Gaseous Environment of the Shuttle Early in the Spacelab 2 Mission

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A cold-cathode ionization gage was flown on Space Shuttle flight STS-51F as part of the Spacelab 2 payload. Neutral pressure data that were taken in the payload bay during the first few hours on orbit are presented. These data show that when the payload bay is oriented such that the atmospheric gases are ramming into it, the pressure rises to a peak of 4×10^{-6} Torr. Pressure is also slightly higher during the sunlit portion of each orbit. Outgassing of the payload bay causes the pressure to be elevated to a few times 10^{-6} Torr early in the mission. In addition, several effects on pressure have been identified that are due to chemical releases. Substantial increases (50–150%) are seen during another experiment's gas purge. Orbiter chemical-release effects include: pressure increases of 200% up to 7×10^{-6} Torr due to Orbital Maneuvering System (OMS) burns, minor perturbations in pressure due to vernier thruster firings and little or no increase in pressure due to water dumps. In the case of vernier thruster firings, effects are seen only from down-firing thrusters in the back of the Orbiter, which are probably due to reflection of thruster gases off Orbiter surfaces.

Introduction

THE Plasma Diagnostics Package (PDP) is a cylindrical subsatellite that has flown on two Space Shuttle flights to date. The PDP carried a complement of 14 instruments, including a cold-cathode ionization gage that measured various plasma parameters. Data were taken in the payload bay and on the Remote Manipulator System (RMS) arm on both flights and as a free-flying satellite on its most recent shuttle flight.

The PDP first flew on STS-3 (Space Shuttle Columbia) as part of the Office of Space Science's first payload (OSS-1) from March 22–30, 1982.[1] The pressure gage on that flight obtained approximately 100 h of neutral pressure measurements from two locations: in the payload bay and on the RMS arm up to 15 m (~50 ft) from the Orbiter. Neutral pressure results from that flight may be found in Shawhan et al.[2] and Shawhan and Murphy.[3]

The PDP's second flight was on STS-51F (Space Shuttle Challenger) as part of the Spacelab 2 (SL-2) payload from July 29–Aug. 6, 1985.[4] On this flight the pressure gage obtained only 3 h of data on the first day of the mission due to a mechanical failure in the gage electronics box, which occurred 7.5 h after launch. However, these data were obtained during a time in which other instruments were being activated, the payload bay was still outgassing, and two OMS burns occurred. For these reasons, these data are vital in understanding the neutral pressure environment of the Space Shuttle early in a mission.

Instrumentation

The vacuum measurement system on the PDP utilizes a cold-cathode magnetron gage similar in configuration to the Redhead magnetron gage developed in the late 1950's.[5] The gage aperture contains a baffle to prevent ram effects of neutrals and ions. A 6-in. extension tube is added to the aperture to allow access to the orbiter payload bay pressure environment outside the PDP skin. The gage works on the principle that a discharge current in a transverse magnetic field is dependent on the pressure of the gas. The gage transforms the vacuum-input signal into a 0–5 V output signal that is proportional to the logarithm of the input pressure. The range of the instrument on SL-2 was 10^{-7}–10^{-3} Torr of equivalent nitrogen pressure. The sampling frequency of the pressure gage on SL-2 was 20 Hz.

Since all of the data presented here were obtained while the PDP was located in the payload bay, it is important to know the orientation of the pressure gage. Figure 1 shows the PDP in its stowed (i.e., pallet) configuration. As may be seen, the pressure gage tube is located near the bottom of the spacecraft and points in a direction midway between starboard and aft of the Orbiter. The extension tube exits the PDP skin 45 deg to the radial direction. The tube aperture is only 0.5 in. from the PDP skin at its closest point. Figure 2 shows the location of the PDP within the SL-2 payload. It is obvious from this figure that other experiments closely surround the pressure gage. In fact, the pressure gage looks directly at the Infrared Telescope (IRT) instrumentation, which is located only a few inches from the PDP structure. This is in contrast to the pressure gage on OSS-1 that had an open field of view in the middle of the pallet where no other instrument was mounted close to it.

Neutral Pressure Results

Orbit-related Effects

A plot of the 3 h of neutral pressure data obtained by the PDP cold-cathode ionization gage on Spacelab 2 is shown in Fig. 3. This plot shows neutral pressure in Torr (equivalent N_2) vs time. The time of this plot, which begins about 4.5 h after launch, is from 0130 to 0430 Greenwich Mean Time (GMT) on day 211 of 1985. The pressure gage actually received power at the time the spacecraft was powered up at 0039 GMT. However, it did not begin to ionize until 50 min later. The possible reasons for this will be discussed below.

One feature to note in Fig. 3 is the rise in pressure from a low of about 1.5×10^{-6} Torr, which begins shortly before 0300 GMT. At this time the payload bay is rapidly rotating into the ram of the gas flow, reaching maximum ram at 0302 GMT, and then gradually rotating out of it as indicated by the angle of attack in Fig. 3. The angle of attack is defined as the angle between the $-Z$ axis of the orbiter (up from the payload bay) and the velocity vector. Thus, maximum ram is

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obtained at an angle of attack equal to 0 deg and deep wake at 180 deg. During the ram event centered at 0302 GMT, the pressure is seen to rise rapidly and then gradually decrease to its previous level, indicating a dependence on the direction of gas flow with respect to the payload bay. The rise actually begins to occur during a 1-min interval of lower pressure, which will be explained in the following section. The PDP is in wake at 0203–0206 GMT, but this wake appears to have no significant effect on pressure. The entire payload bay is briefly in a deep-wake condition (i.e., angle of attack equal to 180 deg) around 0250 GMT, but, once again, no significant effect is noted.

It is also evident that there is some outgassing in the payload bay since ambient pressure for an altitude around 300 km would be $\leq 10^{-7}$ Torr, and contributions from ram flow would only increase the pressure to about 1×10^{-6} Torr. Also evident are the brief, random one-order of magnitude increases in pressure to about 2×10^{-5} Torr throughout the plot. These increases are believed to be due to outgassing in the gage itself. This effect was also seen on the OSS-1 flight[3] and during thermal-vacuum testing prior to the SL-2 launch.

There is also an indication in Fig. 3 that the neutral pressure in the payload bay is slightly less on the nightside than on the day. For example, the slight rise in pressure (approximately 50%) seen at 0350 GMT is probably attributable to the shuttle entering daylight.

Payload-related Effects

One of the more striking features of the plot shown in Fig. 3 is a periodic variation in pressure that begins at 0216:44 GMT. At this time the pressure is seen to rise, thus beginning a cycle of 20 min at a higher pressure and 1 min at the lower pressure that was being recorded before the cycle began. Subsequent to the flight it was discovered that at about 0216:00 GMT the Cosmic Ray Nuclei Experiment (CRNE) of the Univ. of Chicago, shown in Fig. 2, began a gas purge that consisted of releasing a mixture of 80% N_2 and 20% CO_2 for 20 min, pausing for 1 min, and then releasing the gas for another 20 min, etc. The amount of gas being released was about 500 l/h. Its composition changed from the N_2, CO_2 mixture to a mixture of 15% CH_4, 25% Xe, and 50% He with a time constant of about 1 h.[6] Before the CRNE release we assume that the gaseous environment of the payload bay is predominantly water, based on measurements taken by an ion mass spectrometer mounted on the PDP on SL-2.[7] Summers[8] states that the relative sensitivity of H_2O normalized to N_2 is 0.97 over the pressure range 10^{-7}–10^{-5} Torr for a cold-cathode ionization gage. Therefore, when the CRNE release (consisting primarily of N_2) begins, we expect to see a maximum increase in pressure of 3% due to the gage's greater sensitivity to N_2 than H_2O. Since the increase (about 150%) is, in fact, quite large, we know that the CRNE release has a marked effect on the payload environment.

If the payload bay environment is not dominated by water as reported in Ref. 7, but instead, consists primarily of atomic oxygen as expected at shuttle altitudes, then a lower limit on the pressure increase due to the CRNE release can be derived. Since the sensitivity of the gage to atomic oxygen is not given in Ref. 8, we can arrive at an approximate value based on the data given by Summers[8] and the ionization cross sections published in the literature. Redhead et al.[9] state that provided the ions, which are produced within the gage, are formed with zero kinetic energy, the relative gage sensitivities should be nearly proportional to the magnitude of the ionization cross sections near their maximum (approximately 100 eV electron

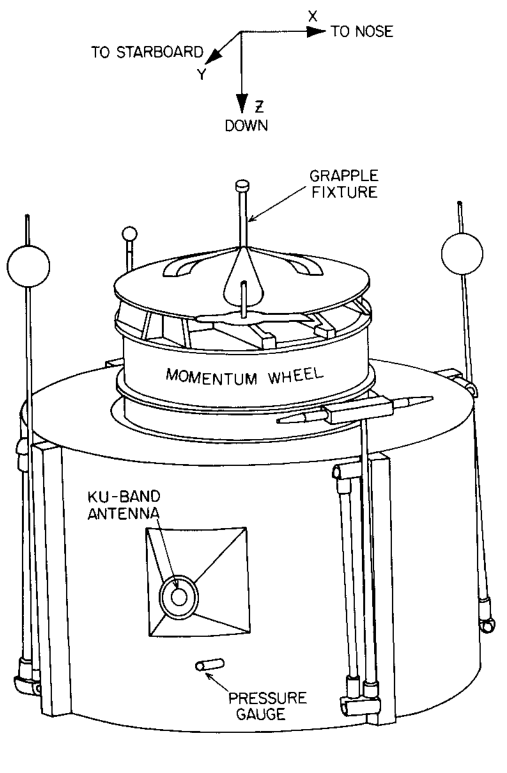

Fig. 1 The Plasma Diagnostics Package subsatellite with neutral pressure gage aperture pointed out.

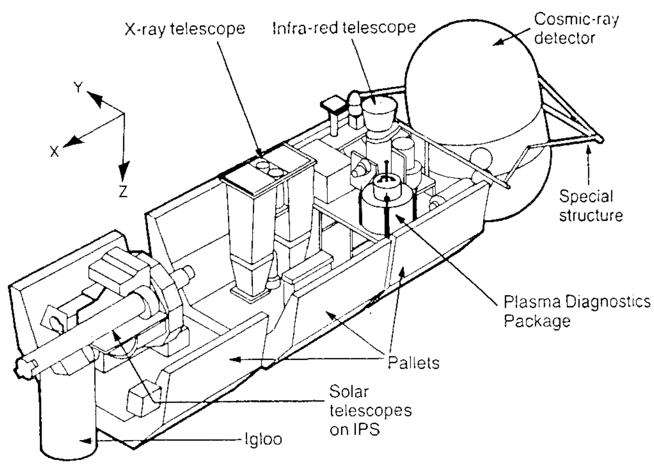

Fig. 2 Layout of the Spacelab 2 pallets showing location of the PDP in relation to the other instruments.

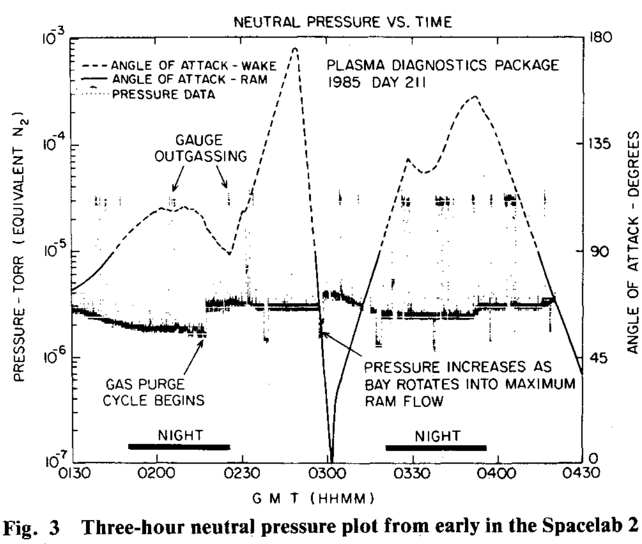

Fig. 3 Three-hour neutral pressure plot from early in the Spacelab 2 mission.

energy). Assuming this to be the case, the sensitivity of the gage to atomic oxygen would be ≥ 0.5. This implies that the increase in pressure due to the CRNE release is only around 50% rather than 150% for the case of a water-dominated environment.

At least two other experiments on SL-2—the Infrared Telescope (IRT) from the Smithsonian Astrophysical Observatory and Super Fluid Helium Experiment (SFHE) from the Jet Propulsion Laboratory – were steadily venting helium at the sill of the Orbiter payload bay at the rate of 20-30 mg/s (approximately 0.4-0.6 l/h at STP). The relative sensitivity of He normalized to N_2 for this stage is 0.15.[8] The effects, if any, from helium ventings, cannot be determined.

Another effect on the pressure that we believe may be due to one of the other experiments located in the payload bay is shown in Fig. 4. This plot covers 30 min from 0200-0230 GMT on day 211. At about 0205 GMT we see a square wave pattern in the data with a period of about 3.5 min. At about 0216:00 GMT the square wave begins to look more like a rectified sine wave with a period of about 0.5 min. (Note that the jump at 0216:44 GMT is the result of the CRNE gas purge.) We considered the possibility that the scanning IRT, which is located very close to the pressure sensor, was the cause of this effect; however, available data appear to rule this out. The drop to zero output seen at 0204 GMT is probably an indication of the impending mechanical failure.

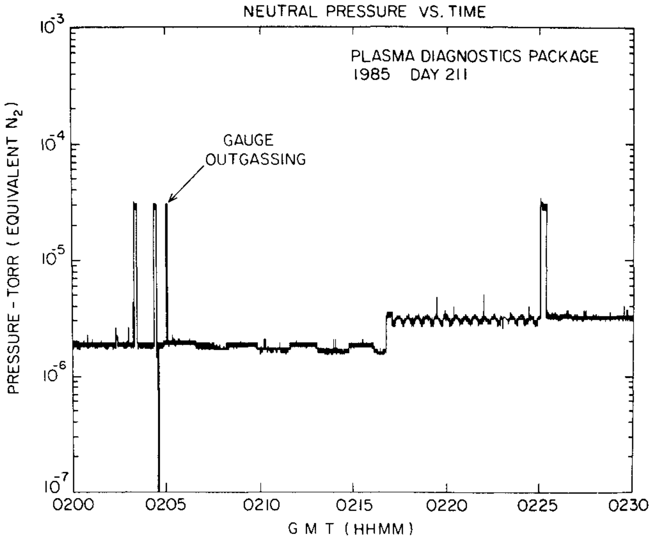

Fig. 4 Neutral pressure changes on a short time scale possibly related to another experiment.

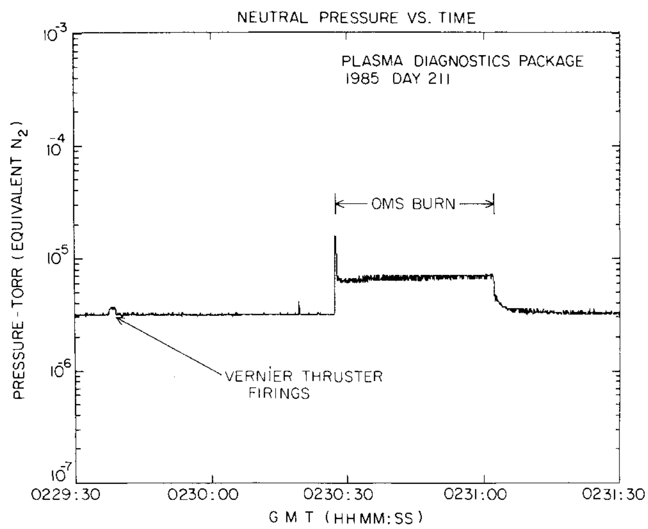

Fig. 5 Effects on neutral pressure of Orbiter gas releases.

Orbiter-related Effects

Figure 5 shows the effects of two types of chemical releases associated with thruster activity on the Orbiter: a continuous firing of two vernier thrusters, which takes place over about 1.1 s, and an Orbital Maneuvering System (OMS) burn. The effect of the OMS-3 burn, which was used on SL-2 to circularize the orbit at approximately 325 km altitude, begins at 0230:27 GMT during daylight, lasts for about 35 s, and is directed antiparallel to the velocity vector. This burn raises the neutral pressure by about a factor of 2 up to 7×10^{-6} Torr. Once the OMS engines are shut off, the pressure returns to its previous level after only 3-4 s. Acceleration data from the SFHE experiment[10] show a sharp drop at 0231:01.0 GMT until about 0231:01.7 GMT and then an exponential decay that approaches zero at about 0231:05 GMT, which is consistent with the pressure data. The reason for the pressure spike (lasting about 0.5 s) at the beginning of the burn is not known. However, the post-mission flightcrew report[11] states that exceptional ignition transients were associated with all OMS burns on STS-51F with the exception of the final deorbit burn. The ignition transient was termed a "hard light" by the crew and was manifested by larger than normal acceleration at the beginning of the burn. The report states further that Johnson Space Center has been unable to confirm this effect or show a cause for it. It is possible that the momentary sharp pressure increase to 10^{-5} Torr, seen at the beginning of the OMS-3 burn, is related to the effect reported by the crew.

Another OMS burn that occurs at 0322:17 GMT during nighttime (not shown in Fig. 5) and that is directed antiparallel to the velocity vector over Millstone Hill Observatory in Westford, Massachusetts also raises the pressure by about a factor of 2 over its preburn level. The pressure spike is also present at the beginning of this burn. We are not able to determine the recovery time associated with this burn since there is a data dropout that begins in the middle of the burn and lasts well past engine shutoff. During the two OMS burns just discussed, both OMS engines were fired, each of which has a thrust of 26,688 N (6000 lb) and burn at a rate of about 85.27 N/s (19.17 lb/s) using a propellant of monomethylhydrazine (MMH) as fuel and nitrogen tetroxide (N_2O_4) as an oxidizer.

The Reaction Control System (RCS) thruster firings, pointed out at 0229:38 GMT in Fig. 5, are vernier thrusters, which have a thrust of 111 N (25 lb) and use a propellant of MMH/N_2O_4. The effect of this series of continuous firings is to raise the neutral pressure in the vicinity of the payload bay by only a small amount. A more detailed analysis of all thruster firings that occur during the time in which pressure data were taken was done in order to determine whether specific thrusters affect the pressure more than others. The authors ascertained that no primary RCS thrusters, which have a thrust of 3870 N (870 lb), were fired during the 3 h of interest. That leaves only six vernier thrusters. Two of them are located in the nose section of the Orbiter and have thrust vectors that point down and slightly starboard or port (F5R, F5L). The remaining four are in the RCS pods in the tail section of the Orbiter. Two of these four are located on the starboard side and point in the starboard (or $+Y$) direction (R5R) and down along $+Z$ (R5D). The other two in the tail section are on the port side of the Orbiter and point in the port (or $-Y$) direction (R5L) and down along $+Z$ (L5D).

Figure 6 is a 2-min plot that shows two sets of vernier thruster firings. Notice that at 0202:22 GMT, the continuous firing of two vernier thrusters in the back of the Orbiter for a period of 2.8 s has a noticeable effect on the pressure, whereas the continuous firing of one forward and one aft vernier for a period of 2.1 s has no effect. Our analysis of all thruster firings from 0130-0430 GMT on day 211 shows that all vernier thruster firings from the back of the Orbiter that involve

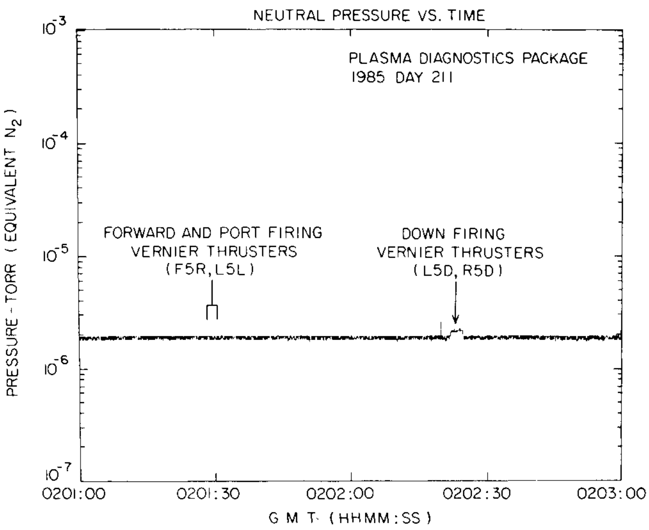

Fig. 6 Comparison of vernier thruster firing effects on neutral pressure.

thrust vectors directed down along the Orbiter $+Z$ axis (R5D, L5D), produce similar effects on neutral pressure as those shown in Fig. 6 at 0202:22 GMT. Vernier thruster firings from the front directed down and slightly out (F5R, F5L) and from the back directed along the $+/-Y$ axes (R5R, L5L) have little or no effect on the neutral pressure as shown in Fig. 6.

Other factors that may be important in the study of thruster-firing effects are discussed in the following section. More details on the thrusters and their effects on the ionosphere during the OSS-1 flight are provided in Refs. 12 and 13.

Finally, an Orbiter water dump that begins at 0414 GMT (see Fig. 3) and continues for about 40 min may be the cause of the slight increase in pressure seen at about that time. However, because the angle of attack has significantly started to decrease and the pressure increase is so slight, no definite conclusions can be drawn.

Discussion and Conclusions

The unusually long time taken for the pressure gage to begin to ionize (about 50 min) may be related to several factors, such as the length of time it was stored at sea level, the temperature at which it is powered up, and the degree to which it has been contaminated during preflight testing. The PDP was at sea level for a considerable length of time due to its integration into the SL-2 payload at Kennedy Space Center over a year prior to launch. The temperature of the deck on which the pressure gage is mounted was about 20° C at the time it was powered up on orbit, and so temperature was probably not a factor. One of the biggest factors could have been that the pressure gage was not cleaned after completion of all preflight testing and prior to launch. Thus, it is possible that contamination may have contributed to the delay in onset of ionization.

Neutral pressure in the payload bay depends to a great extent on the orientation of the gas flow to it and to a lesser extent on the day/night conditions prevailing at the time. SL-2 results show slightly higher pressures during daytime than nighttime, which is in accord with the MSIS-83 atmospheric model,[15] and enhancements in the pressure under ram conditions. The wake conditions encountered produce no significant effects on the pressure probably due to payload bay outgassing. OSS-1 results show a definite modulation in the pressure from ram to wake conditions.[2,3] This effect has also been reported by Yanagisawa et al.[16] from measurements obtained by a BN-type ionization pressure gage that was part of the SEPAC investigation flown on Spacelab 1.

A relation is given by Hedin et al.[17] for determining ram pressure for a gage consisting of an enclosure within a rocket with a small entrance hole or orifice. Hedin et al.[17] state that if the diameter of the entrance hole is large compared to the length of the hole, but small with respect to the mean free path of the gas, and the gas in the gage comes to thermal equilibrium with the walls of the gage, the result is

$$n_g = n_a \left(\frac{T_a}{T_g}\right)^{1/2} F(S) \tag{1}$$

where

n_g = number density of particles in gage
n_a = ambient particle number density
T_g = temperature of gage walls
T_a = ambient temperature

$$F(S) = \exp(-S^2) + S\pi^{1/2}(1 + \operatorname{erf} S) \tag{2}$$

where

S = V/C_{pa}
V = component of rocket velocity normal to gage opening
C_{pa} = most probable speed of ambient particles

The significance of Eq. (1) is that the number of particles entering the gage per unit time is equal to those leaving. Substituting gage pressure P_g and ambient pressure P_a for n_g and n_a, respectively, in Eq. (1) we obtain

$$P_g = P_a \left(\frac{T_a}{T_g}\right)^{1/2} F(S) \tag{3}$$

For the one maximum ram condition on SL-2 (0302 GMT), the authors ran the MSIS-83 atmospheric model[15] and found that $P_a = 7.7 \times 10^{-8}$ Torr, $T_a = 894$ K, and $C_{pa} = 1.07$ km/s. At 0302 GMT, $T_g \sim 293$ K and V = orbiter velocity normal to the payload bay = 7.8 km/s. Substituting these values in Eq. (3) gives $P_g = 3.5 \times 10^{-6}$ Torr, which is in good agreement with the SL-2 data. In applying Eq. (3) to the orbiter, it is assumed that the orifice is the payload bay.

The enhancement under ram conditions is most likely primarily related to the fact that under ram conditions there is a great increase in the number of atmospheric molecules in the vicinity of the payload bay, which are reflected from various Orbiter and instrument surfaces at thermal velocities corresponding to temperature of the bay.[16,18] A much smaller contribution may come from erosion of materials due to atomic oxygen bombardment.

Outgassing in the payload bay and ram flow to the bay as discussed above cause the neutral pressure in the bay to be elevated to a few times 10^{-6} Torr early in the mission. Shawhan et al.[2] state that it took nearly 24 h for the payload bay to outgas to the ambient level on OSS-1. Koch[14] reports that pressure measurements obtained by an identical pressure gage to the PDP's as a part of the IRT investigation on SL-2 are around an order of magnitude higher than the PDP's. However, the IRT pressure gage, including sensor, were located inside a box that had only a 2-in.-diam opening at the top. Due to the greatly decreased volume of this box compared to the relative openness of the payload bay and the outgassing within the box itself, it is expected that the IRT gage would obtain consistently higher pressure measurements than the PDP gage. Scialdone[19] derived an equation for open-bay pressure as a function of time based on previous measurements from the payload bay. The pressure for open bay is

$$P_s(t) = 1.3 \times 10^{-5}\, t^{-1} \text{ (Torr)} \tag{4}$$

where t is in hours and greater than 0240 MET (Mission Elapsed Time). The data shown in this paper appear to follow this relationship until the CRNE gas purge begins. Scialdone[19] states that the outgassing pressure will vary depending on temperatures of outgassing materials, which are related to the angle of the payload bay to the sun and length of time at that angle.

Experiments that release gas in the operation of their instruments can and do affect the neutral pressure environment in the payload bay. These gas releases, together with outgassing of the payload bay and ram flow pressure enhancements early in a shuttle mission, can lead to a substantial increase in the neutral pressure over ambient.

Orbiter OMS burns on SL-2 are shown to increase the neutral pressure in the payload bay by a factor of 2. A review of PDP pressure gage data from OSS-1 shows no increase in pressure during the two OMS burns that occur late in the mission. However, these two burns are performed under ram conditions that produce higher pressures than those shown to be associated with OMS burns. Further, the pressure spikes seen at the beginning of the SL-2 OMS burns are not present at the beginning of the OSS-1 burns. However, the sampling frequency was only 1 Hz on the earlier flight. Thus, if these sharp pressure increases, which last about 0.5 s, are present, they would probably not be evident in the data. Narcisi et al.[20] report results similar to those shown in the present paper for OMS burns. Their instrument, a quadrapole mass spectrometer flown on an early shuttle flight, shows the spike at the beginning of the burn, a pressure pulse of about 10^{-6} Torr, and a return to background in 1–2 s.

Although no primary thrusters are fired during the time of interest on SL-2, it is important to mention them since they can affect neutral pressure more than an OMS burn. The L2U primary thruster firing sequence that occurs during the OSS-1 flight raises the pressure to 3×10^{-4} Torr.[2,3,12] This sequence consists of the pulsed firing of two primary thrusters in the back and the continuous firing of one in the front, all of which have thrust vectors that point up (parallel to the Orbiter $-Z$ axis).

Even though the emission rate for the OMS firing is twice as great as for the combination of the three up-firing primary thrusters, the OMS burn on SL-2 causes pressure in the payload bay to rise to a value that is at least 1.5 orders of magnitude less than that for the L2U primary thruster sequence test. There are several factors that probably contribute to this. The L2U sequence takes place when the payload bay is in the wake of the orbiter. There is probably some reflection of the thruster plumes of the two primaries in the back off of the vertical stabilizer. Further, the PDP is closer to the primary thruster plumes than to the OMS plumes, thus being in a better position to see any backscatter from the plumes and their interactions with each other. Finally, the PDP is in a more open environment during the L2U event on OSS-1.

A summary of the questions that must be given consideration in order to adequately analyze the effects from any thruster firings are the following:

1) Is the payload bay in wake or ram? If in wake, any measurements made during thruster firings will probably show a much greater pressure increase in a relative sense than at nonwake times due to the lower background pressure in the wake. If in ram, effects may not be seen at all if ram pressure is extremely high.

2) What is the location of the pressure gage with respect to each thruster? The closer the gage is to the thruster and its exhaust plumes, the greater the possibility of recording an effect due to backscatter from the plume. This means that the emission pattern of the plume is also important. For instance, the exhaust plume of the primary thrusters is much broader than that of the verniers. Coupled with this is that certain thruster plumes are reflected into the payload bay by various Orbiter surfaces, such as the wings, elevons, and vertical stabilizer. Another important consideration is the presence of barriers and obstructions between the pressure gage and the thruster, which may tend to hinder the gage's ability to detect an effect.

3) What is the direction of the velocity vector with respect to the thrust vector? Although no one has yet done a thorough study of this, the possibility exists that a thruster fired upstream of the Orbiter may have a different effect than one fired downstream. If such an effect was detected for a thruster fired upstream, it would most likely be a second-order effect. Although the velocity of the Orbiter is much greater than the thruster exhaust, the thruster plume interacts with the environment on a much faster time scale.

4) How many thrusters are firing simultaneously? In the case of vernier thrusters, generally, two or three will fire simultaneously throughout a given period of time. It is, therefore, very difficult to determine the effects due to any one thruster. Thus, it is often necessary to study the effects of groups of thrusters, such as the down-pointing ones. In this connection it has been reported by Wulf and von Zahn[21] that there is some evidence that the simultaneous firing of several vernier thrusters produces higher signals than would be calculated for the sum of the individual contributions. Primary thrusters are more likely to be fired one at a time; however, they are not used as extensively on orbit as verniers and so the study of their effects may be limited.

In the authors' analysis of vernier thruster firing effects on neutral pressure, the following conclusions are drawn based on the above:

1) In general, vernier thruster firings are only minor perturbations to the pressure. Although the authors have no examples of firings while the payload bay is in wake, the ones made while in ram show a very small enhancement in pressure.

2) Effects observed from downward-pointing verniers (along $+Z$) in the back are probably due to the thruster plume impinging on Orbiter surfaces, such as the body flap, elevons, main engines, etc., and thus being reflected into the payload bay. The two forward-mounted vernier thrusters have a relatively unobstructed path in the primary direction of the expanding thruster plume compared to the aft verniers, which could partially explain why little or no effect is seen on neutral pressure during those firings. In addition, the location of the pressure gage on SL-2, well down in the center of the payload bay near other structures, may have been another factor, particularly for the aft, sideways-pointing verniers whose plumes can be reflected off the wings. It is not possible to do a thruster direction dependence analysis on the OSS-1 data set since the sampling frequency was only 1 Hz. However, the SL-2 thruster direction dependence results with regard to forward and aft downward-firing verniers are certainly borne out by Wulf and von Zahn,[21] from neutral mass spectrometer results from the SPAS-01 subsatellite on the STS-41B flight, and by Narcisi et al.[20] on an early shuttle flight. Their results for these thrusters differ from the SL-2 results only in that the effects they see are substantially greater. In addition, they see effects from port- and starboard-firing verniers that may be due, in part, to their instruments being located in a more advantageous position with respect to these thrusters than the SL-2 pressure gage.

3) No conclusions can be drawn with regard to the relationship of the velocity vector to the direction of thrust since the data set is limited.

4) No conclusions can be drawn with regard to the effects of one thruster firing vs several firing simultaneously since single-firing events were not available.

A definitive conclusion as to whether Orbiter water dumps affect the neutral pressure in the payload bay cannot be made since enough cases under varying conditions have not been tested. The data seem to indicate, however, that the effect, if any, is minimal. As reported by Pickett et al.,[13] neutral pressure readings on OSS-1 are slightly greater with water being dumped than without when the payload bay is in wake. Narcisi et al.[20] report that there is no increase in neutral pressure during a water dump.

Finally, a comment is in order with regard to the magnitude of effects seen by the SL-2 pressure gage vs those seen by other pressure monitors on this and other shuttle flights. Effects of thruster firings seen by the PDP pressure gage are less in magnitude than those seen on previous shuttle flights. This could be related to a number of things such as location of the sensor in relation to other instruments, Orbiter altitude and attitude, and degree of outgassing in the payload bay. In fact, had the PDP pressure gage on SL-2 been able to obtain measurements later in the flight when outgassing in the payload bay had decreased significantly, the *relative* effects of thruster firings, OMS burns, and payload bay into ram may have been much greater, although the absolute magnitude may have remained about the same due to the gage's location in the bay. Further measurements on future Space Shuttle flights need to be made in order to adequately quantify the various effects on neutral pressure seen as a result of Orbiter and payload operations.

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