Bendix
Aerospace Systems Division

B Miley

NO. ATM-689
REV. NO.
PAGE ______ OF ______
DATE 8/24/67

Effects of the Lunar Module on ALSEP

Attached is a copy of a memo generated by Space Physics Division of MSC further confirming that the LM assent over pressure effects should not affect ALSEP, flying debris is negligible, and it is unlikely that LM will explode.

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OPTIONAL FORM NO. 10
MAY 1962 EDITION
GSA FPMR (41 CFR) 101-11.6

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UNITED STATES GOVERNMENT

Memorandum

TO : TD/Manager, Lunar Surface Project Office

DATE: FEB 21 1967

FROM : TG/Chief, Space Physics Division

SUBJECT: Effects of the Lunar Module (LM) on the Apollo Lunar Surface Experiments Package (ALSEP)

Enclosed is the requested reply to your memorandum EX23/M150-66 on the above subject. The following conclusions are submitted to the specific questions presented in the memorandum.

a. (1) The overpressure at the lunar surface from impingement of the plume of the ascent stage is small and does not create a situation which would damage the ALSEP instrument. However, this pressure is many orders of magnitude above the lunar atmospheric pressure and would interfere with pressure and atmosphere measurements during and for some unknown period after the ascent of the LM.

(2) No secondary effects of flying debris are anticipated as a result of the operation of the ascent engines.

b. The short term venting of the descent tanks will occur before emplacement of ALSEP and should dissipate rapidly. The long-term leakage should result in a maximum helium concentration 5 orders of magnitude below that of the lunar atmosphere. Some surface absorption with subsequent outgassing can be anticipated from the engine exhausts and tank venting. The actual amount of outgassing is difficult to estimate at the present time.

c. The possibility of explosion of the LM descent stage tanks is very remote.

Enclosed with this memorandum is a discussion of each of these items which leads to the conclusions presented above. The discussion of the gross effects on the local atmosphere was prepared by R. H. Manka of the Atmospheric Physics Branch under Mr. D. E. Evans, TG3. The remainder of the investigation was made by R. F. Fletcher and R. W. High. For any further information or questions concerning the discussions, please contact R. F. Fletcher or R. W. High, TG2, extension 4464.

Jerry L. Modisette

Enclosure

TG2:RWHigh:sjr

Effects of the Lunar Module (LM) on the Apollo Lunar Surface Experiments Package (ALSEP)

A. (1) An analysis was made of the plume-surface interaction assuming a plane surface and a shock of infinitesmal thickness (Ref. 1). This analysis was concerned with the descent engine; however, since the expansion ratio of the ascent engine is similar to that of the descent engine, the analysis is considered valid for both stages. Data are presented in Ref. 1 for four (4) combinations of nozzle geometry and ratio of specific heats. The surface pressure distributions for one of these combinations (Contour Nozzle; $\gamma = 1.24$), selected as representative of the plume-surface interaction, are presented in the following table for nozzle heights of 12.5, 25, and 125 feet (h/r_e = 10, 20, 100).

r_e = nozzle exit radius = 1.25 feet approximately
h = height above surface, feet
r = transverse distance from nozzle centerline, feet

r, ft.	Surface Pressure, lb_f/ft^2		
	$h/r_e = 10$	$h/r_e = 20$	$h/r_e = 100$
0	60	12	.4
10	23	8	.39
20	1.6	4.5	.38
30	.18	2	.36
40	.03	.4	.34
50	.008	.12	.31
75	.00034	.013	.26
100	.000041	.0021	.19
150		.00009	.074
300			.0032

Note: Lunar atmospheric pressure is estimated to be between 3×10^{-11} and 3×10^{-13} lb/ft^2.

At the lower heights, this pressure distribution will be altered somewhat by impingement of the exhaust from the engine on the deflector plate in the descent stage. This effect has not been analyzed.

The pressure effect on the ALSEP package is not considered significant except to those instruments measuring the local pressure or atmospheric composition. The ambient pressure will be raised significantly above its normal value however, this pressure effect is not expected to remain long. The Propulsion Division is modifying their analytical analysis of the plume to incorporate a more realistic distribution of pressure at the nozzle exit. This program is not available at the present but the results are not expected to significantly alter the pressures reported here or the erosion effects in the next section.

(2) The effect of the descent plume on the erosion of the lunar surface was the subject of Reference 2. From this study, it is concluded that a short hover at 5 feet above the surface ($h/r_e = 2.1$) should produce erosion no greater than .25 feet based on a surface similar to that experienced by Surveyor I. At a distance of 10 feet ($h/r_e = 4.2$) no surface erosion is anticipated. The general trends were in agreement with Roberts' theory which predicts that the particle weight multiplied by a soil friction coefficient is the force which must be exceeded before soil can erode. Land and Clark applied Roberts' theory to develop the variation of erosion rate with particle size for two height parameters ($h/r_e = 5$ and 10). The results from Roberts' theory show that a factor of two change in the height parameter decreases the erosion depth 1 order of magnitude and the particle size $\frac{1}{2}$ order of magnitude.

For the ascent engine the height parameter (h/r_e) has a minimum value of 7.2 or a nominal value of 8.5. This parameter is approximately twice the value of the descent engine at which no erosion was anticipated. From this and the trends predicted from Roberts' theory, it is concluded that no erosion or secondary debris would be expected if the ascent stage plume impinged directly on the surface. In addition, at lower heights the ascent plume is deflected by a deflector plate on the descent stage thus diverting the gases to a direction normal to that of the exit centerline preventing direct impingement on the lunar surface. No study is available to properly describe this effect.

References

1. "Plume-Surface Interaction Analysis". ASPO Task 5A. TRW Systems Report No. 05952-6001-R000. July 22, 1966, by S. S. Cherry.

2. "An Investigation of Soil Erosion and its Potential Hazard to LM Lunar Landing". ASPO Task 22A. TRW Systems Report No. 05952-6056-R000. October 1, 1966, by R. W. Hutton.

B. Leakage of LM Tanks

After the LM lands (during which a large amount of contamination is dumped into the atmosphere and onto the surface by the descent exhausts), there will be two sources of vaporization before ascent occurs.

The purpose of this note is to calculate some approximate densities of surface and atmosphere contamination on the basis of the information available on the venting and leakage of the descent stage tanks. In addition, some comments will be made on contamination in general and possible calculations to be done concerning the ascent stage.

I. Information on Venting and Leakage

According to the information available there are two sources of vaporization before the ascent begins: (1) a short-time venting of the descent storage tanks and helium pressurizer, and (2) a long-time leak in the helium pressure tank.

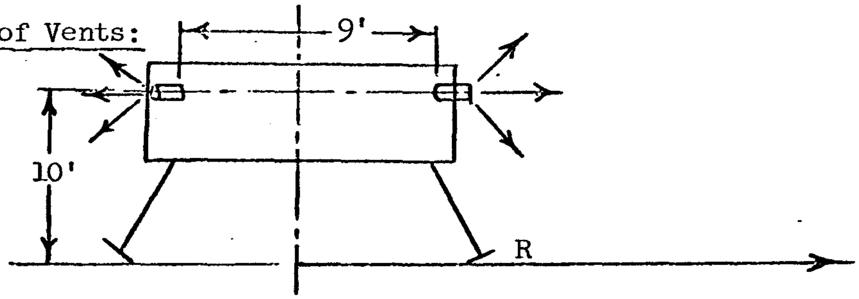
Short-Time Venting:

This presumably occurs just after landing and before the ALSEP package is emplaced. The constituents are approximately 5 pound fuel (molecular weight = 50), 50 pounds oxidizer (molecular weight = 90), and 50 pounds helium (molecular weight = 4).

Long-Time Leak:

This is a steady leak of the helium pressure tank at a rate of 1 x 10^{-3} cc/hr at STP.

Position of Vents:



The gases are vented through two vents nine feet apart, so a reasonable assumption is 4π solid angle flux. The ends of the vents are covered with perforated caps.

II. Quantities and Velocities of Vented Molecules

From the quantities stated above, the number of molecules can be calculated. There are 6 x 10^{23} molecules in one gram molecular weight. Thus the total number of molecules in a quantity of gas is:

$$N_o = (\#\ \text{lb. gas}) \times \frac{454\ \text{gm}}{\text{lb}} \times \frac{6 \times 10^{23}\ \text{molecules}}{M\ (\text{gm molecular weight})}$$

$$N_o = \frac{\#\ \text{lb.}}{M} \times 2.7 \times 10^{26} \quad = \#\ \text{of molecules}$$

so

fuel : 5 lb., $M \simeq 50$ $\quad N_o = 2.7 \times 10^{25} \sim 10^{25}$
oxidizer: 50 lb., $M \simeq 90$ $\quad N_o = 1.5 \times 10^{26} \sim 10^{26}$
helium : 50 lb., $M \simeq 4$ $\quad N_o = 3.4 \times 10^{27} \sim 10^{27}$

And for leaking helium, 10^{-3} cc/hr (STP), we know that 1 mole at STP has 6×10^{23} molecules in 22.4 liters = 2.24×10^4 cc; or there are 2.7×10^{19} molecules/cm^3. Thus the leak is about

$$N_o = 3 \times 10^{19}/\text{cm}^3 \times 10^{-3}\ \text{cm}^3/\text{hr} = 3 \times 10^{16}/\text{hr}$$

or

$$N_o \cong 10^{13}/\text{sec}$$

The velocity (speed) of the vented gas can be approximately calculated by assuming that the gas is vented at the temperature of the lunar surface ($\sim 400^\circ$K in sunlight). The mean velocity is

$$V_{th} = \sqrt{\frac{3kT}{m}} = \sqrt{\frac{3RT}{M}}$$

and for $T = 400^\circ$K,

$$V_{th} = \left[\frac{1000 \times 10^8}{M}\right]^{\frac{1}{2}}\ \text{cm/sec}$$

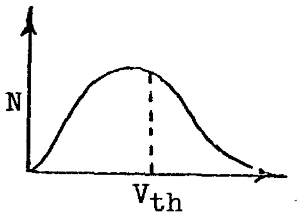
For helium, $M = 4$ $\quad V_{th} = 1.6 \times 10^5$ cm/sec
fuel, $M = 50$ $\quad V_{th} = 4.5 \times 10^4$ cm/sec
oxidizer, $M = 90$ $\quad V_{th} = 3.3 \times 10^4$ cm/sec

The above speeds are the mean speed for a Maxwellian, the density in phase space being given by

$$\rho(s) = \sqrt{\frac{2}{\pi}}\ s^2\ e^{-\frac{s^2}{2}} \quad \text{where } s^2 = \frac{m}{kT}\ V^2$$

i.e.,

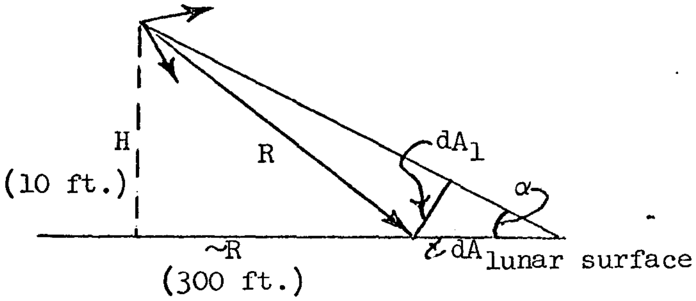
$$dN(V^2) = \sqrt{\frac{2}{\pi}}\ \frac{m}{kT}\ V^2\ e^{\frac{-mV^2}{2kT}}\ d^3\ V$$



which gives a distribution of speeds from zero to infinity. However, for a rough approximation, this distribution of speeds can be replaced by the mean speed, V_{th}.

III. Contamination by Direct Deposition

The simplest case to consider and also the most applicable case for this problem is that of direct deposition of contamination. In this case, the source is at some height above the lunar surface (10 ft. for this problem) and the gas flows radially outward, the proportion of contamination on a given area is just the ratio of the solid angle subtended by the area to 4π solid angle. This form of deposition dominates at close distances, say up to about 1000 meters.



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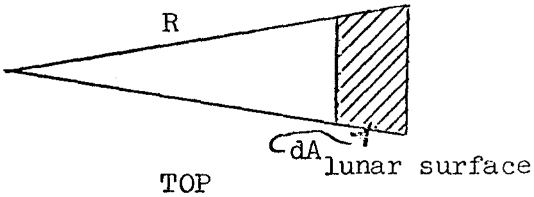


TOP

The number of molecules passing through dA_1 at 300 feet is

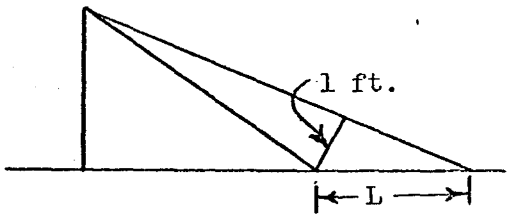
$$\frac{dN_1}{N_o} = \frac{dA_1}{A_{TOT}} = \frac{dA_1}{4\pi R^2}$$

but this number is spread over $dA_{\text{lunar surface}}$

$$\frac{dN_{l.s.}}{N_o} = \frac{dN_1}{N_o} \times \frac{dA_1}{dA_{l.s.}} = \frac{dN_1}{N_o} \times \frac{H}{R} \cong \frac{H}{4\pi R^3}$$

since $\sin\alpha \cong \frac{H}{R} = \frac{1}{L}$

and $\frac{dA_1}{dA_{l.s.}} \cong \frac{1 \text{ ft} \times 1 \text{ ft}}{1 \text{ ft} \times L \text{ ft}} = \frac{H}{R}$



Thus $dN_{\text{lunar surface}} \cong N_o \times \frac{H}{4\pi R^3}$

and for H = 10 ft., R = 300 ft.

$$\frac{dN_{l.s.}}{N_o} = \frac{10 \text{ ft}}{4\pi(300 \text{ ft})^3} = 3 \times 10^{-8}/\text{ft}^2 = 3 \times 10^{-8}/\text{ft}^2 \times \frac{1 \text{ ft}^2}{900 \text{ cm}^2} \cong 3 \times 10^{-11}/\text{cm}^2$$

$\frac{dN_{l.s.}}{N_o} \cong 3 \times 10^{-11}/\text{cm}^2$ at 300 ft. from L.M.

Thus we see that the number of molecules/cm^2 on the lunar surface at 300 ft. is many times smaller than the total emitted at the source.

a. Direct Deposition of Vented Fuel on Lunar Surface

Short Time Venting:
Since this fuel and helium is vented before the ALSEP is emplaced, the number of molecules deposited on the surface is of interest. From the calculations of N_o, we got

$$\begin{aligned} &\text{Fuel} &&: dN_{l.s.} = 2.7 \times 10^{25} \times 3 \times 10^{-11} = 10^{15}/\text{cm}^2 \\ &\text{Oxidizer} &&: dN_{l.s.} = 1.5 \times 10^{26} \times 3 \times 10^{-11} = 5 \times 10^{15}/\text{cm}^2 \\ &\text{Helium} &&: dN_{l.s.} = 3.4 \times 10^{27} \times 3 \times 10^{-11} = 10^{17}/\text{cm}^2 \end{aligned}$$

However, most of the helium at 400°K will probably escape the moon's gravitational field. The only importance of the above molecules will be if they in turn outgas, or are sputtered from the surface by solar wind. This process is too complicated to analyze in this memorandum.

b. Density of Helium in Atmosphere due to Long-Time Leak

The number of helium atoms leaking per second is $N_o = 10^{13}/\text{sec}$. The flux/second through dA_1 is related to the density at 300 ft. by

$$n/\text{cm}^3 \times V \, \frac{\text{cm}}{\text{sec}} = \text{flux}$$

where flux on dA_1 is

$$dN_1 = N_o/\text{sec} \, \frac{dA_1}{4\pi R^2} = N_o \times 10^{-6}/\text{ft}^2 \text{ sec}$$

$$= N_o \times 10^{-9}/\text{cm}^2 \text{ sec}$$

$$n/\text{cm}^3 = \frac{dN_1}{V} \cong \frac{10^{13}/\text{sec} \times 10^{-9}}{10^5} = 10^{-1}/\text{cm}^3$$

so N of He/cm^3 = $10^{-1}/\text{cm}^3$

This is not a very large number compared to the total expected density of atoms and molecules of 10^4 to $10^6/\text{cm}^3$ in the lunar atmosphere.

IV. Thermal Deposition

For a rocket exhaust which is directed downward at the lunar surface and then bounces back with a thermal (Maxwellian) velocity distribution, the orbits of the molecules and resulting surface density can be calculated. The problem has been thoroughly analyzed by Mr. F. G. Hall (Ref. 2). Solution for the density using a thermalized source requires a numerical integration of the Maxwellian velocity distribution. However, some approximate values of surface density due to thermal deposition can be calculated using the tables in Mr. Hall's paper. From Table III, for $R = 0$ Km, $\rho_n = 3 \times 10^{-13}/\text{m}^2$ = normalized density
$R = 1$ Km, $\rho_n = 2 \times 10^{-14}/\text{m}^2$

so by taking the ratio of areas, the density at 100 meters can be estimated

$$\frac{dN}{N} \sim 10^{-11} \text{ to } 10^{-12}/m^2 = 10^{-15} \text{ to } 10^{-16}/cm^2$$

Thus we see that this density is several orders of magnitude lower than direct deposition.

V. Conclusions

Most of the fuel and helium venting (about 100 lb. total) of the descent storage tanks takes place before the ALSEP is emplaced. This venting plus the large amount of descent exhaust then appears as a surface contamination which will effect atmosphere experiments only if these molecules are ejected into the atmosphere by outgassing or sputtering. The estimate of these processes is too complicated for this memorandum, but local pressures in the area of the landing site are high enough that a significant amount of vapor may be absorbed. Later outgassing may take hours or even days, thus some residual contamination may be expected.

The second process - the long-time leak - gives a calculated atmospheric density of $10^{-1}/cm^3$ at R = 300 ft. from the L.M. - this should be a small effect in the atmosphere.

Finally, to determine the total effect on ALSEP experiments, it would be necessary to include the effect of the ascent stage exhaust which will also deposit a relatively large amount of exhaust on the lunar surface. To pursue such a calculation, references such as Mr. Hall's paper mentioned above and the final report of contract NAS 9-4860 will be useful. The ascent and descent deposited gas may well be the largest source of contamination in the atmosphere as it outgasses from the lunar surface.

References

1. "Elements of Theory of Gases". Golden Addison, Wesley Publications, 1964.

2. "A Theoretical Calculation of Lunar Contamination Profiles from Thermalized and Directed Flow Leak Sources on the Lunar Surface". By F. G. Hall, in preparation for publishing.

3. Final Report NASA contract NAS 9-4860.

C. The possibility of the LM descent tanks exploding after lunar landing does exist with the recent operational change not to jettision the propellants. The situation and conditions under which a reaction may occur outside the containment of the tanks is not very realistic. The situation would be unique in that a rupture of both fuel and oxidizer tanks would have to occur simultaneously, the ingredients would have to impinge upon one another and the quantity would need to be large. Theoretically, with conditions prevailing, no explosion of any significance is likely to occur. Also, there is not much likelihood of a mechanical explosion of the helium or fuel tanks because they will be depressurized immediately after landing. Thus the possibility of an explosion resulting from an overpressurized tank or reaction of the fuel is considered remote.

However, this is not the end of the "resulting effects" noted in item C. Whether an explosion occurs or not there will be the potential danger of particles traveling at high velocities. This is so because liquids when exposed to environments below their triple point vaporized rapidly. In undergoing a phase change, a considerable amount of thermal energy is converted to kinetic energy. Little is known about the density, size, or velocity of these particles. An experimental program, now nearing the test stage under contract NAS 9-6105 with Atlantic Research, is to provide data on these particle characteristics. When this definitive information becomes available an appraisal of the "resulting effects" can be made with some degree of realism.