R 527

Technical Report

WINDOWS FOR EXTERNAL OR INTERNAL HYDROSTATIC PRESSURE VESSELS

PART II. Flat Acrylic Windows Under Short-Term Pressure Application

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NAVAL FACILITIES ENGINEERING COMMAND

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WINDOWS FOR EXTERNAL OR INTERNAL HYDROSTATIC PRESSURE VESSELS
PART II. Flat Acrylic Windows Under Short-Term Pressure Application

Technical Report R-527

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by

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ABSTRACT

Flat, disk-shaped acrylic windows of different thickness-to-diameter ratios have been tested to destruction under short-term hydrostatic loading at room temperatures, where short-term loading is defined as pressurizing the window hydrostatically on its high-pressure face at a 650-psi/minute rate till failure of the window takes place. Critical pressures and displacements of windows with thickness to effective diameter ratios less than 1.0 have been recorded and plotted. The critical pressures derived from testing flat windows in flanges with 1.5-inch, 3.3-inch, and 4.0-inch openings have been found applicable also to flanges with larger openings, so long as the larger windows are of the same t/D_i and D_o/D_i ratios, where t is thickness of the window, D_i is the clear opening in the flange and therefore the effective diameter of the window exposed to ambient atmospheric pressure and D_o is overall diameter of the window face exposed to hydrostatic pressure. The performance of flat windows under short-term hydrostatic pressure has been found to be comparable to that of conical windows with included angle equal to, or larger than 90 degrees.

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The Laboratory invites comment on this report, particularly on the results obtained by those who have applied the information.

CONTENTS

TERMINOLOGY

D_i The diameter of the clear opening in the flange and therefore the effective diameter of the window.

D_o The overall diameter of the window, or diameter of opening on high-pressure side of flange (minus clearance).

P_c Critical pressure or the pressure at which complete failure of the window occurs, resulting in explosive release of pressure from the vessel and fragmentation of the window.

t The nominal or exact measured thickness of the acrylic window.

INTRODUCTION

The Naval Facilities Engineering Command is responsible for the construction and maintenance of underwater structures attached to the ocean floor. Such structures may include instrumented or manned underwater surveillance or observation posts that will rely (at least in part) on visual observation and the transmission and reception of electromagnetic radiation through nonopaque areas of the hull for the performance of their mission. The Deep Ocean Laboratory of the Naval Civil Engineering Laboratory (NCEL) is carrying out studies to provide information on the design of underwater windows. The first report[1] on these studies discussed the behavior of conical acrylic windows under short-term pressurization. The report in hand presents information on the behavior of flat, disk-shaped acrylic windows under short-term pressurization.

Flat, disk-shaped acrylic windows for high-hydrostatic-pressure applications have received very limited attention, and only a few facets of their behavior under hydrostatic loading have been investigated.[2] Since flat windows possess characteristics not inherent in conical acrylic windows currently in use in underwater structures, it was considered desirable to investigate this type of window.

The major advantage of flat windows is the commercial availability of glass, acrylic, epoxy, and polycarbonate material in polished transparent sheets or plates. Conical windows require considerable precision machining to adapt flat sheets or plates to the window flange. On the other hand, flat windows require only simple cutting and turning to transform flat material into usable windows. Furthermore, the fabrication of the flat-window mounting flange is also much simpler. Since the mating surfaces of both the window and flange are plane, the problem of replacement of windows is simplified when they become defective due to mechanical damage or the cracking which precedes failure under pressure. There may, of course, be some disadvantages associated with flat windows, such as smaller angle of vision for the same flange opening, but there are sufficient advantages inherent in flat windows to make them worthy of investigation for underwater structural applications.

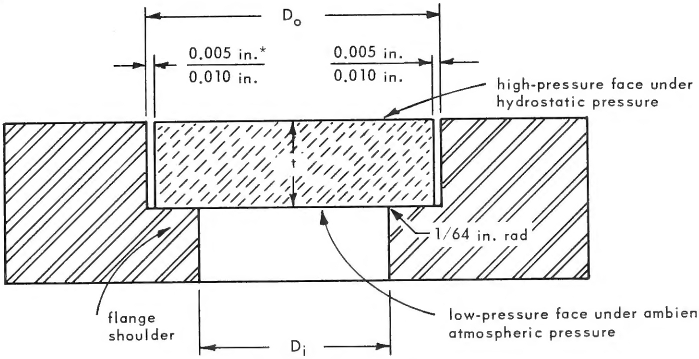
The underwater structures in which flat windows could be incorporated may be subjected to a variety of hydrostatic loadings. Thus a series of studies must be conducted to determine their behavior under short-term, long-term, cyclic, and dynamic loading. The first of the studies conducted deals with the short-term hydrostatic loading of flat acrylic windows, where short-term hydrostatic loading is defined as pressurizing the window on its high-pressure face at a 650-psi/min rate from zero (atmospheric) pressure to its failure pressure. The purpose of this report is to document the first experimental study.

EXPERIMENTAL PROCEDURE

The objective of the experimental study was to generate a set of performance curves that would serve as the basis for designing flat acrylic windows for use under short-term hydrostatic pressure. Also the critical pressures for windows had to be determined before further optical studies could be undertaken. Therefore, experimental data not only had to cover the whole range of depths encountered in the ocean, but also had to be applicable to flat windows of different thicknesses and diameters.

To meet these objectives, window test specimens had to be designed that upon testing would provide the necessary data on which generalized window design curves could be based. This was accomplished by selecting two nondimensional parameters for dimensioning the windows. Use of the t/D_i ratio and the D_o/D_i ratio (see "Terminology" and Figure 1) permitted not only the adequate description of any window, but also scaling window dimensions up or down. In order to cover the whole depth range in the ocean, the thickness component (t) of the t/D_i ratio was varied from 0.125 inch to 2 inches, while to prove the applicability of experimental data to all possible window sizes the flange opening diameter (D_i) component of the ratio was varied from 1.5 inches to 4.0 inches (Table 1). Flanges and some of the windows are shown in Figures 2, 3, and 4. The flange seat diameter ratio (D_o/D_i) was not varied during the generation of the experimental data serving as basis for generalized design curves because there were indications (see Appendix A) that varying this parameter would unduly complicate the study. For the same reason the various methods for retaining the window in the flange were not investigated, although earlier exploratory experimental data shows[3] that for some t/D_i and t/D_o ratios, the type of edge restraint used on the window has a considerable influence on the critical pressure of the window. To avoid confounding the data, the windows in this study were not clamped or lapped in place, but simply sealed with grease into the flange cavity with approximately 0.005 to 0.010 inch radial clearance between them and the flange. This type of flat acrylic window mounting (shown in Figure 1) will be referred to in this report as the DOL type III flange.

Although in designing a flat acrylic window to be safe for underwater application it is necessary to know the behavior of such windows under various types of hydrostatic loading, only the short-term strength of windows was considered in this study. The experimental evaluation of long-term and cyclic hydrostatic loading was relegated to future studies on this subject. In the present study it is considered sufficient for design purposes to have reliable data on only the magnitude of the displacement of the center on the window's low-pressure face and the critical pressure at which a window of any t/D_i ratio fails under short-term loading.



$$D_o = 1.5 \times D_i$$

* Indicates maximum and minimum dimensions allowable.

Figure 1. DOL type III flange configuration for short-term testing of flat acrylic windows.

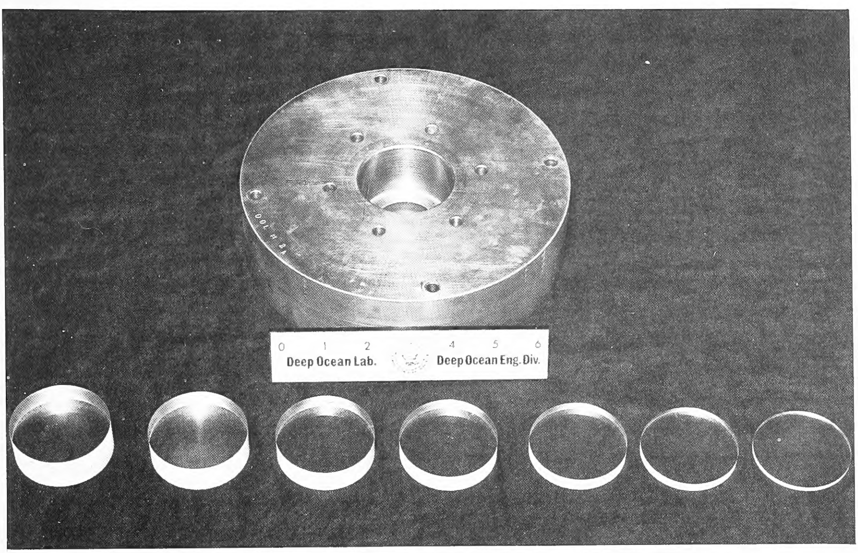


Figure 2. Flat acrylic windows and 1.50-inch (D_i) flange used to determine the relationship between the window's critical pressure and t/D_i ratio.

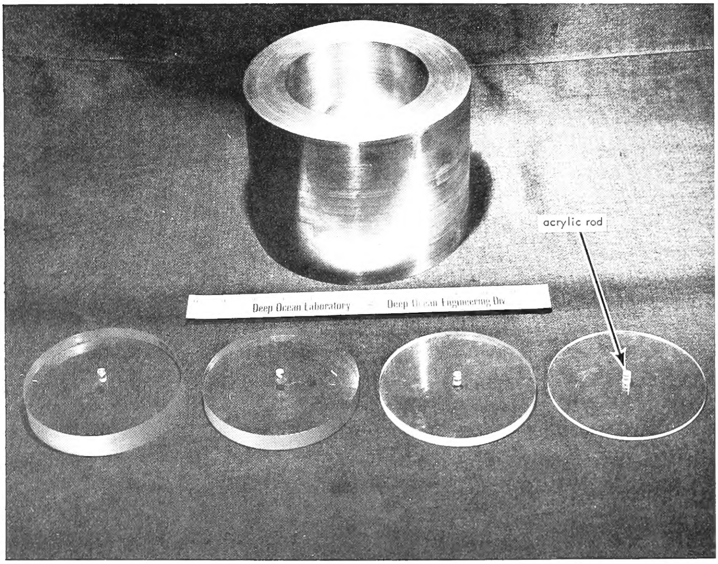


Figure 3. Flat acrylic windows and 3.33-inch (D_i) flange used to determine the relationship between the window's critical pressure and t/D_i ratio.

Figure 4. Flat acrylic windows and 4.00-inch (D_i) flange used to determine the relationship between the window's critical pressure and t/D_i ratio.

Table 1. Flat Disk Window Test Specimens

(* represents a test group of five window specimens)

Nominal Thickness (in.)	D_i = 1.50 in. D_o = 2.25 in.	D_i = 3.33 in. D_o = 5.00 in.	D_i = 4.00 in. D_o = 6.00 in.
1/8	*	*	
1/4	*		*
3/8	*	*	
1/2	*		*
5/8	*	*	
3/4	*		
7/8	*	*	
1	*		*
1-1/8		*	
1-1/2		*	
2		*	*

In order to simulate the loads encountered by flat acrylic windows in underwater structures, window specimens were subjected to hydrostatic pressure loading in a hydrospace simulation chamber. The pressurization of the windows was conducted in a 16-inch naval gun shell converted into a pressure vessel[4] with water at room temperature serving as the pressurization medium. The water was pressurized by two air-driven, positive-displacement pumps whose pumping rate was controlled within ±50 psi/minute. Since previous studies[1] have shown that critical pressure of windows depends on water temperature as well as on pressurization rate, an effort was made to hold these variables constant for all the window tests. The standard pressurization rate was 650 psi/minute, and water temperature was held between 65°F and 75°F.

The window test specimens for this study (Table 1) were fabricated by lathe turning Plexiglas grade G sheet stock. The circular disks (Figure 1) thus formed had an overall diameter (D_o) of 0.010 inch to 0.020 inch less than the flange's high-pressure opening diameter (D_o), permitting the window to seat in its flange cavity with 0.005 to 0.010 inch radial clearance. The manufacturer's tolerances for variation in the nominal thickness of commercial sheets were accepted for the thickness tolerance of the finished circular flat windows. The finish of the disk edges was held to 32 rms. Dimensions recorded were the average of micrometer measurements taken at three different locations for the window's diameter and for its thickness.

The hydrostatic testing consisted of pressurizing a flange-mounted window (Figure 5) until failure occurred. Since the window flange is open on one side to the atmosphere, window fragments were ejected upon its failure (Figure 6). The displacement of the window's low-pressure face during pressurization was measured to ±0.001 inch by means of a wire that transmitted the displacement of the window to a mechanical dial indicator over a pulley system without any mechanical amplification (Figures 5 and 7). To permit the attachment of a displacement indicator wire to the center of the window's low-pressure face, a short acrylic rod with a small transverse hole in one end was bonded to the window's surface with solvent-type cement. The displacement of the window under hydrostatic pressure was read directly from the dial indicator with a closed-circuit television system that permitted the operators to be in a safe location during the ejection of the window from its retaining flange when critical pressure was reached (Figures 8 and 9).

As discussed in Appendix A, silicone grease was used as a pressure seal between the window and flange. The grease was spread by hand on the contact area of the low-pressure face and edge of the window. Sealing was completed when the window was placed in the flange cavity, rotated in place and pushed inward against the flange. This was done to distribute the grease uniformly over the area of contact and also to eliminate any small air bubbles trapped between the window and flange. This procedure proved to be adequate as it allowed no leakage of water to occur between the window and the flange. Care was exercised to insure that both the flange cavity and window were clean, since the flange was used for successive testing and tended to retain small fragments of previously tested specimens.

Since the ejection of windows in many cases fragmented them into very small pieces, a reconstruction of the mechanism of material failure was usually impossible. To provide data that would give an insight into the mechanism of failure, some of the windows were pressurized only to a fraction of the window's critical pressure and then removed for inspection of their deformation and cracks (Appendix B).

The explosive release of energy which accompanied window failure at higher critical pressures was quite harmful to O-rings, bolts, and flanges. To decrease the shock effects of this energy release, the cylindrical passage in the flange and the adaptor flange was filled with water after the window was in place. At the moment the window failed the water was forced through a 1/2-inch-diameter restrictive opening in the adaptor flange. This shock-damping method was sufficient to prevent the breaking of the eight 1/4-inch-diameter high-strength bolts connecting the window flange and adaptor flange.

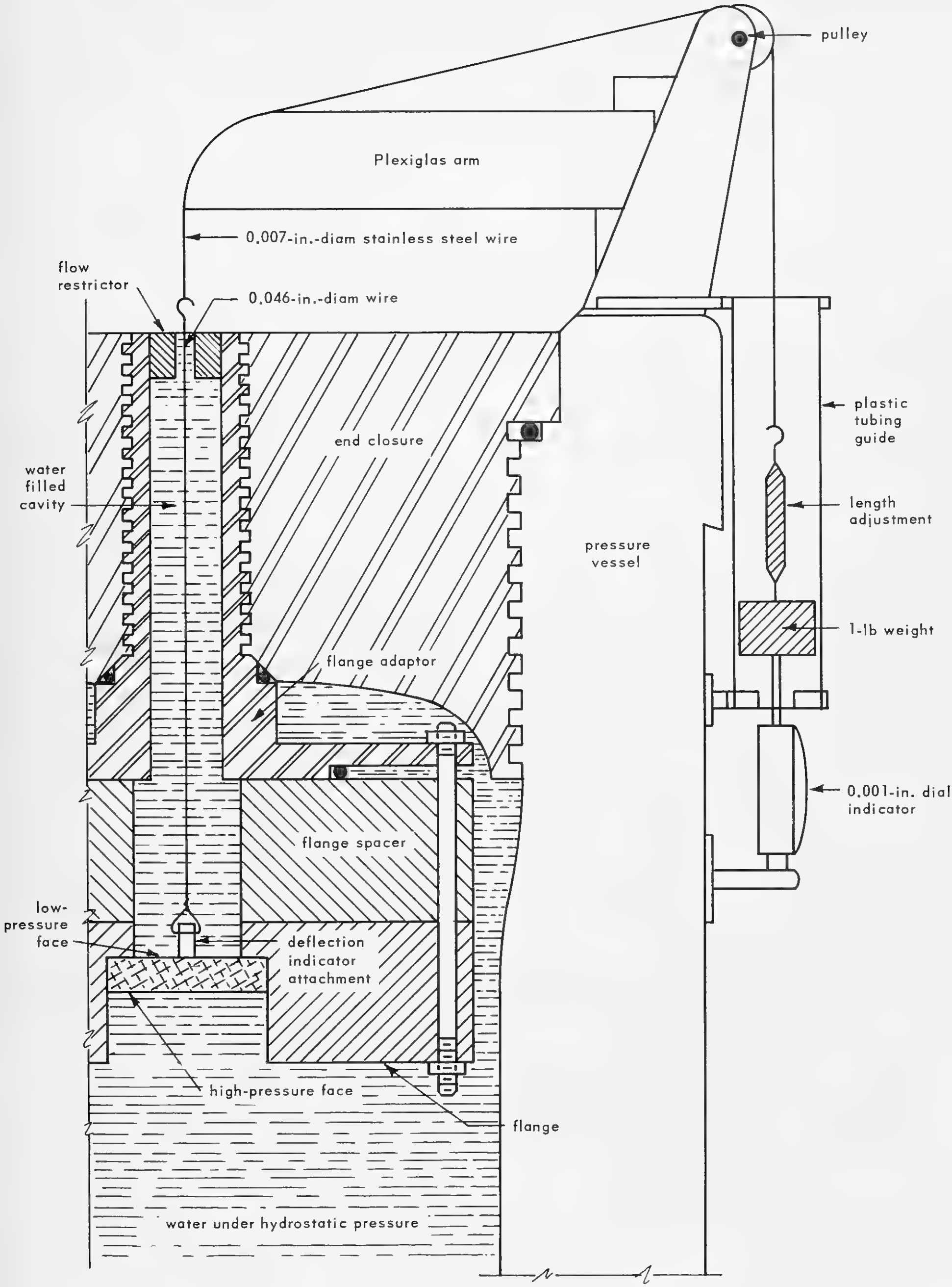


Figure 5. Schematic drawing of deflection measuring apparatus and flange mounting used in the testing of windows.

Figure 6. Ejection of window fragments by a high-pressure jet of water upon failure of the window.

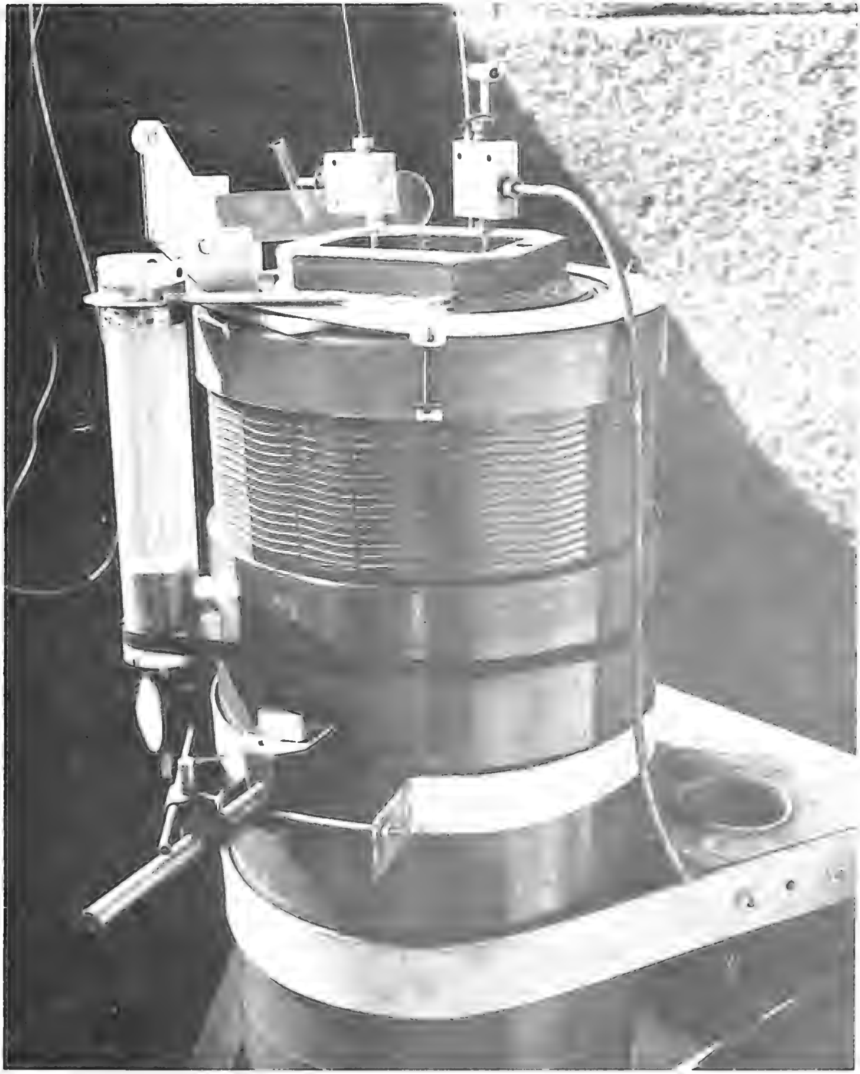
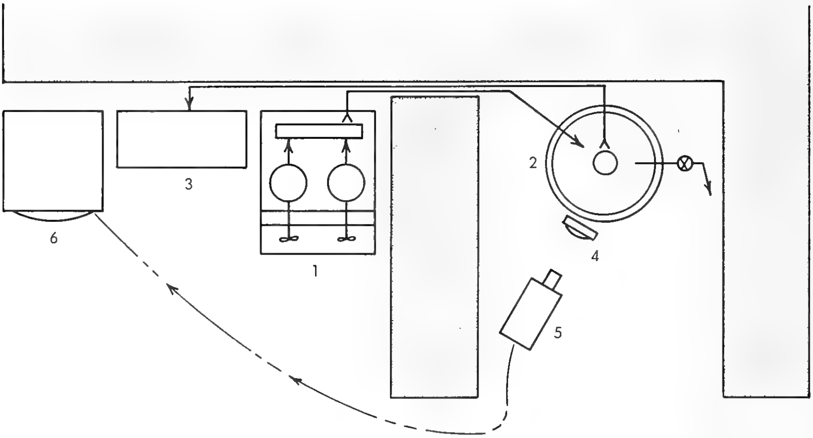


Figure 7. Deflection-measuring apparatus in place on pressure vessel.



Air-driven positive displacement pumps (1) supply water under pressure to the Mk I 9-in. pressure vessel (2). Pressure is monitored by gage (3) and recorded. Dial indicator (4) is watched via closed-circuit television camera (5) and monitor (6). Operator is thus enabled to record data behind safety barricade.

Figure 8. Schematic plan of experimental setup.

Figure 9. Pressure gages, pumps, and closed-circuit television monitor used behind barricade during testing.

DISCUSSION

General

The flat acrylic windows failed either in flexure or in shear, depending on their t/D_i ratio. The failure modes and mechanisms are discussed in detail in Appendix B, and deflection data are presented in Appendix C. In most cases, the center of the window was ejected in the form of small fragments, while in few cases in the low t/D_i ratio range the center was not ejected, as the formation of large cracks in the window at low pressure vented the pressurized water, and thus removed the energy required for ejection of the window. The critical pressures of windows were found to vary exponentially with their t/D_i ratio. When the critical pressures of windows with the same D_o/D_i and t/D_i ratios, and effective diameters of 1.50, 3.33, and 4.00 inches were plotted on the same graph (Figure 10) they were found to fall in the same failure region. This indicates that the critical pressure of a flat acrylic window is dependent only on the t/D_i ratio (and the mounting of the window in the flange).

The displacement of the windows also varied with their t/D_i ratio. Comparison of displacements of windows having effective diameters (D_i) of 1.50 inches (Figure 11), 3.33 inches (Figure 12), and 4.00 inches (Figure 13) shows that the displacements, besides being a function of t/D_i ratio are also a function of D_i. Although there are insufficient experimental data to establish a reliable relationship between the magnitude of displacement and the D_i of the window in DOL type III flange, it appears that the displacement is directly proportional to the D_i of the window.

The critical pressures of flat acrylic windows when compared to the critical pressures of conical acrylic windows investigated in previous studies[1] were found to be approximately of the same magnitude as the critical pressures of conical windows of same t/D_i ratio and having an included angle equal to, or larger than 90 degrees. Thus, it would appear that the flat acrylic windows mounted in the DOL type III flange are as resistant to short-term hydrostatic loading as the conical windows with included angle equal to, or larger than 90 degrees.

A technical discussion of the relationship between the critical pressure, D_o/D_i ratio, radial clearance between the window and the flange, and the method of sealing is presented in detail in Appendix A.

A technical discussion of the mode of failure of flat acrylic windows is presented in detail in Appendix B.

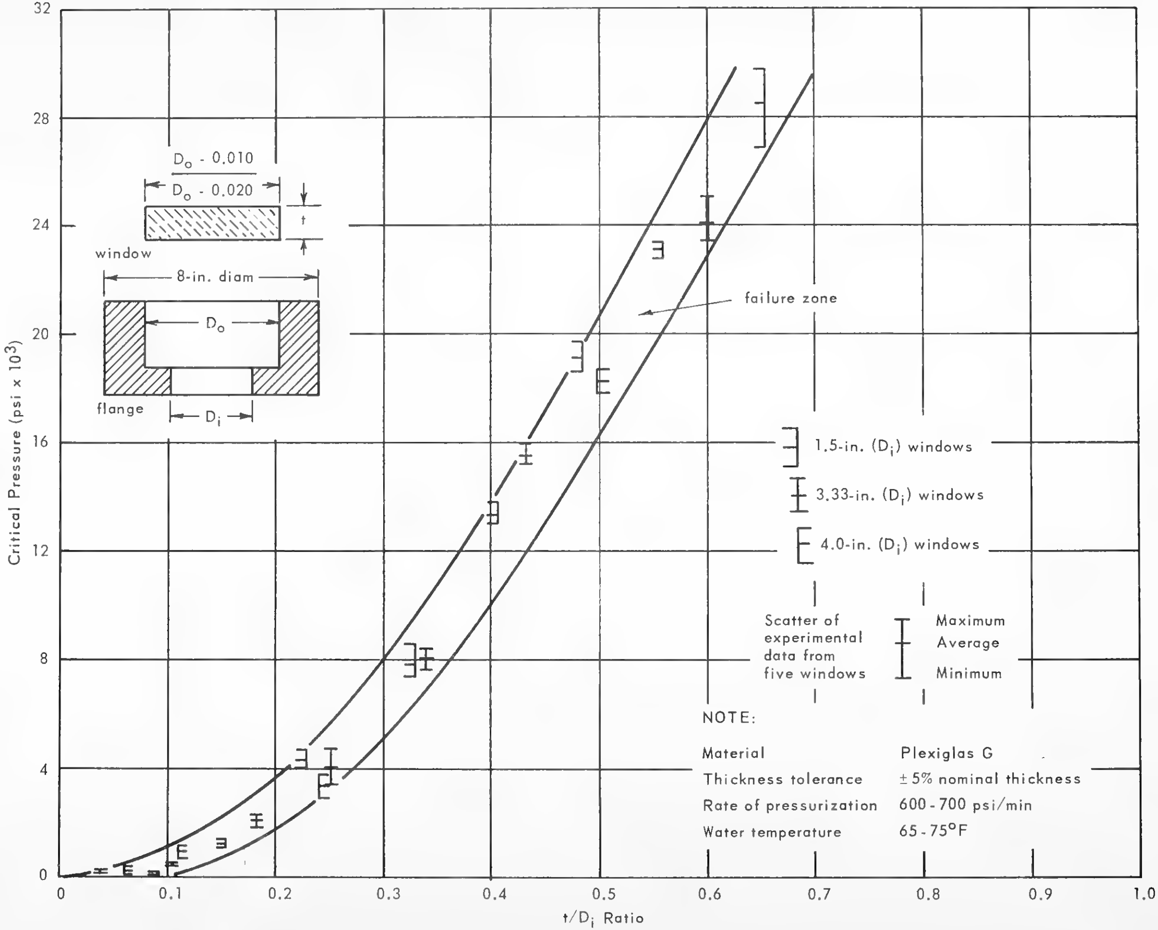


Figure 10. The experimental relationship between critical pressure and t/D_i ratio for flat acrylic windows with D_o/D_i ratio equal to 1.5.

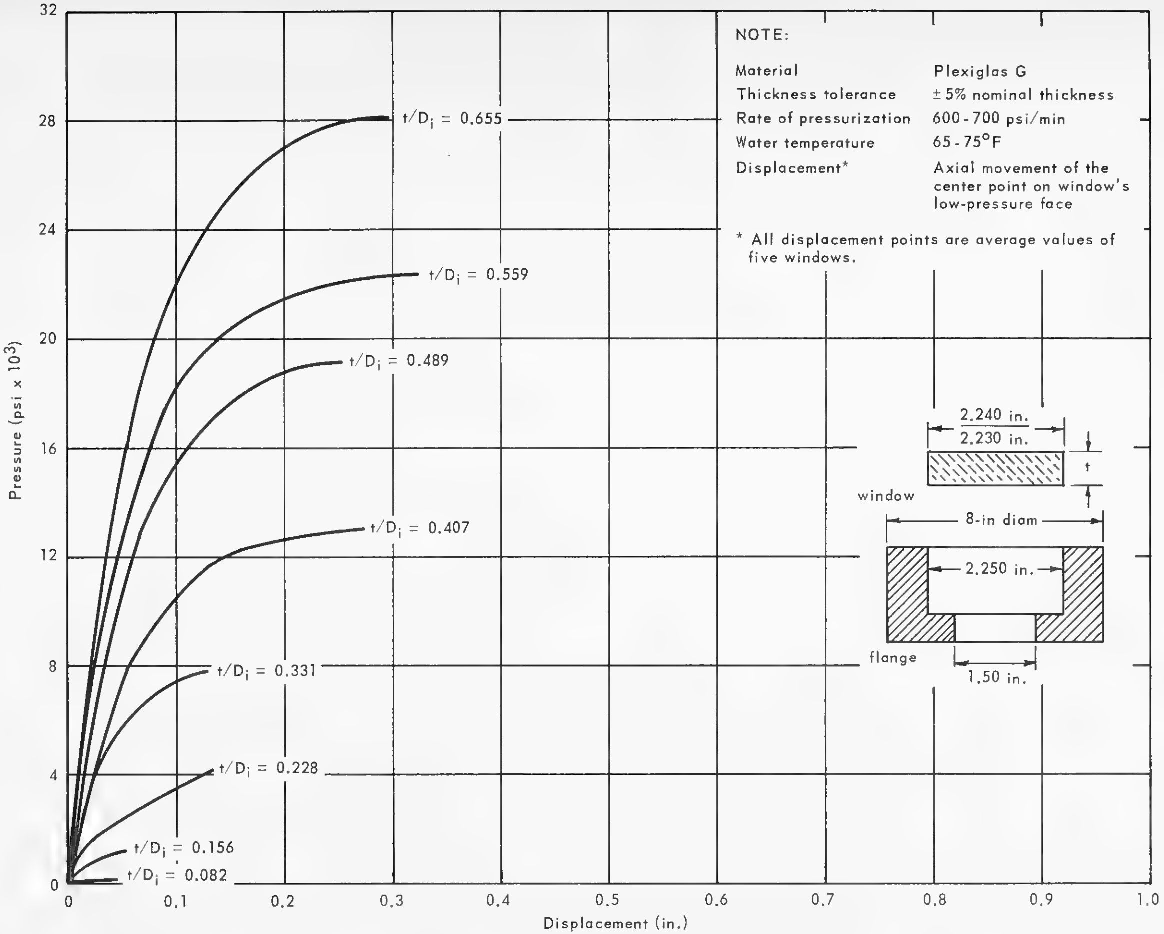


Figure 11. The experimental relationship between displacement and t/D_i ratio of flat acrylic windows with 1.5-inch D_i and with D_o/D_i ratio equal to 1.5.

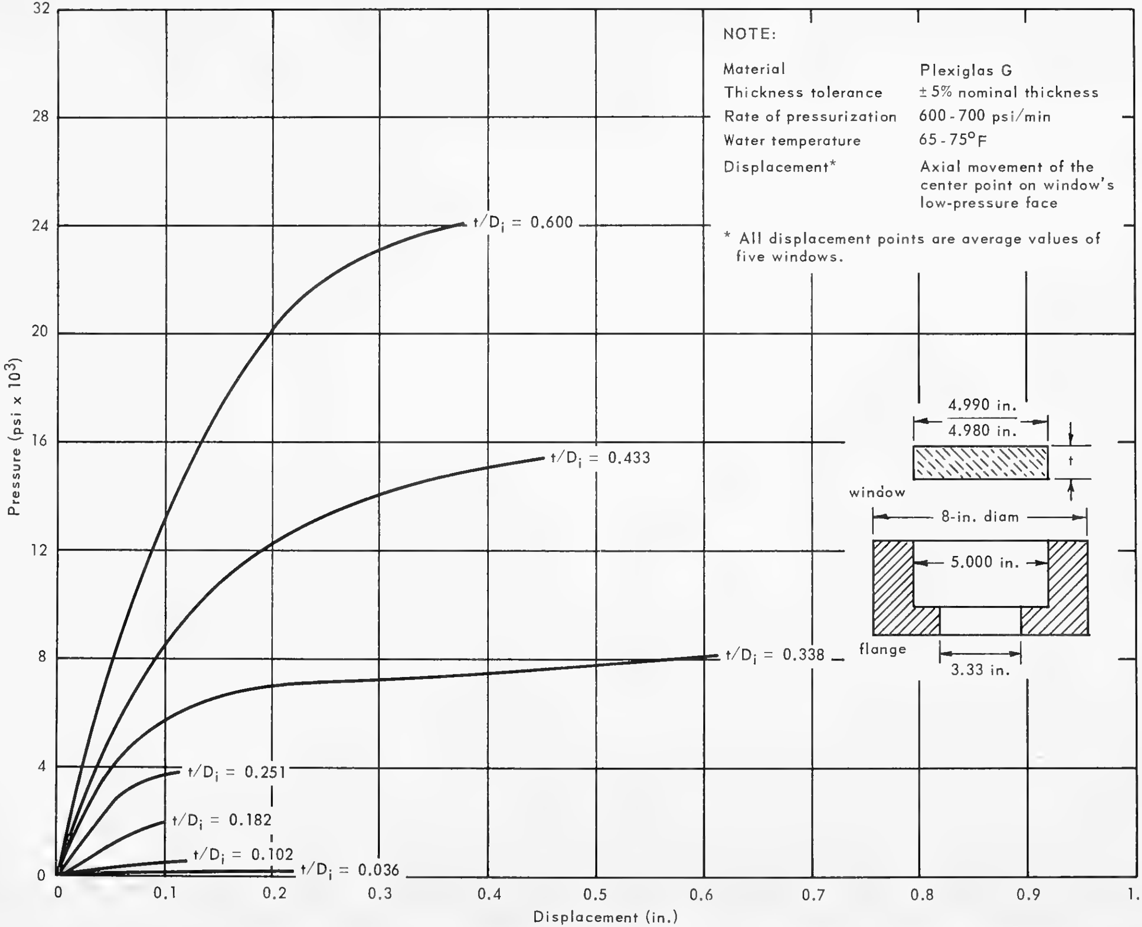


Figure 12. The experimental relationship between displacement and t/D_i ratio of flat acrylic windows with 3.33-inch D_i and with D_o/D_i ratio equal to 1.5.

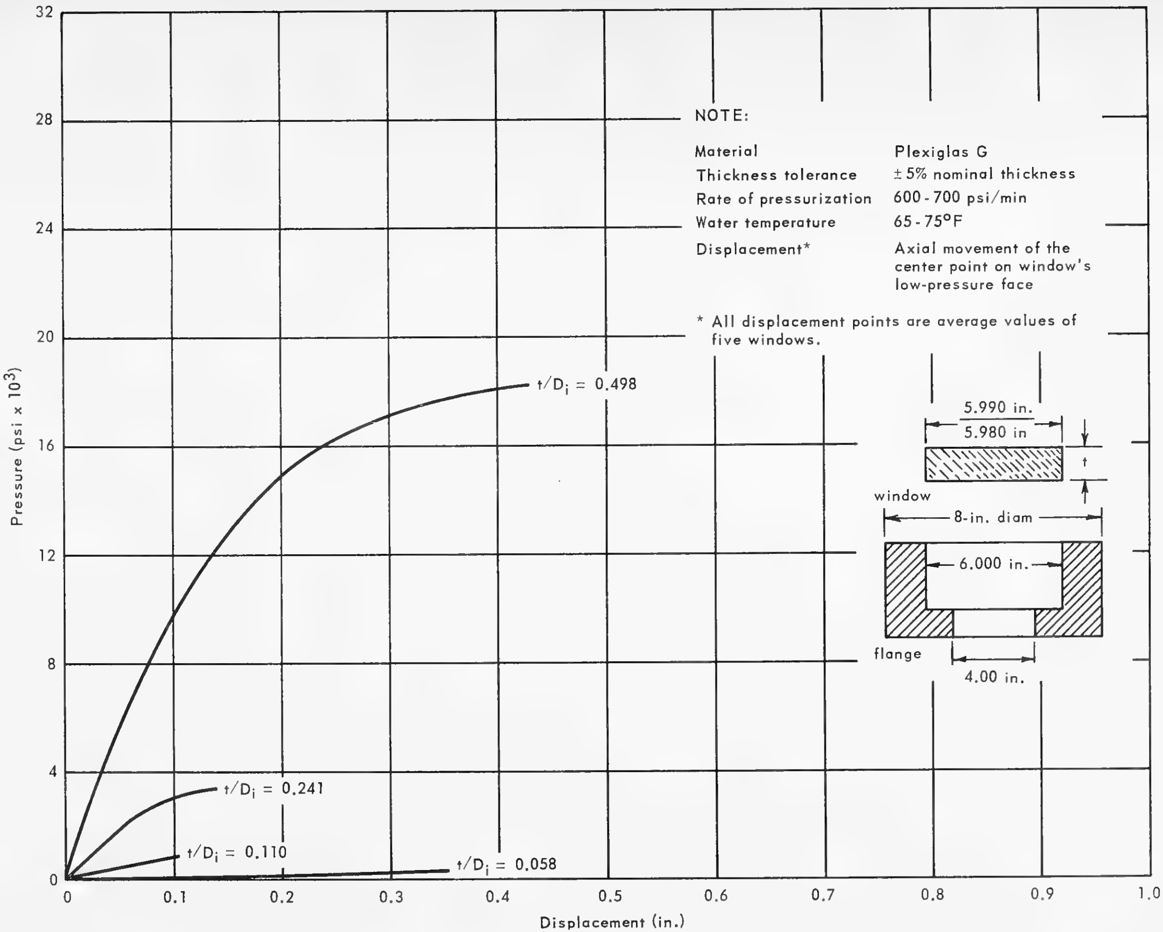


Figure 13. The experimental relationship between displacement and t/D_i ratio of flat acrylic windows with 4.00-inch D_i and with D_o/D_i ratio equal to 1.5.

Effect of Loading Conditions

Preliminary results from other studies in progress indicate that the critical pressures and deflections of acrylic windows are adversely affected by higher temperatures, and sustained or cyclical pressure loading. The designer is therefore cautioned that the data presented in this report pertains only to short-term pressure loading as defined for this study. If the short-term critical pressure data is used as a design basis for windows subjected to long term or cyclical loading, a safety factor of at least four, based on the short-term critical pressure, is recommended for the preliminary selection of window thickness. Subsequently a full-scale window with dimensions selected on the basis previously described should be tested under the full loading expectancy of the design. When experimental data for long-term and cyclical pressure loading become available the presently recommended approximate safety factor will be replaced by precise critical-pressure design curves plotted as a function of loading duration or number of pressure cycles.

Effect of Variations in Flange Design

Effects of flange designs different from DOL type III have not yet been investigated. Variations of direct influence on deflection and critical pressure would be (1) the use of a retaining ring against the high-pressure face, (2) the use of gaskets with or without a retaining ring, (3) using a radial clearance less than 0.005 inch between the window and flange, and (4) using a different flange shoulder thickness at D_i.

It is postulated that use of a retaining ring incorporated in a flange design would increase the critical pressure capabilities and decrease deflections of windows whose t/D_i ratio is less than about 0.4 to 0.5. This size window, failing predominantly by flexure would be more drastically influenced than would be the windows of t/D_i ratios greater than about 0.5, which fail predominantly by shear.

Flat bearing gaskets employed in a flange design are postulated to have varying effects, depending on the gasket's thickness and hardness and whether a retaining ring is also employed. Again the smaller t/D_i ratio windows would probably be more affected than would be the larger t/D_i ratio windows.

The magnitude of the flange thickness should not affect the window's short-term critical pressure so long as it is sufficiently thick to restrain radially the extruding portion of the window's low-pressure face prior to its failure. Also, the flange shoulder must be sufficiently thick to be rigid in comparison to the flexural rigidity of the flat acrylic window supported by the shoulder.

FINDINGS

1. The critical pressure of flat acrylic windows under short-term hydrostatic loading has been found to be solely a function of their t/D_i ratios, so long as their material composition and D_o/D_i ratios, the rate of pressurization, temperature of pressurizing medium, and the method of retaining the window in the flange are the same.

2. The axial displacement of the window's low-pressure face center has been found to vary both with the window's t/D_i ratio and its D_i.

3. The critical pressures of flat acrylic windows under short-term hydrostatic loading in a DOL type III flange have been found to be approximately the same as the critical pressures of conical acrylic windows with included angle equal to, or larger than 90 degrees, tested in DOL type I flanges under the same temperature and pressurization conditions.[1]

CONCLUSIONS

1. Flat acrylic windows have been found to perform successfully under short-term pressure application in pressure vessels and hydrospace structures.

2. Flat acrylic windows may be substituted for conical windows of 90 degrees or greater included angle, of similar thickness and effective diameter for short-term pressurization applications.

Appendix A

DISCUSSION OF WINDOW MOUNTINGS

INTRODUCTION

Variables Investigated

In conjunction with the experimental program investigating the relationship between the t/D_i ratio of flat acrylic windows and their critical pressure, an exploratory study was initiated to investigate several window-mounting variables which probably influence this relationship. The variables investigated were: (1) the relationship between the overall diameter (D_o) of the window disk and the effective diameter (D_i) of the window's unsupported viewing area as defined by the supporting shoulder of the window flange; (2) the method of making a pressure-tight seal between the window and the flange; and (3) the effect of radial clearance between the window and the flange. For these preliminary investigations, several test arrangements were devised and a number of windows were tested using each arrangement (Table A-1).

Experimental Methods

For the evaluation of the effect of the D_o/D_i ratio of windows on their critical pressure, two different flanges were fabricated that had the same D_i but different D_o openings (Figures A-1a, A-1c, and A-2). Windows (Figures A-3a and A-3c) of the same thickness, but with a D_o that matched the D_o of the flanges were tested in these flanges.

To evaluate the influence of the sealing method on the critical pressure of flat windows, two different types of seals were used in both the large and the small D_o/D_i ratio windows. The two types of seals used were an O-ring seal (Figures A-3b, A-3d, and A-4) under radial compression located around the circumference of the window, and a grease, surface-to-surface seal (Figures A-3a, A-3c, and A-5) between the window's low-pressure face and the flange's facing (Figures A-1a and A-1c). If the collapse pressure of windows tested in them remained the same regardless of the seal used, it could be postulated that the two methods of sealing were equivalent, and exerted no influence on the collapse pressure of windows. Collapse pressures of different magnitude resulting from the use of different sealing systems would, on the other hand, be indicative of seal's influence on the collapse pressure, and thus the collapse pressure of windows would have to be evaluated for each different kind of sealing method.

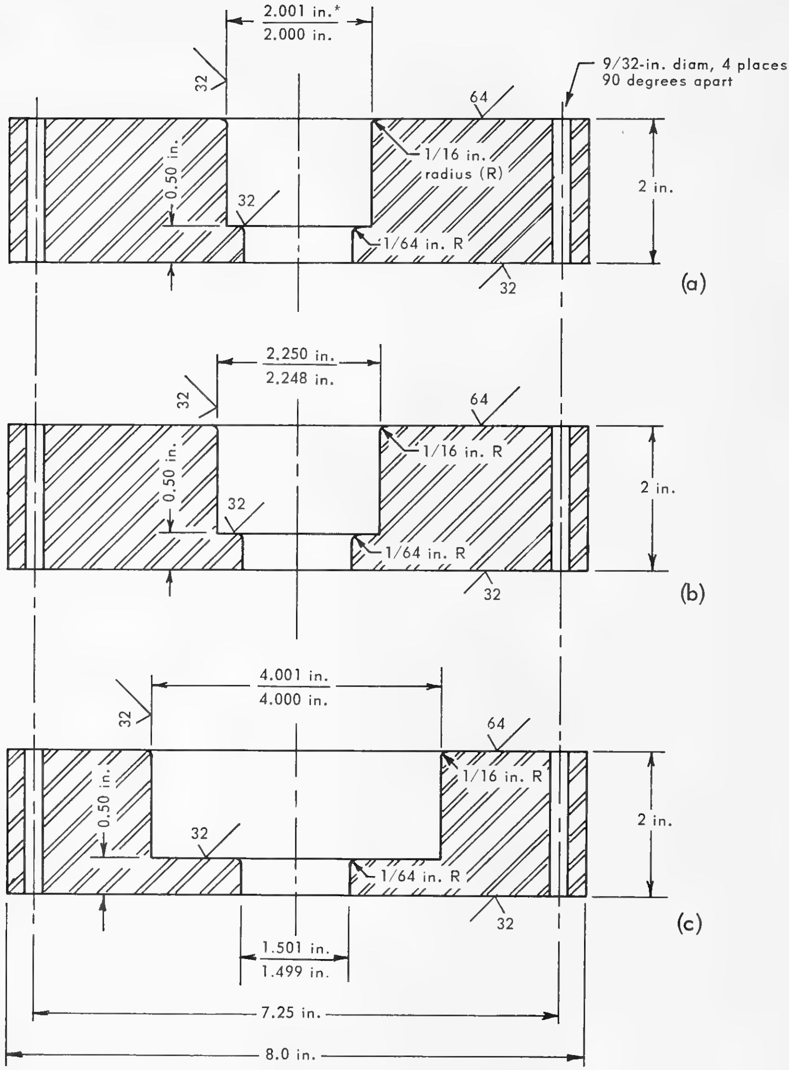
Table A-1. Flanges and Windows Used in the Evaluation of Seals, D_o/D_i Ratios, and Radial Clearances for Flat Acrylic Windows

Flanges			Windows Sealed With Grease					Windows Sealed With O-Rings				
D_i (in.)	D_o (in.)	Figure	D_o (in.)	Thickness[1] (in.)	Critical Pressure[2] (psi)	Displacement[2] at 16,000 psi (in.)	Figure	D_o (in.)	Thickness[1] (in.)	Critical Pressure[2] (psi)	Displacement[2] at 16,000 psi (in.)	Figure
1.501[3] / 1.499	2.001 / 2.000	A-1a	1.960 / 1.940	0.750	18,490	0.100	A-3a	1.999 / 1.998	0.750	19,060	0.086	A-3b
1.501 / 1.499	2.250 / 2.248	A-1b	1.960 / 1.940	0.750	16,960	0.079	A-3a	—	—	—	—	—
1.501 / 1.499	4.001 / 4.000	A-1c	3.960 / 3.940	0.750	19,190	0.117	A-3c	3.999 / 3.998	0.750	19,270	0.112	A-3d

1/ Nominal stock thickness of the five window specimens.

2/ Represents an average value of five window specimens.

3/ Indicates maximum and minimum dimensions allowable.



* Indicates maximum and minimum dimensions allowable.

Figure A-1. Flanges employed in investigation of window mountings.

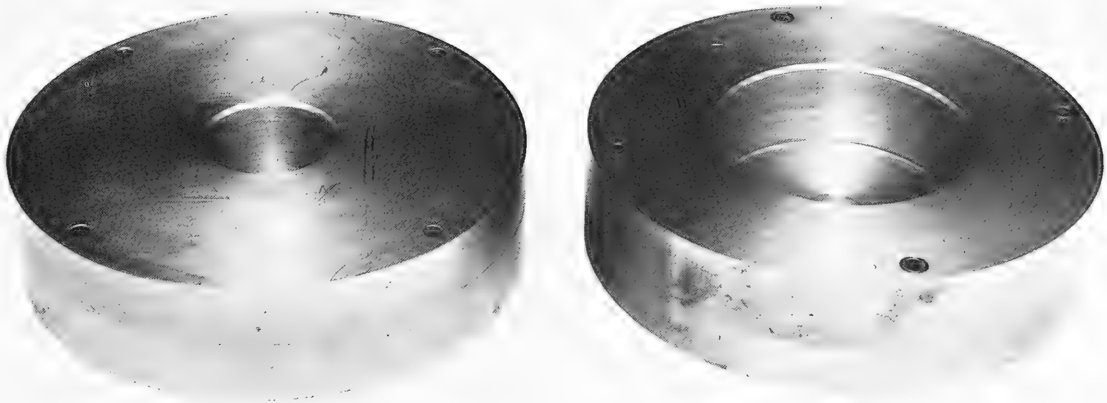


Figure A-2. Flanges (1.5-inch D_i) used in the window mounting investigation; 2.0-inch (D_o) (left) and 4.0-inch (D_o) (right).

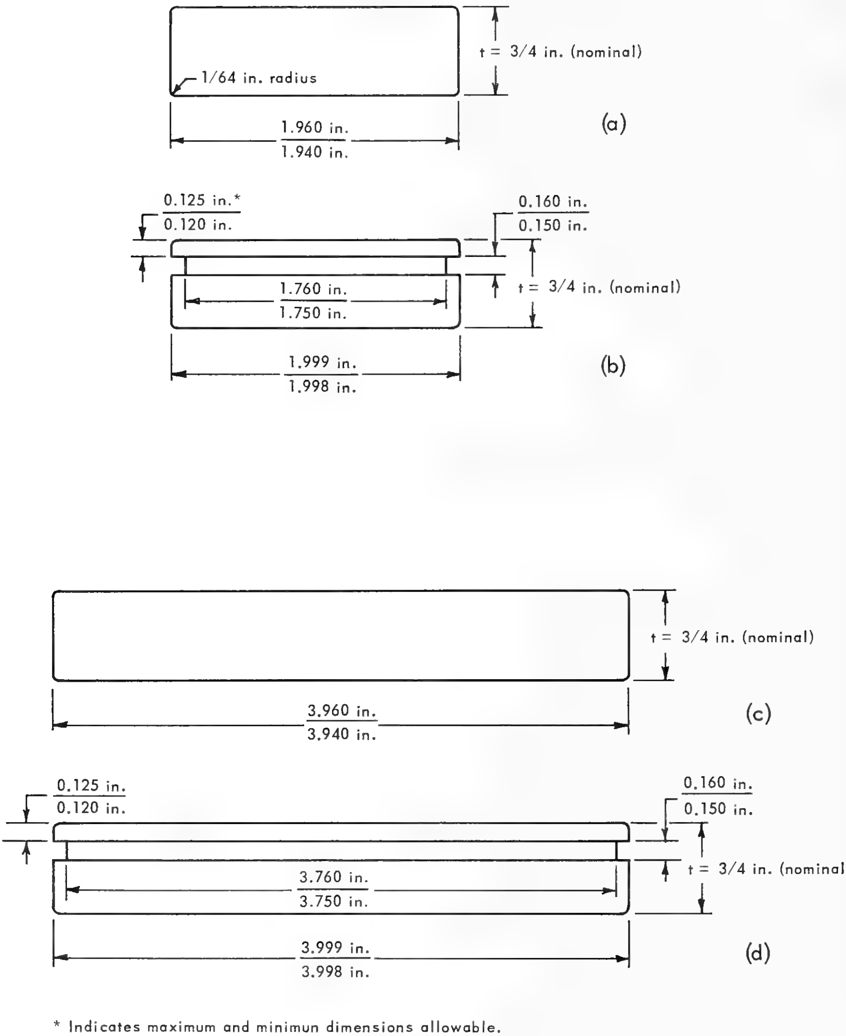


Figure A-3. Details of flat acrylic windows used in investigation of window mountings.

Figure A-4. Flat acrylic windows used with O-ring sealing technique in the investigation of window mountings.

Figure A-5. Flat acrylic windows used with plane surface (grease) sealing technique in the investigation of window mountings.

The influence of window fit on the critical pressure was investigated with windows having the same D_o/D_i ratio and thickness (Figures A-3a and A-3b) fitted into flanges with different major diameters (Figures A-1a and A-1b). In one of the flanges (Figure A-1a) the pretest radial clearance between the windows and the flange was either 0.001 inch (Figure A-3b) or 0.025 inch (Figure A-3a), while in the other flange (Figure A-1b) the clearance was 0.125 inch. A radial clearance of 0.001 or 0.025 inch when the window is subjected to hydrostatic pressures above 10,000 psi is calculated to result in an interference fit between the window and the flange, thus resulting in a lateral constraint of the window. The flange (Figure A-1b) and window (Figure A-3a) assembly with the initially larger radial clearance of 0.150 inch, even when subjected to hydrostatic pressures that destroyed the window, did not cause it to be wedged inside the flange opening. With such an arrangement it was possible to determine whether the wedging in of the window in the flange under hydrostatic pressure had any measurable influence on the critical pressure of flat windows.

DISCUSSION

Relationship Between Critical Pressure and D_o/D_i Ratio

Tests to determine the relationship between critical pressure and D_o/D_i ratio were conducted with five 2-inch (D_o) windows in a 1.5-inch (D_i) flange and five 4-inch (D_o) windows in a 1.5-inch (D_i) flange. The windows were sealed in the flange with the aid of silicone grease, which was liberally applied to the bearing as well as the radial surfaces of the flat circular window. For both the 2-inch and the 4-inch (D_o) windows, the radial clearance between the window and the flange was 0.025 inch.

When tested to destruction, the average critical pressure of 2-inch (D_o) windows was 18,490 psi (Table C-1), while the critical pressure of 4-inch (D_o) windows was 19,190 psi (Table C-16). The small difference between the average critical pressures of the 2-inch and the 4-inch (D_o) windows with a 0.5 t/D_i ratio seemed to indicate that varying the D_o/D_i ratio from 1.33 to 2.67 did not significantly influence the critical pressure of flat acrylic windows, since the maximum collapse pressure found in 2-inch (D_o) windows (18,900 psi, Table C-1) overlapped the minimum collapse pressure found in 4-inch (D_o) windows (18,800 psi, Table C-16).

Since the critical pressures of windows with 1.33 and 2.67 D_o/D_i ratios are approximately the same so long as their t/D_i ratios are identical, a flange with an intermediate D_o/D_i ratio of 1.5 was selected for the conduct of the main flat-window study program.

Relationship Between Critical Pressure and Sealing Technique

The evaluation of window sealing methods was conducted with a total of 20 windows (10 untested windows in addition to the 10 already tested in the evaluation of D_o/D_i ratio study). Five of the additional windows had a 1.33 D_o/D_i ratio and a 0.5 t/D_i ratio and a D_o of 2 inches (Figure A-3b), while the five others had a 2.67 D_o/D_i ratio and a 0.5 t/D_i ratio with a D_o of 4 inches (Figure A-3d). All 10 windows had a nominal 1/8-inch-diameter radial O-ring seal located in a groove machined in the window 0.125 inch below its high-pressure face.

When the windows were tested to destruction in appropriate flanges (Figures A-1a and A-1c), the critical pressures of the O-ring-equipped acrylic flat windows were 19,060 (Table C-2) and 19,270 psi (Table C-17) — reasonably close to the pressures (18,490 and 19,190 psi, Tables C-1 and C-16) of the corresponding windows sealed in the flange with silicone grease. The displacements of the O-ring-equipped windows were approximately the same as the displacements of grease-sealed windows with the identical D_o/D_i and t/D_i ratios (Table A-1).

Thus, both seal designs are of equal desirability, so long as the sole criterion for their selection is their influence on the critical pressure of the flat acrylic window. For the main body of the flat window study program, where the relationship between the t/D_i ratio and critical pressure is investigated, the grease-seal design was selected. This design permitted the investigation of very thin, flat windows into whose body an O-ring seal could not be incorporated.

Relationship Between Critical Pressure and Window Fit

Evaluation of the effect on critical pressure of radial clearance between the flat acrylic window and the steel flange was conducted with a total of 25 windows (5 untested windows in addition to the 20 tested in previous tests). The radial clearance between the acrylic window and its flange varied from one group of window specimens to another. One group of 10 windows tested previously had a radial clearance of 0.001 inch (Figures A-3b and A-3d); another previously tested group of 10 had a clearance of 0.025 inch (Figures A-3a and A-3c). The group of 5 windows tested in addition to the 20 windows tested previously had a radial clearance of 0.150 inch (Figure A-3a). Appropriate flanges (Figures A-1a, A-1b, and A-1c) were used with the windows to result in 0.001-inch, 0.025-inch, and 0.150-inch clearances.

When the critical pressures of all the window groups were compared to each other, no significant difference in critical pressures could be found between the groups of windows possessing radial clearances of 0.001 inch and 0.025 inch, respectively. There was, however, a significant difference between the 16,960-psi (Table C-3) critical pressures of the window group with a radial clearance of 0.150 inch and the pressures of two window groups with the 0.001-inch (19,060 psi and 19,270 psi) and 0.025-inch (18,490 psi and 19,190 psi) radial clearances. The difference in the average critical pressure was approximately 10%, the windows with the 0.150-inch radial clearance failing at the lower critical pressures.

It would thus appear that it is to the designer's advantage to specify small clearances between the flat acrylic window and its flange, since by doing this he accomplishes two desirable objectives. His design not only results in a window that has superior critical pressure, but also is easier to seal in the flange. The small radial clearances are ideal for sealing the window in the flange with a radial O-ring seal, or silicone rubber potting-type seal. Because of these findings, the main body of window test program was conducted with windows that fit into the steel flanges with a 0.005- to 0.010-inch radial clearance.

FINDINGS

The exploratory tests in the window mounting investigation seemed to indicate that (1) varying the D_o/D_i ratio from 1.33 to 2.67, (2) changing the radial clearance between the window and the flange from 0.001 inch to 0.025 inch, and (3) substituting a radial O-ring seal for a grease seal have no significant influence on the critical pressures of flat acrylic windows with a 0.5 t/D_i ratio. When the radial clearance is increased to 0.150 inch, the critical pressure of the 0.5 t/D_i ratio window is reduced.

Whether these conclusions are applicable to flat acrylic windows with t/D_i ratios other than 0.5 is unknown. Some of the data generated in the main body of the flat window program have raised serious doubts that the conclusions hold for the whole t/D_i range. For example, the critical pressure of windows with a nominal 0.167 t/D_i ratio and a 1.5 D_o/D_i ratio was discovered to be 723 psi for a radial clearance of 0.005 inch and 2,100 psi for a radial clearance of 0.001 inch.

Thus, it would appear that for t/D_i ratios less than 0.5, any change in radial clearance below 0.005 inch influences its critical pressure considerably. Future studies will attempt to clarify this problem.

Appendix B

FAILURE MODES OF FLAT ACRYLIC WINDOWS

DISCUSSION

In nearly all cases for all sizes of windows tested, failure began with radial cracking on the window's low-pressure face. Radiating outward from near the center, the cracks commonly formed a nonsymmetrical, three- or four-pointed figure. This form of cracking preceded failure in nearly all cases and is assumed to be the beginning of failure (Figures B-1 and B-2). Depth of cracking was found to be a function of the thickness, t/D_i ratio of the window, and the pressure of the fluid. Since audible cracking was noted during testing, it is postulated that these radial cracks were rapidly formed, terminating at the window's D_i. Depth of cracking in the low-pressure face in most cases was found to be a small fraction of the window's thickness.

With additional pressurization, a second stage of failure began to develop. A conchoidal or "cupped cone" fracture was established, emanating from the base of the radial cracks and proceeding radially inward and circumferentially (Figures B-3 and B-4). The formation of a conchoidal fracture surface preceded failure in all cases observed.

Simultaneously, as the conchoidal fracture surface was formed, the radial cracks increased slightly in depth (Figures B-5 and B-6). Cracks did not deepen uniformly and new cracks developed with further pressurization. The additional cracking gave rise to formation of new and deeper conchoidal fracture surfaces. Additional pressurization caused the circumferential expansion and coalescence of the conchoidal fracture surfaces into one conical fracture surface as well as an increase in fracture depth (Figures B-7 and B-8). Cracking and formation of conchoidal fracture surfaces continued (Figures B-9 and B-10) deeper into the window's thickness until the critical pressure was finally reached resulting in the fragmentation and expulsion of the window's low-pressure face (Figures B-11 and B-12). The size of the central hole was a function of t/D_i ratio and D_i. The conical cavity resulting from the expulsion of the center portion of the window consistently assumed an approximate angle of 30 degrees with the high-pressure face.

Cracking between the window's D_i and D_o occurred concentrically with the window's circumference, nearly perpendicular to and emanating from the low-pressure face. This cracking was sometimes accompanied by small radial intersecting cracks (Figure B-9). This form occurred with larger t/D_i ratios, failure still assuming the conical surface form. The circumferential cracks sometimes penetrated the window's thickness but still did not constitute a plane of failure.

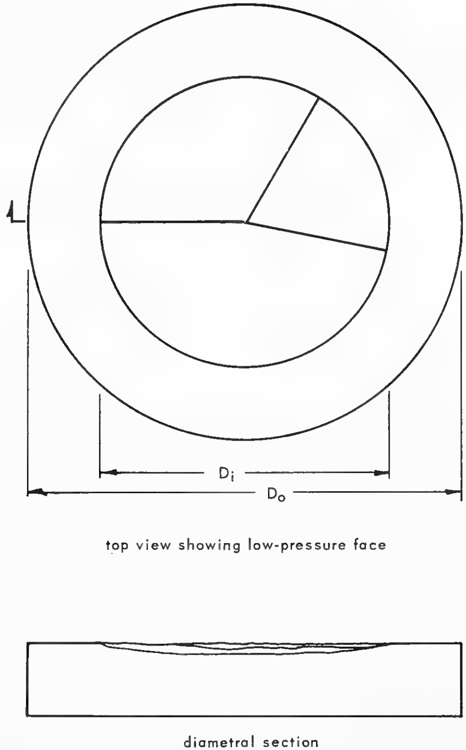


Figure B-1. Initial radial crack pattern in low-pressure face of windows.

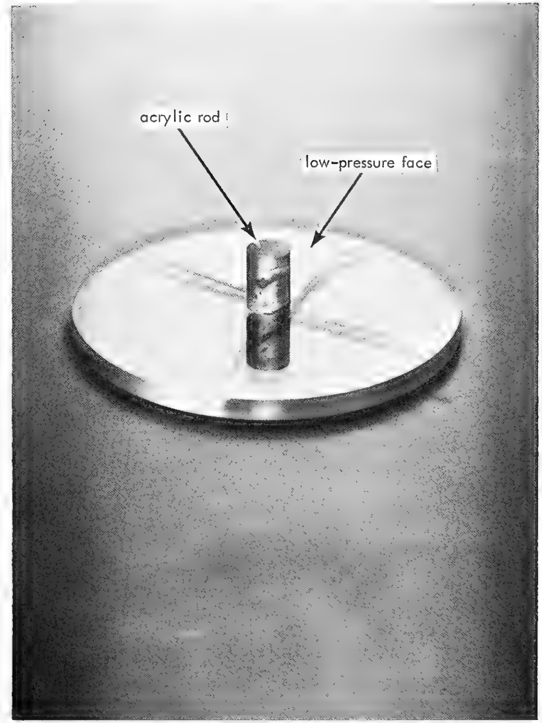


Figure B-2. Crack pattern in failed 0.122-inch-thick window with a t/D_i ratio of 0.081. Maximum pressurization 62 psi.

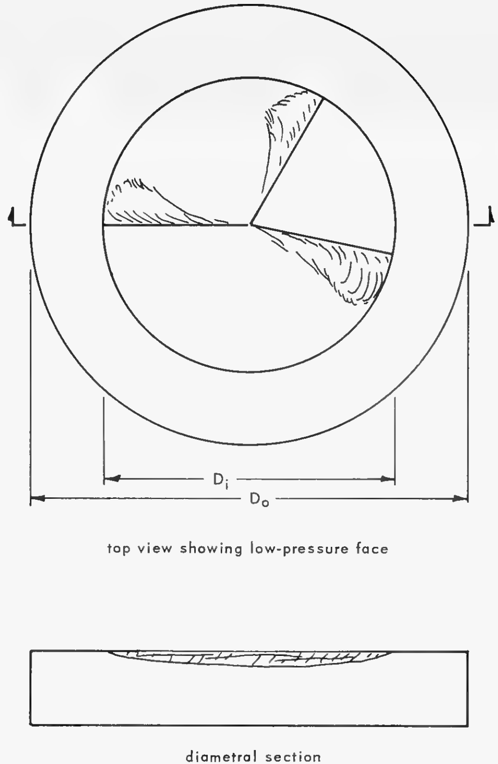


Figure B-3. Second stage conchoidal fracture pattern, early development.

Figure B-4. Conchoidal fracture pattern in partially failed 0.355-inch-thick window with a t/D_i ratio of 0.237. Maximum pressurization 2,990 psi.

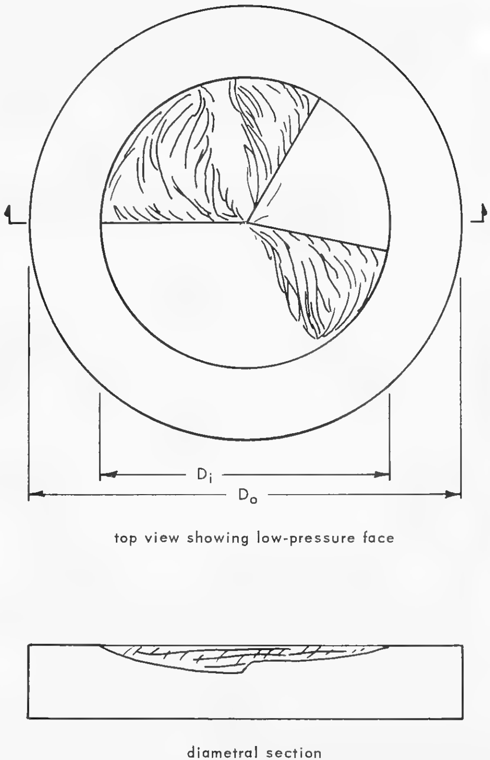


Figure B-5. Conchoidal fracture pattern, advanced stage of development.

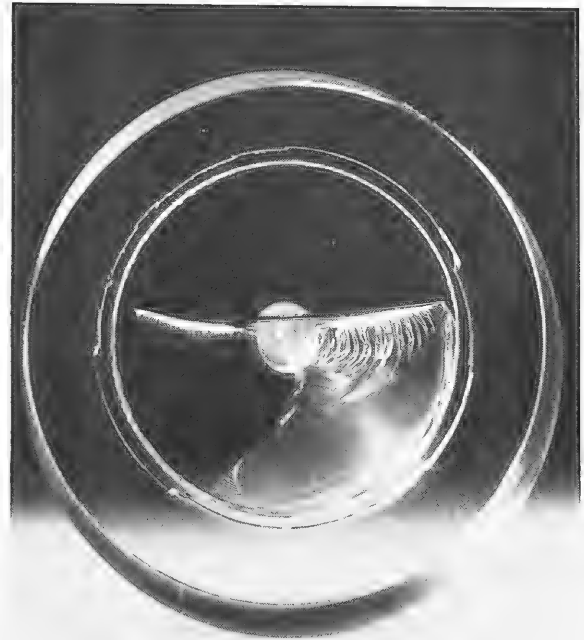


Figure B-6. Advanced stage of conchoidal fracture pattern in 0.857-inch-thick window with a t/D_i ratio of 0.572. Maximum pressurization 20,100 psi.

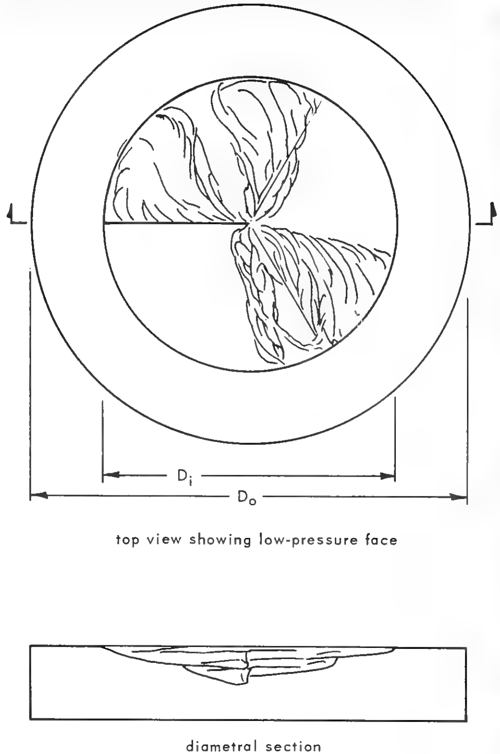


Figure B-7. Imminent coalescence of conchoidal fractures as critical pressure is approached.

Figure B-8. Coalescing conchoidal fractures just prior to failure in a 0.735-inch-thick window with a t/D_i ratio of 0.490; maximum pressurization 18,600 psi.

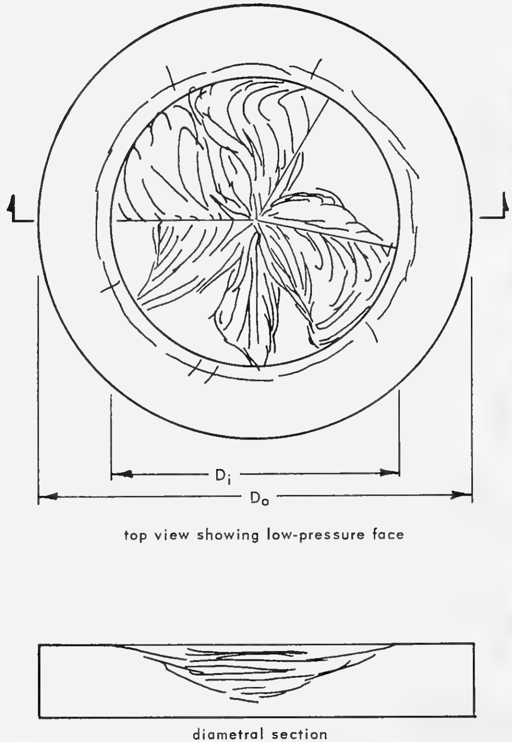


Figure B-9. An advanced stage of coalescence of conchoidal fractures as critical pressure is approached.

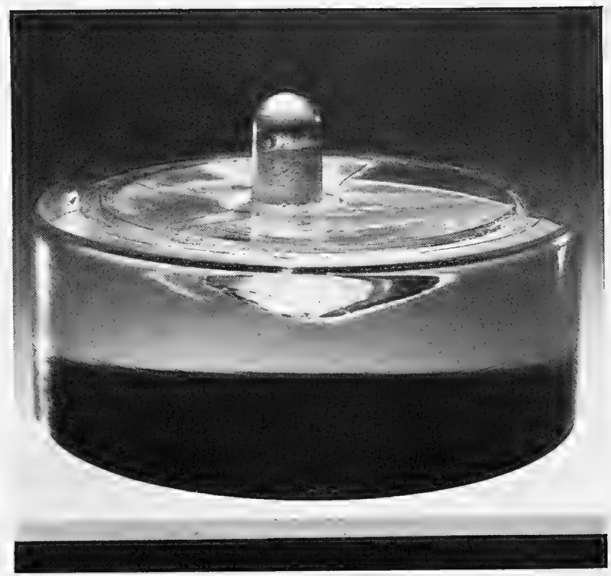


Figure B-10. A 0.735-inch-thick window with t/D_i ratio of 0.490 pressurized to 19,000 psi. Note extrusion at the window's D_i and penetration depth of the conchoidal fracture into the window.

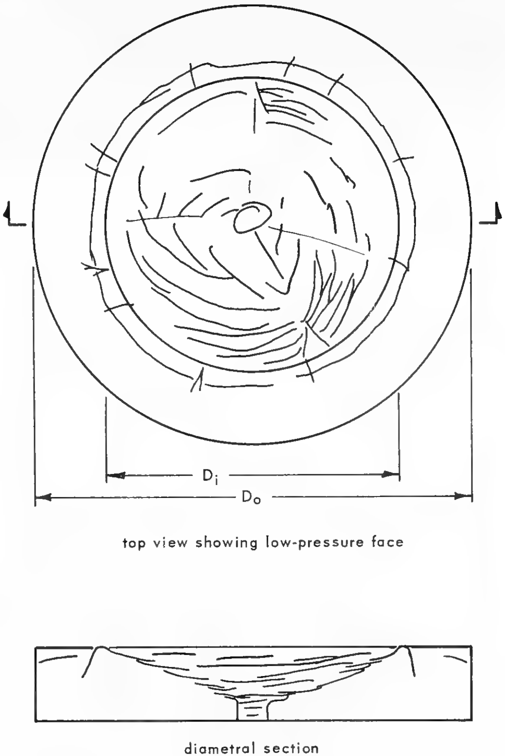


Figure B-11. The type of failure which follows complete coalescence of conical fracture surfaces.

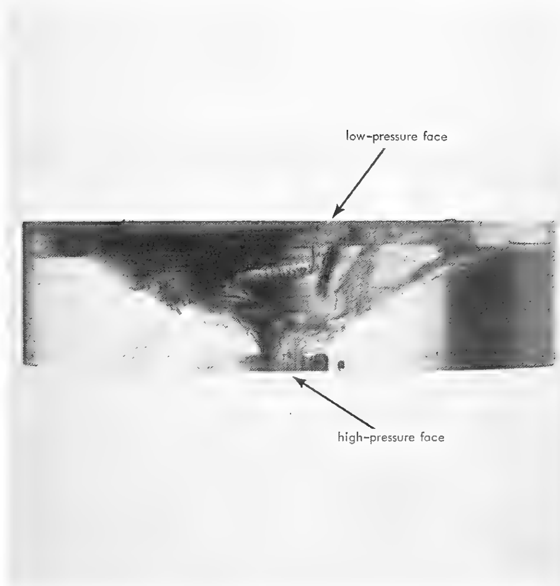


Figure B-12. A 0.600-inch-thick window with a t/D_i ratio of 0.400 which failed at 13,000 psi.

Considerable cold-flow cratering occurred on the high-pressure face before the critical pressure was reached (Figure B-13). Both elastic and plastic extrusion on the low-pressure face were also experienced by the window at this time (Figure B-14).

Windows whose t/D_i ratios exceeded about 0.50 failed predominately by shear; the conical fracture surface was unable to penetrate the thickness of the material (Figures B-15 and B-16). At the critical pressure, the entire window was penetrated by discontinuous cracks and the central portion (bounded by D_i) was completely ejected.

RESULTS OF TESTS

1.5-Inch (D_i) Windows

The 1.5-inch (D_i) windows were tested in groups of five; the nominal t/D_i ratios included the range from 0.083 to 0.667. For each group, critical pressure was plotted against the t/D_i ratio (Figure B-17) and pressure was plotted against the window's central displacement.

The windows having t/D_i ratios less than 0.2 exhibited both flexural and conical failures. Parametric considerations were the window's radial clearance, pressurization rate, and grease-seal thickness. No attempt was made to isolate these effects in this study.

For a t/D_i ratio between 0.2 and 0.4 the principal failure was conical, the cone's apex reaching the high-pressure face toward the upper limit of critical pressure (Figure B-12). Audible cracking during pressurization occurred mostly at levels above 75% of critical pressure and occurred fairly consistently between 90% of critical pressure and failure.

Windows of t/D_i ratios greater than 0.4 failed predominantly by shear, fragmentation being so complete that sometimes none of the window material was retained in the flange. Extrusion of these windows caused audible cracking to occur many times before critical pressure was reached. For t/D_i ratios of less than about 0.25 pressurization to approximately 70% of critical pressure resulted in no visible evidence (to the naked eye) that the windows had been pressurized. For t/D_i ratios between 0.25 and 0.55, the extrusion of the window at 70% of critical pressure caused a shallow impression of the flange seat to appear (Table B-1); however, on examination after release of pressure no visible impairment of optical quality inside this impression was apparent to the naked eye. For windows of t/D_i ratios greater than 0.55, the development of cracks accompanied extrusion and depression.

Details of flanges used in testing the 1.5-inch (D_i) windows are shown in Figure B-18 and an in-place schematic is shown in Figure B-19.

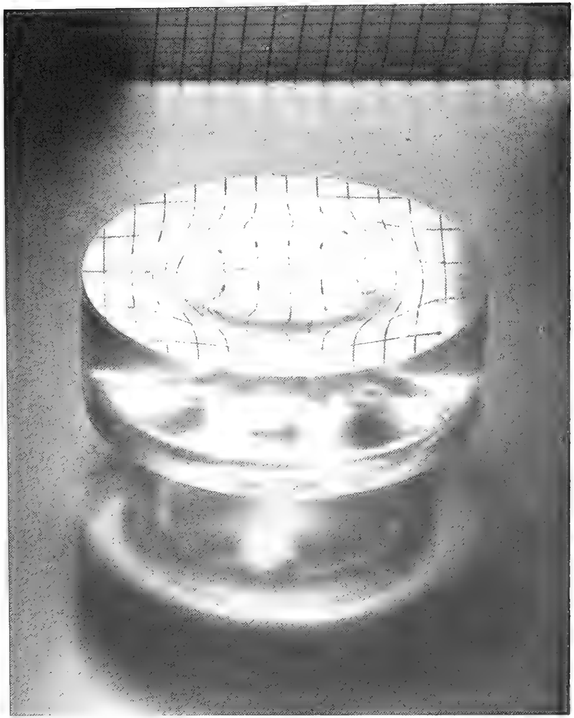


Figure B-13. Plastic flow cratering on the high-pressure side of a 0.735-inch-thick, 0.490 t/D_i ratio window subjected to 18,600 psi pressure.

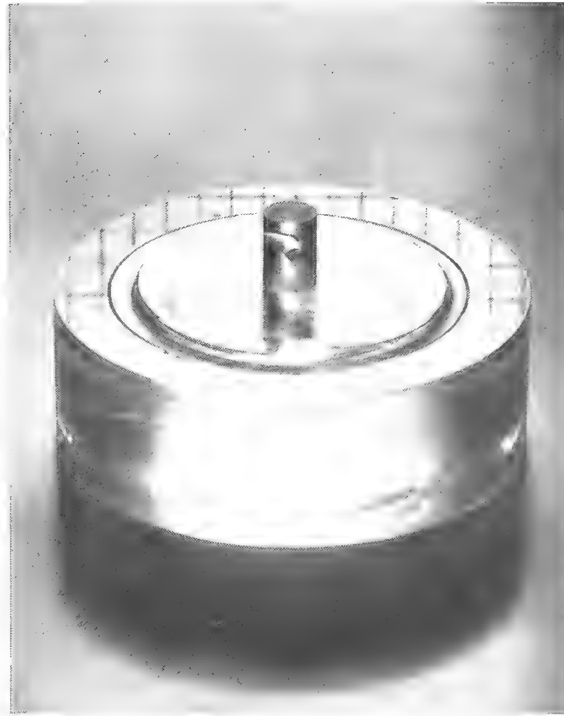


Figure B-14. Extrusion of the unsupported low-pressure face of a 0.735-inch-thick, 0.490 t/D_i ratio window subjected to 18,600 psi pressure.

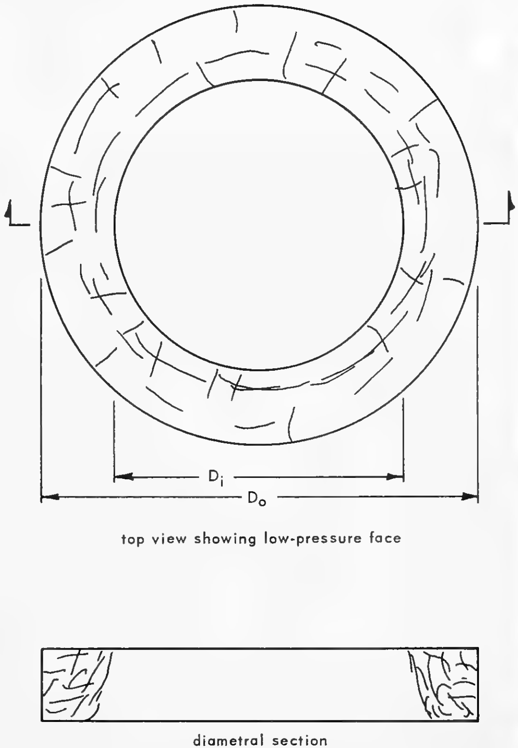


Figure B-15. Shear-type failure common to windows with large t/D_i ratios.

Figure B-16. Shear-type failure in a 1.432-inch-thick, 0.500 t/D_i ratio window which failed at 15,300 psi.

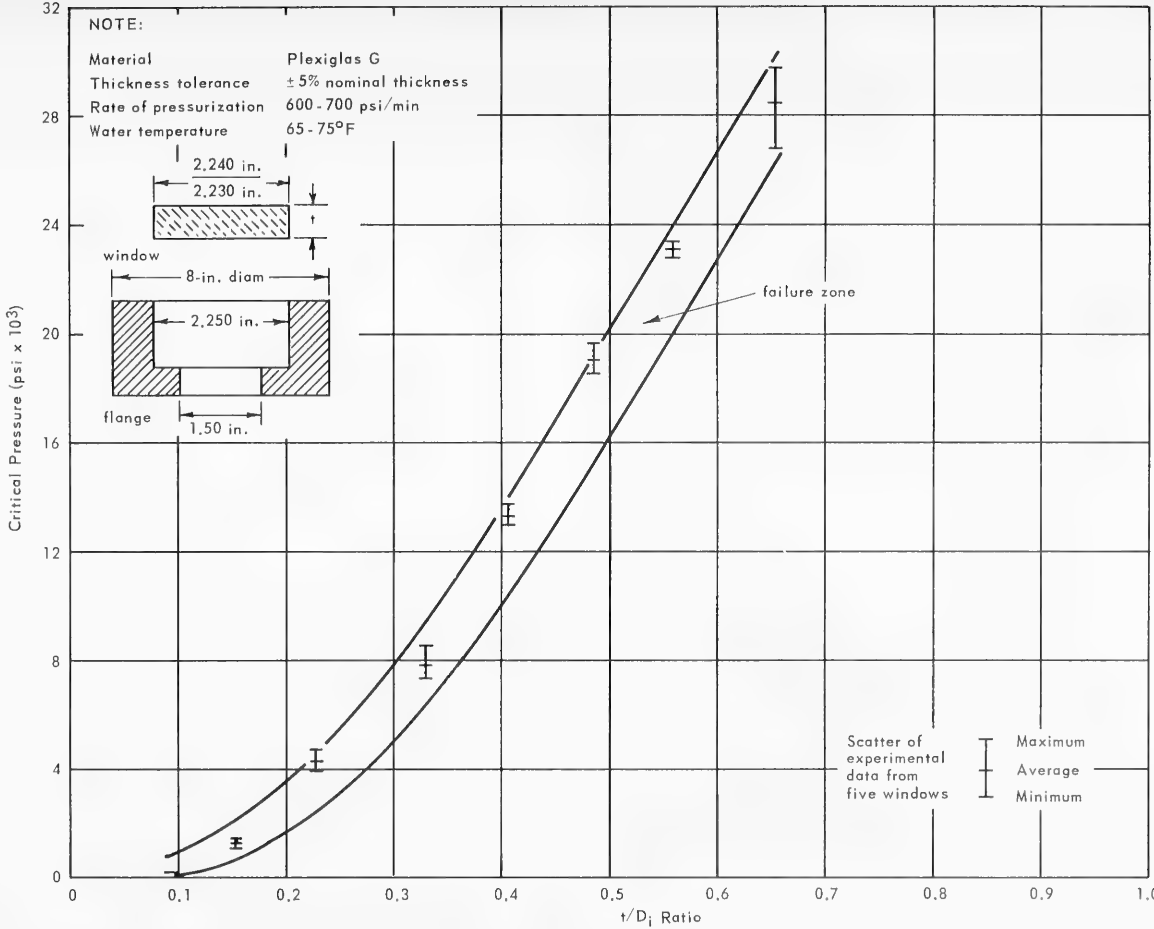


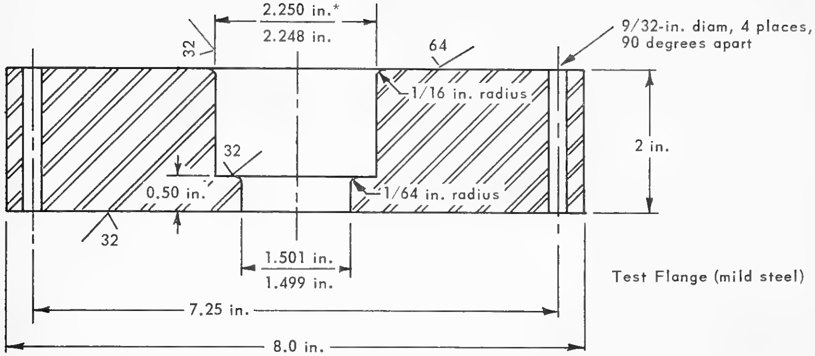
Figure B-17. Relationship between critical pressure and t/D_i ratio of 1.50-inch (D_i) flat acrylic windows.

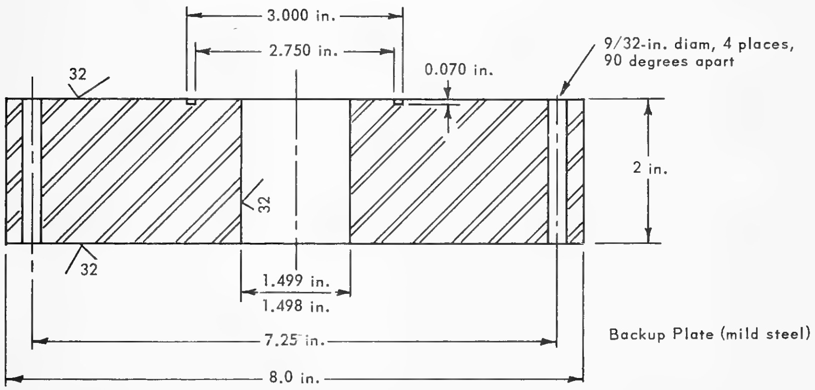
Table B-1. Extrusions of Some Flat Disk Windows Measured After Pressurization

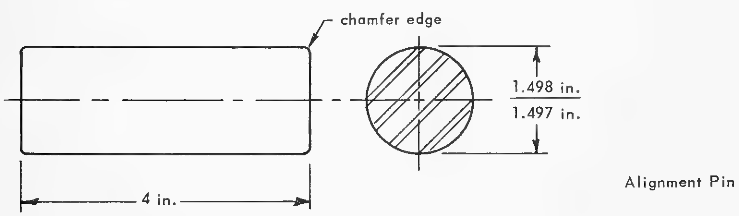
Specimen No.	t 1/	t/D_i Ratio	Measured 2/ Set (in.)	% of Group Average Critical Pressure
141	0.125	0.083	0.000	70
142	0.248	0.165	0.000	70
143	0.355	0.237	0.000	68
144	0.497	0.331	0.001	70
145	0.613	0.409	0.002	70
146	0.735	0.490	0.026	98
147	0.735	0.490	0.002	67 3/
148	0.857	0.572	0.011	87
149	0.982	0.655	0.024	92
150	0.983	0.655	0.029	85
151	0.121	0.036	0.000	70
152	0.349	0.102	0.000	70
153	0.607	0.182	0.000	65
154	0.848	0.254	0.000	70
155	1.130	0.339	0.004	70
156	1.452	0.436	0.003	70
157	2.000	0.600	0.004	68
158	1.991	0.598	0.034	99
159	2.008	0.602	0.037	98
160	0.233	0.058	0.000	64
161	0.455	0.107	0.000	63
162	0.968	0.242	0.000	59
163	1.987	0.496	0.002	55

1/ Thickness measured prior to pressurization.
2/ Measured 7 days after pressurization.
3/ See Figure B-26.

Note: The maximum pressure was immediately relieved by either (a) bleeding pressurized fluid from the vessel or (b) the development of leaks around the window caused by deformation of the window under pressure.







* Indicates maximum and minimum dimensions allowable.

Figure B-18. Details of flange assembly used to determine the relationship between the window's critical pressure and t/D_i ratio for 1.50-inch (D_i) windows.

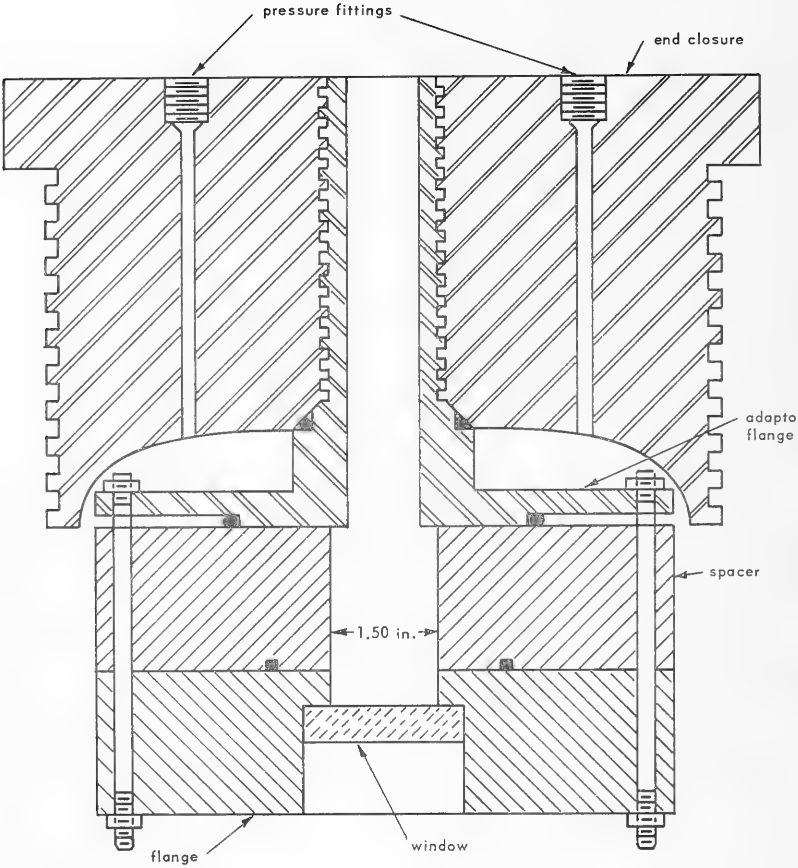


Figure B-19. Schematic of a typical window and flange test assembly secured to the end closure of a Mk I 9-inch pressure vessel.

3.33-Inch (D_i) Windows

The 3.33-inch (D_i) windows were tested in groups of five and had t/D_i ratios ranging from 0.036 to 0.600. For each group the critical pressure was plotted against the t/D_i ratio (Figure B-20) and the pressure was plotted against deflection.

Windows with t/D_i ratios of less than 0.1 exhibited both the conical and flexural failure modes, whereas windows with t/D_i ratios between 0.1 and 0.4 failed only in the conical fracture mode previously described. Concentric cracking was observed toward the upper t/D_i limit. These cracks propagated from the low-pressure face.

Shear failures were characteristic of windows whose t/D_i ratios were greater than about 0.4 (Figure B-16). Combined with the shear failure pattern were the various combinations of radial and circumferential cracks discontinuous throughout the window. Details of flanges used in testing the 3.33-inch (D_i) windows are shown in Figure B-21 and an in-place schematic is shown in Figure B-22.

4.00-Inch (D_i) Windows

The t/D_i ratios of the 4.00-inch (D_i) specimens ranged from 0.058 to 0.498. Four groups consisting of five windows each were used in the comparative study. Critical pressure was plotted against the t/D_i ratio (Figure B-23) and pressure was plotted against deflection.

Results of limited testing of 4.00-inch (D_i) windows were consistently comparable with those for the 1.50-inch, and 3.33-inch (D_i) specimens. Flexural and conical surface failures were witnessed for t/D_i ratios less than 0.1 and conical failures were observed for t/D_i ratios between 0.1 and about 0.4. Shear failure was dominant for t/D_i ratios greater than about 0.4.

Details of flanges used in testing the 4.00-inch (D_i) specimens are shown in Figure B-24 and an in-place schematic is shown in Figure B-25. Extrusion, retained as permanent set in the specimens (Figure B-26), is summarized in Table B-1 for specimens which were not pressurized to critical pressure.

SUMMARY

Failure mechanisms characteristic of the 1.50-inch (D_i) windows were found also to be characteristic of the 3.33-inch and 4.00-inch (D_i) windows so long as t/D_i ratios were similar. Critical pressures derived from testing of windows having a different D_i in the DOL type III flange design were found to be comparable so long as the D_o/D_i ratio was maintained at 1.5, temperatures were within the 65°F to 75°F range, and the radial clearance was kept to less than 0.010 inch.

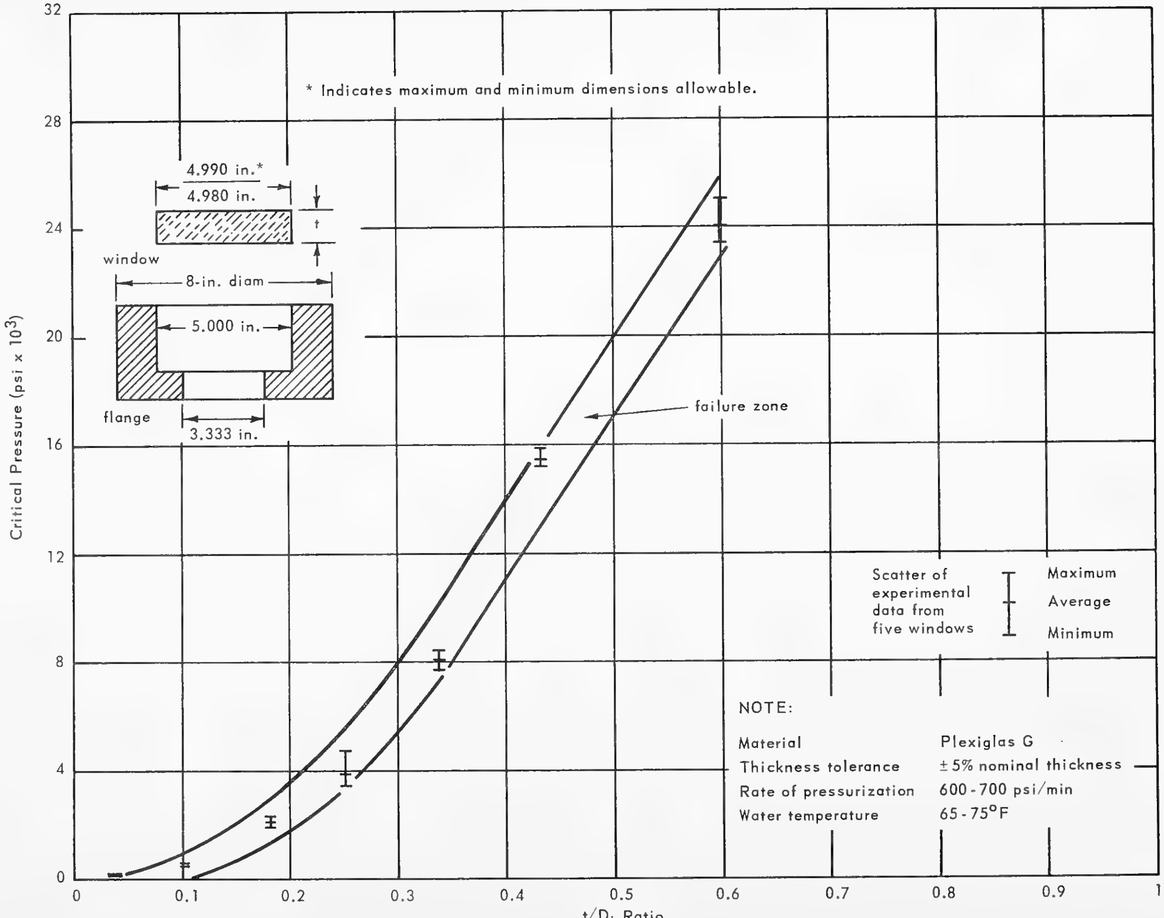


Figure B-20. Relationship between critical pressure and t/D_i ratio of 3.33-inch (D_i) flat acrylic windows.

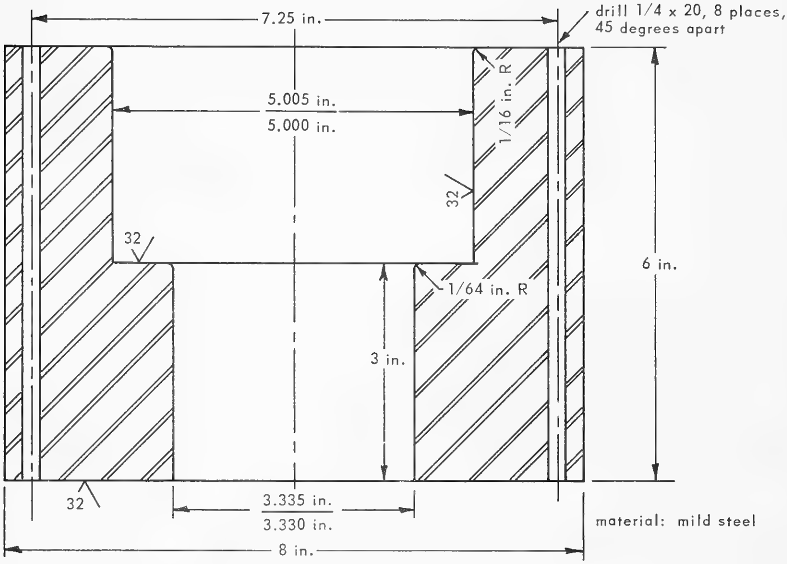


Figure B-21. Details of assembly used to determine the relationship between the window's critical pressure and t/D_i ratio for 3.33-inch (D_i) windows.

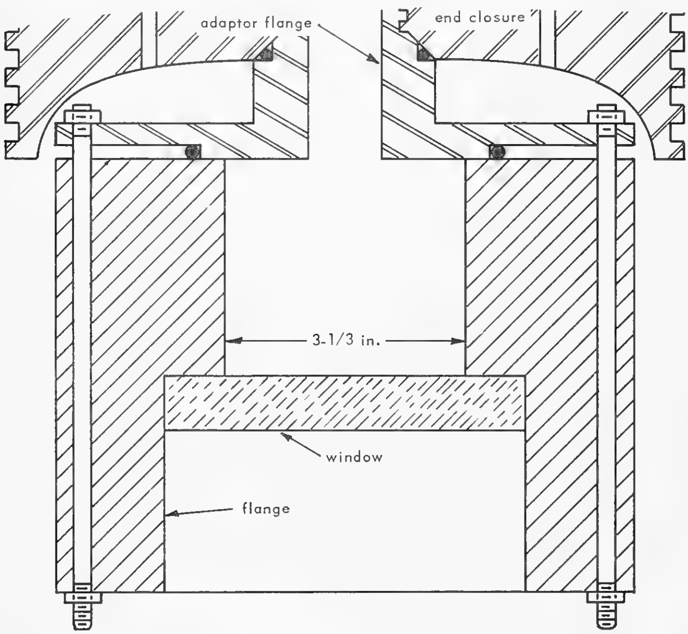


Figure B-22. Schematic of 3.33-inch (D_i) window and flange in end closure of Mk I 9-inch pressure vessel.

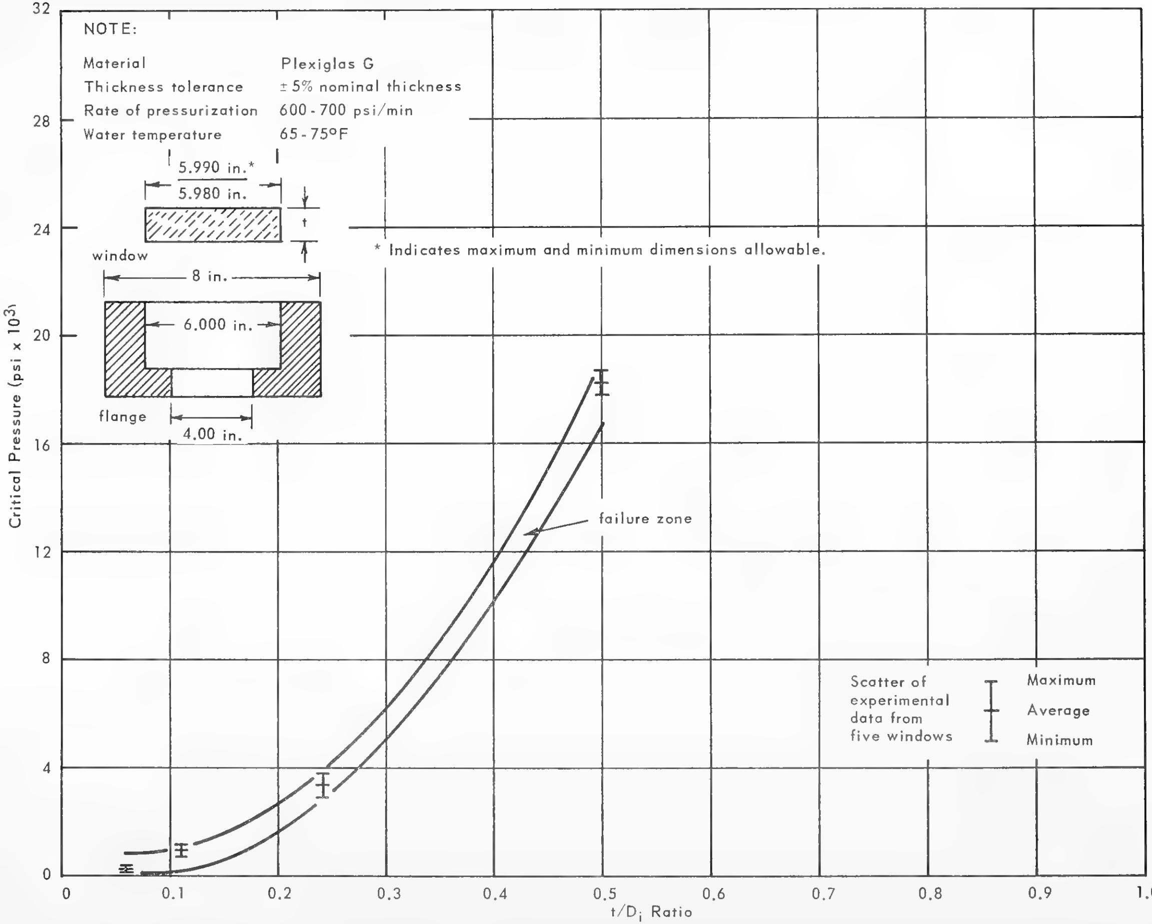


Figure B-23. Relationship between the critical pressure and t/D_i ratio of 4.00-inch (D_i) flat acrylic windows.

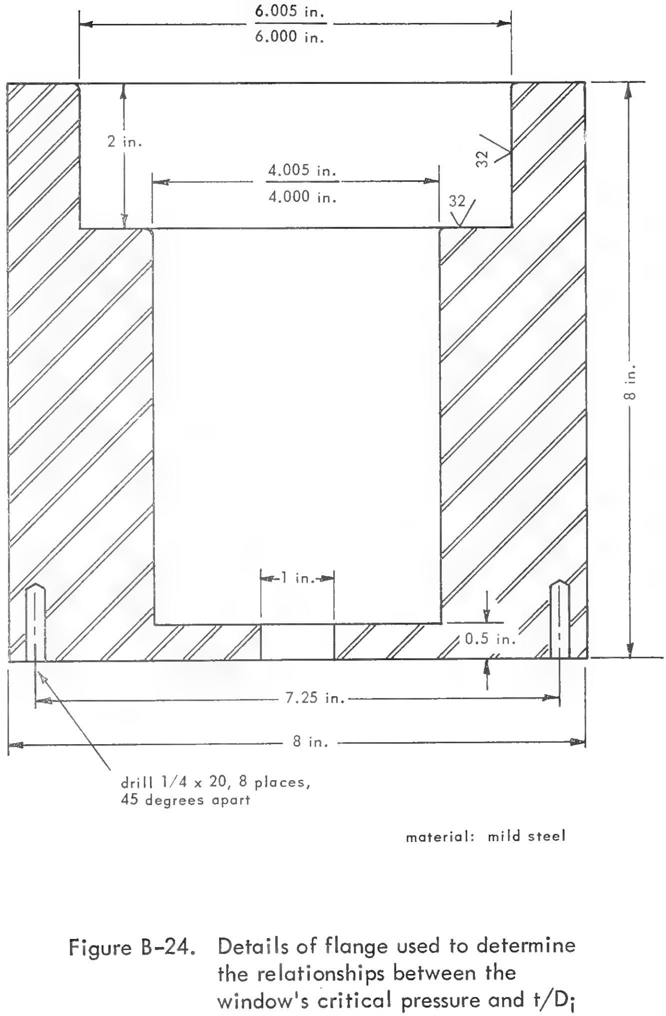


Figure B-24. Details of flange used to determine the relationships between the window's critical pressure and t/D_i ratio for 4.00-inch (D_i) windows.

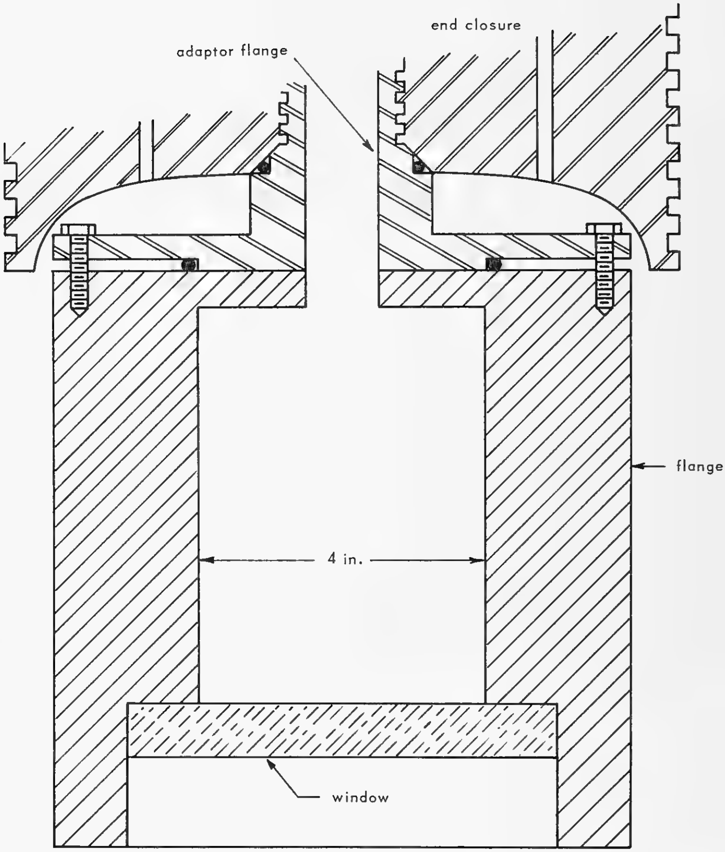


Figure B-25. Schematic of 4.00-inch (D_i) window and test flange assembled to the end closure of the Mk I 9-inch pressure vessel.

Figure B-26. Permanent extrusion of low-pressure face of a flat acrylic window having a 0.490 t/D_i ratio; window pressurized to 67% of ultimate critical pressure.

Appendix C

AXIAL DISPLACEMENT AND CRITICAL PRESSURES OF FLAT ACRYLIC WINDOWS SUBJECTED TO HYDROSTATIC PRESSURE IN DOL TYPE III FLANGES

Table C-1. Hydrostatic Test Data for Nominal 1.50-Inch (D_i) - 2.00-Inch (D_o) Flat Acrylic Windows, Test Specimens 1 - 5

(Sealed with grease; radial clearance 0.020 to 0.030 inch; nominal D_o/D_i ratio 1.33)

Parameter	Specimen Number					Value		
	1	2	3	4	5	Max	Avg	Min
Thickness (in.)	0.735	0.744	0.741	0.730	0.744	0.744	0.739	0.730
D_o (actual, in.)	1.960	1.950	1.955	1.951	1.945	1.960	1.952	1.945
Temperature (°F)	66.0	66.5	64.5	63.5	65.5	66.5	65.3	63.5
t/D_i Ratio (actual)	0.490	0.496	0.493	0.487	0.496	0.496	0.492	0.487
Pressurization Rate (psi/min)	686	662	783	665	1,201[1/]	783	699	662
Pressure (psi)	Axial Displacement of Center Point on Window's Low-Pressure Face (in.)							
1,000		0.001	0.001	0.001	0.002	0.002	0.001	0.001
2,000	0.001	0.003	0.003	0.003	0.005	0.005	0.003	0.001
3,000		0.005	0.005	0.009	0.008	0.009	0.007	0.005
4,000	0.005	0.008	0.007	0.015	0.012	0.015	0.009	0.005
5,000	0.007	0.009	0.008	0.020	0.015	0.020	0.012	0.007
6,000	0.008	0.011	0.010	0.025	0.021	0.025	0.015	0.008
7,000	0.010	0.013	0.011	0.032	0.027	0.032	0.019	0.010
8,000	0.011	0.015	0.013	0.036	0.032	0.036	0.022	0.013
9,000	0.014	0.018	0.031	0.042	0.038	0.042	0.030	0.018
10,000	0.019	0.022	0.032	0.048	0.044	0.048	0.034	0.022
11,000	0.026	0.030	0.034	0.055	0.050	0.055	0.041	0.030
12,000	0.035	0.037	0.036	0.064	0.058	0.064	0.048	0.036
13,000	0.045	0.043	0.054	0.076	0.065	0.076	0.059	0.043
14,000	0.055	0.050		0.086	0.075	0.086	0.071	0.050
15,000	0.074	0.060		0.099	0.086	0.099	0.084	0.060
16,000	0.091	0.087		0.112	0.109	0.112	0.100	0.087
17,000	0.127	0.107		0.127	0.127	0.127	0.120	0.107
18,000		0.137		0.160	0.165	0.165	0.154	0.137
Pressure at Failure (psi)	17,500	18,600	18,600	18,900	18,850	18,900	18,490	17,500

1/ Not included in average pressure value.

Table C-2. Hydrostatic Test Data for Nominal 1.50-Inch (D_i) - 2.00-Inch (D_o) Flat Acrylic Windows, Test Specimens 6 - 10

(Sealed with O-ring; radial clearance 0.0005 to 0.0010 inch; nominal D_o/D_i ratio 1.33)

Parameter	Specimen Number					Value		
	6	7	8	9	10	Max	Avg	Min
Thickness (in.)	0.749	0.745	0.729	0.747	0.733	0.749	0.741	0.729
D_o (actual, in.)	1.999	1.998	1.999	1.988	1.988	1.999	1.998	1.998
Temperature (°F)	65.0	67.5	62.5	64.5	65.5	67.5	65.0	62.5
t/D_i Ratio (actual)	0.499	0.496	0.486	0.498	0.488	0.499	0.493	0.486
Pressurization Rate (psi/min)	668	664	655	651	657	668	661	651
Pressure (psi)	Axial Displacement of Center Point on Window's Low-Pressure Face (in.)							
1,000	0.002	0.001	0.003	0.003	0.002	0.003	0.002	0.001
2,000	0.003	0.006	0.004	0.006	0.008	0.008	0.005	0.003
3,000	0.005	0.010	0.005	0.008	0.014	0.014	0.008	0.005
4,000	0.012	0.011	0.007	0.010	0.020	0.020	0.012	0.007
5,000	0.013	0.021	0.009	0.013	0.024	0.024	0.016	0.009
6,000	0.023	0.026	0.011	0.015	0.030	0.030	0.021	0.011
7,000	0.024	0.032	0.012	0.017	0.033	0.033	0.024	0.012
8,000	0.033	0.038	0.014	0.019	0.039	0.039	0.029	0.014
9,000	0.034	0.043	0.016	0.021	0.044	0.044	0.032	0.016
10,000	0.045	0.049	0.018	0.023	0.050	0.050	0.037	0.018
11,000	0.047	0.054	0.021	0.026	0.058	0.058	0.041	0.021
12,000	0.056	0.063	0.023	0.029	0.065	0.065	0.047	0.023
13,000	0.064	0.070	0.026	0.031	0.074	0.074	0.053	0.026
14,000	0.075	0.081	0.035	0.042	0.083	0.083	0.063	0.035
15,000	0.085	0.091	0.039	0.046	0.096	0.096	0.071	0.039
16,000	0.096	0.103	0.058	0.062	0.110	0.110	0.086	0.058
17,000	0.110	0.122	0.083	0.080	0.137	0.137	0.106	0.083
18,000	0.146	0.155	0.114	0.110	0.185	0.185	0.142	0.110
19,000	0.206	0.206					0.206	
Pressure at Failure (psi)	19,450	19,150	19,000	18,850	18,850	19,450	19,060	18,850

Table C-3. Hydrostatic Test Data for Nominal 1.50-Inch (D_i) - 2.00-Inch (D_o) Flat Acrylic Windows, Test Specimens 11 - 15

(Sealed with grease; radial clearance 0.145 to 0.155 inch; nominal D_o/D_i ratio 1.33)

Parameter	Specimen Number					Value		
	11	12	13	14	15	Max	Avg	Min
Thickness (in.)	0.753	0.743	0.735	0.743	0.734	0.753	0.742	0.734
D_o (actual, in.)	1.960	1.955	1.950	1.945	1.951	1.960	1.952	1.945
Temperature (°F)	69.0	69.0	68.5	69.1	67.2	69.1	68.6	67.2
t/D_i Ratio (actual)	0.502	0.495	0.490	0.495	0.489	0.502	0.494	0.489
Pressurization Rate (psi/min)	665	791	659	665	670	791	690	659
Pressure (psi)	Axial Displacement of Center Point on Window's Low-Pressure Face (in.)							
1,000	0.001	0.001	0.001	0.002	0.001	0.002	0.001	0.001
2,000	0.002	0.002	0.003	0.003	0.003	0.003	0.003	0.002
3,000	0.004	0.003	0.005	0.004	0.005	0.005	0.004	0.003
4,000	0.005	0.005	0.006	0.006	0.006	0.006	0.006	0.005
5,000	0.006	0.006	0.007	0.008	0.007	0.008	0.007	0.006
6,000	0.007	0.008	0.009	0.009	0.009	0.009	0.008	0.007
7,000	0.009	0.009	0.010	0.011	0.010	0.011	0.010	0.009
8,000	0.012	0.011	0.012	0.013	0.012	0.013	0.012	0.011
9,000	0.013	0.013	0.014	0.014	0.014	0.014	0.014	0.013
10,000	0.014	0.015	0.016	0.017	0.016	0.017	0.016	0.014
11,000	0.015	0.017	0.018	0.019	0.018	0.019	0.017	0.015
12,000	0.019	0.020	0.020	0.021	0.020	0.021	0.020	0.019
13,000	0.022	0.024	0.023	0.027	0.037	0.037	0.022	0.022
14,000	0.025	0.040	0.038	0.033	0.040	0.040	0.035	0.025
15,000		0.059	0.068	0.050	0.044	0.068	0.055	0.044
16,000		0.090		0.069	0.079	0.090	0.079	0.069
17,000				0.100				
18,000								
Pressure at Failure (psi)	17,700	16,700	15,650	17,900	16,850	17,900	16,960	15,650

Table C-4. Hydrostatic Test Data for Nominal 1.50-Inch (D_i) - 2.25-Inch (D_o) Flat Acrylic Windows, Test Specimens 16 - 20

(Sealed with grease; radial clearance 0.005 to 0.010 inch; nominal D_o/D_i ratio 1.5)

Parameter	Specimen Number					Value		
	16	17	18	19	20	Max	Avg	Min
Thickness (in.)	0.123	0.112	0.117	0.115	0.120	0.123	0.117	0.117
D_o (actual, in.)	2.245	2.243	2.240	2.238	2.241	2.245	2.241	2.238
Temperature (°F)		68	68	68	69	69	68	68
t/D_i Ratio (actual)	0.082	0.075	0.078	0.077	0.080	0.082	0.079	0.075
Pressurization Rate (psi/min)	153	200	292	144	480	480	254	144
Pressure (psi)	Axial Displacement of Center Point on Window's Low-Pressure Face (in.)							
50	0.010	0.026	0.014	0.027	0.017	0.027	0.019	0.010
100	0.017	0.042	0.030	0.047	0.038	0.047	0.035	0.017
150			0.036		0.046	0.046	0.041	0.036
200			0.041		0.050	0.050	0.046	0.041
250			0.051		0.052	0.052	0.051	0.051
300			0.057		0.057	0.057	0.057	0.057
350					0.063			
400					0.073			
450					0.083			
Displacement at Failure (in.)	0.067	0.060	0.050		0.083	0.083	0.065	0.050
Pressure at Failure (psi)	147	160	338	124	450	450	244	124

Notes:

1. Pressurized slowly to facilitate taking displacement data.
2. Grease sealing and pressurization procedure may have caused erratic results.

Table C-5. Hydrostatic Test Data for Nominal 1.50-Inch (D_i) - 2.25-Inch (D_o) Flat Acrylic Windows, Test Specimens 21 - 25

(Sealed with grease; radial clearance 0.002 to 0.005 inch; nominal D_o/D_i ratio 1.5)

Parameter	Specimen Number					Value		
	21	22	23	24	25	Max	Avg	Min
Thickness (in.)	0.121	0.119	0.119	0.119	0.119	0.121	0.119	0.119
D_o (actual, in.)	2.245	2.244	2.246	2.247	2.246	2.247	2.246	2.244
Temperature (°F)	70	70	70	70	70	70	70	70
t/D_i Ratio (actual)	0.081	0.079	0.079	0.079	0.079	0.081	0.079	0.079
Pressurization Rate (psi/min)	310	293	429	272	326	429	326	272
Pressure (psi)	Axial Displacement of Center Point on Window's Low-Pressure Face (in.)							
50	0.012	0.021	0.008	0.033	0.030	0.033	0.021	0.008
100					0.047		0.047	
150								
200								
Displacement at Failure (in.)	0.028	0.038		0.044	0.049	0.049	0.040	0.028
Pressure at Failure (psi)	90	85	60	79	111	111	85	60

Note: Grease seal was thin.

Table C-6. Hydrostatic Test Data for Nominal 1.50-Inch (D_i) - 2.25-Inch (D_o) Flat Acrylic Windows, Test Specimens 26 - 30

(Sealed with grease; radial clearance 0.002 to 0.005 inch; nominal D_o/D_i ratio 1.5)

Parameter	Specimen Number					Value		
	26	27	28	29	30	Max	Avg	Min
Thickness (in.)	0.122	0.121	0.123	0.124	0.126	0.126	0.123	0.121
D_o (actual, in.)	2.246	2.246	2.245	2.247	2.246	2.247	2.246	2.245
Temperature (°F)	66	67	67	67	68	68	67	66
t/D_i ratio (actual)	0.081	0.081	0.082	0.083	0.084	0.084	0.082	0.081
Pressurization Rate (psi/min)	162	188	210	173		210	183	162
Pressure (psi)	Axial Displacement of Center Point on Window's Low-Pressure Face (in.)							
50	0.003	0.035	0.035	0.012	0.023	0.035	0.021	0.003
100					0.045		0.045	
Displacement at Failure (in.)	0.045	0.043	0.039	0.037	0.050	0.050	0.043	0.037
Pressure at Failure (psi)	74	62	61	83	129	129	94	61

Note: Grease liberally applied.

Table C-7. Hydrostatic Test Data for Nominal 1.50-Inch (D_i) - 2.25-Inch (D_o) Flat Acrylic Windows, Test Specimens 31 - 35

(Sealed with grease; radial clearance 0.005 to 0.010 inch; nominal D_o/D_i ratio 1.5)

Parameter	Specimen Number					Value		
	31	32	33	34	35	Max	Avg	Min
Thickness (in.)	0.236	0.234	0.238	0.231	0.229	0.238	0.234	0.229
D_o (actual, in.)	2.238	2.238	2.236	2.237	2.236	2.238	2.237	2.236
Temperature (°F)	68	69	70	65	66	70	68	65
t/D_i Ratio (actual)	0.157	0.156	0.158	0.154	0.153	0.158	0.156	0.153
Pressurization Rate (psi/min)	682	712	675	685	648	712	680	648
Pressure (psi)	Axial Displacement of Center Point on Window's Low-Pressure Face (in.)							
200	0.003	0.001	0.001	0.002	0.001	0.003	0.002	0.001
400	0.010	0.012	0.001	0.007	0.001	0.012	0.006	0.001
600	0.015	0.017	0.015	0.015	0.002	0.017	0.013	0.002
800	0.023	0.024	0.015	0.022	0.010	0.024	0.019	0.010
1,000	0.031	0.029	0.026	0.030	0.060	0.060	0.035	0.026
1,200	0.075	0.037		0.040		0.075	0.051	0.037
1,400	0.098							
1,600								
Pressure at Failure (psi)	1,430	1,210	1,140	1,320	1,100	1,430	1,240	1,100

Note: Erratic deflection.

Table C-8. Hydrostatic Test Data for Nominal 1.50-Inch (D_i) - 2.25-Inch (D_o) Flat Acrylic Windows, Test Specimens 36 - 40

(Sealed with grease; radial clearance 0.005 to 0.010 inch; nominal D_o/D_i ratio 1.5)

Parameter	Specimen Number					Value		
	118	119	120	121	122	Max	Avg	Min
Thickness (in.)	0.235	0.237	0.240	0.237	0.234	0.240	0.237	0.234
D_o (actual, in.)	2.239	2.237	2.240	2.237	2.240	2.240	2.239	2.237
Temperature (°F)	70	68	69	68	69	70	69	68
t/D_i Ratio (actual)	0.157	0.158	0.160	0.158	0.156	0.160	0.158	0.156
Pressurization Rate (psi/min)	590	497	524	627	560	627	560	497
Pressure (psi)	Axial Displacement of Center Point on Window's Low-Pressure Face (in.)							
100	0.002	0.005	0.001	0.002	0.004	0.005	0.003	0.001
200	0.006	0.007	0.002	0.002	0.006	0.007	0.005	0.002
300	0.007	0.010	0.002	0.002	0.008	0.010	0.006	0.002
400	0.009	0.014	0.003	0.003	0.011	0.014	0.011	0.003
500	0.013	0.017	0.003	0.004	0.015	0.017	0.010	0.003
600	0.016		0.009	0.009	0.018	0.018	0.014	0.009
700	0.019		0.012	0.012		0.019	0.014	0.012
800	0.024							
900								
1,000								
Displacement at Failure (in.)	0.046	0.045	0.048	0.053	0.064	0.064	0.051	0.045
Pressure at Failure (psi)	840	642	733	702	695	840	723	642

Notes:

1. Thin grease seal coating.
2. Amount of cement used on deflection pin may have significant effect on thin windows.

Table C-9. Hydrostatic Test Data for Nominal 1.50-Inch (D_i) - 2.25-Inch (D_o) Flat Acrylic Windows, Test Specimens 41 - 45

(Sealed with grease; radial clearance 0.000 to 0.005 inch; nominal D_o/D_i ratio 1.5)

Parameter	Specimen Number					Value		
	41	42	43	44	45	Max	Avg	Min
Thickness (in.)	0.243	0.246	0.249	0.248	0.249	0.249	0.247	0.243
D_o (actual, in.)	2.249	2.246	2.247	2.249	2.248	2.249	2.248	2.246
Temperature (°F)	66	68	68	67	66	68	67	66
t/D_i Ratio (actual)	0.162	0.164	0.166	0.165	0.166	0.166	0.165	0.162
Pressurization Rate (psi/min)	560	482	673	648	633	673	599	482
Pressure (psi)	Axial Displacement of Center Point on Window's Low-Pressure Face (in.)							
100	0.001	0.000	0.001	0.001	0.001	0.001	0.001	0.000
200	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001
300	0.001	0.012	0.009	0.001	0.001	0.012	0.005	0.001
400	0.002	0.017	0.010	0.002	0.002	0.017	0.007	0.002
500	0.002	0.021	0.016	0.002	0.002	0.021	0.009	0.002
600	0.002	0.024	0.018	0.011	0.003	0.024	0.012	0.002
700	0.003	0.028	0.023	0.012	0.003	0.028	0.013	0.003
800	0.020	0.051	0.024	0.019	0.011	0.051	0.025	0.011
900	0.021	0.055	0.034	0.029	0.014	0.055	0.031	0.014
1,000	0.026	0.059	0.051	0.030	0.040	0.059	0.041	0.026
1,100		0.064	0.057	0.046	0.040	0.064	0.052	0.040
1,200		0.067	0.064	0.046	0.047	0.067	0.056	0.046
1,300	abort	0.075	0.064	0.054	0.047	0.075	0.060	0.047
1,400		0.083	0.072	0.055	0.052	0.083	0.066	0.052
1,500		0.088	0.072	0.063	0.058	0.088	0.070	0.058
1,600		0.092	0.079	0.063	0.062	0.092	0.074	0.062
1,700		0.096	0.086	0.071	0.070	0.096	0.081	0.070
1,800		0.102	0.086	0.071	0.073	0.102	0.083	0.071
1,900		0.124	0.093	0.078	0.078	0.124	0.093	0.078
2,000		0.139	0.099	0.085	0.081	0.139	0.101	0.081
2,100			0.100	0.085	0.088		0.091	
2,200					0.093			
Displacement at Failure (in.)		0.142	0.100	0.085	0.093	0.142	0.105	0.085
Pressure at Failure (psi)		2,000	2,100	2,100	2,200	2,200	2,100	2,000

Notes:

1. Abort caused by use of 1,000-psi gage.
2. Grease liberally applied.
3. Audible cracking at about 900 psi and 1,600 psi.

Table C-10. Hydrostatic Test Data for Nominal 1.50-Inch (D_i) - 2.25-Inch (D_o) Flat Acrylic Windows, Test Specimens 46 - 50

(Sealed with grease; radial clearance 0.005 to 0.010 inch; nominal D_o/D_i ratio 1.5)

Parameter	Specimen Number					Value		
	46	47	48	49	50	Max	Avg	Min
Thickness (in.)	0.338	0.342	0.344	0.341	0.344	0.344	0.342	0.338
D_o (actual, in.)	2.240	2.242	2.238	2.241	2.241	2.242	2.240	2.238
Temperature (°F)	67	67	69	65	65	69	67	65
t/D_i Ratio (actual)	0.225	0.228	0.229	0.227	0.229	0.229	0.228	0.225
Pressurization Rate (psi/min)	660	668	660	665	685	685	668	660
Pressure (psi)	Axial Displacement of Center Point on Window's Low-Pressure Face (in.)							
500	0.003	0.002	0.001	0.001	0.008	0.008	0.003	0.001
1,000	0.011	0.003	0.011	0.002	0.015	0.015	0.009	0.003
1,500	0.037	0.007	0.016	0.022	0.023	0.037	0.021	0.007
2,000	0.052	0.036	0.036	0.030	0.031	0.052	0.037	0.030
2,500	0.067	0.052	0.067	0.059	0.056	0.067	0.060	0.052
3,000	0.085	0.063	0.085	0.072	0.087	0.087	0.078	0.063
3,500	0.106	0.077	0.103	0.089	0.105	0.106	0.096	0.077
4,000	0.134	0.095	0.123		0.121	0.134	0.103	0.095
4,500					0.148			
5,000								
Displacement at Failure (in.)		0.119	0.148	0.106	0.161	0.161	0.134	0.106
Pressure at Failure (psi)	4,100	4,400	4,225	3,950	4,700	4,700	4,275	3,950

Note: Grease liberally applied.

Table C-11. Hydrostatic Test Data for Nominal 1.50-Inch (D_i) - 2.25-Inch (D_o) Flat Acrylic Windows, Test Specimens 51 - 55

(Sealed with grease; radial clearance 0.005 to 0.010 inch; nominal D_o/D_i ratio 1.5)

Parameter	Specimen Number					Value		
	51	52	53	54	55	Max	Avg	Min
Thickness (in.)	0.496	0.497	0.496	0.499	0.497	0.499	0.497	0.496
D_o (actual, in.)	2.237	2.240	2.237	2.237	2.238	2.240	2.238	2.237
Temperature (°F)	69	66	68	68	68	69	68	66
t/D_i Ratio (actual)	0.330	0.331	0.330	0.333	0.331	0.333	0.331	0.330
Pressurization Rate (psi/min)	680	695	689	662	670	695	679	662
Pressure (psi)	Axial Displacement of Center Point on Window's Low-Pressure Face (in.)							
1,000	0.003	0.001	0.001	0.001	0.003	0.003	0.002	0.001
2,000	0.014	0.007	0.012	0.002	0.010	0.014	0.009	0.002
3,000	0.022	0.016	0.018	0.012	0.018	0.022	0.017	0.012
4,000	0.029	0.023	0.028	0.021	0.027	0.029	0.026	0.021
5,000	0.040	0.036	0.036	0.031	0.036	0.040	0.036	0.031
6,000	0.077	0.053	0.065	0.040	0.062	0.077	0.059	0.040
7,000	1/	0.088	0.085	0.052	0.088	0.088	0.079	0.052
8,000		0.120	0.119		1/	0.120	0.120	0.119
9,000								
10,000								
Displacement at Failure (in.)		0.152	0.146	0.122		0.152	0.130	0.122
Pressure at Failure (psi)	7,300	8,550	8,450	7,450	7,300	8,550	7,810	7,300

1/ Deflection wire became disengaged.

Notes:

1. Grease liberally applied.
2. 500-psi preload.
3. Audible cracking at about 7,000 psi.

Table C-12. Hydrostatic Test Data for Nominal 1.50-Inch (D_i) - 2.25-Inch (D_o) Flat Acrylic Windows, Test Specimens 56 - 60

(Sealed with grease; radial clearance 0.005 to 0.010 inch; nominal D_o/D_i ratio 1.5)

Parameter	Specimen Number					Value		
	56	57	58	59	60	Max	Avg	Min
Thickness (in.)	0.607	0.604	0.622	0.620	0.600	0.622	0.611	0.600
D_o (actual, in.)	2.240	2.239	2.240	2.239	2.237	2.240	2.239	2.237
Temperature (°F)	68	67	68	68	64	68	67	64
t/D_i Ratio (actual)	0.405	0.402	0.414	0.413	0.400	0.414	0.407	0.400
Pressurization Rate (psi/min)	670	665	665	668	663	670	666	663
Pressure (psi)	Axial Displacement of Center Point on Window's Low-Pressure Face (in.)							
1,000	0.002	0.009	0.011	0.004	0.001	0.011	0.005	0.001
2,000	0.003	0.015	0.019	0.012	0.009	0.019	0.012	0.003
3,000	0.008	0.021	0.024	0.019	0.012	0.024	0.019	0.008
4,000	0.015	0.028	0.030	0.025	0.023	0.030	0.024	0.015
5,000	0.021	0.037	0.039	0.031	0.030	0.039	0.031	0.021
6,000	0.027	0.043	0.043	0.038	0.036	0.043	0.039	0.027
7,000	0.034	0.050	0.053	0.045	0.043	0.053	0.045	0.033
8,000	0.046	0.057	0.059	0.053	0.055	0.058	0.054	0.046
9,000	0.059	0.055	0.068	0.061	0.070	0.070	0.065	0.059
10,000	0.092	0.073	0.103	0.104	0.083	0.104	0.091	0.083
11,000	0.117	0.084	0.146	0.145	0.114	0.146	0.121	0.114
12,000	0.163	1/	0.199	0.186	0.174	0.199	0.144	0.163
13,000	0.228		1/	0.318	1/	0.318	0.273	0.228
14,000								
15,000								
Displacement at Failure (in.)	0.392							
Pressure at Failure (psi)	13,300	13,800	13,075	13,150	13,000	13,800	13,265	13,000

1/ Deflection wire became disengaged.

Notes:

1. Grease liberally applied.
2. 500-psi preload.
3. Cracking at about 9,000 psi and 13,000 psi.

Table C-13. Hydrostatic Test Data for Nominal 1.50-Inch (D_i) - 2.25-Inch (D_o) Flat Acrylic Windows, Test Specimens 61 - 65

(Sealed with grease; radial clearance 0.005 to 0.010 inch; nominal D_o/D_i ratio 1.5)

Parameter	Specimen Number					Value		
	61	62	63	64	65	Max	Avg	Min
Thickness (in.)	0.733	0.733	0.734	0.735	0.735	0.735	0.734	0.733
D_o (actual, in.)	2.239	2.239	2.241	2.241	2.240	2.241	2.240	2.239
Temperature (°F)	67	69	71	66	68	71	68	66
t/D_i Ratio (actual)	0.488	0.488	0.489	0.490	0.490	0.490	0.489	0.488
Pressurization Rate (psi/min)	670	670	682	669	637	682	656	637
Pressure (psi)	Axial Displacement of Center Point on Window's Low-Pressure Face (in.)							
1,000	0.001	0.000	0.002	0.001	0.002	0.002	0.001	0.000
2,000	0.001	0.000	0.011	0.002	0.003	0.011	0.005	0.000
3,000	0.013	0.012	0.018	0.016	0.003	0.018	0.012	0.003
4,000	0.021	0.012	0.023	0.017	0.004	0.023	0.015	0.004
5,000	0.022	0.018	0.029	0.026	0.017	0.029	0.022	0.017
6,000	0.029	0.025	0.034	0.026	0.017	0.034	0.026	0.017
7,000	0.029	0.033	0.035	0.027	0.018	0.035	0.028	0.018
8,000	0.036	0.033	0.040	0.039	0.035	0.040	0.036	0.033
9,000	0.043	0.038	0.048	0.039	0.035	0.048	0.041	0.035
10,000	0.046	0.045	0.053	0.052	0.036	0.053	0.046	0.036
11,000	0.052	0.052	0.061	0.053	0.047	0.061	0.053	0.047
12,000	0.059	0.059	0.068	0.065	0.048	0.068	0.060	0.048
13,000	0.071	0.064	0.075	0.065	0.063	0.075	0.068	0.063
14,000	0.078	0.090	0.095	0.072	0.076	0.095	0.082	0.076
15,000	0.097	0.099	0.106	0.084	0.095	0.106	0.096	0.084
16,000	0.112	0.121	0.129	0.107	0.109	0.129	0.116	0.107
17,000		0.143	0.145	0.125	0.131	0.145	0.135	0.125
18,000		0.174	0.185	0.143	0.164	0.185	0.161	0.143
19,000		0.236		0.177		0.236	0.202	0.177
Displacement at Failure (in.)		0.252	0.255	0.256		0.256	0.253	0.252
Pressure at Failure (psi)		19,200	18,600	19,650		19,650	19,100 1/	18,600

1/ Averaged with preliminary tests.

Notes:

1. Abort due to pump failure at 16,600 psi.
2. Audible cracking at about 14,000 psi.

Table C-14. Hydrostatic Test Data for Nominal 1.50-Inch (D_i) - 2.25-Inch (D_o) Flat Acrylic Windows, Test Specimens 66 - 70

(Sealed with grease; radial clearance 0.005 to 0.010 inch; nominal D_i/D_o ratio 1.5)

Parameter	Specimen Number					Value		
	66	67	68	69	70	Max	Avg	Min
Thickness (in.)	0.833	0.838	0.840	0.845	0.857[1]	0.845	0.839	0.833
D_o (actual, in.)	2.238	2.238	2.239	2.239	2.238	2.239	2.238	2.238
Temperature (°F)	68	67	68	70	66	70	68	67
t/D_i Ratio (actual)	0.555	0.558	0.560	0.563	0.572	0.572	0.559	0.555
Pressurization Rate (psi/min)	695	662	660	663	650	695	670	660
Pressure (psi)	Axial Displacement of Center Point on Window's Low-Pressure Face (in.)							
1,000	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001
2,000	0.002	0.002	0.002	0.002	0.001	0.002	0.002	0.001
3,000	0.002	0.002	0.003	0.002	0.002	0.003	0.002	0.002
4,000	0.006	0.005	0.004	0.003	0.003	0.006	0.004	0.003
5,000	0.012	0.011	0.005	0.003	0.005	0.012	0.008	0.003
6,000	0.016	0.015	0.010	0.004	0.006	0.016	0.011	0.004
7,000	0.021	0.016	0.015	0.011	0.009	0.021	0.016	0.011
8,000	0.025	0.021	0.021	0.015	0.010	0.025	0.020	0.015
9,000	0.030	0.025	0.027	0.020	0.019	0.030	0.026	0.020
10,000	0.034	0.031	0.031	0.026	0.020	0.034	0.031	0.026
11,000	0.039	0.035	0.036	0.031	0.020	0.039	0.035	0.031
12,000	0.044	0.041	0.041	0.035	0.035	0.044	0.040	0.035
13,000	0.050	0.045	0.047	0.040	0.036	0.050	0.045	0.040
14,000	0.056	0.054	0.052	0.047	0.037	0.056	0.052	0.047
15,000	0.063	0.059	0.059	0.053	0.039	0.063	0.059	0.053
16,000	0.070	0.069	0.066	0.064	0.040	0.070	0.067	0.064
17,000	0.078	0.076	0.077	0.072	0.041	0.078	0.076	0.072
18,000	0.091	0.087	0.087	0.083	0.042	0.091	0.087	0.083
19,000	0.103	0.097	0.099	0.096	0.064	0.103	0.099	0.096
20,000	0.119	0.110	0.118	0.111	0.080	0.119	0.115	0.110
21,000	0.144	0.132	0.139	0.137	1/	0.144	0.138	0.132
22,000	0.180	0.163	0.170	0.183		0.183	0.174	0.163
23,000	0.282	0.232	0.230			0.282	0.248	0.230
Displacement at Failure (in.)		0.325	0.330			0.330	0.328	0.325
Pressure at Failure (psi)	23,100	23,400	23,350	22,800		23,400	23,160	22,800

1/ Abort due to leak at 20,100 psi, not averaged.

Table C-15. Hydrostatic Test Data for Nominal 1.50-Inch (D_i) - 2.25-Inch (D_o) Flat Acrylic Windows, Test Specimens 71 - 75

(Sealed with grease; radial clearance 0.002 to 0.005 inch; nominal D_o/D_i ratio 1.5)

Parameter	Specimen Number					Value		
	71	72	73	74	75	Max	Avg	Min
Thickness (in.)	0.982	0.982	0.982	0.985	0.984	0.985	0.983	0.982
D_o (actual, in.)	2.243	2.242	2.243	2.243	2.243	2.243	2.243	2.242
Temperature (°F)	68	69	69	70	67	70	69	67
t/D_i Ratio (actual)	0.655	0.655	0.655	0.656	0.656	0.656	0.655	0.655
Pressurization Rate (psi/min)	660	670	663	677	665	677	670	660
Pressure (psi)	Axial Displacement of Center Point on Window's Low-Pressure Face (in.)							
1,000	0.000	0.000	0.001	0.000	0.001	0.001	0.000	0.000
2,000	0.006	0.001	0.002	0.001	0.002	0.006	0.002	0.001
3,000	0.010	0.002	0.004	0.001	0.002	0.010	0.004	0.001
4,000	0.015	0.002	0.015	0.001	0.004	0.015	0.007	0.001
5,000	0.019	0.003	0.015	0.002	0.009	0.019	0.010	0.002
6,000	0.023	0.008	0.025	0.003	0.015	0.025	0.015	0.003
7,000	0.027	0.015	0.025	0.010	0.015	0.027	0.018	0.010
8,000	0.031	0.015	0.025	0.012	0.016	0.031	0.020	0.012
9,000	0.035	0.016	0.034	0.016	0.026	0.035	0.025	0.016
10,000	0.038	0.021	0.034	0.021	0.027	0.038	0.028	0.021
11,000	0.042	0.026	0.034	0.026	0.027	0.042	0.031	0.026
12,000	0.046	0.033	0.045	0.030	0.040	0.046	0.039	0.030
13,000	0.050	0.034	0.045	0.035	0.041	0.050	0.041	0.034
14,000	0.055	0.041	0.046	0.039	0.041	0.055	0.044	0.039
15,000	0.060	0.045	0.058	0.044	0.041	0.060	0.050	0.041
16,000	0.066	0.051	0.058	0.049	0.054	0.066	0.056	0.049
17,000	0.071	0.060	0.069	0.054	0.055	0.071	0.062	0.054
18,000	0.075	0.066	0.070	0.060	0.070	0.075	0.068	0.060
19,000	0.083	0.073	0.082	0.067	0.071	0.083	0.075	0.067
20,000	0.088	0.080	0.082	0.076	0.071	0.088	0.079	0.071
21,000	0.095	0.089	0.094	0.084	0.087	0.095	0.090	0.084
22,000	0.103	0.113	0.102	0.093	0.088	0.113	0.100	0.088
23,000	0.112	0.118	0.112	0.104	0.103	0.118	0.110	0.103
24,000	0.132	0.125	0.116	0.114	0.104	0.132	0.118	0.104
25,000	0.138	0.173	0.128	0.129	0.118	0.138	0.129	0.118
26,000	0.150	0.237	0.148	0.148	0.132	0.150	0.145	0.132
27,000	2/	1/	0.180	0.173	0.148	0.180	0.160	0.148
28,000			0.210	0.230	0.160	0.230	0.200	0.160
29,000					0.194			
Pressure at Failure (psi)		26,800	28,800	28,600	29,800	29,800	28,500	26,800

1/ Time stopped to fix leak at 22,000 psi.
2/ Abort due to pump failure at 26,350 psi.

Table C-16. Hydrostatic Test Data for Nominal 1.50-Inch (D_i) - 4.00-Inch (D_o) Flat Acrylic Windows, Test Specimens 76 - 80

(Sealed with grease; radial clearance 0.020 to 0.030 inch; nominal D_o/D_i ratio 2.67)

Parameter	Specimen Number					Value		
	76	77	78	79	80	Max	Avg	Min
Thickness (in.)	0.729	0.731	0.729	0.738	0.730	0.738	0.731	0.729
D_o (actual) in.)	3.951	3.950	3.950	3.960	3.945	3.960	3.952	3.945
Temperature (°F)	64.5	64.0	65.5	65.0	64.0	65.5	64.6	64.0
t/D_i Ratio (actual)	0.486	0.487	0.486	0.492	0.487	0.492	0.487	0.486
Pressurization Rate (psi/min)	674	602	667	606	652	674	640	602
Pressure (psi)	Axial Displacement of Center Point on Window's Low-Pressure Face (in.)							
1,000	0.009	0.003	0.008	0.008	0.008	0.009	0.007	0.003
2,000	0.023	0.008	0.015	0.024	0.015	0.024	0.017	0.008
3,000	0.030	0.013	0.018	0.029	0.023	0.030	0.023	0.013
4,000	0.036	0.018	0.025	0.036	0.031	0.036	0.029	0.018
5,000	0.042	0.023	0.031	0.042	0.035	0.042	0.035	0.023
6,000	0.047	0.032	0.037	0.047	0.042	0.047	0.041	0.032
7,000	0.052	0.037	0.042	0.053	0.047	0.053	0.046	0.037
8,000	0.058	0.040	0.048	0.057	0.060	0.060	0.053	0.040
9,000	0.063	0.046	0.051	0.075	0.065	0.075	0.060	0.046
10,000	0.068	0.052	0.058	0.078	0.071	0.078	0.065	0.052
11,000	0.073	0.057	0.062	0.083	0.078	0.083	0.071	0.057
12,000	0.080	0.062	0.070	0.088	0.084	0.088	0.077	0.062
13,000	0.101	0.068		0.096	0.090	0.101	0.089	0.068
14,000	0.107	0.074		0.113	0.098	0.113	0.098	0.074
15,000	0.115	0.094		0.118	0.106	0.118	0.108	0.094
16,000	0.125	0.102		0.128	0.114	0.128	0.117	0.102
17,000	0.136	0.112		0.142		0.142	0.130	0.112
18,000	0.154	0.133				0.154	0.143	0.133
19,000	0.175							
20,000								
Pressure at Failure (psi)	19,500	18,950	19,100	18,800	19,600	19,600	19,190	18,800

Table C-17. Hydrostatic Test Data for Nominal 1.50-Inch (D_i) - 4.00-Inch (D_o) Flat Acrylic Windows, Test Specimens 81 - 85

(Sealed with O-ring; radial clearance 0.0005 to 0.001 inch; nominal D_o/D_i ratio 2.67)

Parameter	Specimen Number					Value		
	81	82	83	84	85	Max	Avg	Min
Thickness (in.)	0.740	0.733	0.739	0.747	0.738	0.747	0.739	0.733
D_o (actual, in.)	3.999	3.999	3.999	3.998	3.998	3.999	3.998	3.998
Temperature (°F)	65.0	64.0	64.0	63.5	63.0	65.0	63.9	63.0
t/D_i Ratio (actual)	0.493	0.488	0.492	0.498	0.492	0.498	0.492	0.488
Pressurization Rate (psi/min)	651	620	673	666	658	673	654	620
Pressure (psi)	Axial Displacement of Center Point on Window's Low-Pressure Face (in.)							
1,000	0.020	0.009	0.014	0.026	0.001	0.026	0.014	0.001
2,000	0.040	0.019	0.020	0.041	0.005	0.041	0.025	0.005
3,000	0.055	0.027	0.024	0.050	0.011	0.055	0.033	0.011
4,000	0.064	0.036	0.026	0.056	0.019	0.064	0.040	0.019
5,000	0.069	0.039	0.028	0.061	0.026	0.069	0.045	0.026
6,000	0.075	0.046	0.030	0.066	0.032	0.075	0.050	0.030
7,000	0.080	0.050	0.032	0.072	0.037	0.080	0.054	0.032
8,000	0.085	0.055	0.035	0.078	0.043	0.085	0.059	0.035
9,000	0.091	0.067	0.038	0.082	0.049	0.091	0.065	0.038
10,000	0.097	0.075	0.040	0.089	0.055	0.047	0.071	0.040
11,000	0.102	0.080	0.043	0.117	0.060	0.117	0.080	0.043
12,000		0.085	0.065	0.118	0.067	0.118	0.084	0.065
13,000		0.091	0.069	0.120	0.073	0.120	0.088	0.069
14,000		0.099	0.076	0.128	0.079	0.128	0.095	0.076
15,000		0.102	0.082	0.136	0.086	0.136	0.101	0.082
16,000		0.118	0.092	0.145	0.095	0.145	0.112	0.092
17,000		0.130	0.108	0.154	0.106	0.154	0.124	0.106
18,000		0.157	0.121	0.167	0.119	0.167	0.141	0.119
19,000		0.180			0.135	0.180	0.157	0.135
20,000					0.173			
21,000					0.247			
Pressure at Failure (psi)	19,150	19,300	18,300	18,400	21,200	21,200	19,270	18,300

Table C-18. Hydrostatic Test Data for Nominal 3.33-Inch (D_i) -5.00-Inch (D_o) Flat Acrylic Windows, Test Specimens 86 - 90

(Sealed with grease; radial clearance 0.005 to 0.010 inch; nominal D_o/D_i ratio 1.5)

Parameter	Specimen Number					Value		
	86	87	88	89	90	Max	Avg	Min
Thickness (in.)	0.123	0.123	0.119	0.121	0.119	0.123	0.121	0.119
D_o (actual, in.)	4.988	4.988	4.989	4.989	4.990	4.990	4.989	4.988
Temperature (°F)	66	66	66	67	67	67	66	66
t/D_i Ratio (actual)	0.037	0.037	0.036	0.036	0.036	0.037	0.036	0.036
Pressurization Rate (psi/min)	150	111	151	175	192	192	156	111
Pressure (psi)	Axial Displacement of Center Point on Window's Low-Pressure Face (in.)							
50	0.132	0.140	0.150	0.157	0.171	0.171	0.150	0.132
100	0.176	0.194	0.203	0.209	0.224	0.224	0.201	0.176
Displacement at Failure (in.)	0.197	0.194	0.240	0.216	0.244	0.194	0.218	0.244
Pressure at Failure (psi)	112	100	145	105	125	145	117	100

Table C-19. Hydrostatic Test Data for Nominal 3.33-Inch (D_i) -5.00-Inch (D_o) Flat Acrylic Windows, Test Specimens 91 - 95

(Sealed with grease; radial clearance 0.002 to 0.005 inch; nominal D_o/D_i ratio 1.50)

Parameter	Specimen Number					Value		
	91	92	93	94	95	Max	Avg	Min
Thickness (in.)	0.360	0.347	0.347	0.348	0.349	0.360	0.350	0.347
D_o (actual, in.)	4.995	4.996	4.995	4.995	4.994	4.996	4.995	4.994
Temperature (°F)	70	71	65	66	66	71	68	65
t/D_i Ratio (actual)	0.104	0.102	0.102	0.102	0.102	0.104	0.102	0.102
Pressurization Rate (psi/min)	760	690	840 1/	687	688	760	671	687
Pressure (psi)	Axial Displacement of Center Point on Window's Low-Pressure Face (in.)							
100	0.003	0.016	0.024	0.039	0.032	0.039	0.023	0.003
200	0.026	0.032	0.044	0.050	0.046	0.050	0.040	0.026
300	0.039	0.045		0.065	0.060	0.065	0.050	0.039
400	0.053	0.096	0.073	0.079	0.077	0.096	0.076	0.053
500		0.124	0.086	0.092	0.091	0.124	0.095	0.086
600			0.101					
700			0.115					
800			0.132 1/					
Displacement at Failure (in.)		0.131	0.132	0.107	0.103	0.132	0.118	0.103
Pressure at Failure (psi)	570	545	800 1/	590	570	590	569	545

1/ Not included in averaged values.

Table C-20. Hydrostatic Test Data for Nominal 3.33-Inch (D_i) -5.00-Inch (D_o) Flat Acrylic Windows, Test Specimens 96 – 100

(Sealed with grease; radial clearance 0.002 to 0.005 inch; nominal D_o/D_i ratio 1.50)

Parameter	Specimen Number					Value		
	96	97	98	99	100	Max	Avg	Min
Thickness (in.)	0.603	0.604	0.606	0.607	0.607	0.607	0.605	0.603
D_o (actual, in.)	4.994	4.995	4.995	4.994	4.994	4.995	4.994	4.994
Temperature (°F)	66	68	68	68	69	69	68	66
t/D_i Ratio (actual)	0.181	0.182	0.182	0.182	0.182	0.182	0.182	0.181
Pressurization Rate (psi/min)	617	634	668	588	682	682	638	588
Pressure (psi)	Axial Displacement of Center Point on Window's Low-Pressure Face (in.)							
200	0.008	0.025	0.024	0.011	0.004	0.025	0.014	0.004
400	0.015	0.034	0.030	0.019	0.015	0.034	0.023	0.015
600	0.024	0.040	0.040	0.028	0.024	0.040	0.031	0.024
800	0.032	0.049	0.047	0.036	0.037	0.049	0.040	0.032
1,000	0.038	0.055	0.055	0.043	0.039	0.055	0.046	0.038
1,200	0.044	0.066	0.063	0.054	0.052	0.066	0.056	0.044
1,400	0.053	0.071	0.070	0.058	0.055	0.071	0.061	0.053
1,600	0.101	0.079	0.078	0.067	0.064	0.101	0.078	0.064
1,800	0.112	0.087	0.087	0.076	0.074	0.112	0.088	0.074
2,000		0.098	0.095	0.080		0.098	0.091	0.080
2,200		0.106					0.106	
Displacement at Failure (in.)	0.138	0.109	0.100	0.081	0.076	0.138	0.100	0.076
Pressure at Failure (psi)	1,910	2,300	2,100	2,025	1,960	2,300	2,060	1,910

Table C-21. Hydrostatic Test Data for Nominal 3.33-Inch (D_i) - 5.00-Inch (D_o) Flat Acrylic Windows, Test Specimens 101 - 105

(Sealed with grease; radial clearance 0.002 to 0.005 inch; nominal D_o/D_i ratio 1.5)

Parameter	Specimen Number					Value		
	101	102	103	104	105	Max	Avg	Min
Thickness (in.)	0.841	0.836	0.847	0.831	0.830	0.847	0.837	0.830
D_o (actual, in.)	4.995	4.995	4.994	4.995	4.994	4.995	4.995	4.994
Temperature (°F)	70	69	65	65	64	70	67	64
t/D_i Ratio (actual)	0.252	0.251	0.254	0.249	0.249	0.254	0.251	0.249
Pressurization Rate (psi/min)	660	664 1/	669	652	620	669	653	620
Pressure (psi)	Axial Displacement of Center Point on Window's Low-Pressure Face (in.)							
500	0.019	0.010	0.004	0.002	0.011	0.019	0.009	0.002
1,000	0.030	0.018	0.019	0.012	0.022	0.030	0.020	0.012
1,500	0.040	0.025	0.029	0.019	0.031	0.040	0.029	0.019
2,000	0.050	0.039	0.037	0.034	0.042	0.050	0.040	0.034
2,500		0.046	0.045	0.042	0.053	0.053	0.047	0.042
3,000	0.072	0.058	0.052	0.050	0.061	0.072	0.059	0.050
3,500	0.084	0.129 1/		0.130		0.130	0.114	0.084
4,000	0.102				0.084			
4,500	0.117							
Displacement at Failure (in.)	0.124			0.138	0.084	0.138	0.115	0.084
Pressure at Failure (psi)	4,750	3,550	3,400	3,600	4,000	4,750	3,860	3,400

1/ Preloaded pressure unknown, plugged gage line.

Table C-22. Hydrostatic Test Data for Nominal 3.33-Inch (D_i) -5.00-Inch (D_o) Flat Acrylic Windows, Test Specimens 106 - 110

(Sealed with grease; radial clearance 0.005 to 0.010 inch; nominal D_o/D_i ratio 1.5)

Parameter	Specimen Number					Value		
	106	107	108	109	110	Max	Avg	Min
Thickness (in.)	1.109	1.131	1.132	1.131	1.127	1.132	1.126	1.109
D_o (actual, in.)	4.986	4.983	4.984	4.983	4.986	4.986	4.984	4.983
Temperature (°F)	65	69	68	68	69	69	68	65
t/D_i Ratio (actual)	0.333	0.339	0.340	0.339	0.338	0.340	0.338	0.333
Pressurization Rate (psi/min)	710	633	664	655	672	710	669	633
Pressure (psi)	Axial Displacement of Center Point on Window's Low-Pressure Face (in.)							
500	0.001	0.002	0.002	0.001	0.001	0.002	0.001	0.001
1,000	0.011	0.002	0.010	0.001	0.020	0.020	0.009	0.001
1,500	0.012	0.008	0.018	0.010	0.020	0.020	0.016	0.008
2,000	0.021	0.013	0.027	0.019	0.020	0.027	0.020	0.013
2,500	0.030	0.018	0.034	0.026	0.033	0.034	0.028	0.018
3,000	0.039	0.027	0.042	0.032	0.045	0.045	0.037	0.027
3,500	0.048	0.033	0.047	0.036	.0.045	0.048	0.042	0.033
4,000	0.056	0.043	0.054	0.048	0.056	0.056	0.051	0.043
4,500	0.064	0.050	0.059	0.059	0.095	0.095	0.065	0.050
5,000	0.074	0.060	0.067	0.068	0.097	0.097	0.075	0.060
5,500	0.083	0.067	0.114	0.070	0.113	0.114	0.089	0.067
6,000	0.091	0.109	0.128	0.115	0.128	0.128	0.114	0.091
6,500	0.099	0.142	0.136	0.131	0.142	0.142	0.130	0.099
7,000	0.130	0.176	0.255	0.292	0.155	0.292	0.201	0.130
7,500	0.489	0.386	0.336	0.447	1/	0.489	0.415	0.336
8,000	0.572		0.456					
Displacement at Failure (in.)	0.782	0.610	0.456	0.536		0.782	0.596	0.456
Pressure at Failure (psi)	8,300	7,825	8,025	7,650	8,450	8,450	8,050	7,650

1/ Deflection wire disengaged suddenly.

Note: Cracking at about 5,000 psi and 7,000 psi.

Table C-23. Hydrostatic Test Data for Nominal 3.33-Inch (D_i) -5.00-Inch (D_o) Flat Acrylic Windows, Test Specimens 111 - 115

(Sealed with grease; radial clearance 0.005 to 0.010 inch; nominal D_o/D_i ratio 1.5)

Parameter	Specimen Number					Value		
	111	112	113	114	115	Max	Avg	Min
Thickness (in.)	1.446	1.432	1.439	1.437	1.449	1.449	1.441	1.432
D_o (actual, in.)	4.986	4.988	4.986	4.985	4.987	4.988	4.987	4.985
Temperature (°F)	65	66	65	68	65	68	66	65
t/D_i Ratio (actual)	0.435	0.429	0.432	0.431	0.436	0.436	0.433	0.429
Pressurization Rate (psi/min)	673	658	669 1/	645	662	673	661	645
Pressure (psi)	Axial Displacement of Center Point on Window's Low-Pressure Face (in.)							
1,000	0.002	0.001		0.010	0.009	0.010	0.005	0.001
2,000	0.016	0.019	0.027	0.018	0.016	0.027	0.019	0.016
3,000	0.029	0.030	0.037	0.033	0.026	0.037	0.031	0.026
4,000	0.031	0.036	0.049	0.040	0.040	0.049	0.039	0.031
5,000	0.045	0.044	0.060	0.042	0.050	0.060	0.048	0.042
6,000	0.059	0.061	0.070	0.055	0.059	0.070	0.059	0.055
7,000	0.072	0.069	0.081	0.070	0.080	0.081	0.074	0.069
8,000	0.085	0.089	0.094	0.090	0.095	0.095	0.091	0.085
9,000	0.099	0.109	0.107	0.120	0.104	0.120	0.108	0.099
10,000	0.122	0.124	0.123	0.138	0.143	0.143	0.130	0.122
11,000	0.168	0.156	0.175	0.170	0.184	0.184	0.171	0.156
12,000	0.205	0.196	0.211	0.216	0.216	0.216	0.209	0.196
13,000	0.230	0.230	0.253	0.244	0.257	0.257	0.243	0.230
14,000	0.285	0.284	0.310	0.302	0.306	0.310	0.298	0.284
15,000	0.365	0.371	0.427	0.389	0.384	0.427	0.387	0.365
Displacement at Failure (in.)	0.428	0.424	0.464 1/	0.454	0.486	0.486	0.451	0.424
Pressure at Failure (psi)	15,750	15,300	15,200	15,475	15,400	15,750	15,425	15,200

1/ Held 2 minutes at 500 psi to fix leak.

Notes:

1. 500-psi preload.
2. Audible cracks at about 9,000 psi and 11,000 psi.

Table C-24. Hydrostatic Test Data for Nominal 3.33-Inch (D_i) -5.00-Inch (D_o) Flat Acrylic Windows, Test Specimens 116 - 120

(Sealed with grease; radial clearance 0.005 to 0.010 inch; nominal D_o/D_i ratio 1.5)

Parameter	Specimen Number					Value		
	116	117	118	119	120	Max	Avg	Min
Thickness (in.)	2.000	1.991	1.995	1.996	2.008	2.008	1.998	1.991
D_o (actual, in.)	4.993	4.987	4.988	4.987	4.990	4.993	4.989	4.987
Temperature (°F)	65	66	66	66	66	66	66	65
t/D_i Ratio (actual)	0.600	0.598	0.599	0.599	0.602	0.602	0.600	0.598
Pressurization Rate (psi/min)	662	660	665	663	664	665	663	660
Pressure (psi)	Axial Displacement of Center Point on Window's Low-Pressure Face (in.)							
1,000	0.001	0.001	0.004	0.001	0.001	0.004	0.002	0.001
2,000	0.010	0.002	0.013	0.001	0.011	0.013	0.007	0.001
3,000	0.021	0.010	0.022	0.012	0.018	0.022	0.017	0.010
4,000	0.025	0.018	0.030	0.019	0.026	0.030	0.024	0.018
5,000	0.033	0.026	0.037	0.026	0.033	0.037	0.031	0.026
6,000	0.040	0.033	0.044	0.033	0.041	0.044	0.038	0.033
7,000	0.046	0.040	0.052	0.041	0.048	0.052	0.045	0.040
8,000	0.052	0.050	0.059	0.048	0.056	0.059	0.053	0.048
9,000	0.067	0.057	0.066	0.056	0.064	0.067	0.062	0.056
10,000	0.073	0.066	0.074	0.064	0.072	0.074	0.070	0.064
11,000	0.083	0.075	0.083	0.073	0.080	0.083	0.079	0.073
12,000	0.091	0.083	0.092	0.083	0.090	0.092	0.088	0.083
13,000	0.101	0.092	0.101	0.091	0.098	0.101	0.097	0.091
14,000	0.114	0.103	0.111	0.101	0.109	0.114	0.108	0.103
15,000	0.127	0.114	0.122	0.115	0.119	0.127	0.119	0.114
16,000	0.137	0.125	0.132	0.128	0.135	0.137	0.131	0.125
17,000	1/	0.137	0.146	0.140	0.148	0.148	0.143	0.137
18,000		0.152	0.160	0.156	0.161	0.161	0.157	0.152
19,000		0.170	0.177	0.171	0.181	0.181	0.175	0.170
20,000		0.197	0.192	0.191	0.198	0.198	0.195	0.191
21,000		0.221	0.223	0.208	0.220	0.223	0.218	0.208
22,000		0.248	0.252	0.251	0.253	0.253	0.251	0.248
23,000		0.288	0.292	0.294	0.301	0.301	0.294	0.288
24,000			0.380					
Displacement at Failure (in.)		0.359	0.395	0.360	0.326	0.395	0.380	0.326
Extrusion Set (in.)	0.010	0.068 2/			0.076 2/			
Pressure at Failure (psi)		23,900	24,150	23,650	23,450	24,150	24,050	23,450

1/ Abort at 16,250 psi due to pump failure.
2/ Extrusion and bending caused seal to fail, release of pressure.

Note: 1,000-psi preload; smooth deflections.

Table C-25. Hydrostatic Test Data for Nominal 4.00-Inch (D_i) - 6.00-Inch (D_o) Flat Acrylic Windows, Test Specimens 121 - 125

(Sealed with grease; radial clearance 0.005 to 0.010 inch; nominal D_o/D_i ratio 1.5)

Parameter	Specimen Number					Value		
	121	122	123	124	125	Max	Avg	Min
Thickness (in.)	0.236	0.235	0.228	0.231	0.235	0.236	0.233	0.228
D_o (actual, in.)	5.987	5.989	5.988	5.985	5.987	5.989	5.987	5.985
Temperature (°F)	68	69	69	69	69	69	69	68
t/D_i Ratio (actual)	0.059	0.059	0.057	0.058	0.059	0.059	0.058	0.057
Pressurization Rate (psi/min)	157	400	673	425	391	673	409	157
Pressure (psi)	Axial Displacement of Center Point on Window's Low-Pressure Face (in.)							
50	0.084	0.129	0.108	0.111	0.128	0.129	0.112	0.084
100		0.186		0.155	0.160	0.186	0.167	0.155
150	0.174			0.192	0.208	0.208	0.192	0.174
200			0.283		0.240	0.283	0.261	0.240
250					0.270			
300			0.332		0.300	0.332	0.316	0.300
350			0.390		0.320	0.390	0.355	0.320
Displacement at Failure (in.)	0.200	0.186	0.422			0.422	0.269	0.186
Pressure at Failure (psi)	190	100	350	170	360	360	234	100

Notes:

1. Pressurization rate hard to hold due to pumping gage lag and air in line.
2. Reading difficult to make at close intervals.

Table C-26. Hydrostatic Test Data for Nominal 4.00-Inch (D_i) - 6.00-Inch (D_o) Flat Acrylic Windows, Test Specimens 126 - 130

(Sealed with grease; radial clearance 0.005 to 0.010 inch; nominal D_o/D_i ratio 1.5)

Parameter	Specimen Number					Value		
	126	127	128	129	130	Max	Avg	Min
Thickness (in.)	0.451	0.484	0.460	0.463	0.460	0.484	0.464	0.451
D_o (actual, in.)	5.988	5.984	5.989	5.990	5.987	5.990	5.988	5.984
Temperature (°F)	68	68	68	68	65	68	67	65
t/D_i Ratio (actual)	0.106	0.121	0.108	0.108	0.107	0.121	0.110	0.106
Pressurization Rate (psi/min)	689	657	638	669	737	737	678	637
Pressure (psi)	Axial Displacement of Center Point on Window's Low-Pressure Face (in.)							
100				0.022	0.017			
200	0.015	0.010	0.028	0.028	0.027	0.028	0.022	0.010
300	0.029			0.038	0.034			
400	0.038	0.032	0.050	0.048	0.044	0.050	0.042	0.032
500	0.049			0.058	0.060			
600	0.060	0.053	0.075	0.070	0.073	0.075	0.068	0.053
700				0.082	0.090			
800	0.090	0.078	0.096	0.096		0.096	0.090	0.078
900				0.108				
1,000		0.109		0.131				
1,100				0.151				
Displacement at Failure (in.)				0.157	0.090			
Pressure at Failure (psi)	910	1,030	940	1,170	700	1,170	950	700

Note: 50-psi preload.

Table C-27. Hydrostatic Test Data for Nominal 4.00-Inch (D_i) - 6.00-Inch (D_o) Flat Acrylic Windows, Test Specimens 131 - 135

(Sealed with grease; radial clearance 0.005 to 0.010 inch; nominal D_o/D_i ratio 1.5)

Parameter	Specimen Number					Value		
	131	132	133	134	135	Max	Avg	Min
Thickness (in.)	0.957	0.972	0.957	0.976	0.963	0.976	0.965	0.957
D_o (actual, in.)	5.986	5.981	5.984	5.980	5.985	5.986	5.984	5.980
Temperature (°F)	64	65	65	65	66	66	65	64
t/D_i Ratio (actual)	0.239	0.243	0.239	0.244	0.241	0.244	0.241	0.239
Pressurization Rate (psi/min)	651	725	652	685	698	725	682	651
Pressure (psi)	Axial Displacement of Center Point on Window's Low-Pressure Face (in.)							
500	0.009	0.002	0.006	0.014	0.030	0.030	0.012	0.002
1,000	0.023	0.016	0.019	0.026	0.044	0.044	0.026	0.016
1,500	0.036	0.034	0.031	0.051	0.057	0.057	0.042	0.031
2,000	0.048	0.047	0.042	0.062	0.063	0.063	0.052	0.042
2,500	0.060	0.058	0.057	0.076	0.078	0.078	0.066	0.057
3,000	0.105		0.070	0.091	0.092	0.105	0.090	0.070
3,500	0.137				0.106			
Displacement at Failure (in.)		0.068	0.150	0.101	0.106	0.150	0.106	0.068
Pressure at Failure (psi)	3,550	2,900	3,100	3,800	3,500	3,800	3,370	2,900

Notes:

1. 50-psi preload.
2. Audible cracking at about 2,500 psi.

Table C-28. Hydrostatic Test Data for Nominal 4.00-Inch (D_i) -6.00-Inch (D_o) Flat Acrylic Windows, Test Specimens 136 - 140

(Sealed with grease; radial clearance 0.005 to 0.010 inch; nominal D_o/D_i ratio 1.5)

Parameter	Specimen Number					Value		
	136 1/	137	138	139	140	Max	Avg	Min
Thickness (in.)	2.144 1/	1.989	1.997	1.984	1.986	1.997	1.989	1.984
D_o (actual, in.)	5.985 1/	5.984	5.981	5.982	5.982	5.984	5.982	5.981
Temperature (°F)	66 1/	68	67	68	67	68	67	67
t/D_i Ratio (actual)	0.536 1/	0.498	0.500	0.496	0.496	0.500	0.498	0.496
Pressurization Rate (psi/min)	668 1/	663	674	668	678	678	668	663
Pressure (psi)	Axial Displacement of Center Point on Window's Low-Pressure Face (in.)							
1,000	0.009	0.009	0.002	0.001	0.002	0.009	0.005	0.001
2,000	0.018	0.018	0.015	0.012	0.017	0.018	0.016	0.012
3,000	0.027	0.024	0.021	0.028	0.030	0.030	0.026	0.021
4,000	0.041	0.038	0.035	0.037	0.040	0.041	0.038	0.035
5,000	0.046	0.046	0.044	0.045	0.051	0.051	0.046	0.044
6,000	0.055	0.055	0.052	0.055	0.057	0.057	0.055	0.052
7,000	0.067	0.070	0.060	0.070	0.071	0.071	0.068	0.060
8,000	0.083	0.080	0.073	0.081	0.081	0.083	0.080	0.073
9,000	0.095	0.094	0.084	0.090	0.092	0.095	0.091	0.084
10,000	0.107	0.110	0.095	0.103	0.106	0.110	0.104	0.095
11,000	0.122	0.120	0.130	0,121	0.118	0.130	0.122	0.118
12,000	0.135	0.136	0.142	0.136	0.131	0.142	0.136	0.131
13,000	0.155	2/	0.164	2/	0.152	0.164	0.157	0.152
14,000	0.170		0.183		0.173	0.183	0.175	0.170
15,000	0.205		0.213		0.191	0.213	0.203	0.191
16,000	2/		0.238		0.216	0.238	0.227	0.216
17,000			0.280		2/			
18,000			0.350					
Displacement at Failure (in.)			0.427					
Pressure at Failure (psi)	19,550	18,350	18,700	18,100	17,800	18,700	18,240	17,800

1/ Not averaged because of thickness variation.
2/ Deflection post popped off suddenly.

Note: Audible cracking at about 13,000 and 15,000 psi.

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TR-527 77 p. illus May 1967 Unclassified

1. Flat acrylic windows — Hydrostatic pressure tests I. Y-F015-01-07-001

Flat, disk-shaped acrylic windows of different thickness-to-diameter ratios have been tested to destruction under short-term hydrostatic loading at room temperatures, where short-term loading is defined as pressurizing the window hydrostatically on its high-pressure face at a 650-psi/minute rate till failure of the window takes place. Critical pressures and displacements of windows with thickness to effective diameter ratios less than 1.0 have been recorded and plotted. The critical pressures derived from testing flat windows in flanges with 1.5-inch, 3.3-inch, and 4.0-inch openings have been found applicable also to flanges with larger openings, so long as the larger windows are of the same t/D_i and D_o/D_i ratios, where t is thickness of the window, D_i is the clear opening in the flange and therefore the effective diameter of the window exposed to ambient atmospheric pressure and D_o is overall diameter of the window face exposed to hydrostatic pressure. The performance of flat windows under short-term hydrostatic pressure has been found to be comparable to that of conical windows with included angle equal to, or larger than 90 degrees.

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13. ABSTRACT

Flat, disk-shaped acrylic windows of different thickness-to-diameter ratios have been tested to destruction under short-term hydrostatic loading at room temperatures, where short-term loading is defined as pressurizing the window hydrostatically on its high-pressure face at a 650-psi/minute rate till failure of the window takes place. Critical pressures and displacements of windows with thickness to effective diameter ratios less than 1.0 have been recorded and plotted. The critical pressures derived from testing flat windows in flanges with 1.5-inch, 3.3-inch, and 4.0-inch openings have been found applicable also to flanges with larger openings, so long as the larger windows are of the same t/D_i and D_o/D_i ratios, where t is thickness of the window, D_i is the clear opening in the flange and therefore the effective diameter of the window exposed to ambient atmospheric pressure and D_o is overall diameter of the window face exposed to hydrostatic pressure. The performance of flat windows under short-term hydrostatic pressure has been found to be comparable to that of conical windows with included angle equal to, or larger than 90 degrees.

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