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Pressure Measurements and Gas-Flow Analysis in Chambers A and B during Thermal-Vacuum Tests of Spacecraft 2TV-1 and LTA-8

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UNLIKE the actual situation in space, a vehicle in a space simulation chamber is directly exposed to areas that reflect molecules coming from the vehicle and even areas that emit molecules, e.g., cables, pipes, support structures, and other ground support equipment (GSE). Moreover, the test objectives may require the release of large quantities of liquids and gases (such as water, glycol, O_2, N_2, H_2 etc.) from vents of the spacecraft, thus increasing the flow of reflected molecules. At the NASA Manned Spacecraft Center in 1968, a study was made of the pressures and the gas flows in various locations and directions, both in Chamber B which housed the Apollo Lunar Module, LTA-8, and in Chamber A which housed the Apollo Command and Service Module, 2TV-1, during testing that involved these requirements. This Note outlines the determination of specific test-article or chamber conditions by identifying and locating gas sources inside the vacuum chambers during the thermal-vacuum tests and by evaluating the effect of the gases on the simulation of space vacuum. Additional information on the space simulation chambers is available from the literature.[1,2]

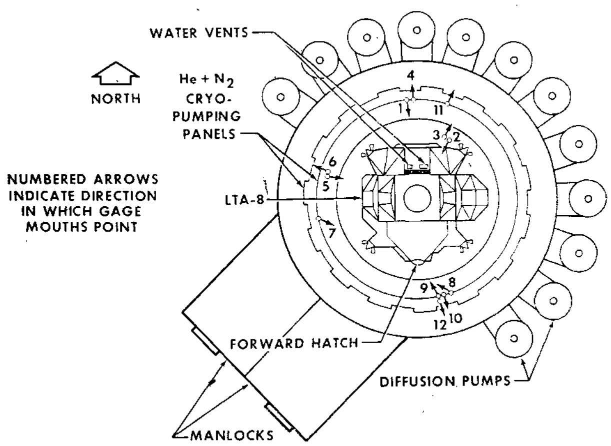

Fig. 1 Ion-gage locations 1–12 in Chamber B for LTA-8. (Chamber B has inside dimensions of 25 ft diam × 30 ft height.)

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Analysis and Gage Features

For simplicity, the spacecraft and the "chamber surface" are represented in the math model by concentric spheres, and it is assumed that the outer sphere has a cryopumping capability equal to the total effective pumping capability of the simulation chamber pumping systems. The capture coefficient (s_c) of the chamber surface (assuming homogeneous spherical distribution) is the fraction of gas molecules pumped during one encounter. By placing pairs of ion gages (with one gage pointing at the test-article surface (inner sphere) and the other gage pointing at the chamber surface) near the surface of the test article or near the chamber surface, one can determine the total directional gas flows and the gas load emitted by the test-article. However, the gages cannot distinguish between reflected and emitted molecules. To determine s_c, the gas emittance of the outer sphere must be known. For good simulation, the degassing and leak rates of the chamber and GSE must be small compared with the degassing and leak rates of the test article. Because gages mounted near the spacecraft usually interfere with spacecraft activities and other test objectives, the use of gages near the chamber surface is preferable.

Let us define[3] Z as the ratio of the number of molecules returning to vehicle surface to the number of molecules initiating at vehicle surface. Then

$$Z = AX/(Y - X) \tag{1}$$

where Y is the gas-flux density at a gage located near the chamber surface and directed toward the test article; X is the gas-flux density at a gage located near the chamber surface and directed toward the chamber surface; and A is the probability that a molecule leaving the chamber surface will strike the vehicle. A low value for Z is desired. It is

$$X/Y \approx 1 - s_c \tag{2}$$

in a good space simulation chamber. Also, it is important to note that s_c varies with the type of gas in the chamber. The relatively high pumping speed of liquid nitrogen (LN_2) panels for gases and vapors which condense at LN_2 temperatures, "condensibles," must be distinguished from the relatively low pumping speed for gases which do not condense at LN_2 temperatures, "noncondensibles." Table 1 gives typical values of Z and X/Y based on estimates of s_c and calculated from Eqs. (1) and (2) (A = 0.3 and 0.06 respectively).

The s_c's and Z's for the condensibles are good, and the corresponding X/Y ratios are sufficiently small to permit determination of the directional gas flow when ion gages with normal calibration error are used for the measurements. The higher values for the noncondensible gases, indicating quasi-

Table 1 Z, X/Y, and s_c; calculated data

	Chamber A (2TV-1)		Chamber B (LTA-8)	
	Noncondensibles[a]	LN_2 cold walls	Noncondensibles[a]	LN_2 cold walls
s_c	0.08	0.95	0.1	0.95
Z	0.7	0.003	2.7	0.015
X/Y	0.92	0.05	0.9	0.05

[a] Pumped by helium cryopumps and diffusion pumps.

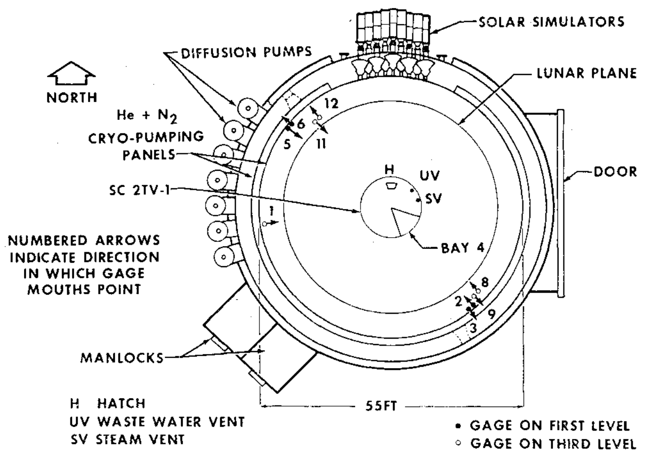

Fig. 2 Ion-gage locations 1-12 in Chamber A for 2TV-1. (Chamber A has inside dimensions of 55 ft diam × 90 ft height.)

equilibrium, are not so bad as to appreciably affect the thermal performance of the spacecraft, but they do require use of special gages and techniques that were not available at this time for meaningful measurements and directional gas-flow analysis. Therefore, pairs of instruments to measure X/Y were placed primarily in areas that were likely to be exposed to the nearly unidirectional condensible gas flow released from leaks and vents on the spacecraft and GSE.

Experimental Setups

The gages used were limited to those that were already installed and calibrated, and those that could easily be relocated and reoriented. Glass-tubulated ion gages with tungsten filaments were used, and the controls required manual range switching. In addition, one metal tubulated ion gage, operated by a power supply having automatic range switching and automatic range recording capability, was used in Chamber A. All gages were mounted in fixed positions and their output connected to four-channel strip chart recorders. The gages were calibrated only for N_2 at ambient temperatures (with an error of ± 1.5 on a scale of 10).

In Chamber B (Fig. 1), the pairs of gages were to determine the directional flow of gases released a) through three vents by two water boilers (2,3 and 1,4), b) from potential leaks on the west side of the spacecraft (5,6), and c) from the area around the forward hatch of the spacecraft (9,10). In addition, gages 7, 8, 11, and 12 were used part time.

In Chamber A (Fig. 2), the pairs of gages were to determine the directional flow of gases released a) through the gap between the service module and its main engine nozzle (2,3 and 5,6) and b) through the various vents on the command module (8,9 and 11,12). The output was expected to depend on the test article rotation and orientation with respect to the gages. Gage 1 was the metal-tubulated ion gage.

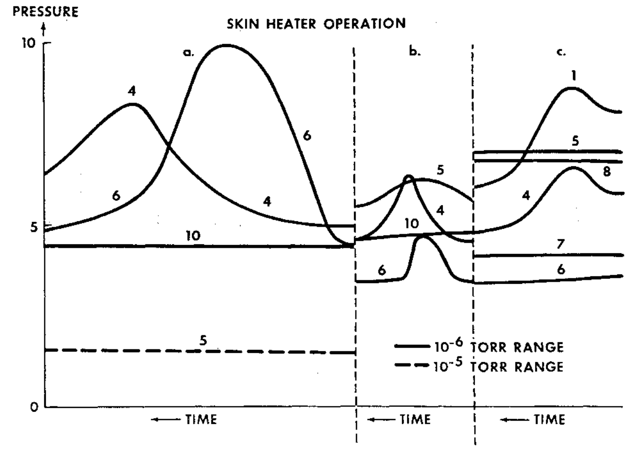

Fig. 4 Gage response in Chamber B (LTA-8) during skin heater operation.

Results of Chamber B Measurements

Generally, the gage readings indicated quasiequilibrium condition with the average chamber pressure in the lower 10^{-6} torr range, a condition which is adequate for thermal vacuum tests. An example, during cabin depressurization, is shown in Fig. 3b. The effect of typical nearly unidirectional gas flow ($X/Y < \frac{1}{30}$) produced during water boiler operation is shown in Fig. 3a. The water vapor released was pumped extremely well ($s_c \approx$ unity). Another example of directional gas flow shown in Fig. 3c is the release of freon (acting as simulated propellant) from a leak in the propulsion system on the west side of the spacecraft, whenever this part of the propulsion system was pressurized with helium. A different type of directional gas flow did occur when, during several tests, the skin heaters on the protective panels of the LTA-8 were operated in sequence at 90-min intervals for certain lengths of time to simulate the effect of sunlight while the spacecraft rotates. Typical recordings, which appear every 90 min are shown in Fig. 4. In Fig. 4a, b, and c the peak readings of the gages that pointed toward the spacecraft increased from zero to a value approximately equal to the readings of the corresponding gages pointed toward the cold wall. Apparently, the additional heat emitted by the spacecraft's

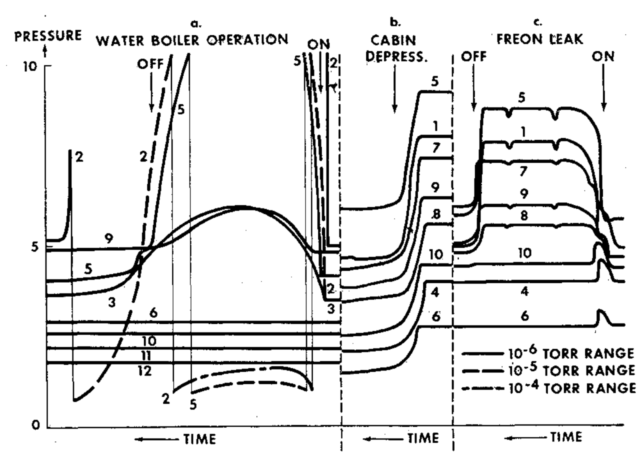

Fig. 3 Gage response in Chamber B (LTA-8) during a) water boiler operation, b) cabin depressurization, c) freon leak.

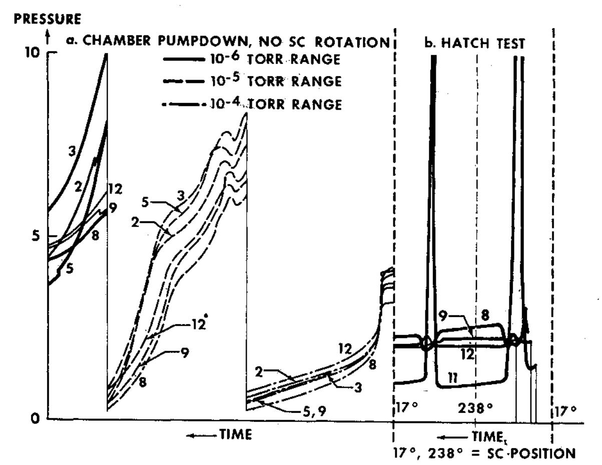

Fig. 5 Gage response in Chamber A (2TV-1) during a) chamber pumpdown; no spacecraft rotation, b) hatch test.

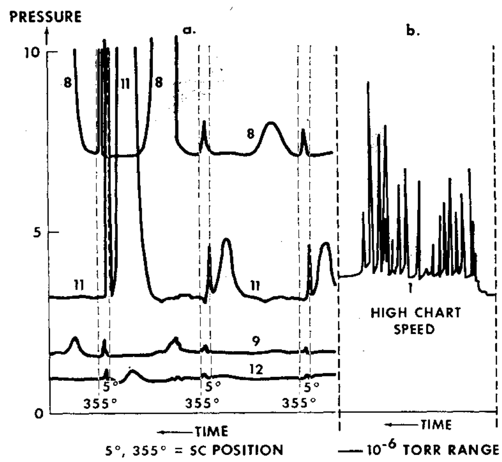

Fig. 6 Gage response in Chamber A (2TV-1), a) during water boiler operation, b) during waste-water dumping, no spacecraft rotation.

protective panels caused the cold wall panels to release part of the adsorbed or cryopumped gas load. Release resulting from higher surface temperatures of gases by the spacecraft may also have occurred. Figures 3 and 4 show the existence of good space simulation during the tests. These figures also indicate that the GSE caused the gases released locally to diffuse throughout the chamber lowering the achievable quality of space simulation to some degree.

Results of Chamber A Measurements

As in Chamber B, the gage readings generally indicated quasiequilibrium condition with average chamber pressure in the lower 10^{-6} torr range. Figure 5a, for instance, shows typical pressure readings during pumpdown of Chamber A from the 10^{-4} torr range to the 10^{-6} torr range. During spacecraft activities, various events causing directional gas flow within the chamber were recorded. Unlike the situation in Chamber B previously described, the gas flow pattern in Chamber A rotated with the spacecraft and created characteristic gage readings that depend on the phase of rotation. This rotation starts at approximately 5° and reverses at approximately 355° or at any intermediate angle. The typical gage response to nearly unidirectional gas flow ($X/Y < \frac{1}{10}$) during spacecraft rotation and continuous water boiler operation (at two different rates) is shown in Fig. 6a. Another type of nearly unidirectional gas flow occurred, when, at various times during the testing, water droplets were ejected from a waste water dump nozzle into the chamber and evaporated several feet from the spacecraft. The gages

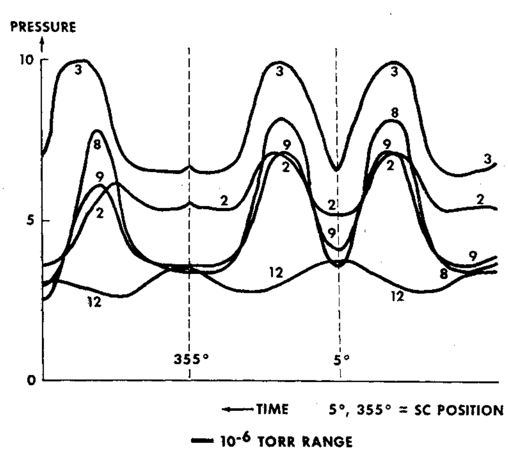

Fig. 7 Gage response in Chamber A (2TV-1) during Bay 4 leak.

directed toward the vent reacted with high pressure spikes (shown for one gage in Fig. 6b). Figure 5b depicts the gage response when the forward hatch of the command module was opened briefly during one of the tests. The angle of the spacecraft changed three times. The reaction of the gages is typical for nearly unidirectional flow of a "condensible" gas. A different type of directional gas flow caused by a leaking GSE connection to the spacecraft near Bay 4 is shown during spacecraft rotation in Fig. 7. Gage reaction indicates leaking of a "noncondensible" gas. Here the original directional gas flow resulted in a localized higher gas concentration. Figures 5–7 show that space simulation was good during the tests, and they indicate the effect of GSE.

Concluding Remarks

The described measuring system proved to be valuable not only for verifying required test conditions, but also for detecting abnormal and characteristic test article or chamber conditions by assisting in leak detection, leak localizing, simple gas analysis (condensibles and noncondensibles), analysis of pumping system performance, and analysis of events (operations of valves, doors, life support systems, water boilers, and waste water dumping). Improvements could be made by the use of: a) pairs of gages supported by rotatable mounts which would permit the same gage to read, in short sequences, the gas flows in one and then in the opposite direction; b) metal-tubulated ion gages provided with instruments to measure gage temperatures; c) small mass spectrometer tubes (replacing some of the ion gages) for measuring partial pressures and for analyzing gas types; and d) power supplies for the gages providing automatic range switching and range recording.

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Emissive Probes for Plasma Potential Measurements on the Sert II Spacecraft

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Two emissive probe (hot wire) systems having different measurement requirements have been designed, fabricated, tested, and delivered for use on the SERT II spacecraft. With emissive probes, emitted electrons are drawn

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