to each controller, flight identification will normally be presented only to the responsible controller. In special cases such as when long departure queues exist or for aircraft in the Penalty Box, the aircraft ID may be suppressed to prevent cluttering of the display with unnecessary data.

An indication of whether an aircraft is stopped or moving is needed on the display. While "blinking" of the "V" could be used, at this time it is proposed that a 3/16 in. line at the apex of the "V" be employed (i. e., $\underline{V}$) for this purpose. Symbol and/or ID "blinking" can be used more effectively for other purposes such as cueing the controller that a certain control function is necessary or that a crucial situation is in progress.

To illustrate the proposed display concepts, use has been made of an actual airfield situation at O'Hare as shown on the two aerial photos of Figures 4-1 and 4-2. These represent traffic somewhat below peak evening hours but are indicative of most of the various types of conflicts that arise as well as the control functions to be performed.

4.2 GROUND CONTROL SYSTEM

An example of the proposed Inbound Ground Controller's display, using the situation of Figure 4-1, is shown in Figure 4-3. Several situations are of interest here. Braniff 112 is shown as entering the ramp area C-D; UA262 is decelerating on the South runway and is expected to be making a right turn on the North-South taxiway. A potential taxiway/taxiway conflict may well exist in the near future between this aircraft and the large heavy departure which is about to turn on to the outer circular. The ramp exit conflict is apparent for the departure aircraft in the E-F ramp throat area. However, this is the responsibility of the Outbound rather than the Inbound Ground Controller.

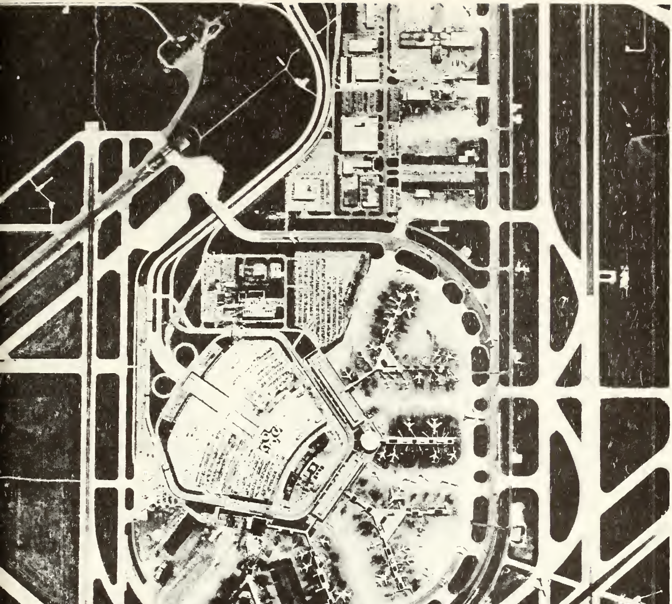


Figure 4-1. Aerial Photo - O'Hare 5/31/73

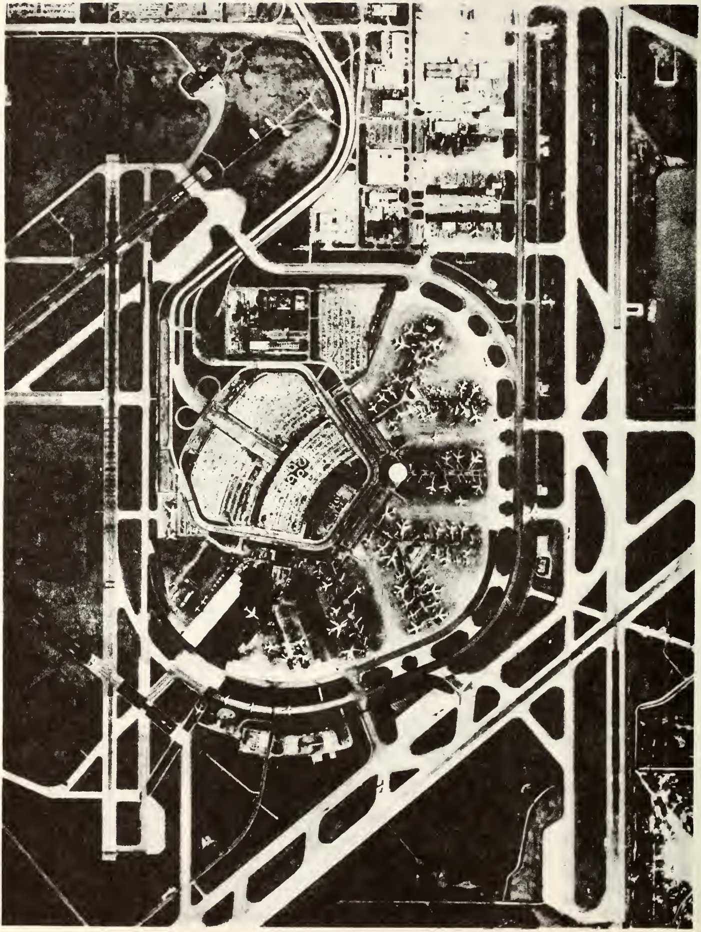
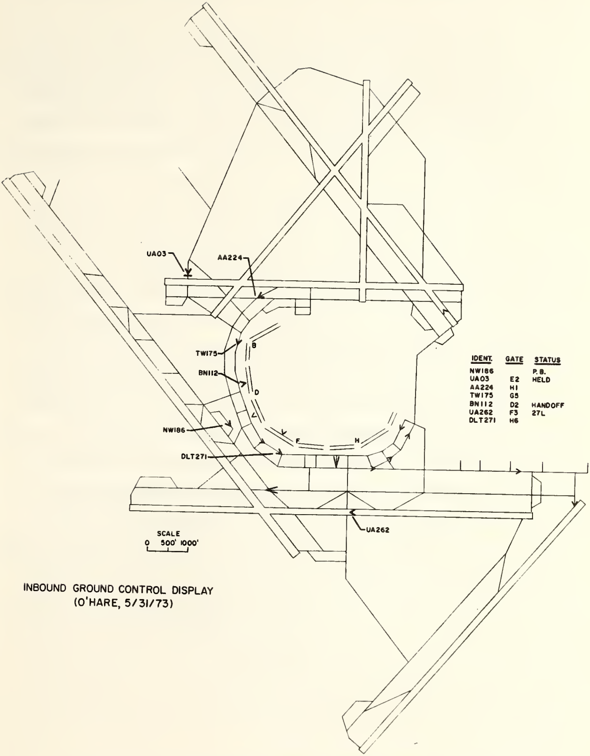


Figure 4-2. Aerial Photo – O'Hare 3/31/74



IDENT.	GATE	STATUS
NW186		P. B.
UA03	E2	HELD
AA224	H1	
TW175	G5	
BN112	D2	HANDOFF
UA262	F3	27L
DLT271	H6	

Figure 4-3. Inbound Ground Control Display (O'Hare 5/31/73)

Flight UA03 is shown "stopped" north of runway 9L/27R and "needs" permission to cross this runway which is now clear since arrival AA224 has recently turned off.

The list on the right shows the surface destination (gate) of the "arrival" aircraft as well as their status. If a gate hold is required, that fact and the minutes of hold required will show under status until the aircraft reaches the penalty box. In addition, the status column may be used to "cue" the controller i.e., to expect an automated taxi request from UA262; to handoff BN112 to the RCS; to clear UA03 across the runway, etc.

A typical scenario for a landing aircraft is as follows. The ID of the arrival aircraft appears on the Inbound Ground Controller's display as a tag and in the status list after its velocity has decreased to exit speed. Upon exiting the runway the appropriate line in the status list starts to blink to cue Ground Control that taxi clearance is required. Any gate delay will show up in the status list along with the runway the aircraft just left. The Ground Controller clears the aircraft to taxi and routes it via voice channel. Verbal acknowledgement of the clearance by the pilot confirms voice channel contact. As the aircraft proceeds away from the runway the blinking stops and the runway in the status list is dropped. Any gate hold is retained until a new cue is required (e.g. in the Penalty Box).

As the arrival aircraft nears the ramp area wherein the Inbound Ground Controller must now handoff the aircraft to the Ramp Control System, the controller will receive a cue from the display if a ramp entrance conflict exists. In this case coordination between the Inbound Ground Controller and Clearance Delivery will be necessary. In most cases the arrival aircraft will have to stop or be diverted in its route. If no ramp entrance conflict exists, the controller will handoff the aircraft to the Ramp Control System. At this time the Inbound Ground Controller will instruct the pilot to turn off his beacon. The track drop by the Surveillance Subsystem will effectively enter the aircraft into the Ramp Control System.

A departing aircraft demanding entrance into the taxiway system will be recognized by the Outbound Ground Controller by receipt of the flight strip as well as by the appearance of the aircraft identification and symbol on his display. This symbol will be generated from the Ramp Control System at time of handoff. Release of aircraft into the taxiway network will be predicated on an evaluation of potential ramp exit conflicts made by the controller using the GCS display. In the ramp exit conflict shown on the Inbound Ground Control example (at the E-F ramp), the Outbound Ground Controller would have available on his display an indication of the flight identification. Upon release of the aircraft into the taxi system the "V" would be seen moving across the ramp throat lines to verify aircraft entrance into the system.

An example of an upcoming taxiway/taxiway conflict is shown on this Inbound Ground Control display example. Here flight UA262 (an arrival) will be making a right turn onto the North-South and can be expected in the near future to conflict with the "heavy" departure currently on the link between the inner and outer. It is expected that this aircraft will make a left turn to generate a conflict at the intersection between the North-South and the Outer Circular.

Controller cueing of an aircraft approaching a runway crossing would be via the CRT display, possibly by the alphanumeric tag. Availability of the runway crossing would be predicated on an exchange of information from the Local Control System into the Data Processing Subsystem and then to the display to indicate the availability of the particular runway crossing. An example of runway crossing conflict is shown on the South Local Control display in Section 4.3--the aircraft going to runway 9L is stopped to await the turnoff of the arrival aircraft from runway 22R.

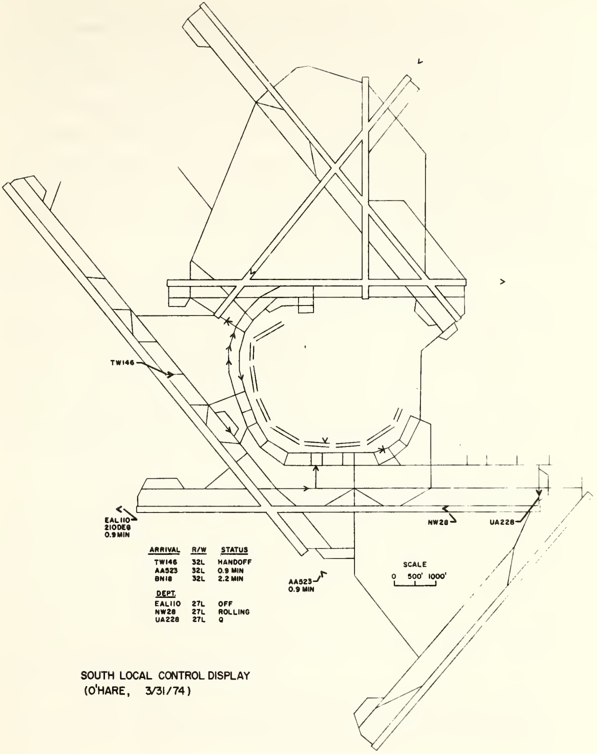
Handoff of the departure aircraft to the Local Controller could be cued to the Outbound Ground Controller when the surveillance system had shown (via the display) that the aircraft had passed the last intersection of importance.

Recognition by the computer that the aircraft had been handed off to Local Control may be based on such factors as the number of aircraft in the Local Control Departure Queue, i.e., recognition by the system that the departure aircraft has come to a stop upon entering the Local Control Departure Queue. If no departure queue exists, the departure aircraft will disappear from the Outbound Ground Controller's display upon reaching a specified point near the head of the departure queue pavement area.

4.3 LOCAL CONTROL SYSTEM

A possible display concept for the Local Controller is shown in Figure 4-4. This represents an example of how the South Local Control display would appear, based upon the situation in the aerial photograph for 3/31/74 (Figure 4-2). Additional airborne arrival and departure aircraft not shown on Figure 4-2 are included on this display example for illustrative purposes.

In the South area the activities on departure runway 27L show Flight Number UA228 in the departure queue area, Flight NW28 rolling toward takeoff on this runway, and Flight EAL110 (the previous departure) airborne for a period of time of 0.9 minute and at a heading of 210 degrees (inputs from TAGS DPS). This heading information would be used by the Local Controller for providing heading information to the next two departures. Arrivals on the intersecting runway 32L include TW146 which has just turned off and AA253 which is predicted to be 0.9 minute from threshold. The aircraft symbols and map representation are the same as those described for the Ground Control display concept.



ARRIVAL	R/W	STATUS
TW146	32L	HANDOFF
AA523	32L	0.9 MIN
BN18	32L	2.2 MIN
DEPT.		
EAL110	27L	OFF
NW28	27L	ROLLING
UA228	27L	Q

Figure 4-4. South Local Control Display (O'Hare 3/31/74)

Under most conditions the ID of the departure aircraft will appear on the Local Controller's display, if no Local Control Departure Queue is in existence, 400 feet or 500 feet before the turn to the runway. If, on the other hand, a queue exists, it is recommended that the display suppress the alphanumeric tag and only show the symbol of most aircraft in the Local Control Departure Queue. The aircraft at the head of this queue (possibly the first one or two), however, would have their alphanumeric tags displayed since these are the only aircraft which, in most cases, will be the concern of the controller. Pilot discipline is exercised in maintaining the order of aircraft within the departure queue.

As the arrival aircraft passes over the runway threshold, its symbol will move from the extension area to the actual runway and its status (as shown on the alphanumerical list) will be suitably modified. As the aircraft decelerates down the runway it will be tracked with its ID displayed so that the Local Controller can issue hand-off instructions on an anticipatory basis as necessary. It is expected that both the aircraft symbol and flight number will remain on the Local Controller's display until a positive indication that the runway is clear has been generated.

While almost all displays used in the ATC system rely on PPI-type indications of the area under surveillance, there are substantial questions whether this is the proper type of display to permit the Local Controller to adequately sequence his arrival and departure operations on the several runways under his jurisdiction. The Local Controller needs not only the status of aircraft on runways and their location on approach paths, but also prediction times that will given him "go/no-go" type of indications for the three major decisions he reaches i.e., clear to enter a runway, clear to take off, and clear to land. These predictive times can be added to the PPI-type display at the extensions of the runways or as separate alphanumeric lists. Both options are depicted in Figure 4-4.

A typical scenario for a set of runway operations would be as follows. Upon release of a departure (e.g. NW28), Local Control will monitor the potential conflicts between that departure and the next arrival; and the previous arrival and the next arrival. In this case, the previous arrival, TW146, is no problem having cleared the arrival runway but the next arrival, AA523, will pass behind the departure quite close being less than a minute from threshold. While performing the conflict monitoring, the next departure (e.g. UA228) will be cleared onto the runway and held. Once the previous departure has lifted off, the controller will monitor his course and the time-since-take-off until conditions indicate that acceptable inter-departure separation between the previous and the next departure will be assured. At that point, if an arrival has cleared the threshold and the next arrival is a safe time away (e.g., time-to-threshold 1.1 minutes), the next departure can be released.

4.4 RAMP CONTROL SYSTEM*

The RCS concept must handle conflicts within the various ramp areas requiring postive control and in addition provide interface capabilities with the Ground Control positions, especially that of Inbound Ground.

It is not envisioned that real-time surveillance of aircraft will be possible in the crowded ramp areas. The proposed display for the Clearance Delivery man, who will exercise ramp control, will be developed empirically on the basis of inputs from Automatic Gate Status Equipment (AGSE) to be operated by the airlines as well as from the Ground Control System.

The display is a logical, rather than actual, PPI-type presentation of the ramp area activities and demands.

Under RCS departures will request pushback via the airline terminal (Automatic Gate Status Equipment). The request will automatically be

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*Concept study only. The RCS will not be a part of the TAGS development.

serviced. If no conflict exists a pushback clearance message will be transmitted to the airline terminal. If a conflict does exist a hold message will be transmitted until no conflict exists. After pushback, engine start-up, etc., the pilot will call Clearance Delivery (as is current practice) to request taxi clearance. Clearance will enter the request into the RCS and receive an indication of whether the pilot should monitor Ground Control (if he has a clear path to the taxiways) or should stay with him. If the indicator is to monitor Ground, the pilot is so informed and the flight strip passed to Ground (as is current practice). If the indicator is to stay with Clearance, Clearance will so inform the pilot and monitor the RCS display until the monitor Ground Control indicator appears.

The proposed display for the RCS is shown in Figure 4-5 which is based upon the example shown in the aerial photo of Figure 4-1. In this figure, occupied gates are indicated by a circle. Gates with heavy aircraft will also have an "H" symbol next to the circle. Somewhat different aircraft symbols than those used in the GCS and LCS displays are shown on this figure; future efforts are expected to minimize these differences. Aircraft in pushback are shown by a cross (+) and the associated ID. The cross will be positioned slightly off the ramp center line to associate the aircraft with the gate from which it is departing. Upon handoff to Outbound Ground Controller (usually when the pilot has indicated he is ready-to-taxi) the aircraft symbol will be modified (Flight OZ94 and UA16, for example). Beacon turnon will take place at this time. Upon acquisition by the Surveillance Subsystem and movement past the ramp throat the symbol for the departing aircraft will be removed from the display.

Arrival aircraft will be entered into the RCS display upon handoff from the Inbound Ground Controller (crossing of ramp throat and beacon shutdown). They will remain on the display until a docking signal is received from the AGSE (or are "timed out") by the RCS data processor.

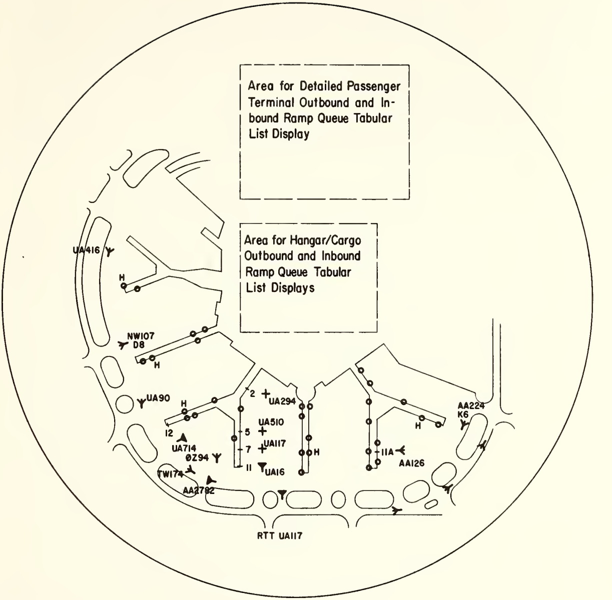

Figure 4-5. Possible Ramp Control Display Design Features

The RCS display also presents activities on the Inner and Outer in order to detect possible ramp entrance conflicts (a joint responsibility of both controllers). This conflict type may possibly be presented solely on a list basis rather than pictorially. In general it is expected that no communications will be necessary between the ramp controller and pilot of the incoming aircraft.

SECTION 5 - DESCRIPTION OF TAGS SYSTEM CONCEPT

5.1 GENERAL

The three major subsystems of the TAGS concept are the Data Acquisition Subsystem (DAS), the Data Processing Subsystem (DPS), and the Display and Data Entry Subsystem (DDES). These three functional subsystems will provide the capability for semiautomation of the various Ground and Local Control functions. Each subsystem will be designed to meet the requirement imposed by both the Ground Control System as well as the Local Control System.

Figure 5-1 illustrates the TAGS system concept which will be discussed in this section. This concept is based upon the use of an ATCRBS Trilateration Surveillance Subsystem as the DAS to provide extremely accurate position data and beacon code information on both surface aircraft as well as those a few miles from runway threshold. While a common Data Processing Subsystem is shown to make use of this information for both the Ground Control System and the Local Control System, separate Display and Data Entry Subsystems are shown for each of these two components of TAGS. (It should be recognized that all major terminals may not require both GCS and LCS.) The Ramp Control System which does not rely upon aircraft surveillance data except on an interface basis is shown separately in this figure. Automatic Gate Status Equipment (AGSE) elements operated by the several carriers are shown as the primary data acquisition source for the RCS.

The experience of ATC developers with the NAS and ARTS systems has no doubt played a major role with the initial concept of simply providing aircraft position and ID information on a display to the several controllers in the cab. This approach may be considered as a basic or minimum semiautomated capability to be used by the respective controllers. While this data may be sufficient for an airborne environment, surface traffic control imposes

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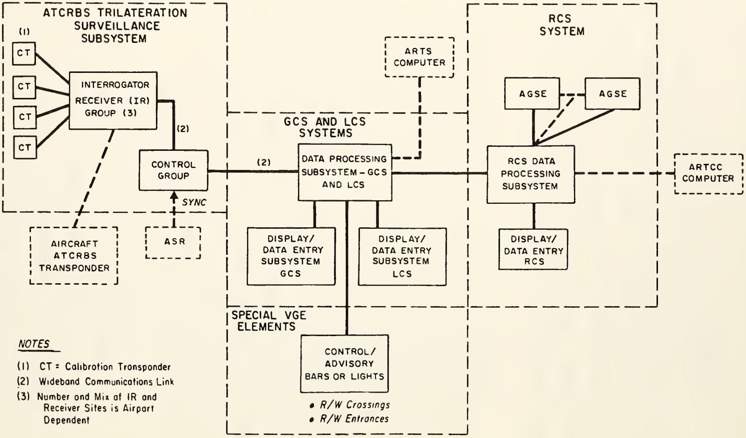


NOTES

(1) CT = Calibration Transponder

(2) Wideband Communications Link

(3) Number and Mix of IR and Receiver Sites is Airport Dependent

Figure 5-1. Overall ASTC System Concept

different control requirements. Additional data needed includes aircraft heading information and movement indication. The ability of the Ground Controller to detect conflicts, verify aircraft movements, and schedule his tasks using primarily a CRT display are some of the major areas of future simulation/study. The information needs of the Local Controller are appreciably different with emphasis on prediction estimation rather than present position data. Since this controller has responsibility for both surface as well as airspace areas, his data requirements are more complex; meeting these needs in a timely manner may require a somewhat different display format than that used in the GCS.

At some future time special VGE elements may well be added to the basic three subsystems involved in both the GCS and LCS. The configuration required by the ATCRBS Surveillance Subsystem will be airport-dependent; by this it is meant that the number of interrogator/receiver stations as well as receive-only stations will be a function of the area to be covered, propagation constraints generated by existing buildings and facilities, etc. Only a small amount of study has been directed toward the manner in which ATCRBS surveillance technique can be used for the LCS.

The displays to be employed will be of a synthetic digital nature with map representations of the surface as well as runway extension areas. These displays, in addition to being used for the identification of demand or control instructions, must be used to verify that these instructions have been complied with. These displays can also provide means for cueing the controller's attention on a priority basis to the various functions which he performs.

The proposed TAGS concept will require no modification of avionic equipment and will rely on existing pilot/controller voice communication. Pilot functions, as set forth in Table 5-1, will remain the same as currently used except that the need for information transfer between the pilots and controllers will be reduced due to the availability of position data, gate status information, and other flight information on the display.

Table 5-1. Pilot Functions

Maintain separation from preceding aircraft on same link or "highway".
Determine partial identity (aircraft equipment type and airline) of nearby aircraft.
Maintain aircraft speed below safe limits consistent with taxiway constraints and flight phase.
Navigate aircraft using VGE references and aircraft instruments.
Maintain lateral (centerline) control.
Select appropriate R/W turnoff.
Stop aircraft clear of intersections, obey runway crossing hold lines.
Provide controller with aircraft status data as needed i. e., Ready-to-Taxi, Position Report, etc.

An operational load in excess of 75 aircraft can readily be handled by TAGS. System response time from measurement to display presentation will be no more than three seconds for most parameters.

Implementation of the DAS for a particular airport will be highly influenced by the physical layout of the runways, taxiways, terminals, etc. At an airport such as Logan the DAS may require three or four interrogation or receiver sites, while at O'Hare a preliminary siting indicates that nine would be required. These sites would be connected to a control facility (probably located in the Tower), via either microwave or wideband cable facilities. The following paragraphs set forth the ATCRBS Trilateration Surveillance

Subsystem concept proposed as the mechanization for the DAS as well as concise descriptions of the two other subsystems comprising the TAGS system. Additional information on these subsystems has been furnished to TSC as a Working Paper under this contract.

5.2 ATCRBS TRILATERATION SURVEILLANCE SUBSYSTEM (GEOSCAN)

5.2.1 Introduction

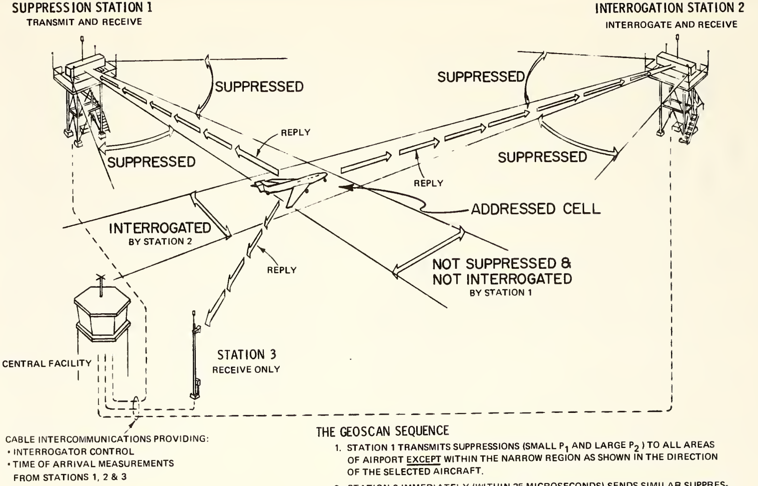
The GEOSCAN technique, to be described, is the proposed Surveillance Subsystem for use in both the Ground Control System (GCS) and Local Control System (LCS) portions of the overall ASTC program. As such it is the primary Data Acquisition System (DAS) employed, although it may interface with and make use of ARTS data. It should be noted that the ATCRBS Trilateration techniques employed in GEOSCAN differ (primarily in the method of interrogation control rather than in the position measurement process) from those set forth in FAA Report FA-RD-73-75 entitled "Feasibility Analysis of an Air Traffic Control Radar Beacon System (ATCRBS) Based Surface Trilateration Surveillance System". The GEOSCAN concept is currently in the developmental and feasibility demonstration phase and some modifications to its basic parameters can be expected. Moreover, since main emphasis has been on its employment for surface traffic control, additional concept development is needed to establish its modus operandi with airborne targets within several miles of the runway.

5.2.2 Overall Subsystem Concept

GEOSCAN is a highly accurate, two-dimensional, position measurement system employing multiple sites for control and measurement of ATCRBS transponder replies. The two major distinguishing characteristics of this technique are (1) the use of triangulation interrogation control so that only one transponder can be selected for reply during a given time slot, and (2) the use of inverse Loran or hyperbolic multilateration techniques to obtain position data. Under the current concept of GEOSCAN, measurement operations would be synchronized to the local secondary ASR signal and take place in a series of time slots (approximately 125 microseconds long) in the last 1500 microseconds of the 2500-microsecond nominal beacon period. Synchronization with the ASR is to minimize interference and is not a basic attribute of the proposed technique per se.

Figure 5-2 shows the minimum configuration that would be employed by a GEOSCAN installation. Stations 1 and 2 serve the interrogation control function and the line between them defines the interrogation baseline. These stations are under the control of a central facility which furnishes "cell assignment" (CA) messages to each station to control the interrogation process which takes place during the individual time slots. The initial transmission within a particular time slot is shown as emanating from the phased array antenna of Station 1 and consists of a P_1' and P_2' code to suppress the transponders of all aircraft except those in the particular angular direction designated by the central facility. Once suppressed, the transponders remain suppressed for a period of time equal to 35 ±10 microseconds. Approximately 17 to 20 microseconds later, Station 2 sends out a complete interrogation code which, because of the angle directivity employed in the P_2 signal generated by the phased array antenna, will result in a correct interrogating signal being received only by an aircraft at the intersection of the two beams. The beams from Station 1 and Station 2, therefore, effectively define a reply "cell" or geographic area from which a transponder reply is anticipated.

The transponder reply is received at Stations 1, 2, and 3, and a time measurement is made, with respect to a local clock, of the leading edge of the first pulse of the Mode 3/A received signal. Transmission of these three time-of-arrival (TOA) measurements to a single site permits two time difference measurements to be computed from which the X-Y coordinates of the aircraft's beacon antenna can be determined to a high degree of accuracy.



THE GEOSCAN SEQUENCE

1. STATION 1 TRANSMITS SUPPRESSIONS (SMALL P_1 AND LARGE P_2) TO ALL AREAS OF AIRPORT EXCEPT WITHIN THE NARROW REGION AS SHOWN IN THE DIRECTION OF THE SELECTED AIRCRAFT.
2. STATION 2 IMMEDIATELY (WITHIN 25 MICROSECONDS) SENDS SIMILAR SUPPRESSION PATTERN WITH THE ADDITION OF P_3 TO FORM A COMPLETE INTERROGATION (LARGE P_1, SMALL P_2 AND LARGE P_3) IN THE DIRECTION OF THE SELECTED AIRCRAFT THUS CAUSING THAT AIRCRAFT (AND ONLY THAT AIRCRAFT) TO REPLY.
3. THE TIME DIFFERENTIALS OF THE THREE REPLY PATHS (HENCE RANGE DIFFERENTIALS) MATHEMATICALLY DEFINE THE PRECISE POSITION OF THE RESPONDING AIRCRAFT.

Figure 5-2. Basic System Interrogation and Trilateration Methodology

During the receiving mode the transponder ID is also decoded at each received station and transmitted to the central facility.

To provide for interrogation control, both the suppression signal as well as the interrogation signal are generated via phased array antennas using sum and difference monopulse techniques. The sequence of suppression and interrogation code signals received by aircraft in different locations with respect to the two interrogators is shown in Figure 5-3. Only those aircraft lying in the direction indicated by the arrow B and receiving a P_2' signal 9 dB less than the P_1' signal are 90 percent certain of being unsuppressed. In a similar manner the complete interrogation signal sent by Interrogator II will suppress those aircraft lying in the beam indicated by the arrow B, except at the intersection of the two beams in the "cell" area (designated by the letter C). The characteristics of the geographic cell formed by these two beams and the relative powers in the first two pulses of the suppression and interrogation codes will determine the resolution capabilities of the GEOSCAN system.

5.2.3 Operational Characteristics

5.2.3.1 Coverage Area

While it is desirable to have the maximum coverage area from a given triad of stations, there are several limiting constraints. Figure 5-4 shows the two signals (suppression and interrogation) as they would be received by an aircraft a distance D_I and D_{II} from the two interrogation control stations. The interval of time, ΔT, between P_2' and P_1 should satisfy two criteria which will determine the maximum interrogator baseline which can be employed. The first is that ΔT should be less than the smallest suppression interval (specified as 25 microseconds). In addition, ΔT should be sufficiently greater than 8 microseconds so that P_2' and P_1 cannot possibly be recognized as a valid but false P_1-P_3 pair. To meet the latter criteria a delay is inserted at the station sending out the complete interrogator code word. As shown by Bendix these criteria limit the interrogation baseline to approximately 9170 ft.

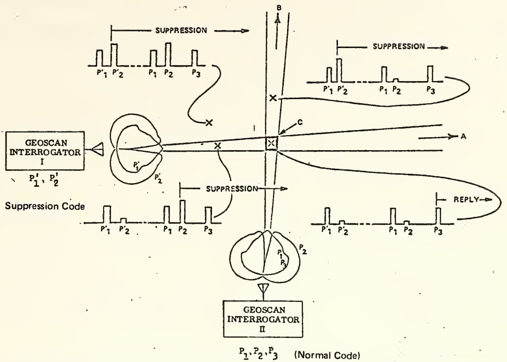
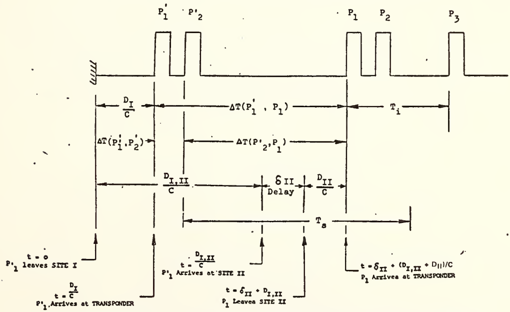


Figure 5-3. Simplified Diagram of the Reply Zone Developed by Intersecting Paths from a Pair of Monopulse Interrogators



Note: Transponder is suppressed if P_1 arrives before T_S has Elapsed. Transponder replies if unsuppressed and $\Delta T\ (P_2', P_1) = T + E$

Figure 5-4. Pulse Arrival Time Sequence at Location of Interrogated Transponder

Figure 5-5 shows an ideal triad of three stations with contour lines generated by the baseline A-B for constant beam intersection angles of 60, 90 and 120 degrees (60 and 120 are equivalent). It is desirable that the cell be as near rectangular as possible and, therefore, the preferred location to be controlled by the interrogators A and B is the shaded area labeled A-B and lying within the triad. If C is also an interrogator site, then the additional baselines of A-C and B-C may be used to control the reply cell in the similar areas along the perpendicular to the other interrogation baselines. It should be noted that in this triad the electrial boresight of the phased array antennas bisects the angle between baselines and, therefore, must scan slightly over ±30 degrees from the aperture direction in order to cover the area within the triad. If the assignment method described above is employed for selection of interrogator baselines, a particular phased array antenna when used with a given baseline would need to scan only one half of this angle.

While the criteria of maintaining the intersection angles ±30 degrees from that of a right angle can be met external to the triad as shown on the figure, it will be seen later that the position measurement accuracy becomes appreciably poorer external to the triad because of geometric dilution effects. For some installations some slight modification of the boresight angle may be desirable. This might include the case where some coverage is needed external to the triad.

5.2.3.2 Resolution

Since only one position measurement can be made during an individual time slot it is essential that only one transponder reply during this interval. The resolution capabilities of the GEOSCAN system are primarily determined by the interrogation control mechanism and specifically the antenna characteristics and relative power control of the $P_1P_2P_3$ pulses. The transponder suppression/nonsuppression specifications as shown in Figure 5-6 represent a starting point from which the system resolution can be determined. The

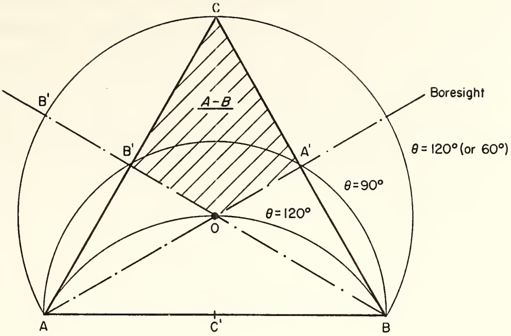


Figure 5-5. Intersection Angles of Interrogation Beams in an Ideal Triad

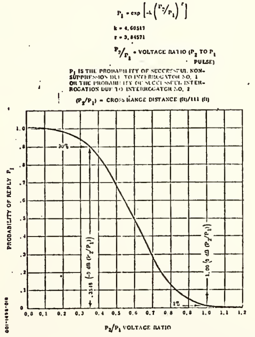


Figure 5-6. Transponder Valid Suppression Decode Probability

one percent and 90 percent points are taken from the National Beacon Transponder specification. At this time the estimated system resolution requirements have been taken in such a manner as to establish a cell dimension of between 220 and 225 feet on a side at the one percent reply probability point shown on the figure. The other significant cell dimension is that area wherein the probability of nonsuppression is specified as 90 percent; with the probability model shown in the figure this is equivalent to approximately one third, or 75 feet, of the cell size defined at the one percent level. Figure 5-7 illustrates the cell dimensions and the reply probability contours for an intersection angle of 90 degrees.

It is the goal of the GEOSCAN system to maintain as near a constant cell size as possible throughout the coverage area. To do this it will be necessary to adjust the beamwidth of the phased array antennas as a function of the cell location with respect to the particular interrogator site involved. Figure 5-8 shows the angular relationships between the P_2 and P_1 patterns as determined by the estimated transponder side lobe suppression performance. When the aircraft (or cell) lies between approximately 6000 feet and 9000 feet from the interrogator site, the angle values required to meet the cell dimensions are shown in Figure 5-9. For ranges below 6080 feet larger beam widths would be employed, for example, to keep the area of nonsuppression between 50 feet and 75 feet.

Figure 5-10 shows the estimated GEOSCAN resolution capabilities for various beam crossing angles based upon the selected cell size of 225 feet previously mentioned. For an average probability of a successful round equal to 0.9, with the desired transponder at the center of the cell, the required separation (resolution) of the interfering transponder is slightly over 100 feet for intersection angles ±30 degrees from the perpendicular. Employment of interrogation sites at each apex of the triad can prevent poorer intersection angles (and decreased resolution).

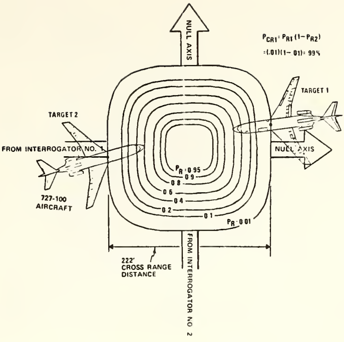


Figure 5-7. GEOSCAN Cell Coverage of Two Aircraft

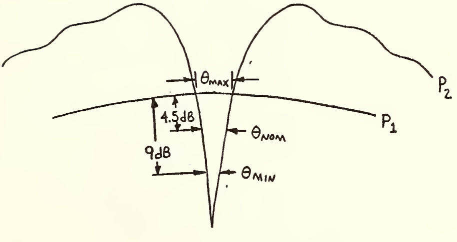


Figure 5-8. Angular Relationships Between the P_2 Null and P_1 Patterns As Determined by Transponder SLS Performance

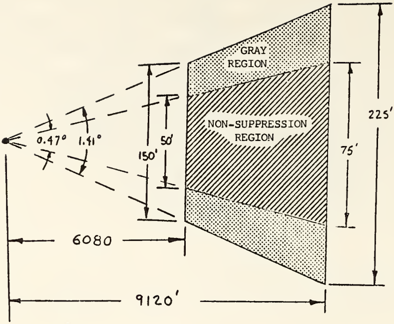


Figure 5-9. Details of Maximum Range Nonsuppression Track Segment for the Brassboard DAS

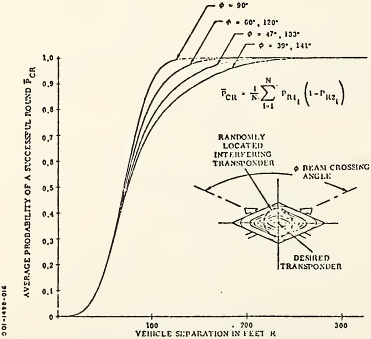


Figure 5-10. Interrogator Resolution

Current system design calls for antenna orientation (or quantizing) steps of 0.25 degree. This is equivalent to approximately 38 feet at the maximum range of 9200 feet or one half of the cell size at the 90 percent probability point.

5.2.3.3 Measurement Accuracy

Estimates of the overall position measurement accuracy based upon the hyperbolic trilateration measurement are shown in Figure 5-11 for an ideal two-mile baseline triad system. Airport siting constraints are expected to modify the triad somewhat but it has been shown that major changes in system accuracy will not result as long as the aircraft is within the triad boundaries.

Correct detection probability of the received Mode 3/A beacon codes has not been adequately established as yet. However, the use of a priori data as well as the availability of three separate received ID signals should permit proper correlation in most instances.

It should be pointed out that employment of triangulation for interrogation control essentially provides an indication of aircraft position as long as any reply is received from the specified cell area. The equivalent system accuracy based solely upon the triangulation aspect may be estimated by noting that the cell size at the 90 percent point corresponds to about 75 feet. This is equivalent approximately to a 1-sigma position error of less than 20 feet based solely upon cell dimensions and probability of a correct reply.

5.2.3.4 Target Handling Capabilities

Since GEOSCAN is a time-ordered system, a finite number of time slots are available. Time slot durations ranging from 80 microseconds to 125 microseconds have been proposed. Using the higher value, a minimum of 12 time slots are available per beacon period or 4800 per second when the ASR PRF is 400. Interference considerations make it highly desirable to minimize the number of time slots employed. The data rate for a particular aircraft is

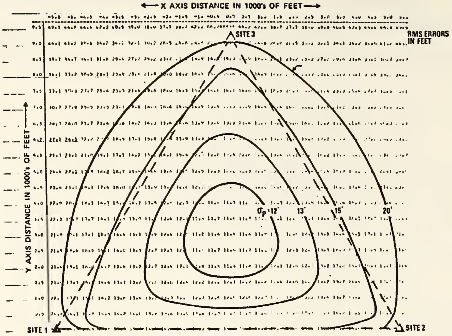


Figure 5-11. Single Triad Accuracy Contours for Two-Mile Baseline Trilateration System

not expected to exceed 10 per second. Since system requirements for GCS and LCS indicate a peak aircraft load of about 50 planes, only 500 slots would be necessary to handle this tracking load. Search and acquisition requirements and reinterrogations are not expected to change this value appreicably. The target handling capability may be stated as in excess of 100 aircraft and will be interference-limited rather than saturated by aircraft.

5.2.3.5 Sequence of Operations

Interrogation control of the GEOSCAN antenna beams requires that a "cell assignment" (CA) message be transmitted to the two selected interrogators from the central or control site. This cell assignment message for each interrogator will include

1. Coordinates of selected cell - p, Θ
2. Cell size to be used

3. Master (suppression) or slave command
4. Time slot ID number
5. Aircraft beacon code - to assist in ID processing of the received signal.

This CA instruction must be available at each site prior to the initiation of the particular time slot. The generation of this cell assignment message is performed at the central site based on the coordinates of the selected cell with respect to the available interrogation sites (baselines). In many cases either one of the two selected interrogators may be the "slave" without influencing system performance.

Following transmission of the two interrogation control codes (suppression and interrogation) from the selected sites, at least three receivers must properly detect the transponder reply. To assist in this effort the receivers, which use separate detection circuits for TOA measurement and beacon code determination, should be range gated. The receivers, therefore, will also require a priori knowledge of the selected cell, i.e., a CA message will be furnished to each receiver. The duration of this window for the TOA message will be consistent with the designated cell size; minimum window values of around 100 ns are expected. Detection of the beacon code return will be improved by comparison with the stored value of the expected code where applicable.

The TOA and beacon code determined at each receiver is then transmitted to the central site where position determination, based upon the three time differentials (TOA_1-TOA_2, etc.), is made if satisfactory correlation exists between the three associated beacon code signals. If this is not possible it will be necessary to generate a new cell assignment message for this aircraft (i.e., reinterrogate) as quickly as possible.

This ID/position information is then added to the aircraft track file (ATF). Continuous processing of this ATF is performed at the central

GEOSCAN site in order to maintain track of each aircraft. This processing will include position smoothing and velocity estimation so that an estimate can be made of the time slot and cell coordinates to be used in the next interrogation of this aircraft. This process can be materially assisted if map information is available to the GEOSCAN computer so that the constraints imposed by the surface pavement are included in the smoothing and velocity estimates.

The individual position measurements, i.e., the ATF data, are made available to the central ASTC data processor since the algorithms used in the latter may be different from those imposed solely by the requirement for track maintenance.

5.3 DATA PROCESSING SUBSYSTEM

A common Data Processing Subsystem (DPS) will be used for the GCS and LCS. This DPS will interface with the ARTS III computer as well as with the small processor used for the Ramp Control System where an RCS exists. A small separate computer will be used for control of the LCS and GCS displays. Large minicomputers should be capable of handling the estimated load. Reliability needs may result in an addition of CPU to those set forth above.

While control of the tracking function will be primarily performed within the ATCRBS Trilateration Subsystem, the DPS will also provide command inputs to this system. These may be either in response to keyboard entries or automatically generated.

An aircraft track file (ATF) will be maintained by the DPS. Special algorithms will be required for movement detection, turn recognition, and heading vector orientation. Control of A/N tags will be more complex than in ARTS because of the constraints imposed by the runway/taxiway map. This may limit the alphanumeric tags to a single line of about 8 characters.

Entry of arrival aircraft into the LCS system will be based upon information exchange with the ARTS data processor. Surface aircraft entering the TAGS system will be handled semiautomatically; this process will be aided by an RCS when positive ramp control is employed.

Predictive capabilities will be provided in the software. These are of significant importance for the Local Controller's functions. At a later date similar capabilities may be provided in the GCS software to assist in the conflict recognition process.

5.4 DISPLAY AND DATA ENTRY SUBSYSTEM

Synthetic digital displays will be employed in both the LCS and GCS systems. These will be a maximum of 16 inches in diameter and show aircraft against a synthetic map of the airport. Aircraft symbols will depict both position as well as heading with the latter parameter based upon aircraft movement rather than fuselage orientation. Alphanumeric tags will be associated with each aircraft under control, but only those associated with a particular control position will be presented on the associated display. Separate displays will be provided for each of the Ground and Local Control positions. The map/aircraft representation will be supplemented by aircraft lists dynamically controlled by the DPS. These lists will indicate aircraft destination and special status information as well as flight number. It is expected that cueing indications to the controller may be furnished either from these lists or from the aircraft symbols.

The symbology employed will also provide the controller with a means of recognizing "stopped" aircraft. Coding of "heavies" by symbol size may also be employed.

Experiments are currently being performed at TSC to evaluate alternate display symbologies and the man/machine interface capabilities which are appreciably different from those of airborne control.

SECTION 6 - ESTIMATION OF REQUIREMENTS

6.1 INTRODUCTION

Functional, operational, and performance requirements represent the three categories which have been examined as part of this concept development process. The orientation of this requirements estimation process has been directed toward a system concept wherein visual surveillance is replaced by a TAGS concept.

While the functional requirements define the tasks which the system is to accomplish, the performance requirements represent an estimate of the desired capabilities of the various system components on a quantitative basis. The operational requirements, on the other hand, define the system load and the environment within which the system must work.

In developing these requirements, the information flow between the major components of the ASTC system, as illustrated in Figure 6-1, was carefully examined. This examination was performed for a variety of mission profiles or scenarios comprising aircraft movement profiles, and the associated controller functions in the different areas of control, i. e., ramp, ground and local. A comprehensive understanding of cab operations at O'Hare Airport (the busiest commercial airport in the world) was derived from an extensive series of observations as well as study of the communication tapes. From these data sources plus interviews with controllers and pilots, controller functions for departure and arrival aircraft as they followed the various steps in their individual scenarios were developed. Each controller function was examined in order to ascertain the information required by the controller in order to perform his task. Consideration was given to system response time based upon the inherent semiautomated nature of the system concept and the reliance on voice communications between the pilot and controller. A summary of these parameters is presented below.

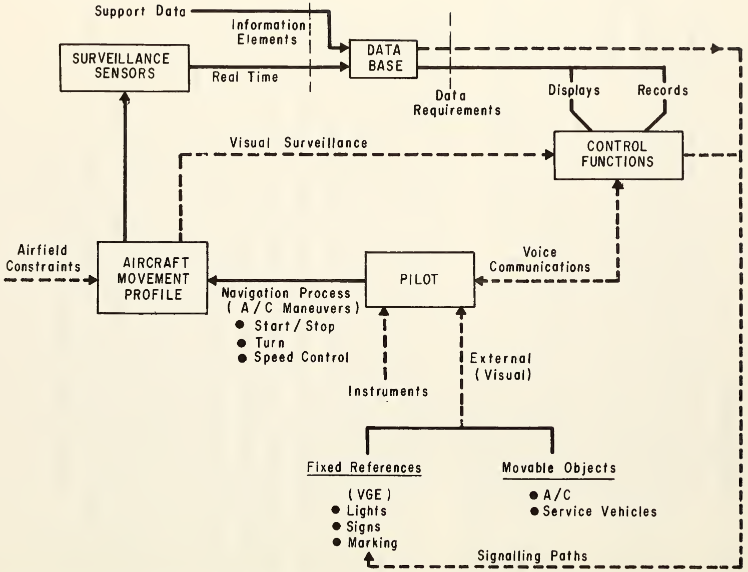


Figure 6-1. Information Flow Between Major Components of Airport Surface Traffic Control System

6.2 GROUND CONTROL SYSTEM

The major qualitative findings in the Ground Control area are summarized below:

1. Most conflicts are deterministic in nature; only the taxiway/taxiway conflict can occur at any time.
2. The Controller needs information as to whether an aircraft is stopped or moving.
3. Velocity information is not essential on the displays since, in general, variations in taxi speed are small.
4. Conflict prediction requires an estimation of the situation as it would be 15 to 30 seconds in the future.
5. Route information is essential to performing the conflict detection process.
6. Aircraft heading information is needed for turn recognition as well as travel direction on the individual links.
7. The large number of aircraft simultaneously under control may make it desirable to suppress, insofar as the display is concerned, the alphanumeric tag for aircraft within Penalty Box areas or in long departure queues.
8. Means for verification that control instructions have been compiled with is highly desirable; the movement indicator symbol can materially assist in this area.
9. Adequate control requires information exchange between the GCS and both the RCS and LCS systems.

The operational requirements for the GCS indicate that the system should handle on a simultaneous basis 30 to 40 aircraft. This excludes aircraft awaiting entry into the taxi system or in the Local Control Departure Queue area and is based upon an operations level of about 200 per hour to accommodate possible future growth.

6.3 LOCAL CONTROL SYSTEM

The major findings in this area insofar as the functional requirements are concerned are:

1. The addition of predictive information for decision-making purposes even during periods of good visibility is critical.
2. Runway configurations play a major factor in Local Control operations.
3. Significant variations occur in runway occupancy time for arrival aircraft.
4. Controller decisions require prediction of aircraft future locations 60 to 100 seconds in the future.
5. Both airborne and ground surveillance data are required.

Exclusive of aircraft in the departure queue the Local Control system at O'Hare (for the two Local Controllers) should be sized to handle approximately 20 aircraft simultaneously under control. This includes airborne arrivals and departures as well as active aircraft on the runways. Such loads are expected to be rare, and perhaps only observable if separation values are reduced somewhat from the present value of 3 n. m.

6.4 SUMMARY OF PERFORMANCE REQUIREMENTS

Table 6-1 presents the estimated performance requirements for the Ground Control System and Local Control System. The Ramp Control System is not addressed since it will not be a part of the TAGS development. In addition, the surveillance requirements have been broken up into those required for airborne aircraft and for ground or surface aircraft.

Table 6-1. Summary of Performance Requirements

Performance Required	Ground*		Airborne
	GCS	LCS	GCS/LCS
Resolution-ft	150	150	1000
Position Accuracy (1σ)-ft	20-30	20-30	150
Velocity Accuracy (1σ)-fps	3	3	8
Acceleration Accuracy-fps^2	N/A	1.5-2	N/A
Response Time-seconds	2-3	1-2	1-2
Directional	±20°	±5-10°	±15°

*Excluding Ramp Areas, Penalty Box, and LC Departure Queues.

The coverage area of the Ground Control System would extend to airborne arrivals within 2.5 nm of the threshold in order to provide the necessary input data to the Ground Controller for the runway crossing control function. The Local Control System appears to require data on aircraft as far out as 5 nm; this will be sensitive to the runway configuration employed. Mixed operations on a single runway are the pacing factor in this area.

While resolution requirements of 150 feet are needed for surface aircraft, 1000 feet should be sufficient for airborne aircraft.

The positional accuracy shown on this table represents those required for conflict prediction and data processing purposes rather than the accuracy to which an aircraft position would be shown on a display. Similar comments hold for the velocity accuracy values. The need for the indicated velocity accuracy on surface aircraft is dictated by the necessity to detect in a timely manner whether an aircraft is moving or stopped. For example, it is vital for the Local Controller to know that an aircraft which has been cleared to takeoff or cross a runway is responding to the command. It should be noted that the velocity requirement is not consistent with the position accuracy requirement when the velocity is estimated from position data with a data rate of 1 sample per 3 seconds (i.e. the response time). In this case the data rate requirement on position is 10 samples per second. The GEOSCAN system is capable of supplying such rates (see Section 5.2.3.4).

Acceleration requirements are solely due to aircraft arriving or departing a runway; this data element would be used for predicting the availability of runway crossings or for recognizing imminent takeoff under poor visibility conditions.

The response time (i.e., the maximum information delay permitted at the stated accuracies) is somewhat more severe in the Local Control System than in the Ground Control System. These relatively low values have been influenced by the fact that the surveillance system should not place a burden on the control process employed, or in the prediction accuracies for the time intervals over which the prediction must be made.

Directional data is needed for a variety of reasons. Turn recognition at runway turnoffs, at taxiway intersections, and at runway entrances is often used by the Controllers on an anticipatory basis or for confirmation purposes. The directional requirements shown under the airborne LCS column is for departure aircraft and should not be construed as representing a recommendation required by the need for conducting parallel approaches of arrival aircraft. The lateral separation assurance function for closed spaced parallel approaches is not part of the ASTC system.

SECTION 7 - PRELIMINARY COST ESTIMATES FOR O'HARE

The costs summarized in Table 7-1 are based upon a simplified Ramp Control System consisting only of airline/cab information exchange and not positive ramp control. In addition, the Ground Control System and Local Control System are assumed to be developed as one unit. It is our understanding that this configuration is that currently planned for initial development by TSC.

The costs are for a prototype engineering model which includes development and one-time costs and for production units in quantities of approximately 10. The ATCRBS Trilateration Surveillance Subsystem production costs were estimated by Bendix Corporation. These include the cost of nine microwave links with associated high speed data modems, estimated to cost $16, 000 to $18, 000 per link. While the Bendix estimate of $335, 000 has been used for the production cost of an O'Hare system, CSC believes this value may be low.

Prototype development costs were not formally estimated by Bendix; based on verbal discussions between CSC and Bendix this cost element has been roughly estimated at one million dollars.

The costs are itemized for the subsystems as depicted in Figure 5-1 and summarized in Table 7-1. The system layout is for O'Hare. Data Processing software developmental costs were estimated on a man-month basis using $4, 000/ man-month. Backup material for this estimate is in the third Working Paper.

As seen in Table 7-1, total production costs for the unit are estimated at about $800,000. These costs are FOB at the contractors site. They do not include shipping to the sites, site preparation, installation engineering, installation checkout and certification procedures. These costs are expected to increase unit costs to approximately $1,400,000.

Table 7-1. TAGS Cost Summary at O'Hare

	Prototype (Thousands $)	Production (Thousands $)
ATCRBS Trilateration Surveillance Subsystem		
Calibration Stations	--	24
Interrogator/Receiver Group	--	301
Control Group/Interfacing	--	10
Subtotals	(1000)	335
Ground/Local Control Systems		
Data Processing	1671	163
Display/DED	1300	250
Subtotals	2971	413
Ramp Control System		
Data Processing	100	40
Display/DED	48	3
Gate Status Equipment	80	15
Subtotals	228	58
TOTAL COSTS	4199	806

SECTION 8 - POTENTIAL TAGS DEPLOYMENTS

Under a separate contract with TSC, the MITRE Corporation has performed an ASTC System Deployment Analysis (Reference 1) for 39 major air carrier airports in the U.S. The models developed in this effort were used to estimate the year in which either an ASDE or an ASE (Advanced Surveillance Equipment) could be economically justified at these airports. The ASE is conceptually the same as a TAGS System having both GCS and LCS capability. The needs of both the Local and Ground Control areas were examined by MITRE under both good and bad visibility conditions.

The results of this deployment analysis are presented in Table 8-1 (Table 4-2 of Reference 1) under the ASDE and ASE columns. Using 1990 as a cutoff date for planning purposes, this table indicates that 15 airports should have a TAGS capability based upon the reduction of Local Control area delays in good visibility and the replacement of an already justified ASDE in bad visibility. These airports are noted in the TAGS requirements column under "complete". In addition, if ASDE were not deployed but rather the GCS portion of TAGS was deployed to the airports justifying ASDE alone, 10 airports would receive the GCS portion of TAGS. These airports are noted in the TAGS requirements column under "GCS only". Finally, if TAGS were installed at Miami where only the LCS capability is required, the total number of complete TAGS systems required would increase to 16.

Table 8-1. Potential ASTC Deployments: 39 Airports

	ASDE		ASE		TAGS Requirements Prior to 1990	
Airport	Date	Determining Factor	Date	Determining Factor	Complete	GCS Only
ORD	1973*	GCBV	1973	LCGV, GCGV, GCBV	✓	
ATL	1973*	GCBV	1975	GCBV	✓	
LAX	1973*	GCBV	1976	GCBV	✓	
JFK	1973*	GCBV, LCBV	1982	LCGV	✓	
LGA	1973	GCBV	1982	LCGV	✓	
SFO	1973*	GCBV	1978	LCGV	✓	
DFW	1973	GCBV	1995	GCGV, GCBV		✓
MIA	>2000	--	1974	LCGV	See Note 1	
DCA	1973	GCBV	1973	LCBV	✓	
BOS	1973*	GCBV	1984	LCGV	✓	
PIT	1973	GCBV	1978	LCGV	✓	
DEN	1979	GCBV	1982	LCGV	✓	
STL	1973	GCBV	1983	LCGV	✓	
DTW	1973	GCBV	1995	LCGV		✓
EWR	1976*	GCBV	1988	LCGV	✓	
PHL	1973	GCBV	1981	LCGV	✓	
CLE	1973*	GCBV	1980	LCGV	✓	
IAH	1978	GCBV	>2000	--		✓
MSP	1989	GCBV	1995	LCGV		✓
MSY	1985	GCBV	>2000	--		✓
SEA	1973*	GCBV	1983	LCGV	✓	
MEM	1996	GCBV	>2000	--		
MCI	1978	GCBV	>2000	--		✓
IND	1988	GCBV	>2000	--		✓
CVG	>2000	--	>2000	--		
BAL	1983	GCBV	1990	LCGV		✓
PDX	1991*	GCBV	>2000	--		
PHX	>2000	--	>2000	--		
SAN	1992	GCBV	>2000	--		
BUF	>2000	--	>2000	--		
MKE	1985	GCBV	>2000	--		✓
CLT	>2000	--	>2000	--		
CMH	>2000	--	>2000	--		
IAD	1992*	GCBV	>2000	--		
SDF	>2000	--	>2000	--		
DAY	1989	GCBV	>2000	--		✓
OAK	>2000	--	>2000	--		
BDL	1992	GCBV	>2000	--		
SAT	>2000	--	>2000	--		
TOTAL					15	10

*ASDE Currently Installed

Determining Factors

GCGV - Ground Control in Good Visibility
GCBV - Ground Control in Bad Visibility
LCBV - Local Control in Bad Visibility
LCGV - Local Control in Good Visibility
Note 1: LCS Only

APPENDIX A - REPORT OF INVENTIONS

A diligent review of the work performed under this contract has revealed no innocation, discovery, improvement, or invention.