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NASA TM -86559

VIEWPORT CONCEPT FOR SPACE STATION MODULES

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Science and Engineering Directorate

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INTRODUCTION

The Space Station (SS), as shown in Figure 1, will be an Earth orbiting facility for science and industry. It can be used for physical and biological science experiments as well as pharmaceutical and manufacturing processes. This technical memorandum addresses the generic design of a 20-in. diameter viewport for the modules. The capabilities of this viewport are meteoroid/debris protection (with no metallic outer cover), redundancies in its meteoroid/debris protection and in its pressure sealing systems, and ease of changeout for maintenance or repair.

BACKGROUND

In the development of this viewport concept, existing designs were investigated to pool the best features and learn from past experiences. The previous SS type vehicles, such as Skylab and Spacelab, had metallic covers to protect their viewports. This study will investigate the application of a non-metallic cover for the modules viewports. Information for this investigation was gathered from as far back as the Apollo missions and included information from the Skylab, Space Shuttle, and Spacelab missions (Fig. 2).

REQUIREMENTS

The Space Station Reference Configuration Description [2] identified the need for viewports to be located throughout the module cluster. This would permit viewing by two or more persons at a time (Fig. 3). The Reference Configuration also identified the quantity of viewports; two 20-in. diameter and four 10-in. diameter viewports in the habitate modules and four 10-in. diameter viewports to be located in the laboratory modules.

In general, viewports should retain their characteristics over the 10-year life of the modules with a minimum of maintenance and repair. Viewports also should provide ease of changeout and a means of controlling factors indigenous to spacecraft viewports. These factors include ultraviolet (UV), infrared (IR), sun glare, moisture buildup, meteoroid/debris penetrations, and temperature extremes. The selected viewport design will incorporate a glass outer cover that allows continuous Earth and celestial viewing.

GLASS SELECTION AND SIZING

Considering the desired capabilities, it was concluded that meteoroid/debris protection would be the "driver" of the entire design. The probability of no penetration (P_O) for the four modules is 0.97. For one module the associated P_O is 0.992 and for

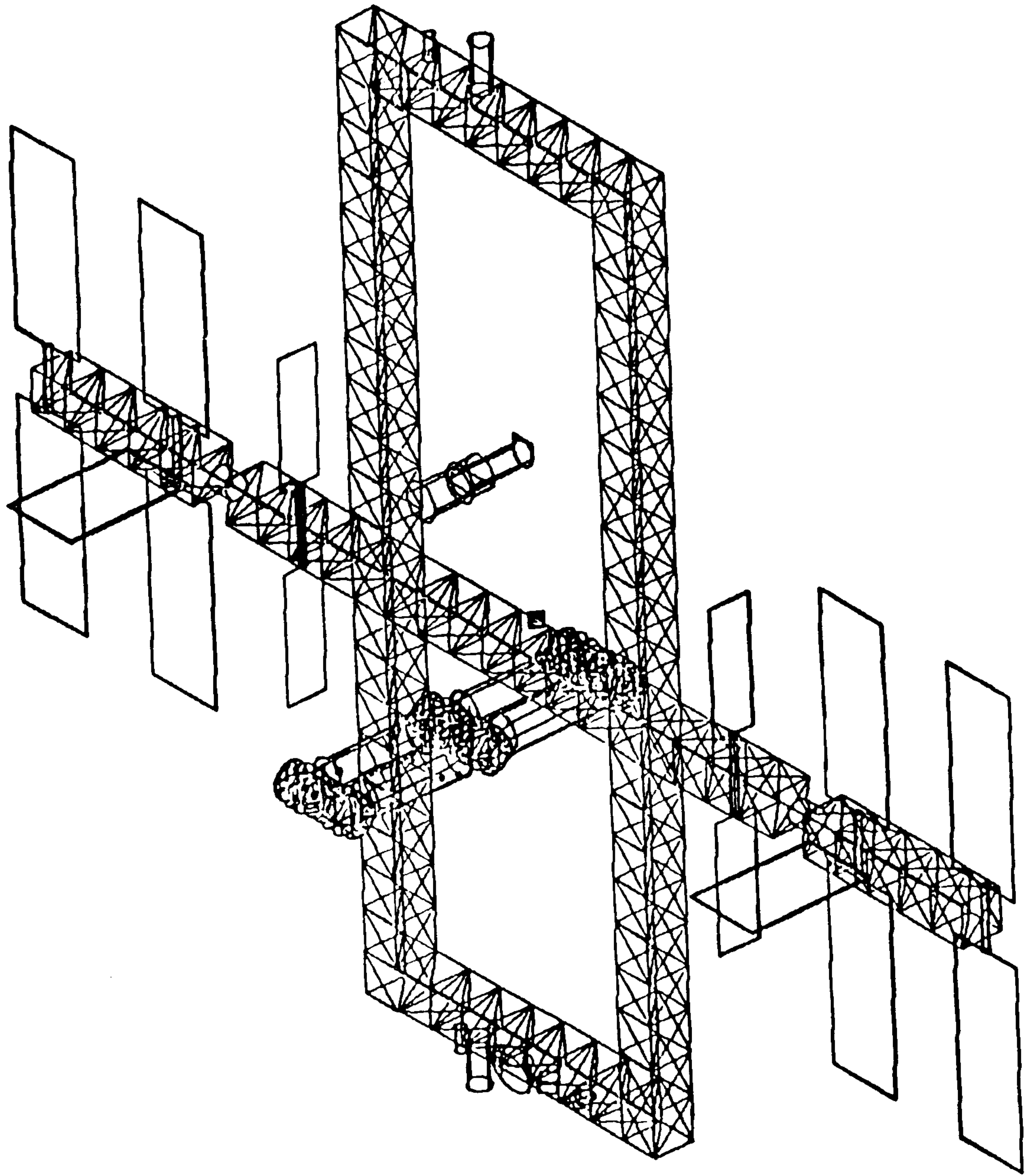


Figure 1. Space Station configuration.

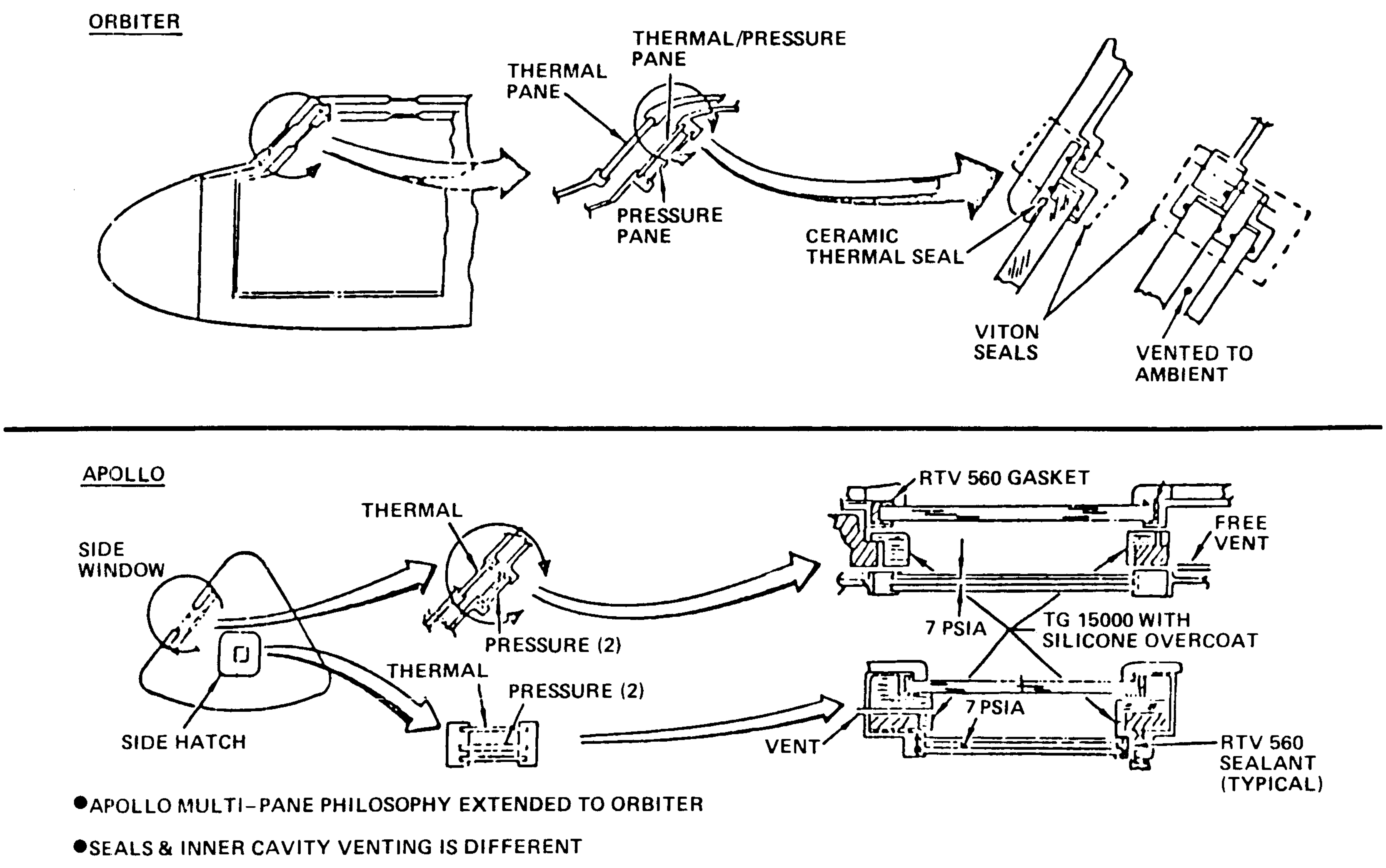


Figure 2. Window comparison study.

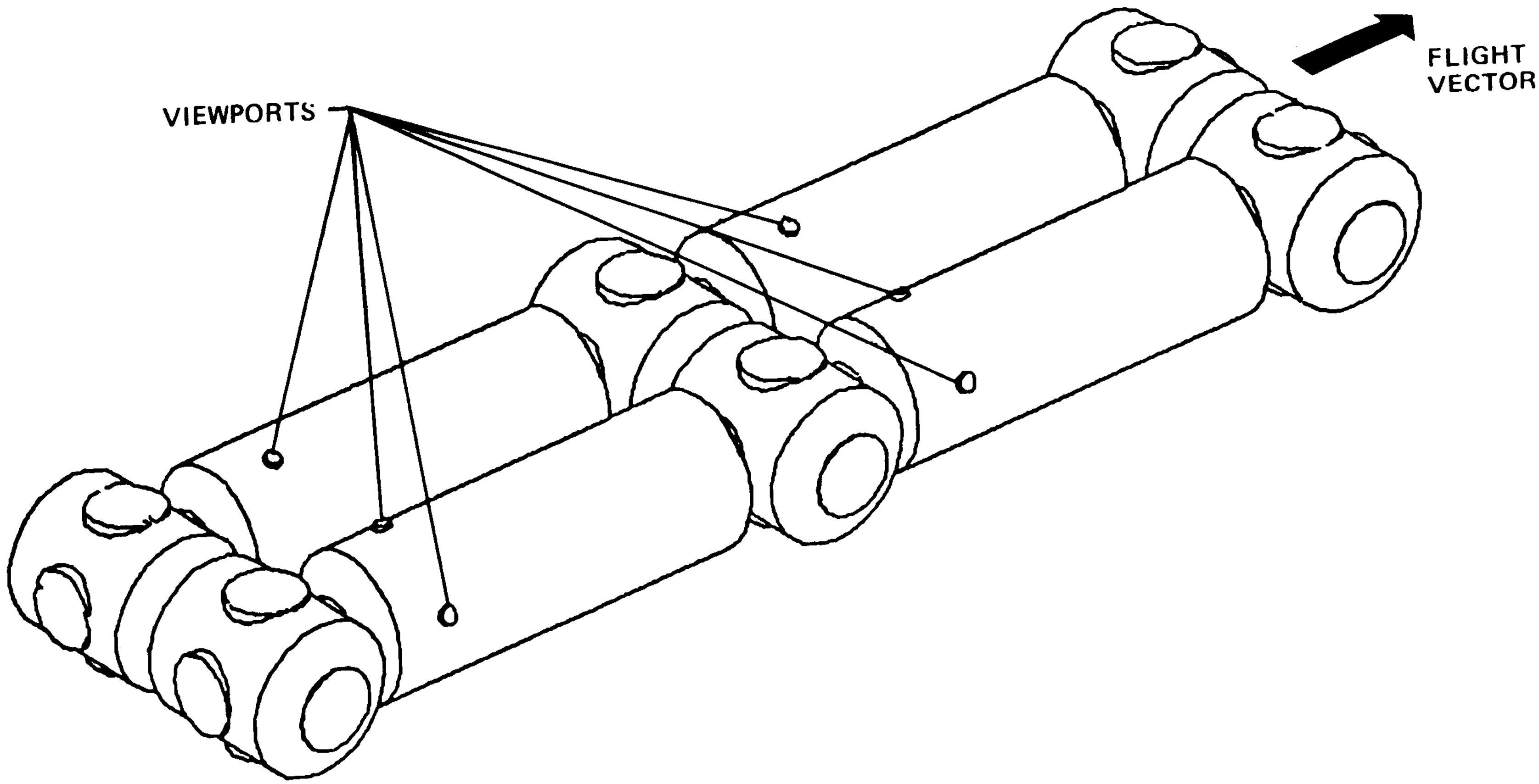


Figure 3. Module cluster.

the viewports, P_0 is 0.996. (For more detail, see Appendix A.) The probabilities, the particle densities and velocities, and the altitude were used to determine the mass of the particle the viewport would have to defeat. This information is used to determine the expected penetration depth of a direct impact on the viewport.

TABLE 1. REQUIRED GLASS THICKNESS

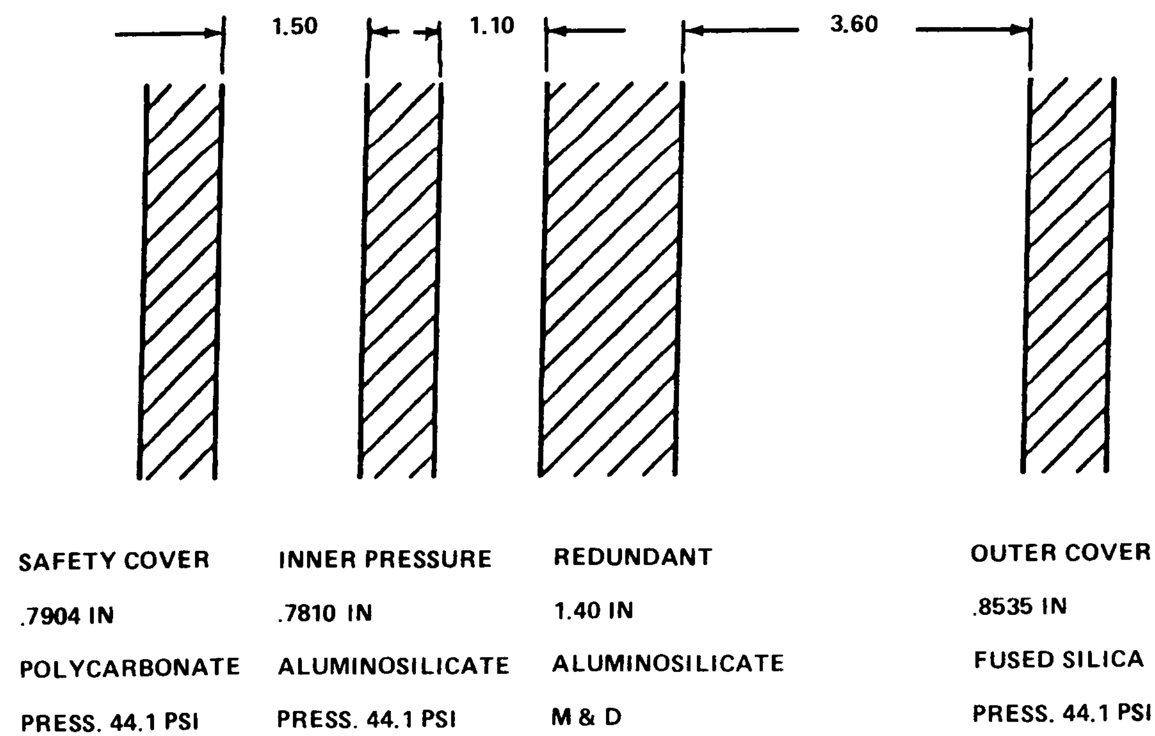
	Meteoroid	Debris
Probability	0.9999	0.996
Particle Diameter (cm)	0.00128	0.1397
Density of Particle (g/cc)	0.500	2.81
Velocity of Particle (km/s)	20	10
Expected Penetration (cm)	2.37×10^{-3}	0.508
No-Spall* Thickness (cm)	1.66×10^{-2}	3.56

* To prevent spalling on the back side of the glass, the necessary glass thickness is seven times the expected penetration [13, 15].

The effect of the outer glass and the next pane (the redundant pane) acting as a bumper-shell combination, was not taken into account when considering meteoroid/debris protection. A meteoroid/debris analysis was run only on the redundant pane itself. At this time, means of determining the bumper effect are not available, later design refinements will incorporate the bumper effect.

Because of the desire to changeout on orbit, all panes (other than the redundant pane) are designed to hold the internal pressure of the module. The expected operating pressure will be 14.7 psi. The proof pressure the viewport must support will be three times the operating pressure or 44.1 psi [8]. To provide enough glass area such that ample support can be given by the frame, all panes will be 22.80 in. in diameter. Each of the panes in this design is required to hold 44.1 psi, with one pane being the main source of meteoroid/debris protection (Fig. 4).

The glass and polycarbonate panes of this viewport configuration are expected to perform as follows. The outer pane is not expected to survive a meteoroid/debris impact by the design particle but to act as a sacrificial shield for the primary meteoroid/debris protection pane. In addition, the outer pane is expected to hold the module internal pressure for the sole purpose of changeout on orbit. The redundant pane serves as the primary means of meteoroid/debris protection. In routine operation, this pane is not under the module internal pressure, in an effort to inhibit flaw growth and prolong the useful life of the pane. The inner pressure pane will be the load carrying pane (when the safety cover is not in use). The safety pane provides protection from nicks and scratches during routine operation. The safety pane is not required to be in place at all times; its main purpose is to provide quick pressure sealing during changeout.



SCALE = 1/2

Figure 4. Pane arrangement.

On orbit, the SS will go from an extremely high temperature to an extremely low temperature; for this reason fused silica, which has a low thermal expansion, was chosen as the glass material for the pane exposed to the space environment. Since the SS will have no atmosphere to filter out UV rays, some means of controlling crew exposure must be inherent to the system. Aluminosilicate glass, which has UV absorption as one of its properties, satisfies this requirement. In addition, of all the glasses considered for meteoroid/debris protection, aluminosilicate has the highest modulus of rupture. It was selected to serve in this area as well as being the material for the primary pressure load carrying pane. Polycarbonate material was selected for the safety pane because of its high strength and light weight. The table below gives a listing of the pane materials and their design benefits that make up this generic design.

TABLE 2. MATERIAL SELECTION [5,6,14,16]

Pane Type	Material	Design Benefit
Outer	Fused Silica	Low Thermal Expansion Coefficient
Redundant	Aluminosilicate	High Strength, UV Control
Inner	Aluminosilicate	High Strength, UV Control
Safety	Polycarbonate	High Strength to Weight

The glass materials in this concept are tentative selections, and have not been confirmed by materials evaluation. The ability of the glass arrangement to prevent penetration or the sealing arrangement's ability to control atmospheric leakage from the module have yet to be qualified by testing. In the evaluation or use of any portion of this concept, it should be kept in mind that the design is based on a generic study and not a complete detail design and analysis. Design verification will be achieved through a structural and hypervelocity impact test program.

OUTER COVER

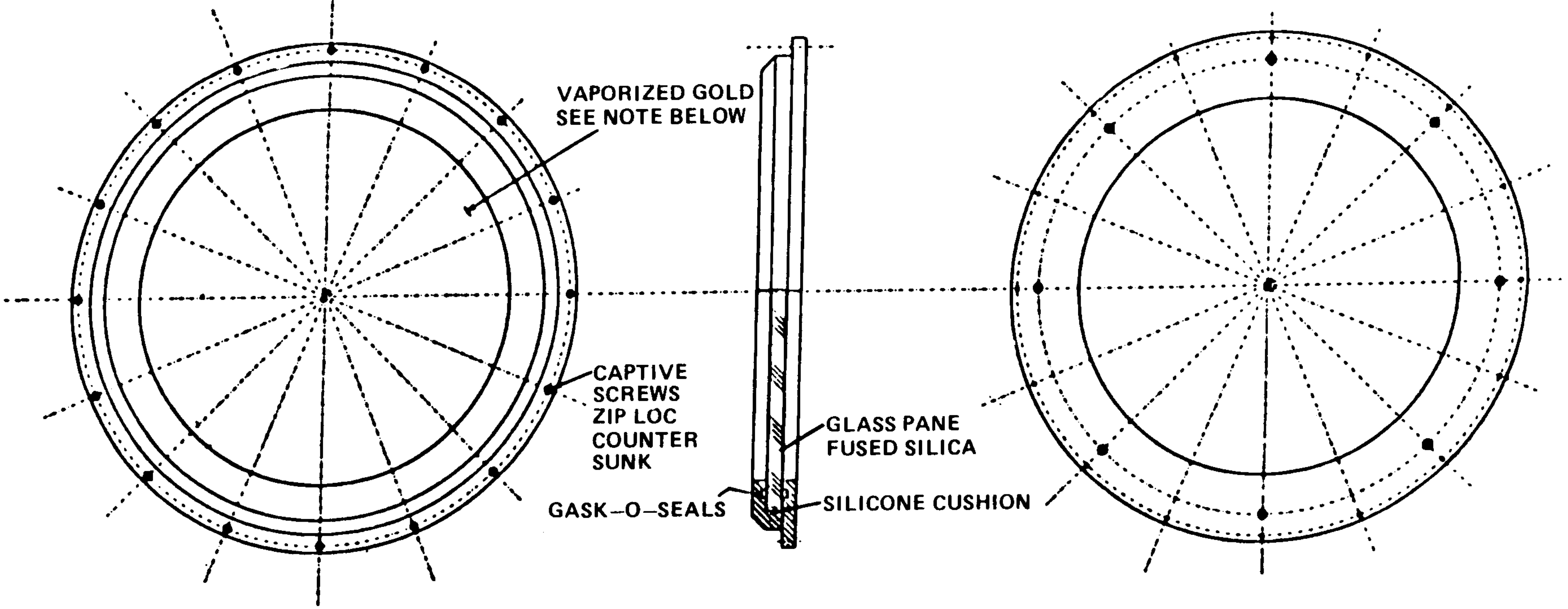
The frame that supports this pane and all the others is made of 2219-T87 Al [3,7]. The pane is supported by Gask-O-Seal rings, 0.70-in. from the edge of the 20-in. diameter clear viewing area. These rings help prevent glass-to-metal contact which would increase the possibility of failure in the pane. For additional protection against glass-to-metal contact, a silicone rubber cushion is placed between the pane and the frame wall. The frame is held together by eight screws, 45-deg apart, mated with tapped holes and inserts. The cover is attached to the viewport frame by 16 countersunk, captive screws placed 22.25-deg apart (Fig. 5).

INNER PANE ASSEMBLY

This frame will provide easy access (for changeout) to either the redundant or inner pressure pane. The combination of these two panes and their frame is called the inner pane assembly (IPA) (Figs. 6 and 7). The location of Gask-O-Seals and

NOTE:

DESIGNED TO HOLD
PRESSURE (44.1 PSI)
FUSED SILICA (.8535 IN.)



NOTE:

A COATING OF VAPORIZED GOLD IS PLACED
ON THE OUTSIDE OF THE OUTER COVER.
THIS COATING WILL HELP REDUCE THE RADIATION
HEAT BUILD UP INSIDE THE WINDOW.
ALSO IT WILL REFLECT A LOT OF THE SUN'S
GLARE AWAY FROM THE WINDOW

Figure 5. Outer cover.

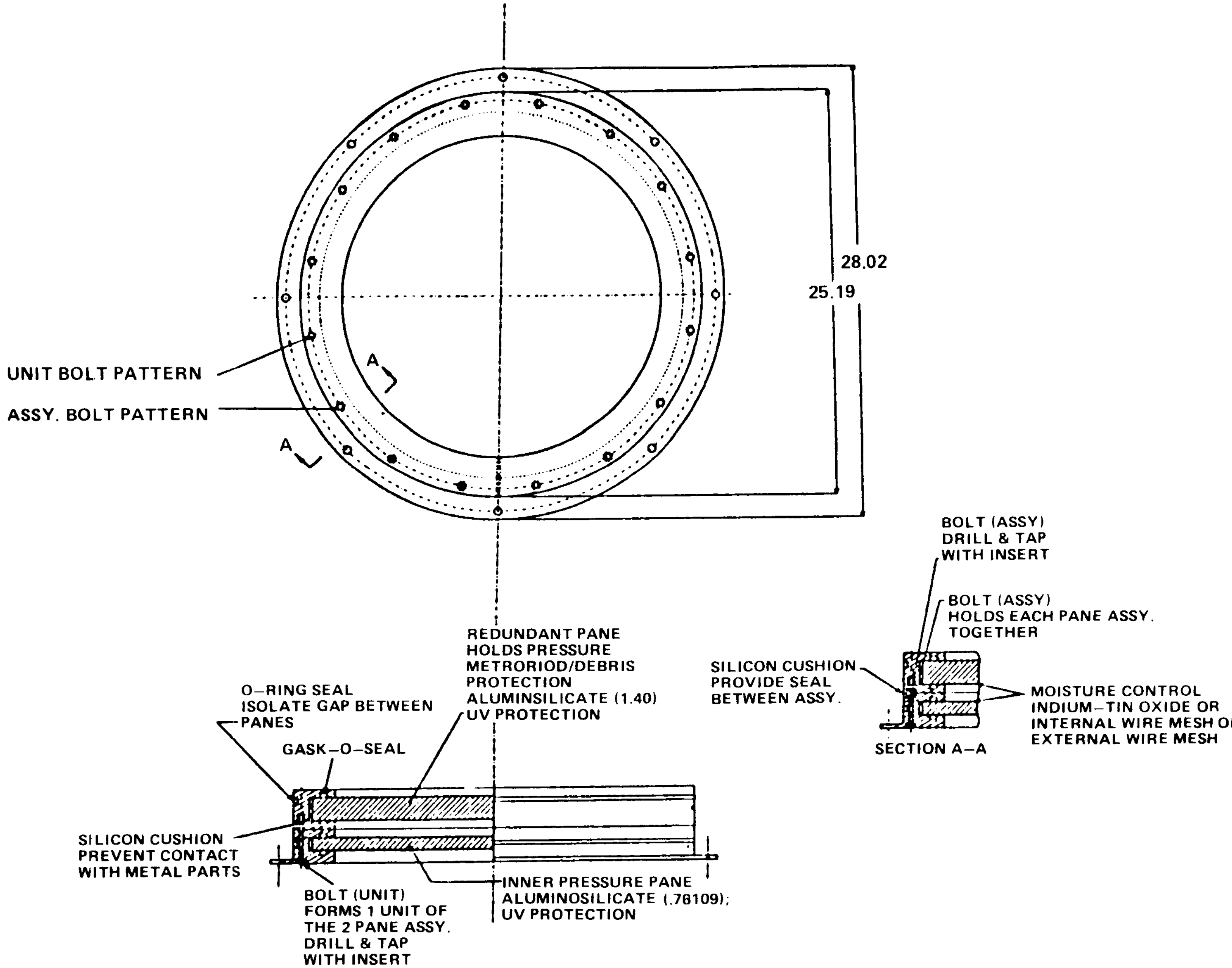


Figure 6. Inner pane assembly.

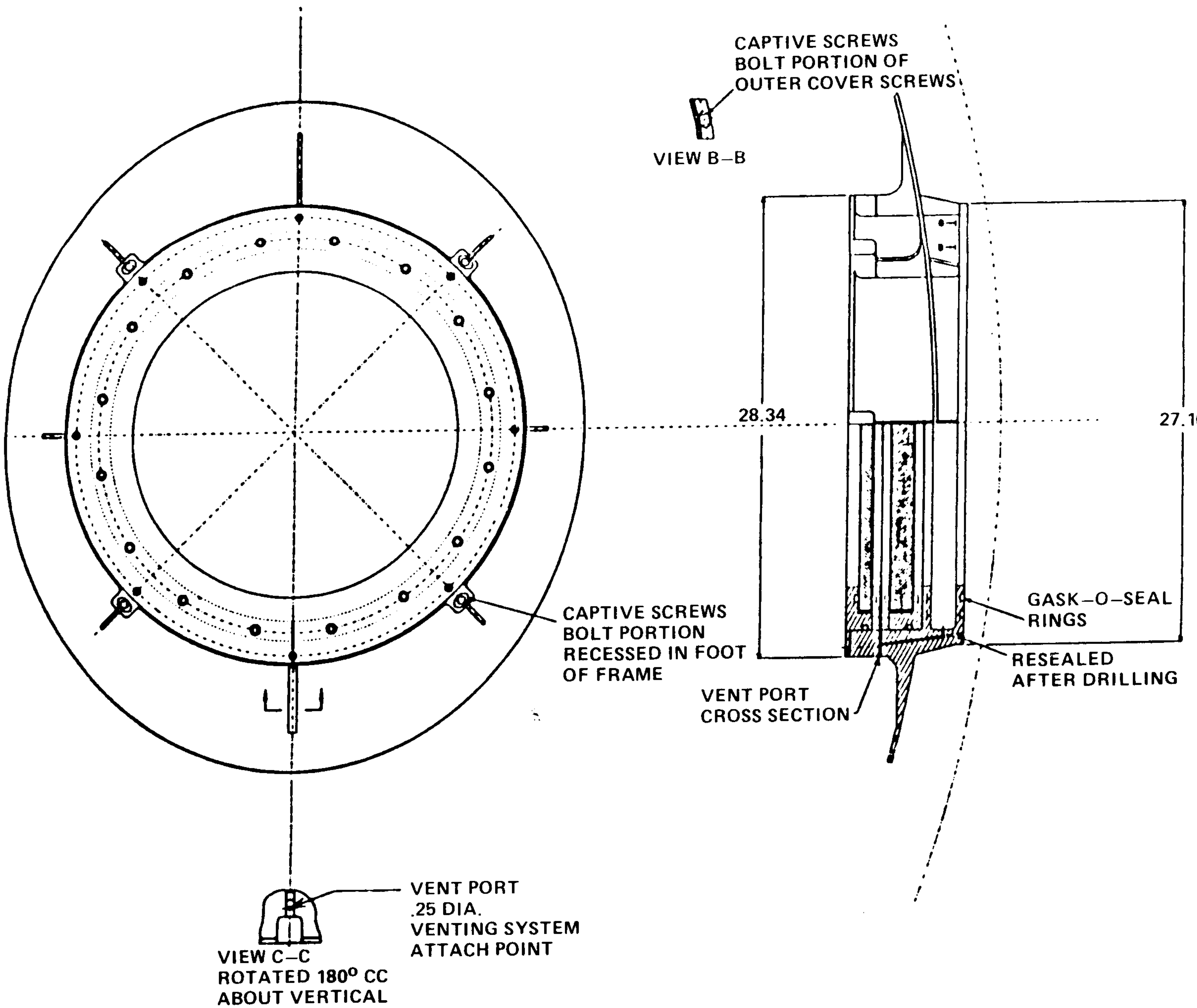


Figure 7. Inner pane assembly and frame.

silicone rubber cushions is the same as that in the outer cover. The redundant pane frame is held together by 8 bolts, 45-deg apart. These bolts mate with tapped holes with inserts to eliminate possible leak paths. The inner pressure pane frame has the same bolt configuration as the redundant pane frame except that it uses standard nuts instead of tapped holes with inserts. It also has an extension which facilitates attachment to the viewport frame (Fig. 7).

A vent path to the inside of the module was provided to prevent pressure build-up between the panes of the inner pane assembly. The path is a 0.25-in. hole with its center line at the point where the redundant and inner pane frames meet (Fig. 6). The center line of this hole is aligned with the vent path provided for the rest of the viewport system in the viewport frame. To facilitate the venting process, O-rings are placed around each frame to even more isolate the area between the panes and to meet a desired capability of redundancy in pressure sealing. At the point where the two frames meet, a layer of silicone rubber is placed to add to the seal between the frames (see Appendix B).

SAFETY COVER

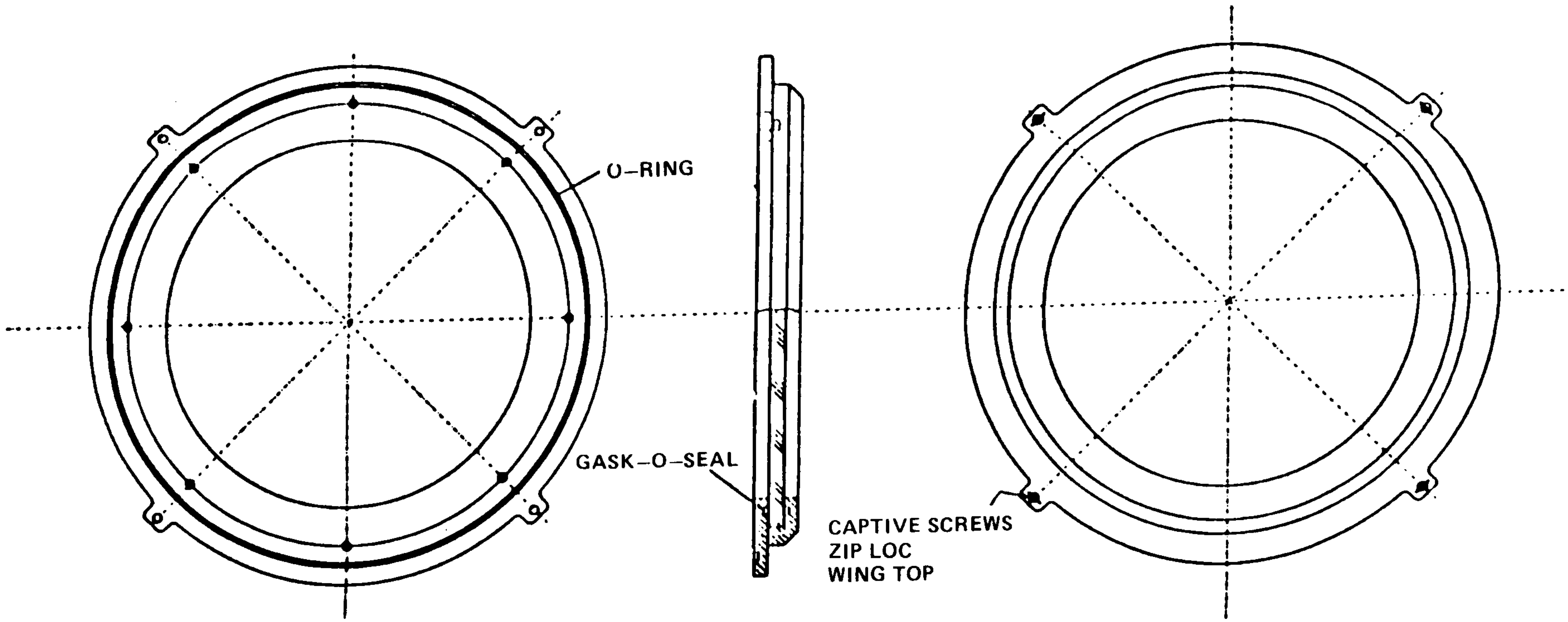
The safety (internal) cover's attachment method is very similar to that of the outer cover except that extensions are placed 45-deg from the vertical and horizontal at four places (Fig. 8). This facilitates the placement of four wing-top captive screws; one on each extension. Therefore, attachment of the safety cover to the inboard side of the viewport frame can be accomplished with a minimum amount of effort on the part of an astronaut. This cover will prevent accidental contact with the inner pressure pane. Each time contact is made with any of the panes, their strength properties are reduced. This is due to the fact that all glass materials have flaws in them and contact with any glass pane can initiate flaw propagation and greatly increase its chances of failure. In the same manner, chemicals, greases and other substances may cause crazing of the glass which is a form of flaw propagation.

COATINGS

Another problem associated with spacecraft windows is moisture collection on the panes. This condensation can be controlled by coating the panes with various types of tin oxides (differences are due to electrical power requirements and thicknesses), or internal and external wire mesh (Fig. 7). In this design the coatings are placed on the surfaces of each pane facing the airspace and possibly the inboard surface of the outer pane. It is also suggested that a coating of vaporized gold be placed on the outboard side of the outer pane to control IR and sun glare (Fig. 5). This type of coating was used on the Skylab S190 window.

VIEWPORT FRAME

The viewport frame provides all the attach points for the outer and safety covers in addition to those required for the inner pane assembly (Fig. 6). It also provides the necessary vent paths and means of attachment to the skin of the module.



NOTE:
DESIGNED TO HOLD
PRESSURE (44.1 PSI)
POLYCARBONATE (.7984 (N)

Figure 8. Safety cover.

On the inboard side of the viewport frame, safety cover captive screw mating points are 45 deg from the vertical and horizontal, four places, as described above for the safety cover attachment (Fig. 6). At the alternate 45-deg positions, extensions are flush with the outer edge of the attachment area. These, along with the other extensions are the points where the inner pane assembly attaches to the viewport frame via countersunk screws. These screws also align the center line of the inner pane assembly's vent port with the vent port in the viewport frame.

On the outboard side of the viewport frame, the outer cover captive screw mating points are placed beneath the overhang of the viewport frame (Fig. 6), as described previously for the outer cover attachment.

For additional support of the viewport frame, seven stiffeners of 0.25-in. wide cross section and one stiffener of 0.50-in. cross section (in which the vent port is located) are placed at 45-deg increments, on the inboard side of the viewport (Fig. 9). The same total number of stiffeners are used on the outboard side; each having a 0.25-in. wide cross section.

To meet the desired venting capabilities, a 0.25-in. diameter vent port is used to relieve pressure buildup between the redundant and inner pressure pane. This vent port also vents the area between the redundant pane and the outer cover. The center line of this vent coincides with the center line of the stiffener and is at the same stiffener inclination (see Appendix C). At the mouth of the vent port on the inboard side, a quick disconnect or a permanent attachment can be installed to facilitate the venting of the areas between the panes. The design of a venting system is not addressed in this report.

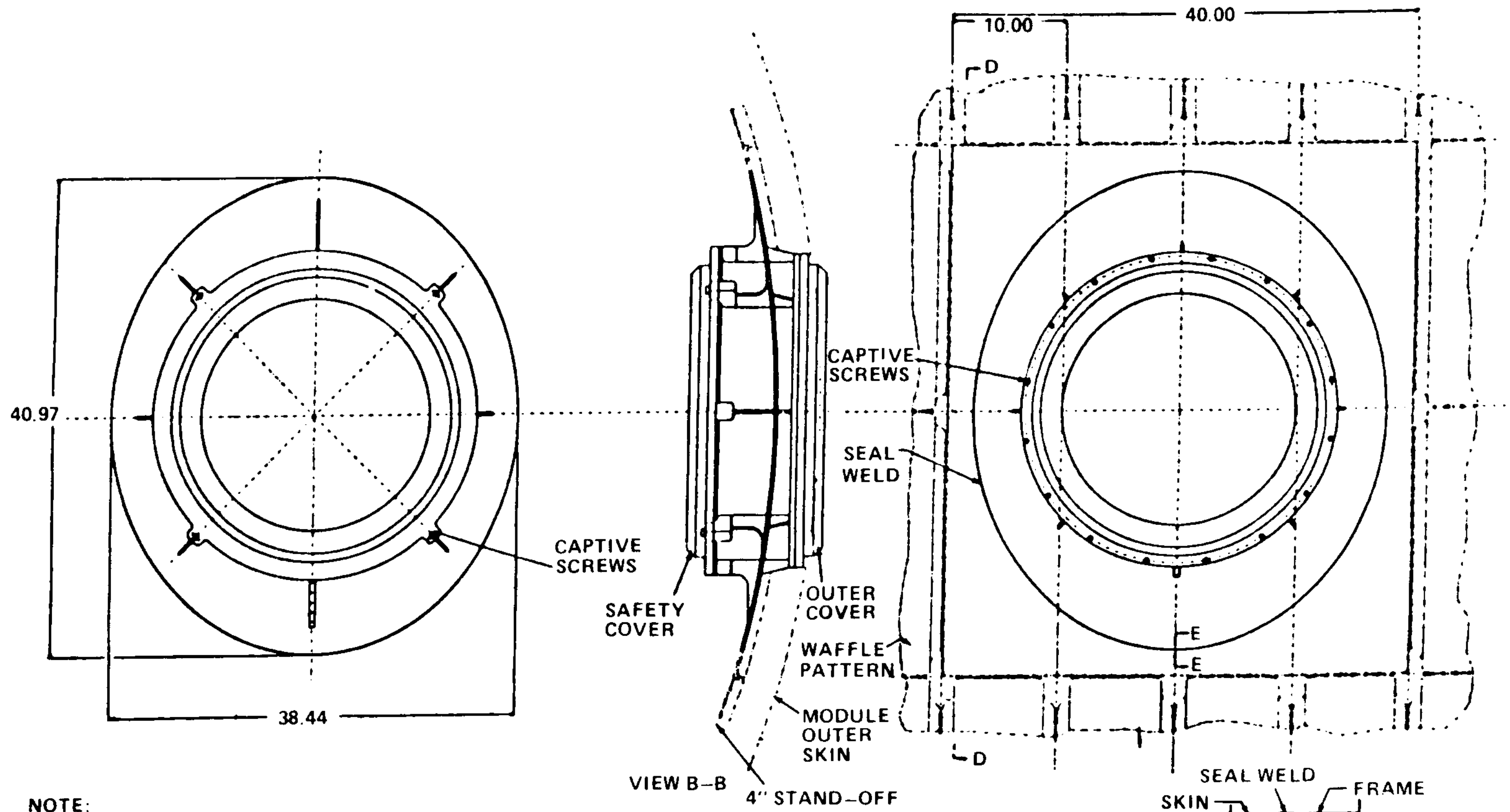
The module waffle pattern consists of rings 10 in. apart along the length of the module and longitudinal stiffeners 15-deg apart along the circumference. At the intersection of these rings and stiffeners is a node that provides a place for attachment to the shell of the module. Part of this waffle pattern will be modified to facilitate viewport assembly.

In attaching the frame to the module shell, a section of the module waffle pattern is modified: three complete nodes, eight half nodes, and four quarter nodes will be removed. Also, the area where the viewport will be inserted shall be machined to 0.25 in. rather than its normal 0.125 in. The skin of the frame is 0.25-in. thick. It is welded in place with a double "v" weld on the inboard and outboard sides [10]. This weld serves not only as a load carrier but also as a pressure seal weld.

MAINTENANCE AND REPLACEMENT

In the event of failure in one or more panes, a replacement scenario is required (see Appendix D). This is where unit construction, minimal number of parts, and easy access comes into play. This scenario can be applied to general maintenance as well.

It is expected that a minimal amount of maintenance will be required to maintain peak operating properties; O-rings and Gask-O-Seal rings will require the most attention. The actual changeout time interval has not been determined.



NOTE:

ALL METALLIC MATERIALS USED ARE 2219–T87 WITH THE EXCEPTION BEING ALL NUTS & BOLTS WHICH ARE OF STAINLESS STEEL & O–RINGS WHICH ARE OF SILICON RUBBER

NOTE:

SEAL WELD IS LOAD CARRYING & PRESSURE SEALING WELD

SECTION E–E
SCALE = 2:1

Figure 9. Viewport assembly.

WEIGHT

The weight for the 20-in.-diameter viewport is approximately 300 lb. Optimization of the structural parts is a potential method of reducing the weight by decreasing the amount of material used in the framework. Also, possible savings can be achieved by using higher strength glass with the same desired capabilities mentioned earlier (UV control and low thermal expansion). Without any changes to the present configuration, the weight is not unreasonable. The Spacelab Window Adapter Assembly (SWAA) weighs in excess of 300 lb. If Skylab's Multiple Docking Adapter (MDA) window, which was 1.60 in. thick, and weighed approximately 90 lb, is compared to the redundant pane used in this configuration, it can be seen that their weights are about the same (see Appendix E). Therefore this configuration's weight is within reason [17].

CONCERNS

The location of the viewports in the module cluster relative to the flight vector is important (Fig. 3). It is recommended that they be placed in areas they will see the smallest flux of meteoroid/debris particles. This position may be 180 deg from the flight vector. This may be the worst position for Earth and celestial viewing because it may fall in the middle of the module cluster. If the viewports are placed facing in the same direction as the flight vector, the possibility of impact increases in addition to the size of particle that must be defeated. This in turn increases the required glass thickness, the weight of the viewport, and the overall weight of the module itself. If the weight of the module is too high, there is some question as to whether the orbiter can lift the module to its correct orbit. Therefore, the location of the viewport is not a task that should be taken lightly.

CONCLUSION

At this time the reference configuration calls for 20- and 10-in.-diameter viewports for nonexperimental, continuous viewing (Fig. 10). The viewport design presented in this document incorporates various qualities that hopefully will make it viable in the C/D phase of the module development program. Its design was derived from concepts used in the Apollo, Skylab, and STS mission series (Fig. 2).

This design provides meteoroid/debris protection, ease of changeout, unit construction, moisture buildup control, UV and IR control, vent paths to prevent pressure build-up between the panes, and anytime Earth or celestial viewing by two persons. The viewport concepts used in the past (long duration flights) rendered designs that use metallic outer covers to protect the glass from meteoroid/debris penetrations. This provided limited viewing, as well as the task of removing the outer cover, and from a design point of view, another leak path to seal. These factors were taken into consideration in developing this viewport design. A design having a non-metallic cover will save time in not having to follow opening and closing procedures, and will eliminate possible leak paths in the area where the handle of a metallic cover would be installed. Once testing begins, it is expected that this viewport design will meet all requirements.

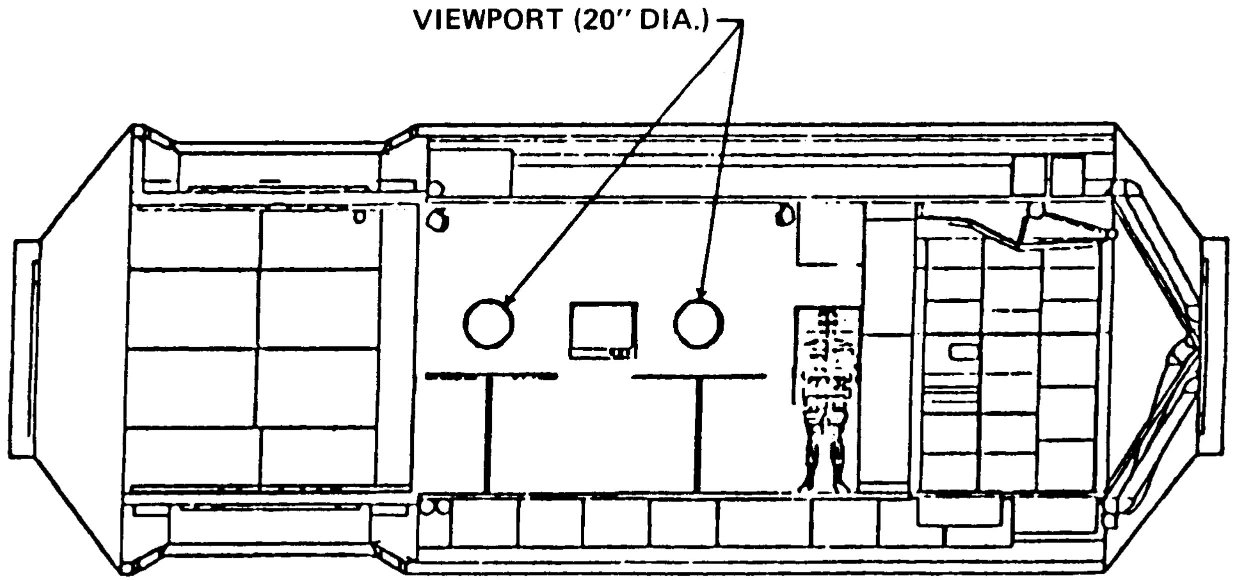


Figure 10. Possible position and application of viewports.

APPENDIX

A. Calculations

1. Particle Sizing

The probability of no penetration (P_o) for four modules is 0.97.

P_o (1 module) = $(0.97)^{0.25} = 0.992$

$0.992 = P_o$ viewport * P_o module.

For equal distribution of P_o between viewports and modules:

P_o viewport = $(0.992)^{0.50} = 0.996$

Furthermore

P_o viewport = P_o meteoroid * P_o debris

P_o module = P_o meteoroid * P_o debris .

For these probability breakdowns, it is shown that the debris particle size is the dominant one. It in turn would be the design driver. Also from the data, the particle size associated with 0.996 probability is the selected design particle size. This particle size was selected because at the assigned probability, it represents a particle size twice as big as the size that the module will see.

The equations used to generate the tables below [11,12] are as follows:

Probability of no penetration

$$P_o = e^{-N\,A\,T}$$

where

N = meteoroid/debris flux ($/m^2$ yr)

A = projected area (m^2)

T = exposure time (yr)

Flux equation

meteoroid

$$\log N = -14.37 + \log G + \log S - 1.213 \log m$$

where

G = gravitational defocusing constant

S = Earth shielding constant

m = mass of particle (g/cc)

debris

$$\log N = -5.46 - 2.52 \log d$$

where

d = diameter of particle (cm).

From the following tables, it can be inferred that the debris particle would be the design driver for the viewports.

TABLE 3. VIEWPORT METEOROID/DEBRIS ANALYSIS

	Particle (Diameter cm)	
P_o	Meteoroid ($\times 10^{-3}$)	Debris
0.999	1.87	0.240
0.998	1.55	0.184
0.997	1.39	0.157
0.996	1.28	0.139
0.995	1.20	0.128
0.994	1.14	0.119
0.993	1.10	0.112
0.992	1.06	0.106

TABLE 4. MODULE METEOROID/DEBRIS ANALYSIS

	Particle (Diameter cm)	
P_o	Meteoroid ($\times 10^{-3}$)	Debris
0.999	5.66	1.20
0.998	4.68	0.91
0.997	4.19	0.78
0.996	3.90	0.69
0.995	3.64	0.63
0.994	3.46	0.59
0.993	3.32	0.55
0.992	1.69	0.25

2. Expected Penetration

The equation is as follows [9]:

$$P = 0.53d^{1.06}\,\rho^{0.50}\,v^{0.667}$$

d = diameter of particle (cm)

ρ = density of particle (g/cc)

v = velocity of particle (km/s)

p = penetration (cm)

p = 0.5092 cm (0.200 in.)

3. Glass Pane Sizing

Redundant Pane [13,15]

$$t = 7 * p$$

t = thickness (in.)

t = 1.40 in.

Outer Pane

$$t = d[(3qFS(3m + 1)/(32mSy)^{0.50}]$$

d = diameter (in.)

q = uniformly distributed load (psi)

FS = factor of safety

Sy = modulus of rupture

m = inverse of poisson ratio

t = 0.8535 in. [1] .

Inner Pressure Pane

t = 0.7610 in.

Safety Pane

t = 0.7904 in.

B. Sealing Material

O-Rings - Silicone

Gask-O-Seals - Silicone

Silicone Sheet - Silicone

All per SAE-AMS-3304 - (Silicone Rubber).

C. Vent Port Drilling

The vent port in the viewport frame is made by drilling from the outboard side of the frame, 97 deg from the outboard surface. This location is slightly beyond the intersection of the vent port center line of the inner pane assembly. After drilling, the vent port section above the vent for the area between the redundant and outer panes is resealed.

D. Damaged Pane Replacement Scenario

Case 1. Outer Cover

A. Replace outer cover on EVA

B. Vent air space.

Case 2. Outer Cover and Redundant Pane

A. Replace outer cover, EVA required

B. Remove safety cover

C. Remove inner pane assembly, repair as needed [to remove the IPA from the frame, the IPA handle is provided (Fig. 11)].

D. Replace inner pane assembly

E. Replace safety cover

F. Vent air spaces

Case 3. Outer Cover and Both Inner Pane Assembly Panes

A. Same as Case 2.

Case 4. Outer Cover, Inner Pane Assembly, Safety Cover

A. Same as Case 2, steps A-D

B. Repair safety cover as needed and replace

C. Evacuate air spaces.

NOTE: The maintenance scenario will be the same as presented above. The phrase "repair as needed" or "replace" will usually mean replacement of pane and frame as a unit and replaced with another complete unit.

E. Itemized Weights

Frame (skin included)		46.12
Safety cover		56.80
Outer cover		64.68
IPA		144.70
	Total	312.30 lb
Glass only		
Redundant		54.30
Pressure		29.52
Outer		27.72
Safety		14.20
	Total	125.74 lb
Frame only (Total Al)		186.56 lb

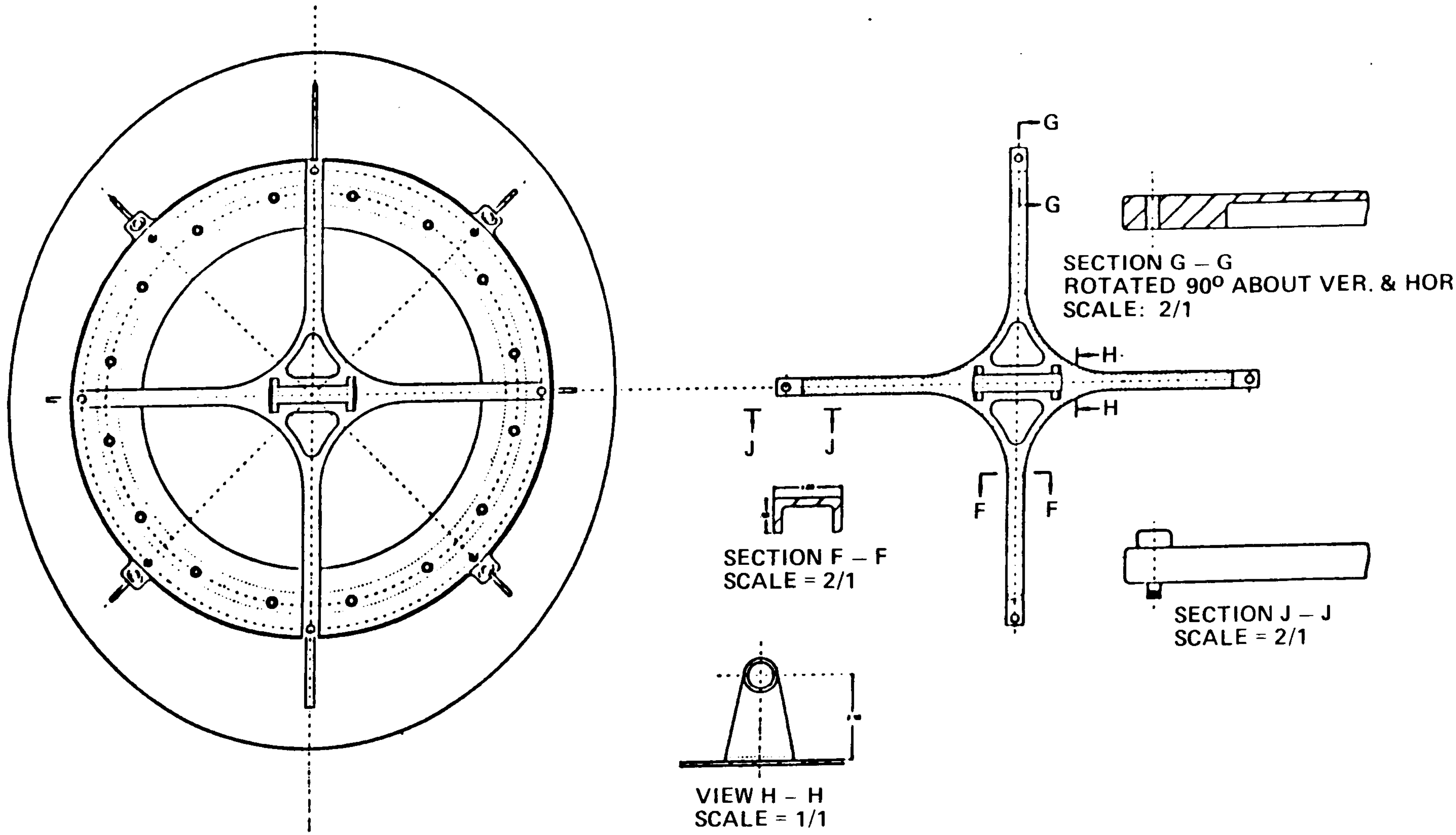


Figure 11. Inner pane assembly handle.

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APPROVAL

VIEWPORT CONCEPT FOR SPACE STATION MODULES

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The information in this report has been reviewed for technical content. Review of any information concerning Department of Defense or nuclear energy activities or programs has been made by the MSFC Security Classification Officer. This report, in its entirety, has been determined to be unclassified.

A. A. McCool

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Director, Structures and Propulsion Lab.

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16. ABSTRACT

This report addresses the generic design of a 20-in. diameter viewport for the space station modules. It should possess the capabilities of meteoroid/debris protection (with no metallic cover), redundancies in its meteoroid/debris protection, and pressure sealing systems. In addition, it should provide ease of change out for maintenance or repair. The design does not take into account the bumper-shield effect of the outermost panes in the meteoroid/debris analysis.

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