Design of Space Stations for Low Atmospheric Leakage

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Space Station designs can include sealing concepts that reduce atmospheric leakage to negligible quantities. Meteoroid penetrations are infrequent and are eliminated as sources of continuous leakage because necessary repairs are made immediately. All other pressure-shell penetrations can be reduced to static O-ring seals with estimated leakage at 1 atmosphere of about 6×10^{-2} cc/day/in. of seal. This leakage, when applied to the 33-ft-diam Space Station resulted in a total atmospheric loss of about 0.002 lb per day. Test data from flight-weight designs and ground vacuum chambers are presented.

Introduction

AN important consideration in the design and use of a long-duration Earth-orbiting Space Station is leakage of atmosphere from its pressurized compartments. The gases comprising the original atmosphere are, of course, launched with the Space Station. Compensation for atmosphere that has escaped is accomplished with an onboard supply which is periodically replenished, as required, with the Earth-to-orbit logistics system. The amount of leakage is then directly related to the demand on the logistics system and if the leakage is excessive, it contributes to the problems of contamination of the local (near the station) space environment and to maintaining effective thermal control.

The authors found in researching applicable leakage test data and in discussions with various engineers in the aerospace industry, that a wide range of estimates for spacecraft leakage rates exists. Primarily this has resulted because no real effort has been made to design manned spacecraft to meet the state-of-the-art design and fabrication for low leakage. This paper presents an assessment of the atmospheric leakage (approximately 0.002 lb/day) for a typical Space Station concept.[1] The Space Station has been designed to provide a research facility that can accommodate a 12 man scientific crew over an orbital lifetime of at least 10 yr. The internal atmosphere is a mixture of O_2 and N_2 at a pressure of 14.7 psia; this constitutes approximately 2,000 pounds of gas.

The paper begins by identifying the potential sources of atmospheric losses that are of particular concern to the designer. Meteoroid and accidental punctures of the pressure shell are shown to present special problems and, hence, require special solutions. Considerations of long-term leakage are then limited to known penetrations of the pressure shell. Data are presented to show that leakage through these joints can be reduced to that which passes through the sealant material itself. Test data are reviewed and the most applicable data used to derive a basis for estimating Space Station leakage. An effective design for leakage monitoring and control is also presented. Finally, design requirements are presented, which would result in spacecraft designs that leak orders-of-magnitudes less than anything previously flown.

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Atmospheric Losses

Space Station atmospheric losses may be either planned or unplanned. Planned losses are those from such items as airlock evacuation, ullage dumps from the waste management system, and the gaseous N_2 that is inadvertently combined with the CO_2 gases used for propulsion. These planned losses are known in advance and allowed-for in the atmospheric supply and control subsystem design.

Unplanned losses result from leakage through sealed pressure-shell penetrations or from penetrations occurring from meteoroid or accidental punctures. A leakage allowance must then be provided for these unplanned losses because this represents the area of uncertainty.

The most significant consideration in choosing a design approach to minimize unplanned atmospheric leakage is shown in Fig. 1. This figure presents the theoretical relationship between atmosphere loss and hole size for the molecular or capillary flow and the sonic flow regimes. The importance of minimizing the effective penetration is evident: as the hole diameter increases one order of magnitude, from 0.01–0.10 in., the atmospheric loss increases by two orders of magnitude, from approximately 2–200 lb/day. Adopting a design approach that permits leakage in the sonic flow regime, e.g. 5 lb/day, then would be a definite risk because, as Fig. 1 shows, a small change in accumulative hole size would result in an unacceptable leakage that could not be economically compensated for by gas reserves. Therefore, a required design objective should limit leakage to that through the sealant material itself, which would then correspond to molecular or capillary flow.

The potential of achieving negligible leakage is illustrated

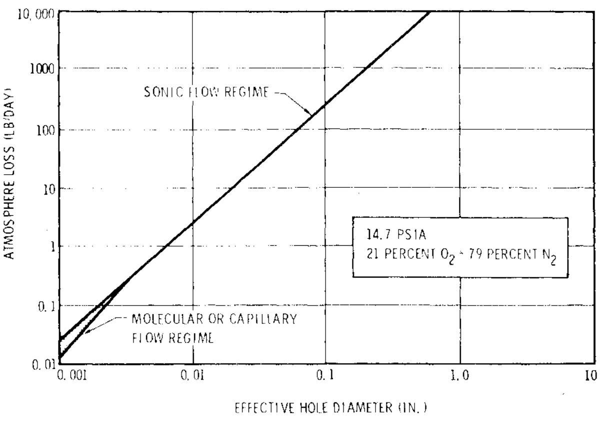

Fig. 1 Atmospheric leakage vs hole diameter.

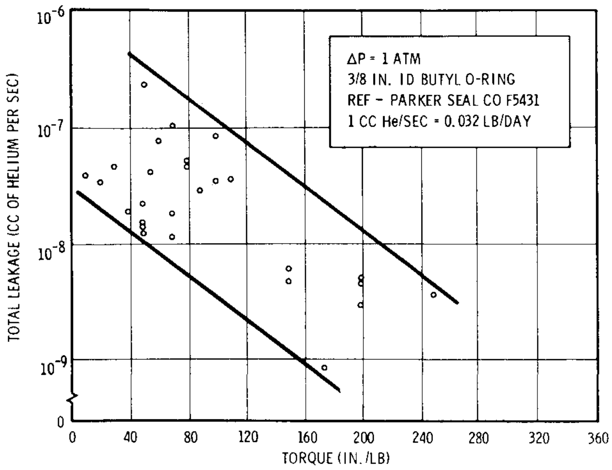

Fig. 2 Diffusion rates.

by Fig. 2 which shows typical peformance data for Butyl O-ring seals. It indicates that leakage through properly d-signed seals is actually reduced to the diffusion of the molecules through the sealing material itself. Admittedly, the size of this seal is such that one cannot immediately jump to the conclusion that comparable performance can be expected on O-rings 33 ft in diameter. This paper will attempt to show, however, that all Space Station seals are designed in the same way and that comparable results can be expected.

Meteoroid Punctures as a Source of Leakage

One of the unplanned losses previously noted was caused by meteoroid punctures of the pressure shell. Consideration must then be given to the expected frequency of meteoroid punctures, the estimated damage caused with respect to leakage, and the required remedial action if and when punctures occur. The structural details of the meteoroid shield, pressure shell, and thermal insulation are shown in Figs. 3 and 4. This meteoroid and thermal protective system is designed to a thermos-bottle concept that keeps the pressure shell at ambient temperature and eliminates the thermal cycling effects that would be detrimental to maintaining sealed interfaces.

The selected meteoroid protective system exceeds the NASA requirement of 0.90 probability of the spacecraft experiencing no pressure-shell punctures in 10 yr. Actual tests of the meteoroid protective system established its performance to be 0.989 probability of no puncture occurring in 10 yr or 11 chances in 1,000 of sustaining a puncture. Furthermore, from the test data, it was concluded that: 1) a meteoroid that clearly penetrates the pressure shell will result in a sizeable hole. Referring to Fig. 1, it is evident that the atmosphere lost through holes of this type cannot be compensated for by a reasonable leakage allowance; and 2) a meteoroid that damages the pressure shell (near the ballistic limit of the structure) may or may not produce a leak, depending on local yielding at the point of impact. However, the bulge produced is significant and readily visible, not to mention the sound of the impact. Therefore, each hit should be treated as a potential puncture.

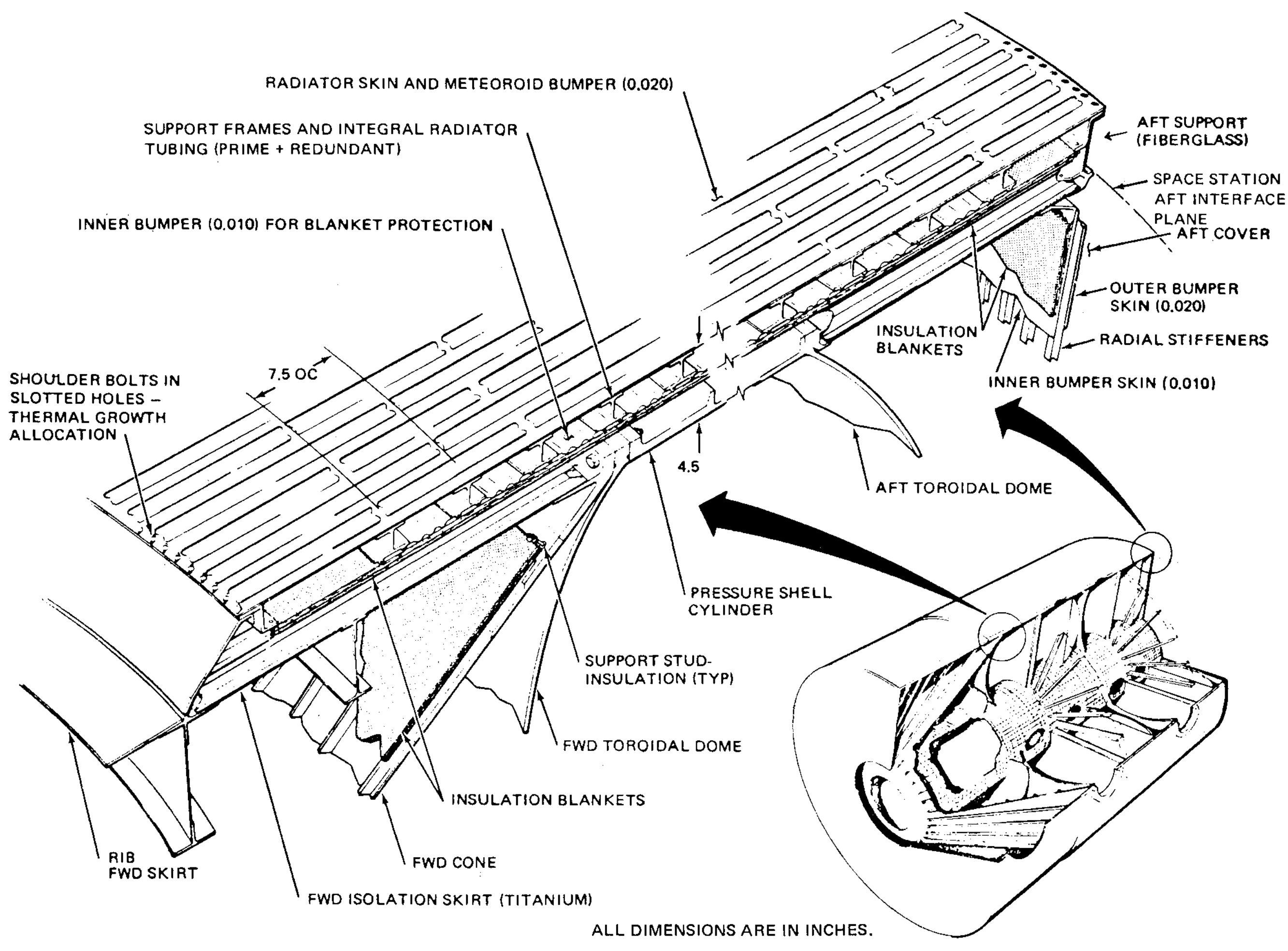

Fig. 3 Space station structure details.

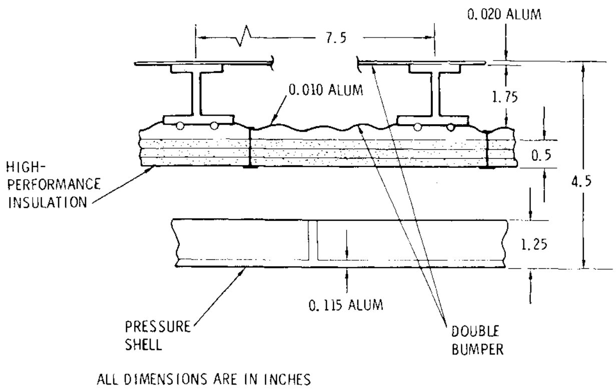

Fig. 4 Section through outer shell.

Additional tests to establish the ballistic limit of the intermediate bumper indicated that approximately 2 penetrations of both outer and inner meteoroid shields are to be expected in 10 yr; therefore, only 2 hits of the pressure shell are expected.

The over all conclusions are that: 1) meteoroid penetrations must be repaired as quickly as possible because they can result in unacceptable losses of atmosphere: 2) atmosphere supply to compensate for losses caused by meteoroid punctures should be in the form of a stored reserve, e.g., the gaseous contingency supply for repressurization of a pressure compartment; 3) this stored reserve must be capable of providing very large amounts of atmospheric make-up for short periods of time; and 4) the reserve should be capable of storage for very long periods of time because although the probability of needing it is very small, its use may occur anytime during the 10 yr mission.

Leak-Test Data

Applicable leak-test data from past and present space programs have been collected and reviewed to provide a basis for estimating Space Station leakage. The data include results from pressure-decay tests using air and from mass spectrometer tests using helium as a trace gas.

Pressure-decay leak-test data for Gemini and Apollo are shown in Tables 1 and 2. These spacecraft contain some riveted and bolted structural joints sealed with RTV compounds. These types of structure and sealing concepts, although satisfactory for short-duration missions (i.e., 14 days) and vehicles designed for re-entry, are not proposed for the Space Station. Referring to Table 2, variations in measurements on the same spacecraft between the North American Rockwell facility in Downey, California with Kennedy Space Center are not significant.[2] Variations between ground and flight-derived data show a consistent difference. This can be partially explained because the ground tests were not conducted with critical pressure ratios. Most significant is the variation in equivalent flight leakage from spacecraft to spacecraft which covers a range of a factor of 12. Again, Fig. 1 emphasizes this sensitivity.

Table 1 Gemini leakage

	Standard cc/min	lb lost per day
Specification allowance		
(N_2 at 5.1 psig)	670	2.5
Test results:		
Spacecraft 4	400	1.5
Spacecraft 10	630	2.4
Spacecraft 11	390	1.5

Table 2 Apollo leakage test results (lb/day)[a]

Specification allowance = Command module (CM) 4.8 lb/day
lunar module (LM) 4.8 lb/day

Vehicle	Ground measurements	Kennedy Space Center measurements	Equivalent flight-oxygen
CM 101	...	5.83	...
CM 103	5.35	3.97	1.98
CM 104	1.74	2.32	0.64
CM 106	3.59	3.11	1.33
CM 107	2.21	2.32	0.82
CM 108	8.04	6.24	2.98
CM 109	1.06	1.54 and 1.73	0.40
CM 110	0.69	...	0.25
LM 4	3.69		0.81
LM 5	5.30		1.10
LM 6	6.79		0.84
LM 7	5.47		0.36

[a] CM data—Ref. 2, LM data—MSC Apollo Program Office. Note: Ground test pressure 5.1 psig—air.

Leak-test results from the Skylab multiple docking adapter (MDA), a welded structure with a minimum of bolted interfaces, are shown in Table 3. These tests, which were conducted in the NASA-MSFC laboratories under controlled conditions, show that a different structural concept can yield structures with dramatically reduced leakage.

The McDonnell Douglas Astronautics Company Space Simulation Laboratory located in Huntington Beach, Calif., provided experience on both small and large-diameter vacuum chambers using O-ring seals. The 39-ft diam vacuum chamber has been in cyclic operation for over 7 yr with nearly 1 yr of cumulative space vacuum test operation. During this time, the 30-ft-diam lid seals were replaced once after 2 yr of operation; the second set of seals is still in operation after more than 5 yr. Other pertinent information on the laboratory sealing experience is shown in Table 4. It should be noted that the

Table 3 MDA leakage test results, January 1970[4]

	Standard in.^{3}/min	Standard cm^3/sec	lb/day
Specification Allowance	38.0		2.4
Total leakage Tests[a]			
1	0.23		14.52×10^{-3}
2	0.52		32.84×10^{-3}
Docking cylinder Joint tests[b]			
1		2.8×10^{-7}	9.04×10^{-9}
2		3.5×10^{-9}	0.11×10^{-9}
3		0.8×10^{-9}	0.03×10^{-9}

[a] Pressure decay test—air at 5 psig.
[b] Mass spectrometer test—helium at 5 psig.

Table 4 Experience on 39-ft-diam vacuum chamber

Total normal leakage	$<3 \times 10^{-10}$ lb/day of helium
Type of seals	Buna "N" O-rings
Design	ASME standards
Replacement history (7-yr operation)	
Two 30-ft-diam lid seals	Replaced after 2 yr second set still in use after more than 5 yr
Eight 5-ft-diam pump seals	Never replaced
One 4- by 7-ft man-lock seal	Replaced every 1–1½ yr because of mechanical damage

Table 5 Langley Research Center/MDAC airlock[3]

Size	Cylinder, 48 in. ID 81-in. total length in 21 in. and 60-in. Secs.
Weight	377 lb
Hatches:	
A	Circular, symmetric, single butyl O-ring
B	Oblong, unsymmetric, molded butyl O-ring
C	Circular, contoured, inflatable butyl seal
Closure	Latching mechanism, pressure equalization valve for each hatch
Other	Window in hatch "A" 4-in. diam Lighting Communication Hatch Δp gages

total leakage of the large vacuum chamber is expressed as less than 3×10^{-10} lb/day of helium because that is the limit of the capability of the mass spectrometer used during measurement. Seal replacement in the laboratory is usually required because of seal damage during test setup. Seals on unbroken interfaces have been operating satisfactorily for 7 yr.

Perhaps the most pertinent leak test data were obtained on an airlock designed for the express purpose of testing sealing concepts applicable to Space Stations.[3] Table 5 presents the general characteristics of the airlock. Three hatch and seal design concepts were provided in the airlock structure to correspond to potential types for use on the Space Station. In addition to the hatch seals, each endplate and the cylindrical segment joint were sealed with butyl O-rings. Table 6 presents a summary of the applicable test data. A mass spectrometer was used to measure the leakage. Leakage rates as low as 1×10^{-6} cc/sec, or 0.24×10^{-6} lb/day, of helium were attained. After 2 yr of use, the original seals continued to seal satisfactorily.

Space Station Leakage Estimate

The structure for the 33-ft-diam Space Station was designed to minimize atmospheric leakage as follows. 1) The pressure shell is an integrally-machined waffle structure with the smooth surface inside the station. 2) The main structural joints are either welded or bolted and sealed with O-rings. 3) Penetrations through the pressure shell are minimized and all are reduced to static seals. Faying surfaces, fillet seals, and riveted or unsealed bolted joints are not used.

Assessing the Space Station atmospheric leakage allowance requires the assignment of a design-to-leak rate and a compilation of all potential Space Station leakage sources. A review of the available data (presented in this paper) led to the selection of applicable leak rates from the Langley Research Center (LaRC) airlock tests on all types of seals planned for the Space Station. This selection appears justified because of the commonality in design of the airlock and Space Station structures (both have light-weight welded structures, use O-ring seals on the main structural joints, and use inflatable seals on the hatches) and because the tests are among the most accurate available.

The selected leak rates, adjusted to the amount of leakage per inch of seal length, are shown in Table 7. These leak rates originated from the maximum values, for the LaRC airlock, as indicated. Note that the largest values were chosen without regard for test temperature conditions although the pressure shell is maintained at ambient temperature. These leak rates are conservative to a further degree because they are based on tests that used helium gas and purposely were not corrected for the slower rate of leakage to be expected from the mixture of O_2 and N_2 used for the Space Station atmosphere.

Tables 8 and 9 are compilations of the potential structural leak sources and subsystem penetrations through the Space Station's pressure wall. In Table 8 seal length is separated

Table 6 Summary of LaRC airlock leakage tests[3]

Test[a]	Type of hatch[b]	Direction of pressure loading[c]	Temperature[d] °F	°C	Maximum leakage flow rate, cc/sec	Maximum leakage weight rate, lb/24 hr $\times 10^{-6}$
1	A	Closed (1 cycle)	Room		3.1×10^{-6}	0.71
2	A	Closed (50 cycles)	Room		1.0×10^{-5}	2.28
3	A	Open (1 cycle)	Room		6.2×10^{-6}	1.43
4	A	Open (50 cycles)	Room		2.6×10^{-6}	0.57
5	B	Closed (1 cycle)	Room		5.4×10^{-6}	1.24
6	B	Closed (50 cycles)	Room		4.8×10^{-6}	1.11
7	B	Open (1 cycle)	Room		5.2×10^{-5}	11.89
8	B	Open (50 cycles)	Room		1.4×10^{-5}	3.21
9	B	Closed (1 cycle)	Room		2.8×10^{-6}	0.64
10	C	Closed (1 cycle)	Room		1.7×10^{-5}	3.90
11	C	Closed (50 cycles)	Room		1.5×10^{-5}	3.44
12	C	Open (1 cycle)	Room		2.1×10^{-5}	5.56
13	C	Open (50 cycles)	Room		5.9×10^{-5}	12.82
14	A	Closed (1 cycle)	150	65	6.4×10^{-5}	14.65
15	A	Closed (1 cycle)	201	94	7.2×10^{-5}	16.48
16	B	Closed (1 cycle)	140	60	1.2×10^{-5}	2.76
17	B	Closed (1 cycle)	193	89	1.7×10^{-5}	3.90
18	C	Closed (1 cycle)	150	65	2.4×10^{-6}	0.56
19	C	Closed (1 cycle)	177	80	1.0×10^{-6}	0.24
20	B	Closed (1 cycle)	−48	−44	9.7×10^{-4}	222.10
21	B	Closed (1 cycle)	−39	−39	9.3×10^{-4}	212.93
22	C	Closed (1 cycle)	−34	−37	3.9×10^{-5}	8.93
23	C	Closed (1 cycle)	−44	−42	2.8×10^{-5}	6.41

[a] Test condition—10^{-6} torr vacuum, He at 1 atm pressure.
[b] Hatches A, B, and C are defined in Table 5.
[c] Closed, pressure loading forces the hatch against the seal; open, pressure loading forces the hatch away from seal.
[d] Room temperature is 75°–80°F (24°F–27°C).

Table 7 Leak-rate assessment from LaRC airlock test data

Type of joint	Type of seal	Measured leakage,[a] cc/in. of seal length per 24 hr	LaRC airlock test
Structural flange	O-ring	0.34×10^{-2}	60-in.-long cylinder acceptance test at MDAC[3]
Penetration fitting	O-ring	6.00×10^{-2}	Test 15, Hatch A (Table 6)
Hatches, view ports	Inflatable labyrinth	4.77×10^{-2}	Test 13, Hatch C (Table 6)

[a] From Ref. 3.

Table 8 Space station structural leak sources

	No. of penetrations	Seal diam, in.	Type of seal	Total seal length, in.		
				O-ring	Inflatable	Labyrinth
Pressure shell						
Toroidal dome to cylinder	4	398	O-ring	5,002		
Toroidal dome to tunnel	8	120	O-ring	3,016		
Hatches						
Docking port	6	60	Inflatable		1,170	
Remote maneuvering satellite hangar	1	80	Inflatable		258	
Navigation sensor access	3	30	O-ring	285		
Extravehicular activity airlock	1	42	Inflatable		95	
Tunnel	1	60	Inflatable		195	
Propulsion high-thrust	2	30	O-ring	190		
Propulsion low-thrust	8	12	O-ring	304		
Experiment airlock	2	24	Inflatable		151	
View ports						
Crew (2 leak paths)	24	10	Labyrinth			1660
Experiment (2 leak paths)	1	18	Labyrinth			120
Bolt seals						
Tunnel to domes (50% factor)	1410	0.375	O-ring	1,794		
Total				10,591	1,869	1780

Table 9 Space station subsystem penetration leak sources (all seals are O-ring)

	No. of penetrations	Seal diameter, in.	total Seal length, in.
Propulsion			
High-thrust system conduit	2	6	38
Low-thrust system conduit	4	1	13
Umbilicals (refueling)	2	6	38
Communications			
Waveguides	12	2	75
Coaxial	8	1	25
Electronics (connectors)			
Instrumentation	100	2	630
Lights	75	1	236
TV Camera	16	1	50
Power feed to buss	6	3	57
EC/LS			
Docking port disconnects and lines	14	4	176
	14	2	88
	14	0.5	22
Tunnel to pressurizable	6	0.375	8
compartment lines	1	2	7
Dump and relief valves	2	8	51
Thermal control and	8	0.5	13
radiator lines	4	0.375	5
Waste management			
can	4	10	126
valve	1	2	7
Total			1665

into the three basic types of seals used in the Space Station. Lengths for various seal types, assigned leak rates (from Table 7), and the total estimated leakage through the sealed interfaces are presented in Table 10. The estimated atmospheric leakage through the subsystem components is summarized in Table 11. Finally, the total estimated Space Station leakage, summarized in Table 12, is 1.216×10^{-3} lb/24 hr.

Outboard Leakage Control System

Although the anticipated leakage is very low, it is still necessary to monitor and control leakage because some seals can fail, e.g. due to mechanical damage as in a docking port hatch, or the pressure shell can be punctured by a meteoroid. The leakage control concept selected for the Space Station consists of: 1) monitoring the over all leakage rate by computing the N_2 use rates; 2) monitoring meteoroid hits on the pressure shell by means of wall-mounted transducers; 3) locating meteoroid leaks visually or by using ultrasonic devices; and 4) monitoring seal effectiveness. The onboard checkout and data management subsystems are used to accomplish these tasks.

Measurement of Space Station Leakage Rate

The over all Space Station leakage rate is monitored by computing the N_2 use rate. A schematic of this system is shown in Fig. 5. The pressure control system that feeds N_2 to the cabin contains a pressure regulator, a calibrated orifice, and a feed valve that opens for a fixed 10-sec period. The regulator controls the N_2 pressure to a known value, and the

Table 10 Estimated seal leakage

Type of seal	Type of joint	Seal length, in.	Assigned leak rate, cc/24 hr/in.	Estimated leakage cc/24 hr	Estimated leakage lb/24 hr[a]
O-ring	Flange	8,018	0.34×10^{-2}	27.26	0.072×10^{-3}
	Penetration fittings	2,444	6.00×10^{-2}	146.64	0.389×10^{-3}
	Bolt seals	1,794	6.00×10^{-2}	107.64	0.285×10^{-3}
Inflatable-Labyrinth	Hatches, viewports	3,649	4.77×10^{-2}	174.06	0.461×10^{-3}
Total					1.207×10^{-3}

[a] 1 cc/24 hr = 2.65×10^{6} lb/24 hr.

Table 11 Estimated component leakage

Component	Number of components	Total seal length, in.	Assigned leak rate, He at 1 atm	Estimated leakage cc/24 hr	Estimated leakage lb/24 hr
Connector Coaxial waveguides	217	1,073	2.74×10^{-3} cc/24 hr/in.[a]	2.94	0.0078×10^{-3}
Valves	3	...	0.12 cc/24 hr[b]	0.36	0.0009×10^{-3}
Total					0.0087×10^{-3}

[a] From MIL-S-8484.
[b] From NASA SP-5019.

Table 12 Summation of estimated leakage

Source	Estimated leakage, lb/24 hr
Seal	1.207×10^{-3}
Component	0.0087×10^{-3}
Diffusion (Aluminum)	1×10^{-13}
Total	1.216×10^{-3}

orifice passes a fixed amount of gas during each 10-sec interval. The computer counts the number of times the feed valve pulses, and thus maintains a continuous record of N_2 lost overboard. Planned overboard atmospheric dumps are also recorded and thus, the unplanned N_2 losses can be determined.

The onboard checkout subsystem will warn the crew whenever the N_2 use rate increases significantly, and the crew can obtain a visual CRT display of this use rate over any desired period. With this capability, the crew will know when a significant increase in leakage has occurred.

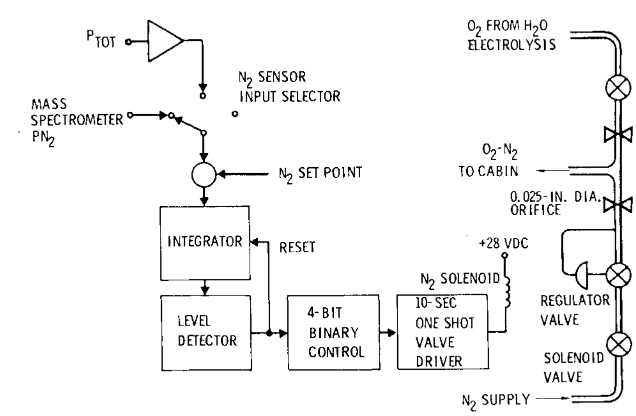

Fig. 5 N_2 **use-rate monitoring system.**

Leak Location

Unfortunately, the N_2 use-rate data can only identify the compartment that contains the leak. (A separate pressure control system is provided for each compartment.) Leak location within the compartment must be accomplished in another manner.

As previously stated, the meteoroid shield design reduces the number of expected hits on the pressure shell to a reasonable number (less than two in 10 yr), thus permitting inspection of the damaged area each time. The simulated meteoroid test shots further showed that any hit capable of producing a leak will probably cause a significant bulge in the pressure shell. Piezoelectric transducers, attached to the pressure wall, as shown in Fig. 6, pick up signals whenever a meteoroid strikes the shell; triangulation from several sensors then gives an approximate location, e.g., which deck (floor) within a compartment and which segment (direction). Visual inspection, assisted by a leak detector (several promising concepts are in development) if required, can then locate the exact strike point, and the leak can be patched.

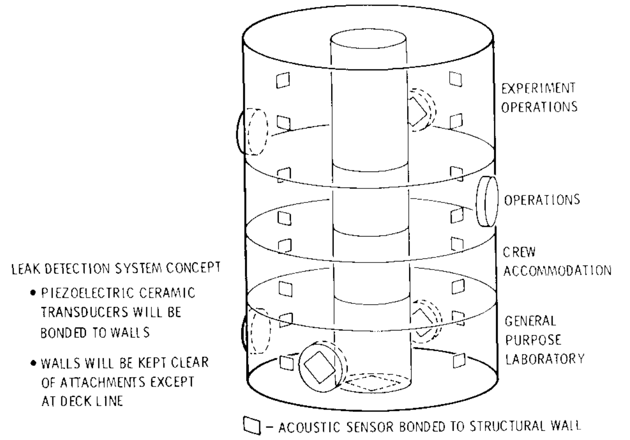

Fig. 6 Damage-control subsystem meteoroid protection acoustic sensor location.

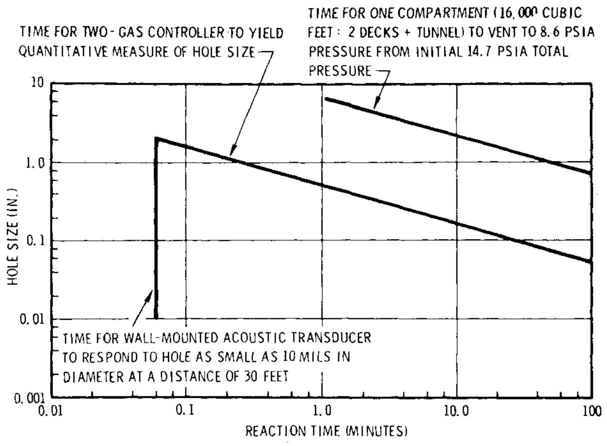

Fig. 7 Space station leak-detection and damage-control system effectiveness.

Leakage caused by seal failure cannot be as easily located. As previously noted, there are many individual seals on the Space Station. Ideally, a system is required that provides individual sensors to monitor the sealing effectiveness of each seal independently. Then, when the N_2 use rate indicates a leak but no meteoroid strike is recorded, the onboard checkout and data management systems could interrogate the effectiveness of each seal and pinpoint the seal that has failed. This seal then is repaired or replaced. An effective sensor to monitor individual seal leakage is not yet available. Several promising concepts and requirements for additional design and development have been identified.

Crew Reaction Time

Figure 7 diagrams the amount of time available to the crew for reacting to pressure shell leaks. The upper line represents the time required at a given hole size for the pressure to fall from the control point, to a point where the crew is in danger. As can be seen, even if a hole is 1 in. in diameter, the crew has about 60 min to locate and repair the leak; this will usually be sufficient time. If additional time is needed, the crew can retreat to the undamaged compartment and crewmen in pressure suits can repair the hole. The middle line shows the time required for the N_2 use-rate system to sense the leak. The vertical line indicates that meteoroid hits are sensed instantly.

Design Requirements for Low Leakage

The Space Station imposes stringent but achievable requirements on the structure to prevent unacceptable atmosphere leakage. These requirements can be met with presently available seal materials and design technology and have been implemented in the MDAC-designed Space Station.

Design requirements for achieving low leakage are as follows: 1) pressure-shell penetrations must be held to a minimum. 2) All penetrations to sections of the shell that are continuously pressurized should be limited to welded joints or bolted joints with static seals. 3) The seals and sealing surfaces of the bolted joints must be free of defects. When installed, the required seal compression must be maintained through both static and dynamic loading. 4) All seals must be replaceable or at least repairable from inside the Space Station. High-speed sliding or rotating surfaces should not be used unless designed in an intermediate airlock-type enclosure. 5) Seals should be protected from significant cyclic temperature excursions. (This can be accomplished with a "thermos-bottle" design concept.) Exceptions, e.g., externally located inflatable seals on docking ports, should contain redundant seals and be protected when not in use. 6) All electrical connectors that penetrate the pressure shell should be designed with hermetically sealed leads, in accordance with MIL-S-8484 (or equivalent). 7) All valves that must prevent loss of atmosphere to space should be designed to ensure minimum leakage with static seals. The installation should be such that these valves can be repaired or replaced without requiring compartment decompression. 8) A leak detection and repair system should be provided on the Space Station. This system should have the capability of: a) continuously monitoring the leakage status of the station; b) indicating when a significant change in leakage has occurred; and c) providing for location and repair of the leak.

Conclusions

Space Station atmospheric leakage (less than 0.002 lb/day) can be reduced to diffusion through the sealing material using current technology and careful design practices. Meteoroid and accidental punctures are infrequent, if they occur at all, and generate conditions requiring immediate remedial action; they are not considered as sources for the long-duration leakage problem. Available leakage test data provide a substantial basis on which to determine conservative estimated leakage rates for advanced spacecraft; the data generated by NASA's Langley Research Center is particularly appropriate. A leakage monitoring and control system is required to maintain high performance during long-duration missions.

In summary, future designs of Space Stations and other similar spacecraft, e.g., manned planetary vehicles, should be designed for negligible leakage. Atmospheric stores, currently provided for compartment repressurization contingencies, should be adjusted to account for infrequent rapid atmospheric demands due to meteoroid and accidental punctures and for losses associated with replacement and repair of failed seals.

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