Bendix

Aerospace Systems Division

ALSEP Emplacement Study

NO.	REV. NO.
ATM-762	

PAGE ___1___ OF __73__

DATE   1 June 1968

This ATM presents the analysis and results of a study conducted during the period of 20 May to 1 June, the purpose of which was to examine the effect of the LM on the ALSEP.

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Approved by: _R. D. Ormsby (signature)_
R. D. Ormsby

	NO.	REV. NO.
	ATM-762	

Bendix

Aerospace Systems Division

ALSEP Emplacement Study

PAGE __2__ OF __73__

DATE 1 June 1968

TABLE OF CONTENTS

NO.	REV. NO.
ATM-762	

Bendix

Aerospace Systems Division

ALSEP Emplacement Study

PAGE __3__ OF __73__

DATE 1 June 1968

1.0   INTRODUCTION

During the past 2 1/2 years various studies have been conducted with regard to the emplacement of the ALSEP on the lunar surface. All previous studies have assumed that the LM ascent from the lunar surface is vertical to a height where it no longer affects the ALSEP.

The purpose of this study is to: (1) review and evaluate the pertinent previous efforts; and, (2) re-evaluate the emplace distance and azimuth with respect to the LM landing site based on these studies and the assumption that the Apollo crew will know the ascent azimuth heading before the ALSEP emplacement takes place.

Parameters of interest in the study were: (1) dynamic pressure as it affects both the central station and the experiments; (2) thermal effects in terms of both gas dynamic heating and dust accumulation on the ALSEP; and, (3) experiment compatibility with the LM magnetic field, venting and outgassing, and shadow.

2.0   SUMMARY AND CONCLUSION

It was determined that ALSEP can be deployed at a distance of 100-125 feet from the LM and not experience an overpressure problem. Knowledge of the LM trajectory does not enable reduction of the maximum pressure experienced by the ALSEP since this occurs when the LM is still in its vertical rise. The experiments themselves can be deployed

Bendix

**Aerospace
Systems Division**

ALSEP Emplacement Study

NO.	REV. NO.
ATM-762	

PAGE __4__ OF __73__

DATE 1 June 1968

at distances less than 300 feet from the LM also. The most affected of

the experiments is the Heat Flow (which should not be emplaced within

50 feet of the LM shadow). It was found that with the present side curtain/

reflector/radiator arrangement the ALSEP will have to be deployed nearly

due East or West of the LM. Deployment in other directions would permit

radial flowing dust to enter the end of the central station and deposit on the

radiator. This dust will act as an insulator, raising the central station

electronics temperature approximately 4°F per .001 inch of dust. The

situation possibly can be alleviated by extension of the side curtain. With

one man deployment the due East or West direction would prevent observa-

tion by the second crew member in the LM. Finally, it was found that a

potential problem exists in the area of aero/thermo heating due to the LM

exhaust. In order to conduct this analysis in the time allotted it was

necessary to rely on previously derived experssions or the heating rate.

These expressions are conservative but degree of conservatism can be

determined only by a more extensive study. The analysis indicates that

a deployment distance greater than 500 feet from the LM is required for

the central station if the side curtain temperature is to be kept below its

maximum acceptable temperature of 270°F. Because of the complexity

involved in the derivation of temperatures, time did not allow calculation

of temperatures for the experiments.

Bendix

Aerospace Systems Division

ALSEP Emplacement Study

NO.	REV. NO.
ATM-762	

PAGE __5__ OF __73__

DATE 1 June 1968

The results therefore indicate that the ALSEP cannot be deployed closer than 300 feet from the LM and that a more accurate analysis or design modification must be made to insure a compatibility with the thermal environment at this range.

3.0   RECOMMENDATIONS

The obvious criticality of the values derived for the heating due to the LM ascent warrants further analysis. If the predicted temperatures had been reasonable, the apparent conservatism in the analysis model could be accepted. However, the potential over-heating of materials indicated herein imply that either a more precise analysis be performed to assess any available margin or design changes must be immediately incorporated.

4.0   PROBLEM STATEMENT

It is desirable to emplace the ALSEP as close as possible to the LM landing point so that the crew EVA time may be most effectively utilized and to enhance crew safety. Furthermore it is desired to determine what areas, with respect to azimuth from the LM, are acceptable so that contingency emplacement sites may be identified.

A multiplicity of parameters enter into the selection of an acceptable emplacement site. In addition to the lunar surface itself, these are:

(1) dynamic pressure resulting from the LM Ascent Stage motor plume;

Bendix

**Aerospace
Systems Division**

ALSEP Emplacement Study

NO.	REV. NO.
ATM-762	

PAGE __6__ OF __73__

DATE 1 June 1968

(2) thermal shock from the plume and degradation of the ALSEP thermal control due to eroded dust accumulation; and (3) LM magnetic, outgassing, and shadow compatibility with the ALSEP experiments.

As is seen, the problem is therefore of two parts. First, criteria must be established with respect to the parameters of interest for determining the acceptibility. Secondly, analyses must be performed to determine the actual anticipated environment so that, in combination with the criteria, areas of acceptability are determined.

Previous studies of dynamic pressure and thermal shock have assumed a LM ascent trajectory that is vertical until the thermal shock and dynamic pressures are no longer significant. The LM actual trajectory may modify results and is to be considered.

5. 0   LM ASCENT TRAJECTORY

The LM trajectory parameters affecting the study are illustrated in Figure 5-1. These include the surface range, altitude of motor (h), flight path angle with respect to local horizontal ($\propto$), angle between the motor center line and local vertical (β), and the distance of the ALSEP from the LM site (R).

Data regarding the LM ascent trajectory are taken from References (1) and (2). The LM rises vertically until it reaches a velocity of 50 fps. This occurs approximately 10-12 seconds after lift-off and

Bendix

Aerospace Systems Division

NO.	REV. NO.
ATM-762	

ALSEP Emplacement Study

PAGE __7__ OF __73__

DATE 1 June 1968

Figure 5-1   LM Trajectory/ALSEP Parameters

Bendix

**Aerospace
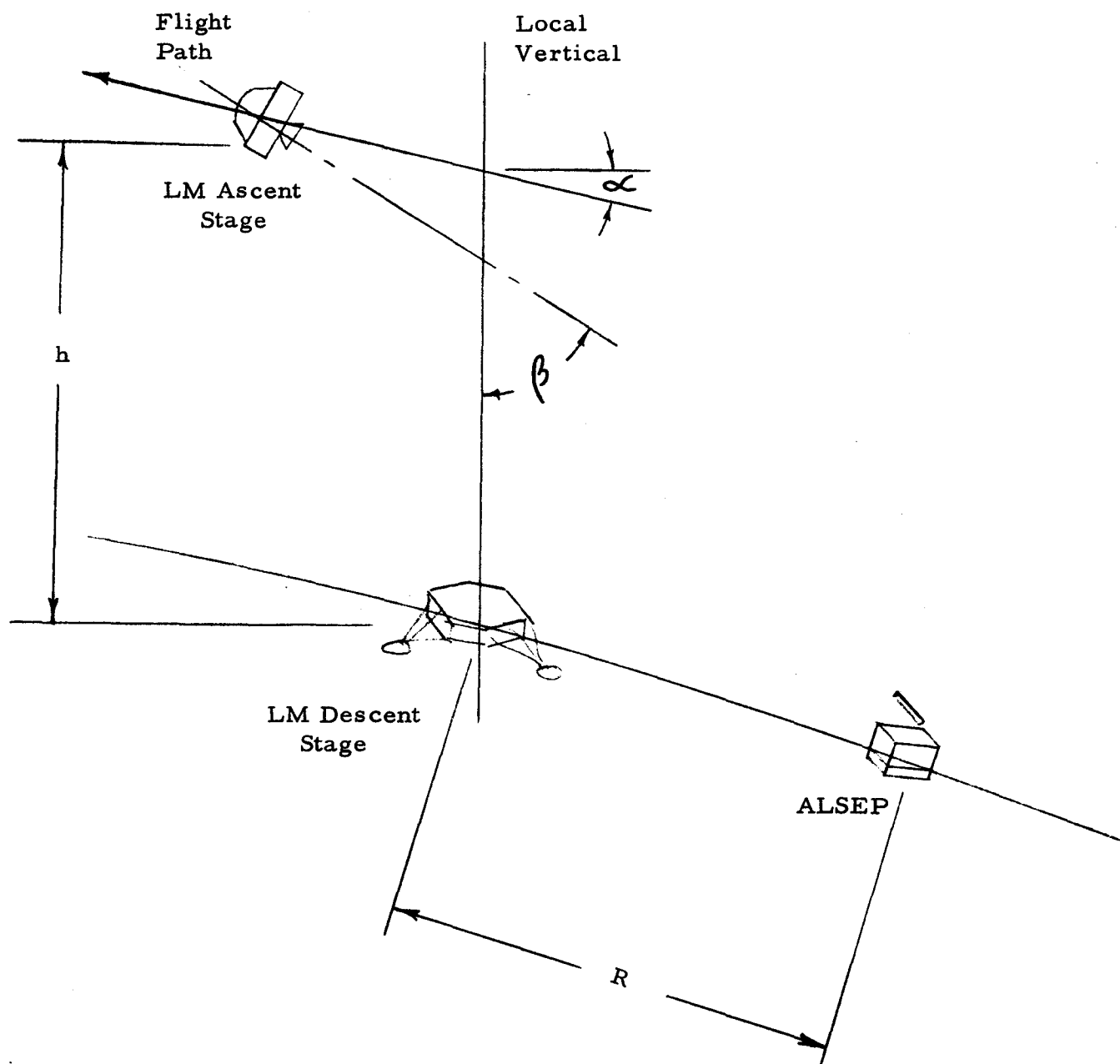Systems Division**

ALSEP Emplacement Study

NO. ATM-762   REV. NO.

PAGE 8 OF 73

DATE 1 June 1968

allows for the roll program to come in and clearance of local terrain

obstacles. At termination of the vertical rise there is a rapid pitch over

maneuver followed by a gradual pitch over as shown in Figure 5-2.

Figure 5-3, taken from Reference (2), presents the main trajectory param-

eters with respect to time.

The LM mass at lift-off is 10,729 lb of which 4,962 is propellant

(Reference 1). The motor has a constant thrust of 3,500 lb and consumes

approximately 11 lb of fuel per second (Reference 2). Based on these

factors, and the knowledge that the LM rises vertically until a velocity of

50 fps is reached, the altitude (h) at which the rapid pitch over commences

is computed to be 237 feet (Appendix A). Therefore, if maximum dynamic

pressure and thermal shock is experienced by the ALSEP before the LM

reaches an altitude of 237 feet knowledge of the ascent azimuth will not

affect the ALSEP emplacement.

6.0   ACCEPTABILITY CRITERIA ANALYSES

Definition of the acceptable LM ascent environment criteria is

contained in this section. These criteria are derived from the ALSEP

itself and are divided into three categories: (1) dynamic pressure, (2) thermal

control, and (3) experiment compatibility.

Bendix
Aerospace Systems Division
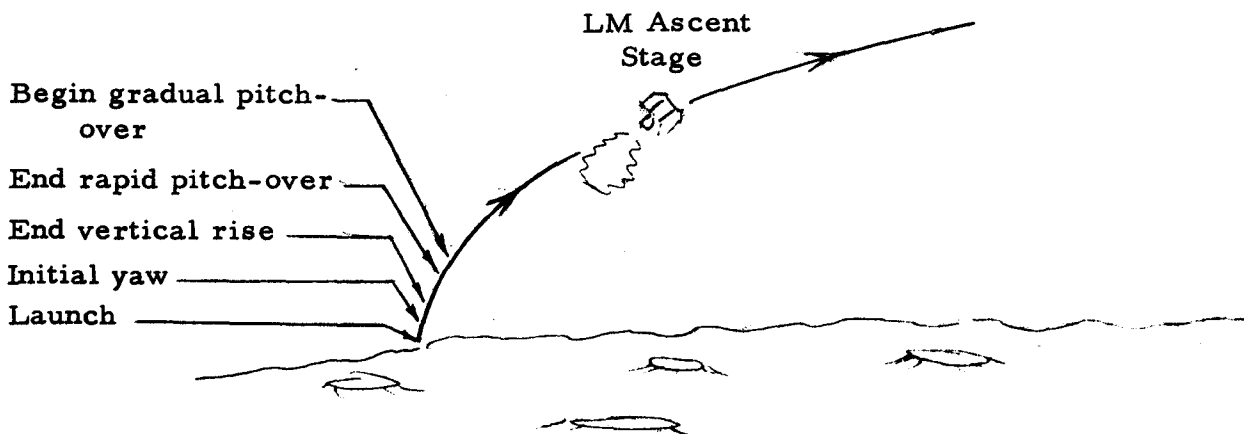
Figure 5-2   Main Events of LM Ascent
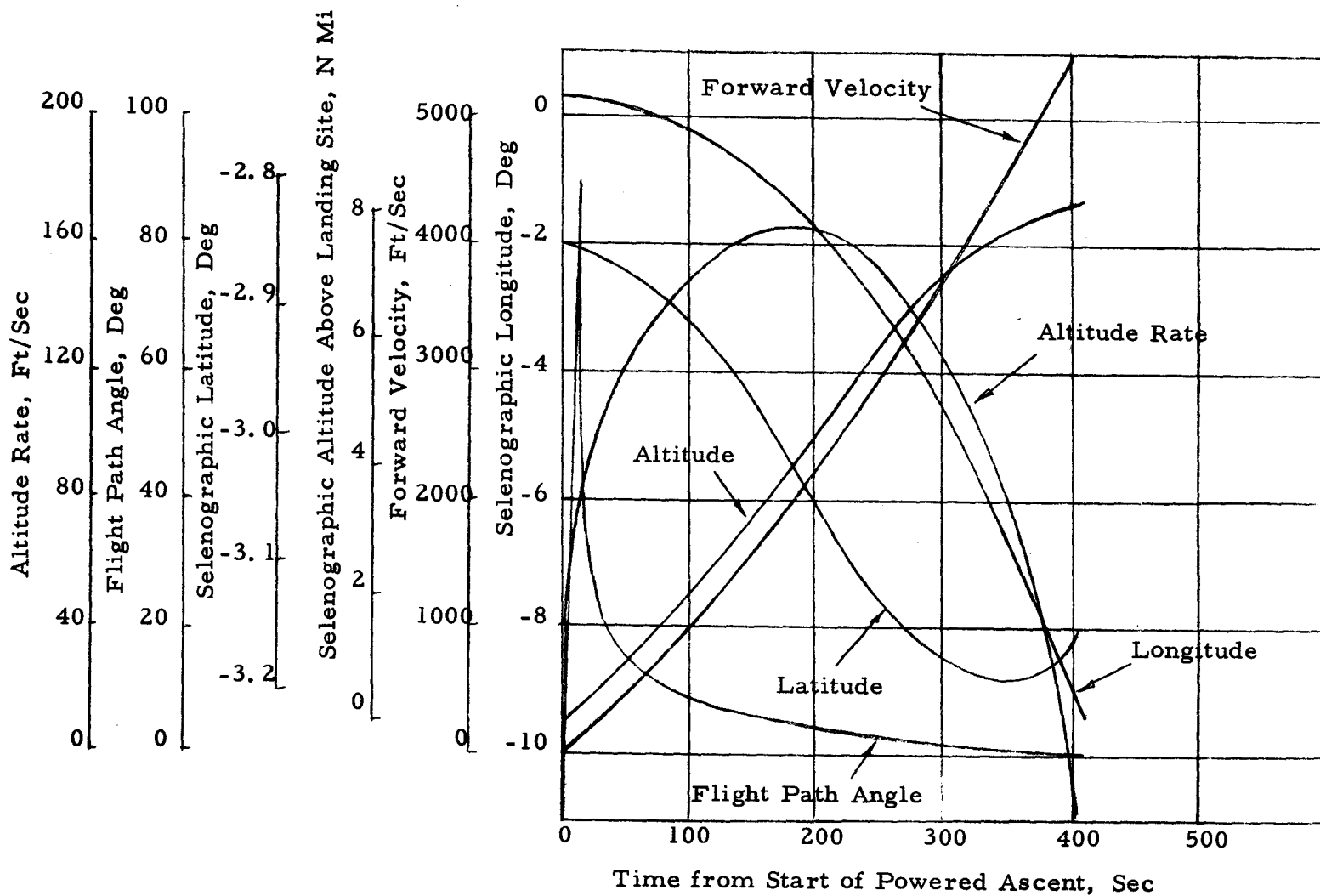
Figure 5-3   LM Powered Ascent, Trajectory Parameters

Bendix

Aerospace Systems Division

ALSEP Emplacement Study

NO. ATM-762

REV. NO.

PAGE 11 OF 73

DATE 1 June 1968

6.1   Dynamic Pressure

Determination of an acceptable dynamic pressure from the ascent stage plume necessitates analysis of the pressure effects on the central station and the experiments. In all cases the underlying assumption is that no movement due to the dynamic pressure, either by tipping or sliding, is permissible. In addition, some experiment sensors may be sensitive to pressures lower than that required to physically move it. The lowest acceptable dynamic pressure must thus be derived, and, in actuality several pressure values, at different distances from the LM corresponding to the spacial relationship between the central station and experiments, may be the determining criteria. For example, the acceptability criteria may be: 0.1 pounds/ft^2 at 200 feet or 0.15 pounds/ft^2 at 250 feet, the more critical of which thus becomes the determining factor.

6.1.1   Central Station Analyses

Geometrical and mars factors required for the following computations were extracted from References 3 and 4, respectively. Pressure on the central station can affect it by causing tipping or sliding on the surface. Any movement, no matter how slight, is unacceptable since even a minute movement could misalign the antenna causing loss of ALSEP data for extended periods of time.

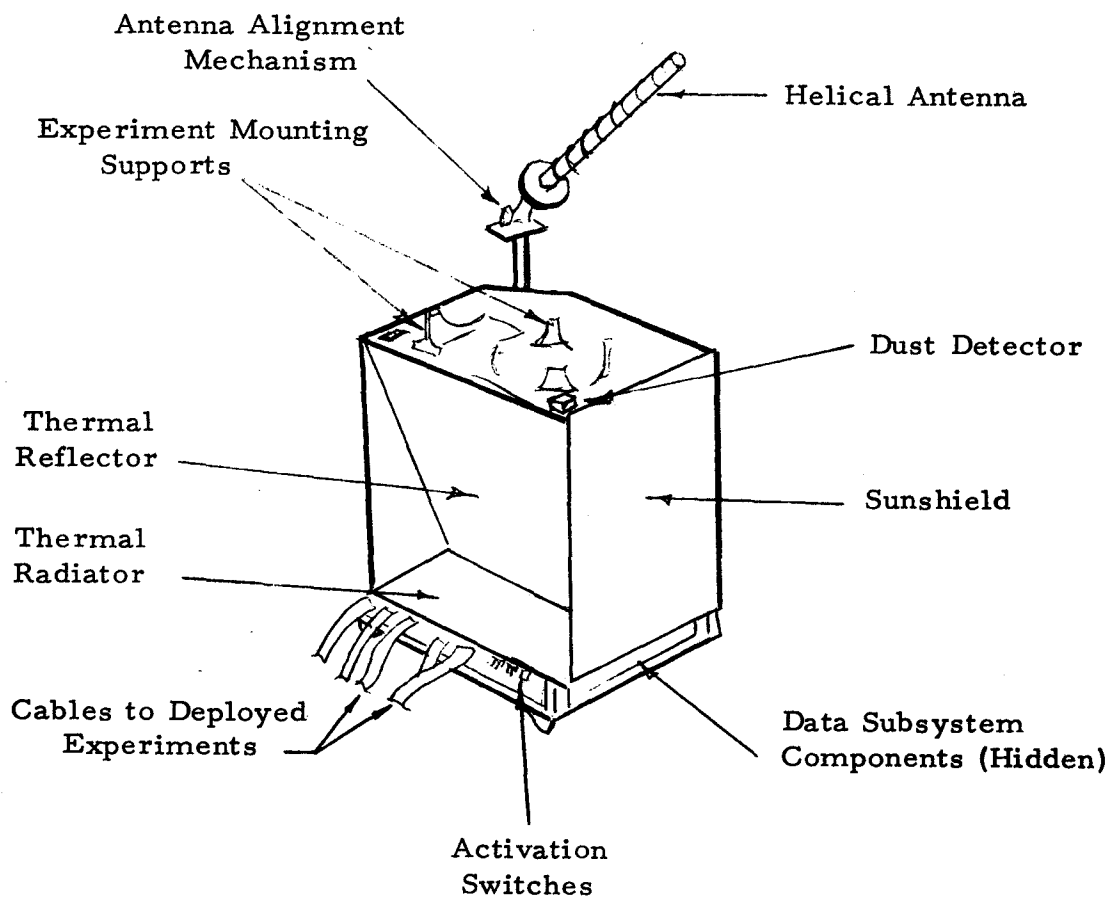The central station and its components are identified in Figure 6-1.

FIGURE 6-1

CENTRAL STATION DEPLOYED CONFIGURATION

6.1.1.1   Central Station Tipping

Figure 6-2(a) shows the geometry of the force on the central station with respect to tipping due to the dynamic pressure.

Since the point of rotation is "a", setting the summation of moments about this point equal to zero yields the maximum dynamic pressure acceptable.

$$\sum M_a = 0 \qquad\qquad (6\text{-}1)$$

or,

$$F_p l_3 - W l_1 = 0 \qquad\qquad (6\text{-}2)$$

$$F_p = P_d (A) C_d$$

where A is the cross-sectional area of the central station (4 ft^2), C_d is the drag coefficient (assumed = 2.0), and P_d is the acceptable dynamic pressure.

W = the lunar weight of the central station = 12.5 lb

and

$$l_1 = 1 \text{ ft}$$

$$l_3 = 1 \text{ ft}$$

Therefore,

$$P_d (A) C_d l_3 - W l_1 = 0 \qquad\qquad (6\text{-}3)$$
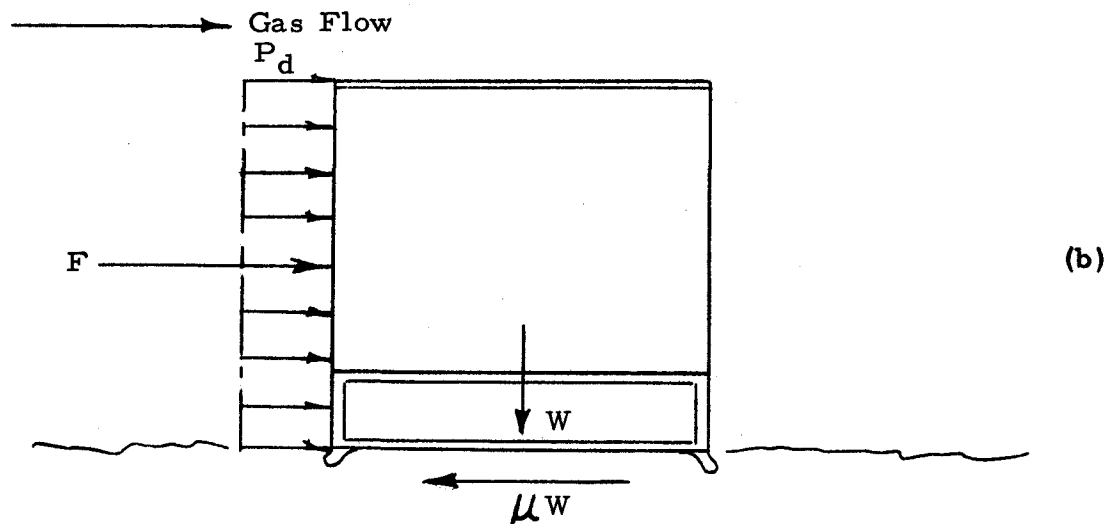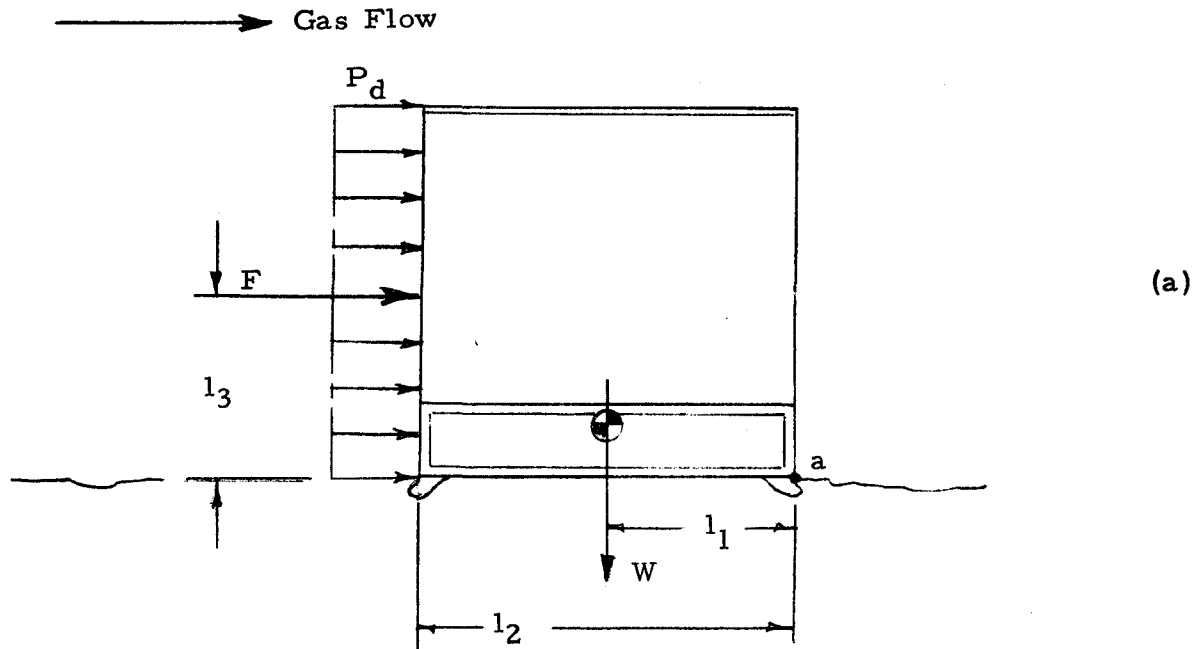
ALSEP Emplacement Study

FIGURE 6-2

CENTRAL STATION TIPPING AND SLIDING
GEOMETRY AND FORCES

Bendix

Aerospace Systems Division

ALSEP Emplacement Study

NO.	REV. NO.
ATM-762	

PAGE ___15___ OF ___73___

DATE 1 June 1968

or,

$$P_d = \frac{W l_1}{A\ C_d\ l_3}$$

$$P_d = \frac{(12.5)(1)}{(4)(2)(1)} = 1.56 \text{ pounds/ft}^2 \qquad (6\text{-}4)$$

6.1.1.2   Central Station Sliding

Prevention of central station sliding is dependent upon the coefficient of friction between the lower surface of the ALSEP central station and the lunar surface.   This value is not known and some conservatism will therefore have to be employed.

The force tending to move the central station is the same as that which tended to tip it in the above calculation.   The resisting for due to friction is shown in Figure 6-2(b), where μ is the coefficient of friction and W is the central station lunar weight.

Setting the summation of the horizontal forces equal to zero yields the maximum pressure tolerable without experiencing sliding:

$$\sum F_h = 0$$

or,

$$F - \mu W = 0$$

$$P_d (A) C_d - \mu\ W = 0 \qquad (6\text{-}5)$$

Bendix

Aerospace Systems Division

ALSEP Emplacement Study

NO. ATM-762

REV. NO.

PAGE 16 OF 73

DATE 1 June 1968

$$P_d = \frac{\mu W}{A \, C_d}$$

$$= \frac{12.5 \, \mu}{8} = 1.56\mu \qquad (6-6)$$

This expression therefore yields the critical dynamic pressure for the central station since μ will be less than 1.0 and the resulting P_d in that case is less than P_d obtained in the expression for tipping (Equation 6-4).

As mentioned above, the coefficient of friction cannot be exactly determined. However, an estimate can be obtained. Reference 5 gives a value for the angle of friction between soil grains (ϕ) of 32^0. Surveyor III and V data indicate a value of μ in the range of 0.75 to 0.84 based on the angle of internal friction indicated by the Surveyor III surface samplor test and the movement of the alpha-scattering instrument when the vernier engine was fired. (Reference 5A) In Figure 6-3 a soil grain is shown on an inclined surface of soil. Since the forces along the plane must equal zero, the frictional force must be equal and opposite in direction to the gravitational component along the plane:
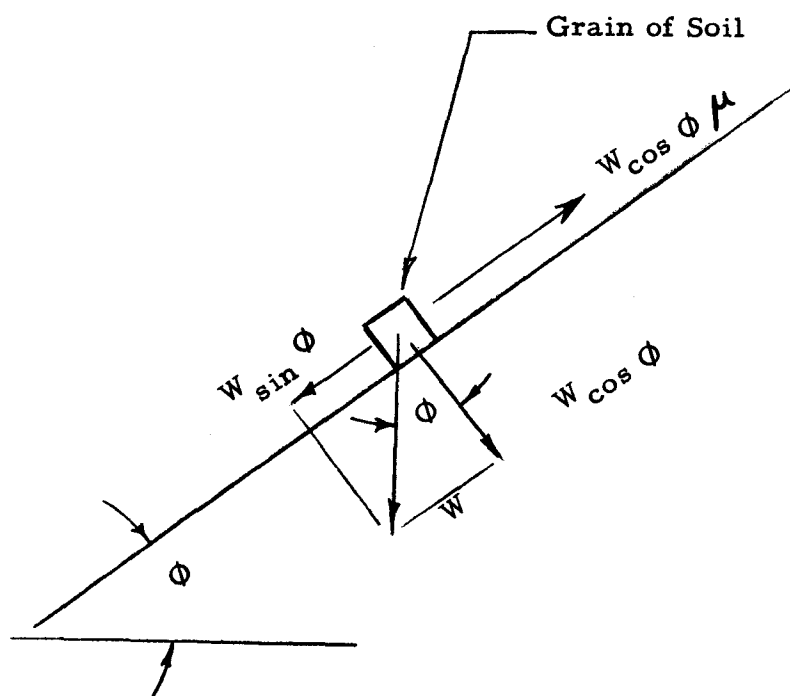
Figure 6-3   Definition of Angle of Friction and
Forces Leading to Calculation of
Coefficient of Friction

Bendix

Aerospace Systems Division

ALSEP Emplacement Study

| NO. ATM-762 | REV. NO. |
| PAGE 18 OF 73 |
| DATE 1 June 1968 |

$$W \sin \phi = W (\cos \phi)\mu \qquad (6\text{-}7)$$

then

$$\mu = \frac{\sin \phi}{\cos \phi} = \tan \phi \qquad (6\text{-}8)$$

For $\phi = 32°$, μ therefore is 0.625. This is the soil on

soil coefficient of friction. The value between the bottom of the central

station and the surface may be somewhat lower. Where tabs and other

irregularities on the bottom of the central station protrude into the sur-

face, they should help raise the value of μ. It is felt reasonably con-

servative to assume a value of 0.3 μ therefore. Substituting this into

Equation 6-6:

$$P_d = 1.56 (.3) = 0.468 \text{ pounds/ft}^2 \qquad (6\text{-}9)$$

6.1.2   Experiment Analyses

The ALSEP ecperiments are: 1) passive seismic

experiment, 2) solar wind experiment, 3) suprathermal ion detector

experiment, 5) charged particle lunar environment experiment, 6)

active seismic experiment, 7) heat flow experiment, and 8) lunar sur-

face magnetometer experiment. Each of these experiments must be

analyzed with respect to tipping, sliding, or any other adverse reaction

to the dynamic pressure resulting from the LM ascent. For purposes of

these analyses it will be assumed that the experiments present their least

advantaged projection to the gas flow.

Bendix

Aerospace Systems Division

ALSEP Emplacement Study

NO.	REV. NO.
ATM-762	

PAGE __19__ OF __73__

DATE   1 June 1968

6.1.2.1   Passive Seismic Tipping

Geometrical and mass properties factors for the Passive Seismic Experiment are taken from References 6 and 4, respectively. Figure 6-4 illustrates the external diminsions of the experiment and its stand. As is seen, the Passive Seismic Experiment has a cross-sectional area of 180 in.^{2} or 1.25 ft^2 and the center of pressure is 0.67 ft above the surface. From the stand geometry, it is seen that the moment resisting tipping is $\frac{2.06}{12}$ (W), or 0.171 W. The lunar weight of the experiment is $\frac{20.60}{6}$ = 3.44 pounds. To find the acceptable pressure, the summation of moments is set equal to zero:

$$(0.67) \, 1.25 \, P_d \, C_d - 0.171 \, W = 0 \qquad (6\text{-}10)$$

or,

$$P_d = \frac{0.171 \, (3.44)}{1.25 \, (2) \, (0.67)} = 0.35 \text{ pounds/ft}^2 \qquad (6\text{-}11)$$

6.1.2.2   Passive Seismic Sliding

A value of $\mu = 0.3$ is assumed here as was for the central station. The allowable dynamic pressure is found by setting the summation of horizontal forces equal to zero:

$$1.25 \, P_d C_d - \mu \, W = 0 \qquad (6\text{-}12)$$

or,

$$P_d = \frac{0.3 \, (3.44)}{1.25 \, (2)} = 0.412 \text{ pounds/ft}^2 \qquad (6\text{-}13)$$

Bendix

Aerospace Systems Division

ALSEP Emplacement Study

NO.	REV. NO.
ATM-762	

PAGE 20 OF 73

DATE 1 June 1968

15.25"

11.75"

4.12"

120°
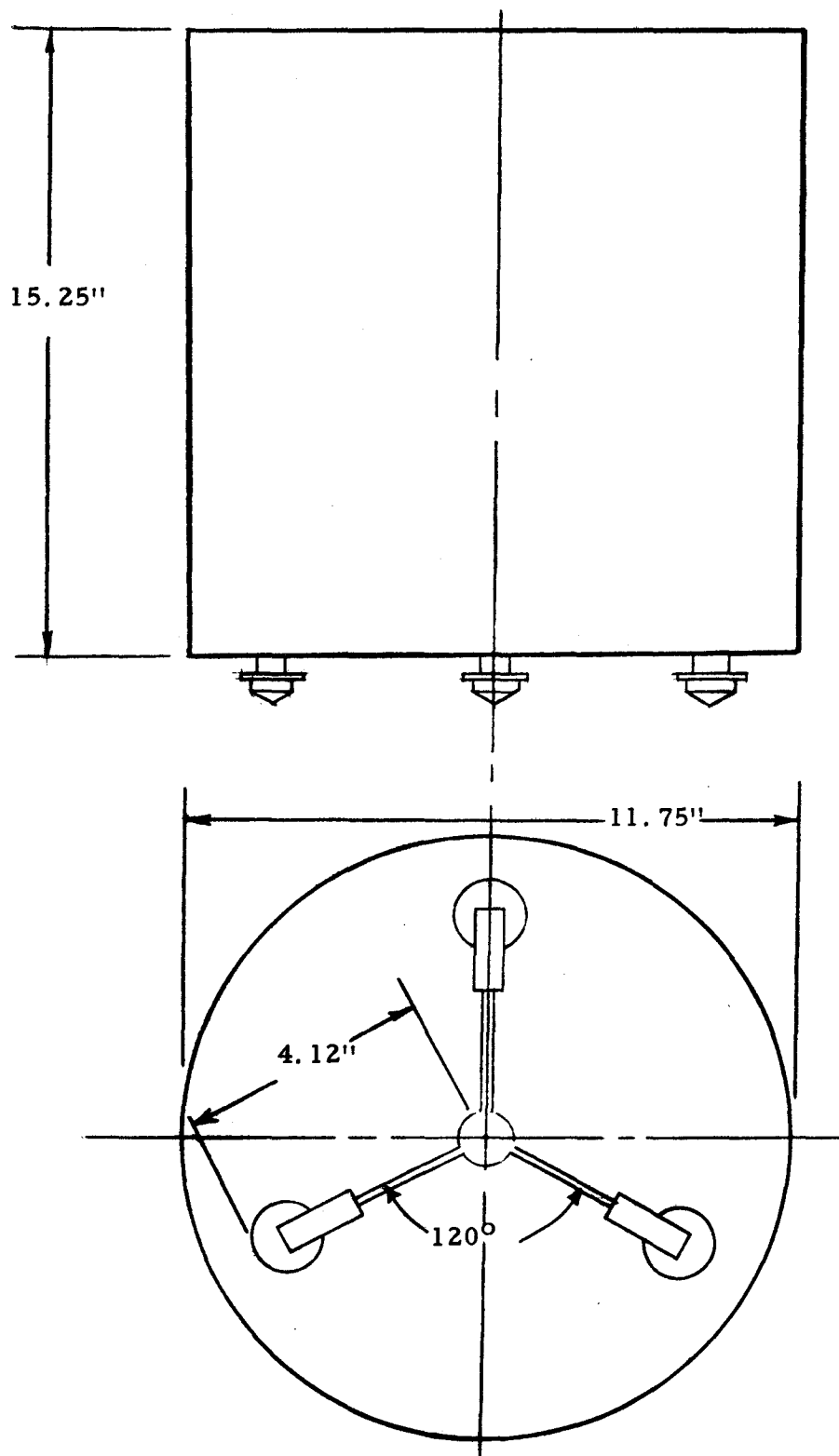
FIGURE 6-4

PASSIVE SEISMIC EXPERIMENT AND STAND DIMENSIONS

Bendix

Aerospace Systems Division

ALSEP Emplacement Study

NO. ATM-762

REV. NO.

PAGE 20a OF 73

DATE 1 June 1968

6.1.2.3   Solar Wind Tipping

The geometrical and mass properties data for the Solar Wind experiment are taken from References 4, 7, and 8. From these the projected area is found to be 0.875 ft^2 with the center of pressure 0.75 ft above the surface. The experiment rests on four "pads" as shown in Figure 6-5, with a gravitational restoring moment arm of 3.625 in., or 0.3 ft. The lunar weight of the experiment is 1.965 pounds.

Setting the moments equal to zero yields the critical dynamic pressure for tipping:

$$(0.75)\ P_d(0.875)\ C_d\ -\ 1.965\ (0.3)\ =0 \tag{6-14}$$

or,

$$P_d\ =\ \frac{1.965\ (0.3)}{2\ (0.875)\ (0.75)}\ =\ 0.45\ \text{pounds/ft}^2 \tag{6-15}$$

6.1.2.4   Solar Wind Sliding

The horizontal forces are set equal to zero to find the acceptable dynamic pressure with respect to sliding of the Solar Wind Experiment:

$$P_d\ (C_d)\ (0.875)\ -\ 1.965\ \mu\ =\ 0 \tag{6-16}$$

or,

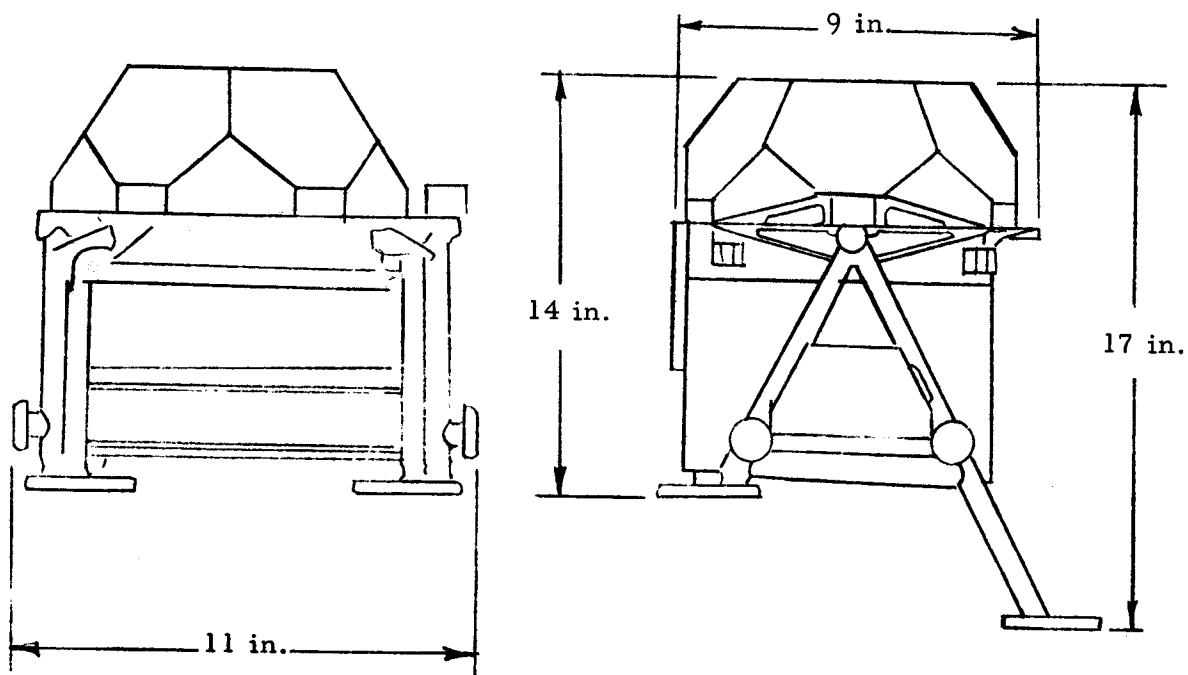$$P_d\ =\ \frac{1.965\ (0.3)}{2\ (0.875)}\ =\ 0.337\ \text{pounds/ft}^2 \tag{6-17}$$

FIGURE 6-5

SOLAR WIND EXPERIMENT SIZE AND WEIGHT

EARTH wt, lb = 11.68

Bendix

**Aerospace
Systems Division**

ALSEP Emplacement Study

NO.	REV. NO.
ATM-762	

PAGE __22__ OF __73__

DATE   1 June 1968

6.1.2.5   Suprathermal Ion Detector Tipping

The general arrangement of the Suprathermal Ion Detector Experiment is shown in Figure 6-6. Dimensions are taken from Reference 9. A lunar weight of 3.24 pounds is found in Reference 4. The center of pressure is approximately 1.0 ft above the surface and the restoring - gravitational moment acts on an arm of approximately 0.35 ft. Summing moments:

$$P_d (1.0) (C_d) A - 3.24 (0.35) = 0 \qquad (6-18)$$

The cross-sectional area (A) is 1.38 ft^2.

$$P_d = \frac{3.24 (0.35)}{(1.0) (2.0)(1.38)} = 0.41 \text{ lb/ft}^2 \qquad (6-19)$$

6.1.2.6   Suprathermal Ion Sliding

The maximum allowable pressure for this experiment with respect to sliding is found when the horizontal forces are set equal to zero:

$$P_d (C_d) (1.38) - 3.24 \mu = 0 \qquad (6-20)$$

or,

$$P_d = \frac{3.24 (0.3)}{(2) (1.38)} = 0.35 \text{ lb/ft}^2 \qquad (6-21)$$

6.1.2.7   Cold Cathode Gauge Tipping

Mass data for this experiment are obtained from Reference 4 while geometrical data are taken from Reference 10. The general

	NO.	REV. NO.
	ATM-762	

Bendix

Aerospace Systems Division

ALSEP Emplacement Study

PAGE __23__ OF __73__

DATE   1 June 1968

arrangement of the experiment is shown in Figure 6-7. The experiment

sets directly on the lunar surface, has a cross-sectional area of 0.918 ft

and the center pressure is 0.61 ft above the surface. The gravitational

restoring moment acts about a moment arm of 0.17 ft.

The lunar weight of the experiment is 2 pounds.

Setting the summation of the moments equal to zero gives the

maximum dynamic pressure the experiment can withstand without tipping.

$$P_d (C_d) (.918) (0.61) - (0.17) (2) = 0 \qquad (6-22)$$

$$P_d = \frac{0.34}{(2) (.918) (0.61)} = 0.30 \text{ lb/ft}^2 \qquad (6-23)$$

6.1.2.8   Cold Cathode Gauge Sliding

Setting the horizontal forces equal to zero:

$$P_d (C_d) (.918) - (2) (\mu) = 0 \qquad (6-24)$$

or

$$P_d \approx \frac{2 (0.3)}{2 (.918)} = 0.33 \text{ lb/ft}^2 \qquad (6-25)$$

6.1.2.9   Charged Particle Lunar Environment Tipping

Mass and geometrical factors for this experiment are

taken from References 4 and 11, respectively. The experiment has a

lunar weight of 1.04 pounds. The pertinent physical dimensions are

Bendix

**Aerospace
Systems Division**

ALSEP Emplacement Study

NO.	REV. NO.
ATM-762	

PAGE 23a   OF   73

DATE   1 June 1968
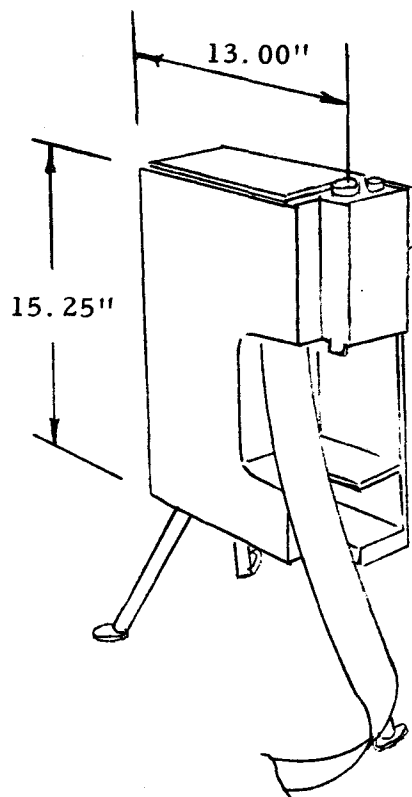
FIGURE 6-6

SUPRATHERMAL ION DETECTOR EXPERIMENT

Bendix

**Aerospace
Systems Division**
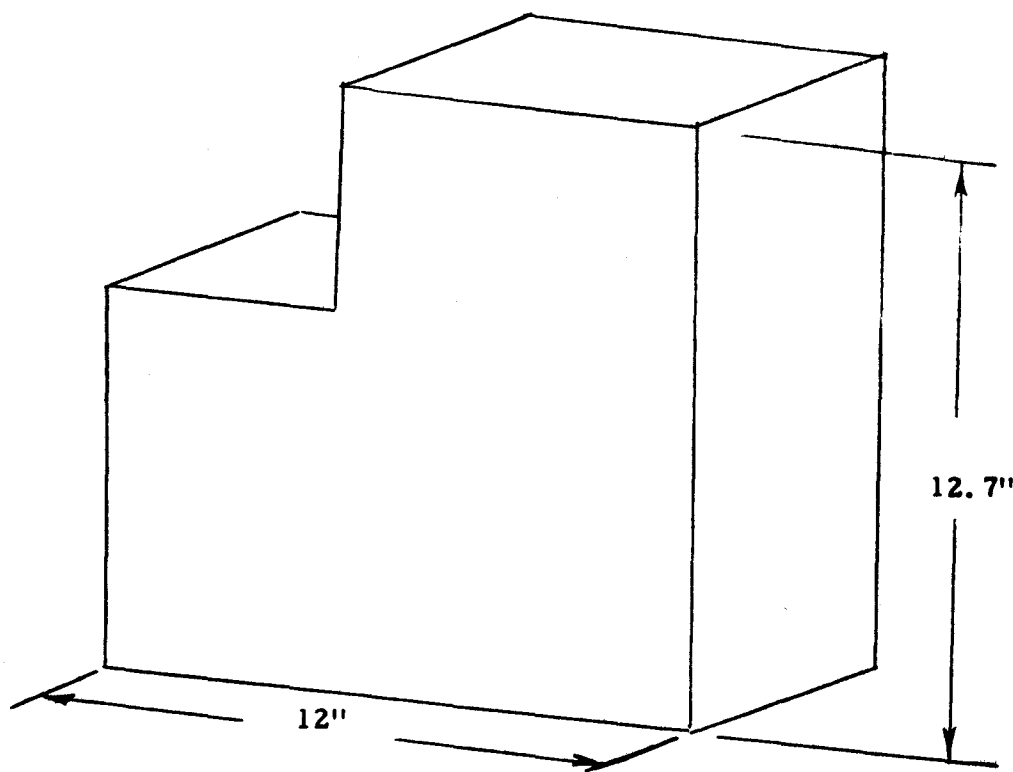
Figure 6-7. Cold Cathode Gauge Experiment Dimensions.

shown in Figure 6-8 from which it is seen that the experiment has a cross-sectional area of 0.45 ft, a center of pressure height above the surface of about 0.5 ft, and a gravitational restoring moment arm of approximately 0.2 ft.

Setting the moments equal to zero:

$$P_d (C_d) (0.45) (0.5) - (0.2) (1.04) = 0 \qquad (6\text{-}26)$$

$$P_d = \frac{0.208}{(2)(.45)(0.5)} = 0.46 \text{ lb/ft}^2 \qquad (6\text{-}27)$$

6.1.2.10 Charged Particle Lunar Environment Sliding

Setting the horizontal forces equal to zero:

$$P_d (C_d) (0.45) - (1.04) (\mu) = 0 \qquad (6\text{-}28)$$

or

$$P_d = \frac{(1.04)(0.3)}{(2)(.45)} = 0.35 \text{ lb/ft}^2 \qquad (6\text{-}29)$$

6.1.2.11 Active Seismic Mortar Box Tipping

Mass and geometrical properties of the Active Seismic Ecperiment mortar box are taken from References 4 and 7. The box and its dimensions are shown in Figure 6-9. The lunar weight of this assembly is about 3.3 pounds while the cross-sectional area is 1.0 ft^2 and the height of the center of pressure above the surface is 0.75 feet.

Bendix

Aerospace
Systems Division

ALSEP Emplacement Study

NO.	REV. NO.
ATM-762	
PAGE 26 OF 73	
DATE 1 June 1968	
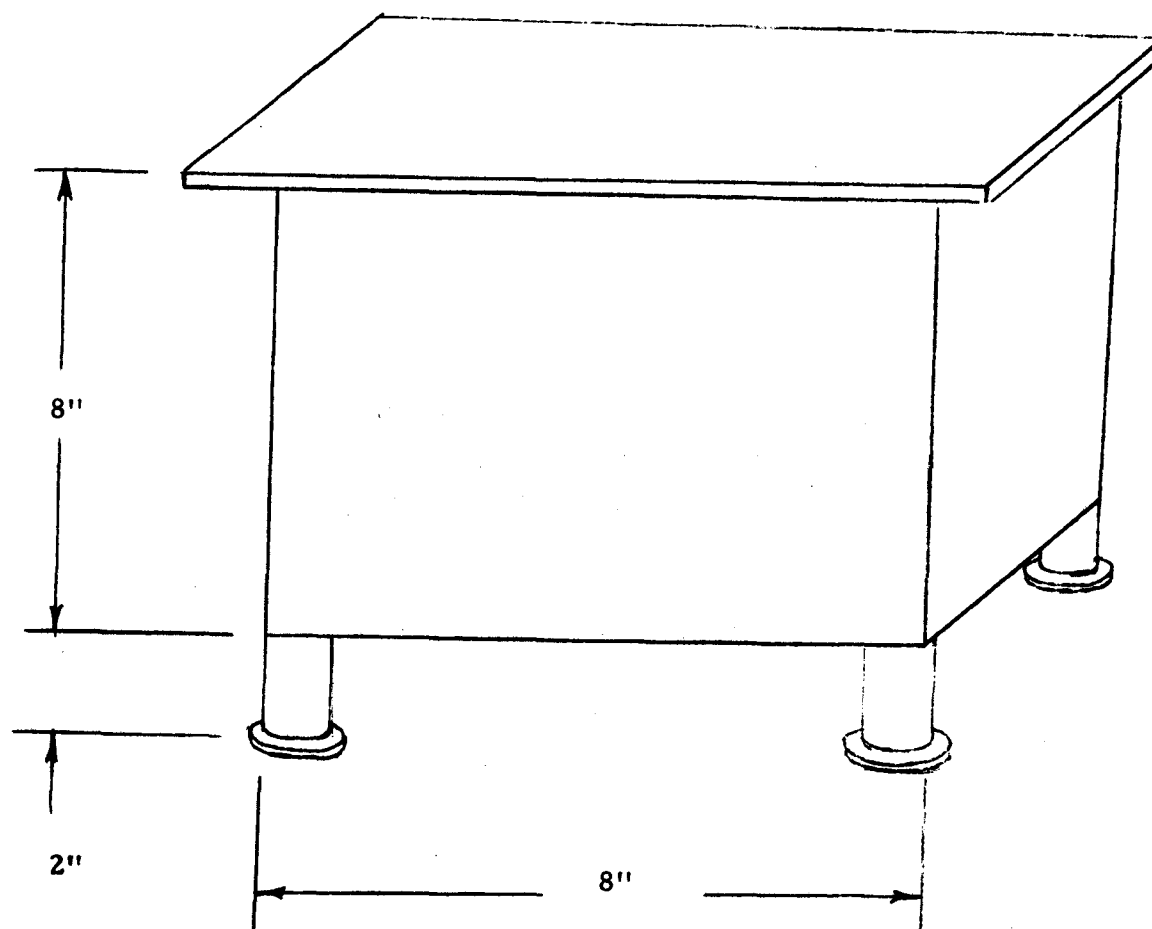
Figure 6-8. Charged Particle Lunar Environment Experiment
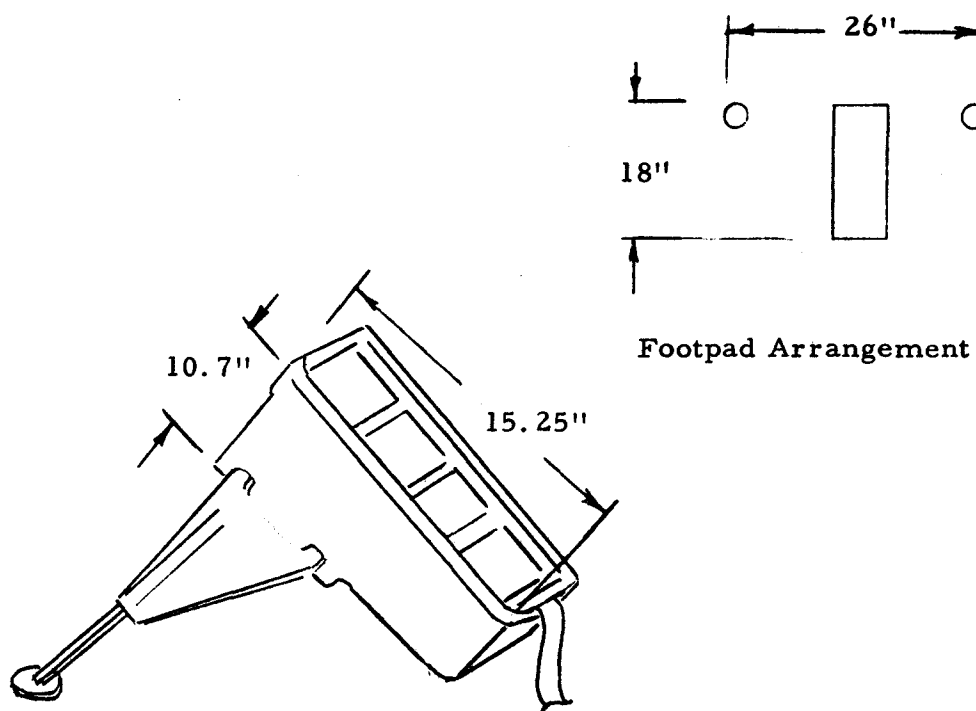
26"

18"

Footpad Arrangement

10.7"

15.25"

FIGURE 6-9

ACTIVE SEISMIC MORTAR BOX GEOMETRY

Considering the deployment leg geometry, the gravitational restoring moment arm is calculated as 0.54 feet.

Setting the moments equal to zero:

$$P_d \ (1.0) \ C_d \ (0.75) - (3.3) \ (0.54) = 0 \qquad (6\text{-}30)$$

or

$$P_d = \frac{(3.3) \ (0.54)}{(2.0) \ (0.75)} = 1.19 \ \text{pound/ft}^2 \qquad (6\text{-}31)$$

6.1.2.1?   Active Seismic Mortar Box Sliding

Setting the horizontal forces equal to zero:

$$P_d \ C_d \ (1.0) - (3.3) \ (\mu) = 0 \qquad (6\text{-}3?)$$

$$P_d = \frac{(3.3) \ (0.3)}{2} = 0.495 \ \text{pounds/ft}^2 \qquad (6\text{-}33)$$

6.1.2.13   Heat Flow Tipping and Sliding

Not applicable.

6.1.2.14   Lunar Surface Magnetometer Tipping

Data for the LSM are taken from References 4 and 7 and the geometry is shown in Figure 6-10.

The lunar weight of this experiment is 3.1 pounds, and the cross-sectional area is about 1.9 ft^2 with a center of pressure 1.7 feet above the surface. The gravitational restoring arm moment is approximately 1.0 foot.

Bendix

**Aerospace
Systems Division**

ALSEP Emplacement Study

NO.	REV. NO.
ATM-762	

PAGE __29__ OF __73__

DATE 1 June 1968

51 in.

40 in.
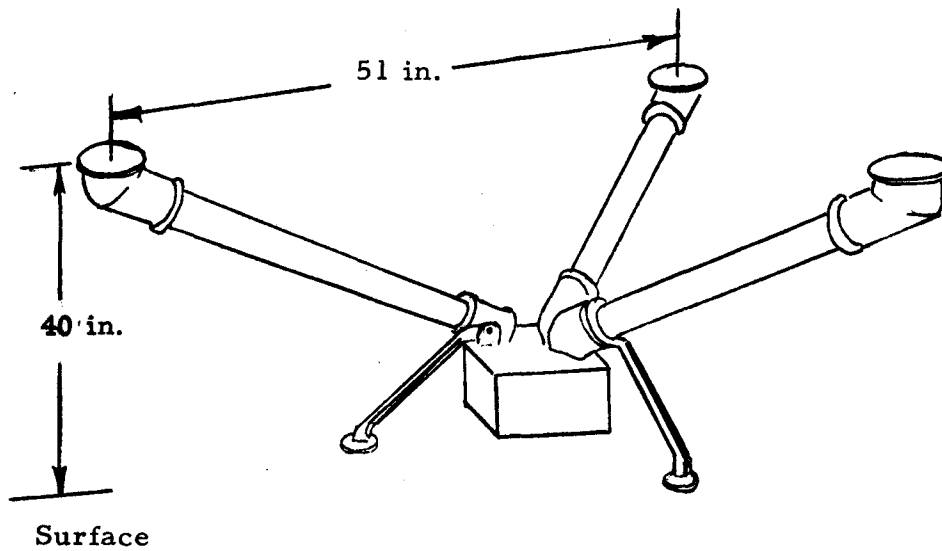
Surface

FIGURE 6-10

LUNAR SURFACE MAGNETOMETER EXPERIMENT

Bendix

Aerospace Systems Division

(

ALSEP Emplacement Study

NO.	REV. NO.
ATM-762	

PAGE 30 OF 73

DATE 1 June 1968

Setting the moments equal to zero:

$$P_d (C_d) (1.9) (1.7) - (3.1) (1.0) = 0 \qquad (6\text{-}34)$$

$$P_d = \frac{3.1}{(2) (1.9) (1.7)} = 0.48 \text{ pounds/ft}^2 \qquad (6\text{-}35)$$

6.1.2.15   Lunar Surface Magnetometer Sliding

Setting the horizontal forces equal to zero:

$$P_d (C_d) (1.9) - 3.1) \mu = 0 \qquad (6\text{-}36)$$

or,

$$P_d = \frac{(3.1) (0.3)}{(2) (1.9)} = 0.?45 \text{ pounds/ft}^2 \qquad (6\text{-}37)$$

6.1.3   Summary of Critical Dynamic Pressures

Table 6-A summarizes the critical dynamic pressures derived above. As is seen, the LSM is the most critical component.

Bendix

Aerospace Systems Division

ALSEP Emplacement Study

NO.	REV. NO.
ATM-762	

PAGE ___31___ OF ___73___

DATE   1 June 1968

TABLE 6-A

CRITICAL DYNAMIC PRESSURE

Component	Critical Tipping Pressure $\sim$ pounds/ft^2	Critical Sliding Pressure (μ = (0.3) $\sim$ pounds/ft^2
Central Station	1.56	0.468
Passive Seismic Experiment	0.35	0.41
Solar Wind Experiment	0.45	0.34
Suprathermal Ion Experiment	0.41	0.35
Cold Cathode Gauge Experiment	0.30	0.33
Charged Particle Lunar Environment Expt.	0.46	0.35
Active Seismic Experiment	1.19	0.50
Heat Flow Experiment	N/A	N/A
Lunar Surface Magnetometer Experiment	0.48	0.25

6.2   THERMAL CONTROL

The two most critical effects of deployment distance and direction upon the thermal control of ALSEP are as follows:

1. Convective heating of the exterior surfaces of the ALSEP packages by the LM ascent stage exhaust gases;

2. Effect on thermal control of the deposition of lunar dust which is blown outward by the ascent stage engine.

In addition to these, there are several secondary effects such as possible contamination of thermal control surfaces by adsorption of the products of combustion of the LM propellants. However, these effects are believed to be small, and they were not investigated in this study.

Because of the limited time and funding of this study, all of the thermal effects investigated were based upon the central station (C.S.). Because of the sensitivity of certain experiments to slight temperature changes, it is recommended that the thermal effects of deployment distance and position upon each of them be investigated in detail. Such investigations will require a very high degree of cooperation and information exchange between BxA and the experiment designers.

The most temperature-critical C.S. component from the standpoint of LM exhaust heating is most probably the Mylar used in the side curtain

Bendix

**Aerospace
Systems Division**

ALSEP Emplacement Study

NO.	REV. NO.
ATM-762	

PAGE ___33___ OF ___73___

DATE 1 June 1968

insulation blankets. The upper temperature limit for this material is given by the manufacturer as 270°F. Although the S-13G paint used on the thermal plate and the side structural members has an upper limit of only 250°F, it is probably not as critical because it is generally applied to members having higher thermal capacity than the insulation sheets. For the type of short-duration high intensity heating characteristic of plume impingement, the thermal capacity of the heated surface is the single most important parameter influencing the peak temperatures which will occur.

The seriousness of the plume impingement problem can be appreciated by considering the following numerical example.

The outer sheet of insulation can be thought of as a piece of plastic .00125 inches thick. In the worst case it is initially at 160°F when the ascent stage commences firing (due to solar heating and radiant interchange with the moon and with space). Assuming no losses, the total energy required to raise one square foot of this sheet the 110°F to the point of overheating is less than 0.3 Btu. (Which is somewhat less heat than that required to raise the temperature of a tablespoonful of water 10°F.) Thus it can be seen that a careful analysis of plume heating is required even at large distances from the LM.

According to the Statement of Work, ALSEP was to be designed for total degradation due to lunar dust of the radiative properties of all thermal

control surfaces exposed to direct sunlight. Nothing was stated regarding

any possible insulating effect of such dust or the effects of dust on surfaces

which are not illuminated by the sun. Consequently, the ALSEP central

station design is based upon the assumption that any dust accumulation affects

only the radiative properties of the covered surfaces, and has absolutely no

insulating effect. Also, the radiative properties of the specular reflector

are assumed to be unaffected by dust. Both of these assumptions are optimistic.

They were based upon Reference 11A which states that total dust accumulation

on ALSEP is expected to be less than 28 microns/year. However, this

reference pertains to gradual dust accumulation on the lunar surface, and

does not consider dust raised by the LM exhaust. Consequently, the ALSEP

dust criterion should be reviewed in the light of a detailed study of LM-

raised dust based upon the latest available experimental (Surveyor) and

theoretical information.

To estimate the insulating effect of lunar dust on radiator surfaces,

a computation of the temperature drop across a .001 inch thickness of dust

on the central station radiator was made. First, it was assumed that lunar

dust has a thermal conductivity equal to that of the worst-case lunar soil

model described in Reference 20. The computation indicates a temperature

drop of about $4^{\circ}F$ per thousandth of an inch of dust accumulation on the central

station radiator (for a 2 ft^2 radiator dissipating 42 w of power).

Reference 21 indicates that there is litte, if any, margin in the operating temperatures of the ALSEP central station under worst-case conditions. Any appreciable insulating effect due to lunar dust would further widen the expected temperature range, thus greatly reducing the reliability of the electronic components. This is clearly unacceptable. Hence, it is concluded that dust accumulation having any appreciable insulating effect cannot be tolerated. For the lowest-conductivity dust of Reference 20, this means a maximum allowable dust thickness of less than one-thousandth of an inch.

6.3 EXPERIMENT COMPATIBILITY

The major limiting factors on experiment deployment from the LM are:

1. Magnetic contamination

2. Thermal effects due to LM shadow on or near the experiment

3. Outgassing from the LM due to venting of the descent stage after landing and exhaust gases from the ascent stage.

4. Deposition of dust on the experiment (caused by ascent stage take-off) and resulting effects on experiment operation.

5. Dynamic pressure from the LM ascent exhaust mechanically damaging or overturning experiments.

	NO.	REV. NO.
ALSEP Emplacement Study	ATM-762	
	PAGE 36 OF 73	
	DATE 1 June 1968	

Bendix

Aerospace Systems Division

6.3.1   Magnetic Contamination

The experiment most affected by magnetic contamination from the LM is the magnetometer experiment.   The magnetometer experiment has a sensitivity of 0.25 gamma.   In order to fully utilize this sensitivity, the magnetic contamination of the magnetometer deployment location should be less than 0.1 gamma.   Also, since the rest of ALSEP will produce some magnetic field, the magnetic contamination from the LM should not exceed 0.05 gamma.

6.3.2   LM Shadow Effects

The effect of operating an experiment in or near the shadow of the LM will be most pronounced on the heat flow experiment.   Since this experiment measures very small subsurface temperature differences, being near to the LM shadow will alter the subsurface temperature distributions and perturb the experiment.   This effect would be minor if the shadowing occured for only a very short period of time (i.e., for a few minutes just after sunrise or just before sunset.)   Otherwise the heat flow experiment should be deployed at least 50 feet (and preferably about 100 feet) away from areas shadowed by the LM.

6.3.3   Outgassing from LM

The experiment that could be most affected by outgassing is the CCGE. The CCGE measures the neutral particle density of the lunar atmosphere, and

Bendix

Aerospace Systems Division

ALSEP Emplacement Study

NO.	REV. NO.
ATM-762	

PAGE 37 OF 73

DATE 1 June 1968

can operate at pressures of about 10^{-7} torr to 10^{-13} torr. At pressures

higher than about 10^{-6} torr, the CCGE sensor could be damaged if high

voltage is applied. Thus, the CCGE high voltage should be off during LM

ascent and for some time thereafter. After the CCGE is turned on, it will

monitor the pressure decay from the LM ascent gases, which is one of the

objectives of the experiment. This should be capable of being handled

operationally, and should not significantly affect deployment distance.

6.3.4 Deposition of Dust

The ALSEP experiments have been designed to operate after exposure

to wind-blown dust from the LM ascent. Thus, the SIDE, CPLEE, and Solar

Wind experiments have dust covers that protect the experiment sensors. The

passive seismic experiment has a thermal shroud which completely covers

the deployed part of the experiment. The heat flow electronics and the CCGE

each have a sunshield and a reflector to ensure adequate thermal control,

even when the thermal control surfaces are covered with dust. Thus, ex-

posure of the experiments to dust from take off of the LM ascent stage should

not be a limiting factor on ALSEP deployment.

6.3.5 Dynamic Pressure

Treated in Section 6.1.

6.3.6 Summary

A summary of the limitations that the experiments may place on ALSEP deployment are listed in Table 6-B.

TABLE 6-B

EXPERIMENT DEPLOYMENT CHARACTERISTICS

Deployment Criterion	ALSEP Experiment	Limitation
Magnetic Field	Magnetometer	Magnetic contamination from LM should be no more than 0.05 gamma.
LM Shadow	Heat Flow	Should be deployed at least 50 feet from nearest area shadowed by LM.
LM Outgassing	CCGE & SIDE	Should be turned off during LM ascent.
Dust Deposition	------	Can be tolerated by all experiments.

7.0 DYNAMIC PRESSURE ANALYSIS

The problem of analyzing the flow of the LM rocket exhaust gas against the lunar surface is complex. Within the time of this study it was not undertaken to derive the analytical expressions or extend the theoretical work in relation to this problem. Rather, a survey of previous work was undertaken and the reasonableness of various assumptions assessed.

Within the constraint of an analytical solution, the following assumptions were considered reasonable and necessary:

1. a smooth lunar surface

2. exhaust gas is a perfect gas with a constant ratio of specific heats, γ, = 1.3

3. flow is isentropic.

Two geometrical configurations are to be analyzed - first, when the LM is in its vertical rise and the exhaust vector is normal to the surface; second, during pitch-over when the exhaust vector is not normal to the surface.

7.1 EXHAUST NORMAL TO LUNAR SURFACE

Figure 7-1 shows the geometry of this situation. h is the altitude of the LM motor above the lunar surface, R is the distance of the ALSEP from the sub-LM point (and in this case the descent stage), and $\theta = \tan^{-1} \frac{R}{h}$.

Several studies of the problem, directed either to ascent or descent stage, were found in the brief survey conducted. In particular, three significant, and probably independent, studies agree on the expression for the gas velocity as a function of L and R.

The expression for the velocity is:

$$V = \left\{ R' \, T_c \left(\frac{2\gamma}{\gamma - 1} \right) \left[1 - (p/p_s)^{\frac{\gamma - 1}{\gamma}} \right] \right\}^{1/2} \qquad (7-1)$$
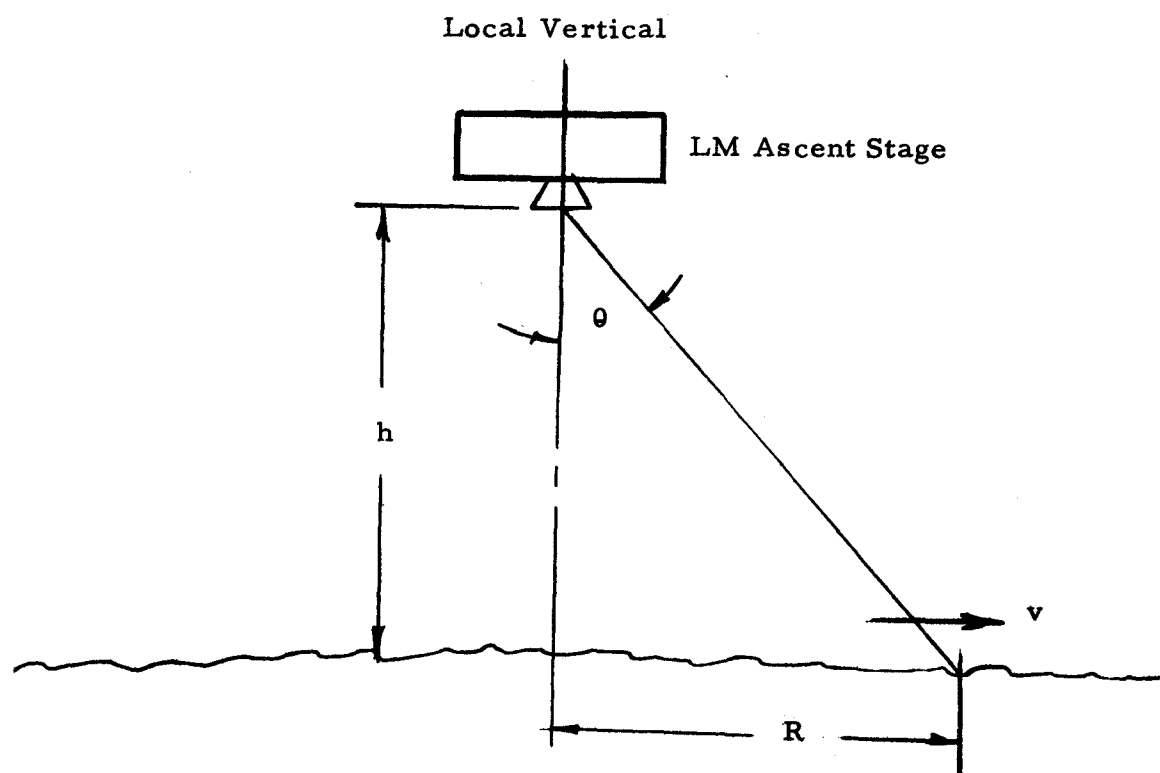
Bendix

**Aerospace
Systems Division**

Local Vertical

LM Ascent Stage

θ

h

v

R

FIGURE 7-1

LM EXHAUST NORMAL TO LUNAR SURFACE

Bendix

**Aerospace
Systems Division**

ALSEP Emplacement Study

NO.	REV. NO.
ATM-762	

PAGE __41__ OF __73__

DATE 1 June 1968

where

R' = gas constant

T_c = chamber temperature

p = static pressure

p_s = stagnation pressure.

This expression is found in Equation 5.2-7 of Reference 12, Equation 10 of Reference 13, and Equation 61 of Reference 14.

From this the dynamic pressure is derived as:

$$P_d = \frac{\gamma \, p_s}{\gamma - 1} \left[1 - (\cos \theta)^{\frac{\gamma - 1}{\gamma}} \right] (\cos \theta)^{\frac{k + 4}{\gamma}} \qquad (7-2)$$

where

$$k = \gamma (\gamma - 1) \, M_n^2 = 9.75$$

and

M_n = Mach Number at nozzle exit

Which reduces to:

$$P_d = \frac{32,100}{h^2} \left[1 - (\cos \theta)^{3.17} \right] (\cos \theta)^{10.58} \qquad (7-3)$$

and

$$\cos \theta = \frac{h}{(h^2 + R^2)^{1/2}}$$

Bendix

**Aerospace
Systems Division**

ALSEP Emplacement Study

NO.	REV. NO.
ATM -762	

PAGE __42__ OF __73__

DATE 1 June 1968

This expression was solved for various values of h and R and the results

are presented in Appendix B. However, as a result, it was found that the

maximum dynamic pressure varies inversely with R^2:

$$P_{d\ max} \sim \frac{1}{R^2} = \frac{900}{R^2} \qquad (7-4)$$

Furthermore, it is found that maximum dynamic pressure at a range R

occurs when the LM is at an altitude (h) of 1.5R. These results are plotted

in Figure 7-2.

Since the maximum dynamic pressure during the vertical rise occurs

when the LM is at an altitude of 1.5R and pitch-over begins at an altitude of

237 feet, the effect of non-vertical flight can be ignored if the ALSEP is

emplaced at a distance of less than 160 feet.

It should be noted that one document, Reference 15, takes exception

to the above results. This computation derives a high value for the dynamic

pressure but is in error in use of a LM ascent motor mass flow of 113.6

pounds/sec as compared to the correct value of approximately 11 pounds/sec

as reported in Section 5.0. However, the use of a drag coefficient of 2.0

(as opposed to the C_d = 1.0 used in Reference 12) is probably advisable in

assessing the pressure effects and was utilized in Section 6.0 of this report.

Reference 16 states some values for pressure. These are taken from

the plots in Reference 17. The surface pressures stated are not the maximum
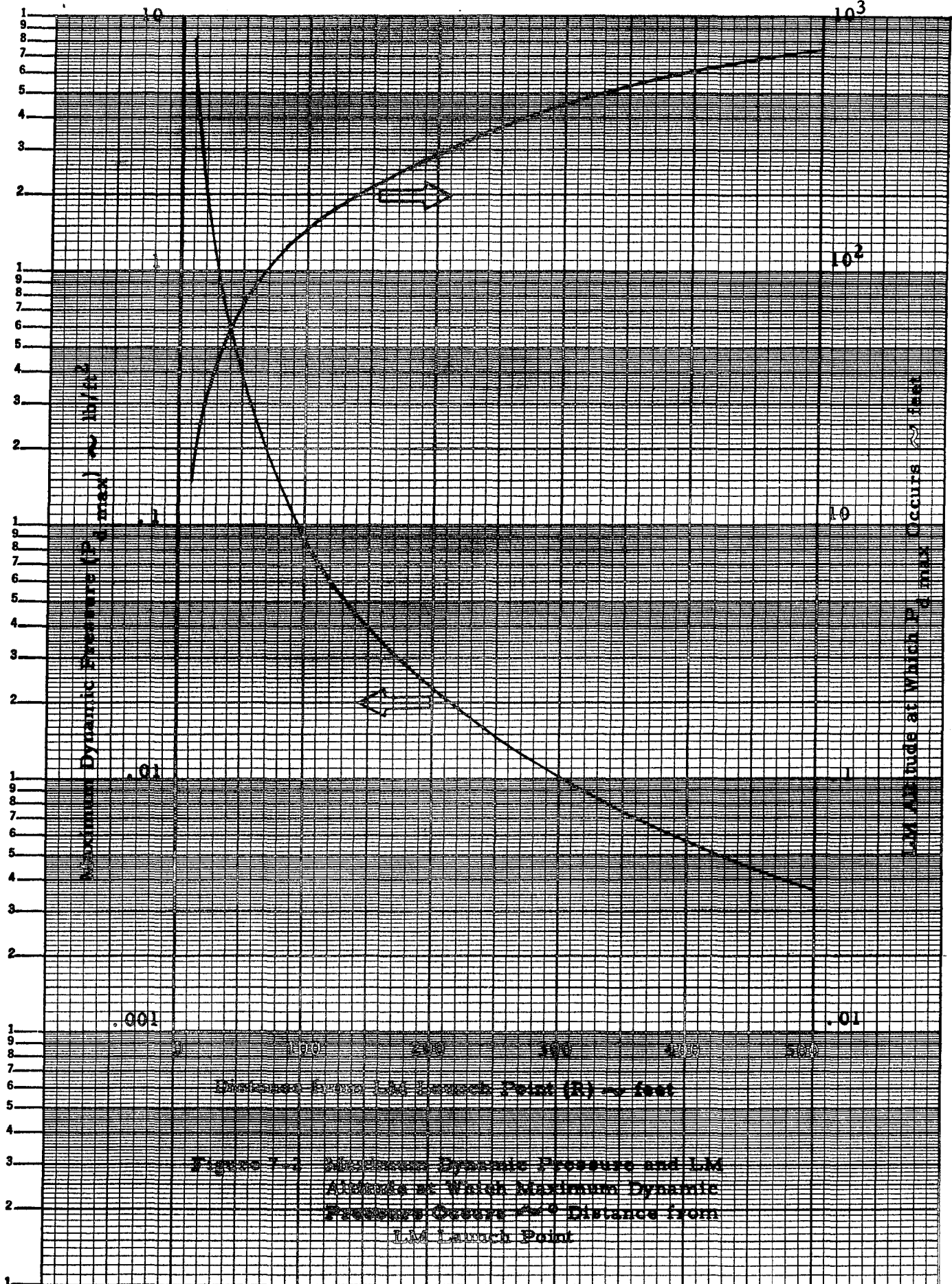
Figure 7-3   Maximum Dynamic Pressure and LM
Altitude at Which Maximum Dynamic
Pressure Occurs A~S Distance from
LM Launch Point

dynamic pressure however. The variance is two-fold: (1) the pressures

stated are total pressures and not simply the dynamic pressure, and (2)

the maximum cynamic pressure was not found (pressures were taken only

at LM heights of 12.5, 25, and 50 feet). The consequences of these errors

are consistent. The total pressure reading is of course greater than

simply the dynamic pressure but the use of the wrong LM altitude yield a

lower dynamic pressure.

7.2 EXHAUST NOT NORMAL TO THE LUNAR SURFACE

Reference 12, being concerned with soil erosion, utilized a motor/

surface geometry which takes into account the local surface slope as shown

in Figure 7-3. It should be noted, however, that the angle β is in this case

assumed to be circumferential about the local vertical. Still it was felt that

this model could provide a useful approximation of the dynamic pressure

along a surface path coincident with the LM trajectory path both fore and

aft of the launch point.

Equation 10 of this document derives the dynamic pressure as:

$$P_d = \frac{\gamma}{\gamma - 1} \left[1 - \left(\frac{P}{P_s} \right)^{\frac{\gamma - 1}{\gamma}} \right] \left(\frac{P}{P_s} \right)^{\frac{1}{\gamma}} P_s \qquad (7-5)$$

and:

$$\frac{P}{P_s} = (\cos \theta)^{k + 4} (\cos \beta)^2 \left[1 - \tan \theta \tan \beta \right]^2 \qquad (7-6)$$
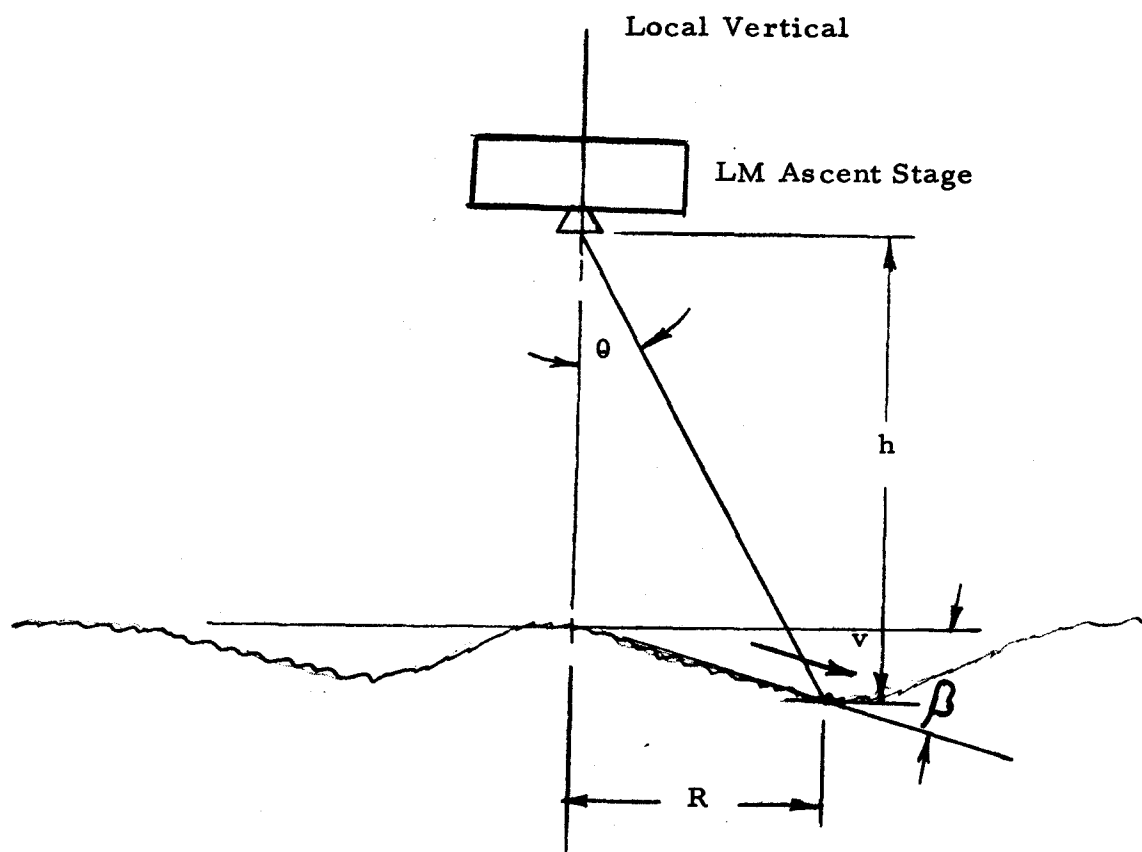
Bendix

**Aerospace
Systems Division**

FIGURE 7-3

LM EXHAUST ON NON-NORMAL SURFACE

This therefore is in agreement with References 12 and 14 which use:

$$\frac{P}{P_s} = (\cos \theta)^{k + 4} \qquad (7-7)$$

when stating that the flow is normal to the surface ($\beta = 0$).

$$P_s = \frac{F}{\pi R_1^2} \quad \text{for } h > h_c \qquad (7-8)$$

or

$$P_s = \frac{F}{\pi \gamma_e^2} \quad h < h_c \qquad (7-9)$$

where:

$$h_c = \gamma_e \sqrt{\frac{2 + k}{2}}$$

$$F = \text{motor thrust (3500 \#)}$$

$$\gamma_e = = \text{motor exit radius} = 1.25 \text{ ft}$$

and

$$R_1 = h \sqrt{\frac{2}{2 + k}} \qquad (7-10)$$

For the application being considered $h > h_c$ and Equation 7-8 is used

for the stagnation pressure.

7.3 EFFECT OF DYNAMIC PRESSURE ON ALSEP EMPLACEMENT DISTANCE

From Figure 7-2 and the critical dynamic pressure of 0.25 pounds/ft^2

derived in Section 6, it is seen that the ALSEP can be emplaced at a distance

Bendix

Aerospace Systems Division

ALSEP Emplacement Study

NO. ATM-762

REV. NO.

PAGE 47 OF 73

DATE 1 June 1968

of 65 feet from the LM take-off site without experiencing overpressure. Some margin should be used however. Part of this margin is inherent in the conservatism of the analysis. For instance, the assumption of a smooth surface for the gas dynamics calculations results in higher dynamic pressure than will be encountered on a real non-smooth surface because more energy will be dissipated in turbulent interaction with the surface in the real case. Secondly, the assumption of coefficient of friction of 0.3 appears fairly conservative. However, an actual deployment distance of 100 to 125 feet does not seem unreasonable. The maximum dynamic pressure thus occurs when LM is at an altitude of approximately 180 feet. This is below the pitch-over altitude (237 feet) and the ALSEP deployment distance, as determined by dynamic pressure solely, cannot be reduced any further by consideration of the LM drajectory.

	NO.	REV. NO.
	ATM-762	
ALSEP Emplacement Study	PAGE __48__ OF __73__	
	DATE 1 June 1968	

Bendix

Aerospace Systems Division

8.0   THERMAL CONTROL ANALYSIS

8.1   INTRODUCTION

Because of time and funding limitations, the scope of the thermal analysis performed for this study was not as extensive as it should have been. There was time only to roughly estimate the thermal effects of a vertical LM ascent upon the ALSEP central station. Although the effect on most of the experiments would probably be similar, there was not sufficient time to study it carefully.

In addition to these limitations in scope, the applicability and accuracy of some of the analyses used is open to question. The specific deficiencies in these analyses are discussed in the following sections. Once again the deficiencies are due to the requirement for a "quick" analysis compatible with the time and funding.

The ALSEP deployment distance and direction requirements have a direct effect on astronaut safety and the survivability of the package itself. Consequently the influence of thermal considerations upon ALSEP emplacement should be studied with much greater precision before any decision is made in this area.

8.2   PLUME HEATING

All of the plume heating calculations performed in this study were based directly upon the heating rates given in Reference 12, pp. 13 thru 23. These are cold-wall heating rates based upon the assumption of radially-symmetrical continuum flow. This assumption is highly questionable for

the case of LM ascent for reasons discussed in Reference 18. Because of the extremely short duration of this study, there was no opportunity to perform an independent analysis of the plume heating problem. Consequently the temperatures presented below must be regarded as highly questionable and no firm conclusions regarding ALSEP emplacement should be drawn from them.

The basic heating rates used in this study are plotted in Figure 4 of Reference 12 as functions of h (LM altitude) and r (radial distance from the ALSEP to the centerline of the LM ascent stage nozzle). These values were obtained from Equation 5.3-12 of the same reference. For this study, heating rates were calculated directly from this equation because of the difficulty of accurately reading the referenced curves and because these curves do not cover the entire range of radii and altitudes pertinent to this study.

To obtain more accurate heating rates, a computer program was written to solve Equation (5.3-12) for a number of values of h and r. Several values of heating rate calculated by this program were compared with the curves of Figure 4 and agreement was found to be satisfactory (although impossible to verify with certainty because of the difficulty of reading the curves). These values are plotted in Figure 8-1.

FIG. 8-1 ALSEP HEATING RATES DUE TO LM ASCENT STAGE PLUME IMPINGEMENT

Bendix
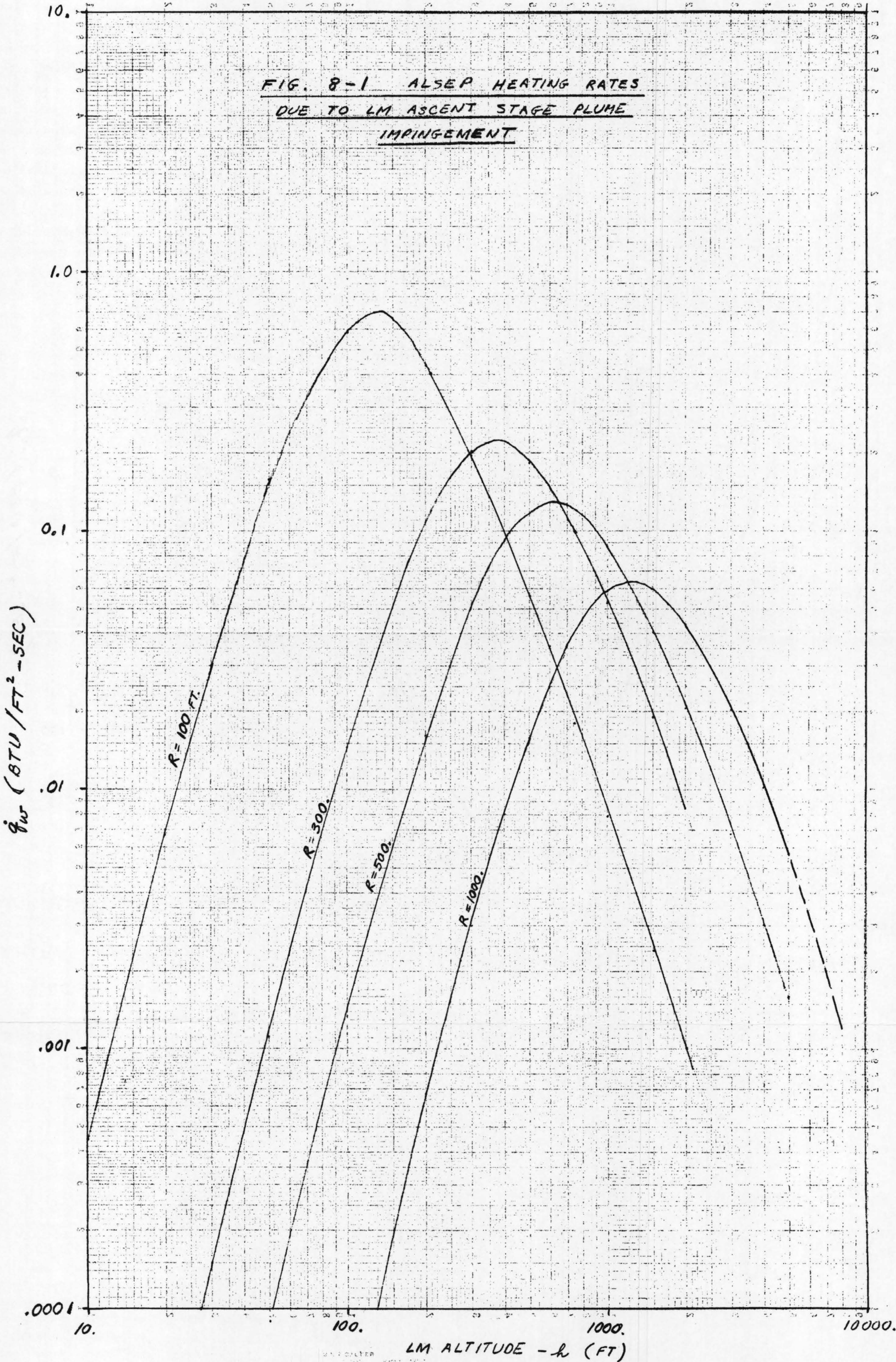
**Aerospace
Systems Division**

ALSEP Emplacement Study

NO.	REV. NO.
ATM-762	

PAGE _51_ OF _73_

DATE 1 June 1968
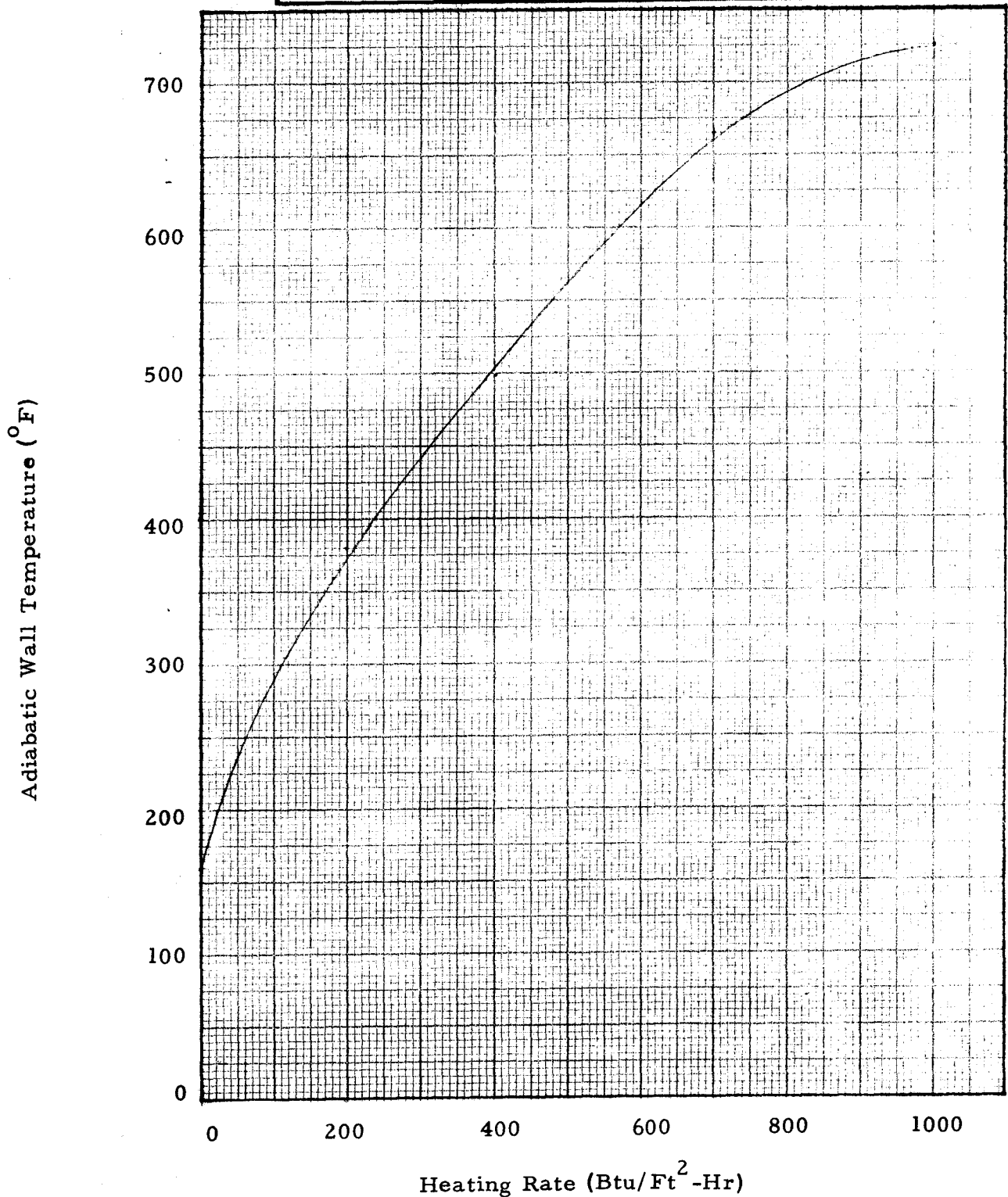
Figure 8-2 Steady-State ALSEP Surface Temperature
Vs. Heating Rate

Assuming the ALSEP to be an east-facing vertical plane, the following equation was derived for its steady-state temperature:

$$T_a = \sqrt[4]{\frac{\alpha\, S\, \cos\theta + \dot{q}_w}{\sigma\, \epsilon} + .5\, T_{l.s.}^4} \qquad (8\text{-}1)$$

where

T_a = ALSEP surface temperature ($^{\circ}$F)

α = solar absorptance of outermost surface of ALSEP (dimensionless)

S = solar constant (442 Btu/ft^2 - hr)

θ = sun angle above horizon (degrees)

$\dot{q}_w$ = convective heating rate from LM exhaust gases (Btu/ft^2 - hr)

σ = Stefan-Boltzmann constant (.173 x 10^{-8} Btu/ft^2 - hr - $^{\circ}$R^4)

ϵ = infrared emittance of outermost surface of ALSEP (dimensionless)

$T_{l.s.}$ = lunar surface temperature ($^{\circ}$R).

The principal assumptions used in deriving this equation are as follows:

1. The ALSEP surface in question is perfectly insulated on its rear side (adiabatic wall surface temperature assumption)

2. The moon is a diffusely radiating black body

3. The ALSEP is a diffusely radiating body having a view factor of 0.5 to both the lunar surface and to space

4. Space is a black body at 0°R.

	NO.	REV. NO.
	ATM-762	
ALSEP Emplacement Study	PAGE 53 OF 73	
	DATE 1 June 1968	

Bendix

Aerospace Systems Division

It should be noted that assumption (1) is conservative because it neglects both the thermal capacity of the wall and the heat transfer from it into the package.

The relationship between temperature and heating rate expressed by Equation 8-1 is plotted in Figure 8-2. In plotting this relationship, the following worst-case assumptions were made:

1. ALSEP radiative properties: $\alpha = .1$, $\epsilon = .333$

2. Solar angle: $\theta = 63.2^\circ$

3. Lunar surface temperature: $T_{l.s.} = 690^\circ R$ (Ref. 19).

From Figure 8-1 we see that the peak heating rate for a radius of 300 ft is about .225 Btu/ft^2-sec or 810 Btu/ft^2-hr. From Figure 8-2 we see that the ALSEP surface temperature corresponding to this rate is $695^\circ F$. Because this value is considerably higher than the maximum allowable temperature of $270^\circ F$ for Mylar insulation, it was decided to recompute these temperatures on a transient basis to eliminate some of the conservatism.

In the revised approach the ALSEP was assumed to be deployed with one of its directly facing the LM. The reason for this assumption is discussed in the following section. For the analytical model, the outer sheet of 1 mil Kapton and the 0.25 mil Mylar sheet adjoining it were lumped together as one node. The Mylar sheet was included because it has a much lower maximum allowable temperature ($270^\circ F$) than the Kapton.

A three-node computer model was then set up which permitted the calculation of the transient temperature of these outer sheets by considering the following phenomena:

1. Radiant interchange with space and with the lunar surface

2. Solar heating

3. Convective heating due to LM ascent stage exhaust

4. Thermal capacity of the plastic sheets.

A sketch of this model and a summary of the assumptions used in formulating it are given in Figure 8-3. The computer program used was a general purpose heat transfer program developed at BxA and having both transient and steady-state solution capability.

The altitude of the LM ascent stage was determined as a function of time by assuming a constant vertical acceleration of 5.28 ft/sec^2. For a 300 ft radial distance from the LM nozzle centerline, instantaneous heating rates were read from Figure 8-1 at altitudes corresponding to the LM position starting at liftoff, and progressing at time increments of approximately 1 second. This set of points was then used to construct a time-varying heating rate curve which was used as an input to the program.

It will be noted that the curves of Figure 8-1 are plotted on log-log paper. The program however uses linear interpolation to obtain heating
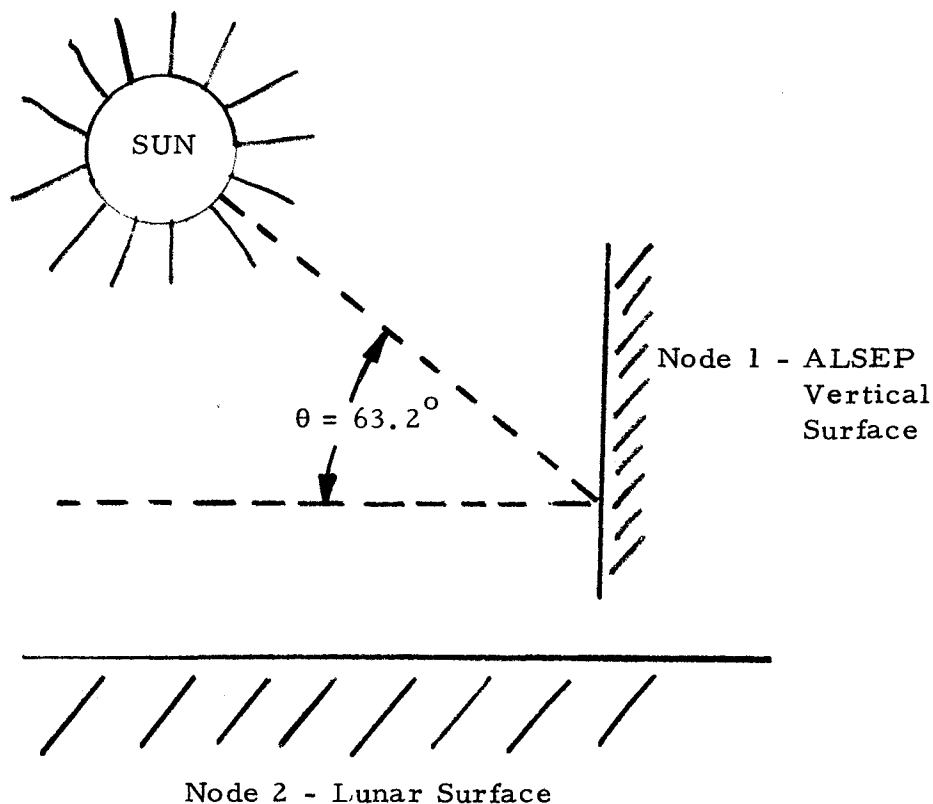
Node 3 - Space

Node 1 - ALSEP Vertical Surface

$\theta = 63.2°$

Node 2 - Lunar Surface

ASSUMPTIONS

1. $F_{12} = F_{13} = 0.5$

2. $\alpha_1 = .11 \quad \epsilon_1 = .333$

$\alpha_2 = \epsilon_2 = 1.0$

$\epsilon_3 = 1.0$

3. $T_2 = 690°R$ (constant)

$T_3 = 0°R$ (constant)

4. $MC_{p1} = .00261$ Btu/$°R$ (constant)

Figure 8-3 Sketch of Computer Model of ALSEP Vertical Surface

rates at times which fall between any two input points. Because of this, there is some error in the total amount of heat which is imposed on the ALSEP, although it is not believed to have a large effect on the resulting temperatures.

The above-described calculations were repeated for radial distances of 100 ft and 500 ft from the LM. The peak temperatures thus calculated are plotted versus distance in Figure 8-4. These computer runs indicate that the outer surfaces of the ALSEP side curtain become overheated for about 25 seconds even when the radial distance from the LM is 500 ft. However, no firm conclusion regarding ALSEP emplacement can be drawn from this observation because of the questionable magnitude of the heating rates used. However, the temperature calculations presented above clearly indicate the need for a more thorough investigation of this phenomenon, to determine whether an overheating problem indeed exists.

8.3   DUST ACCUMULATION

Although several references were found which discuss erosion of the lunar surfaces due to firing of the LM ascent engine, none of these contained information on total dust accumulation on the ALSEP thermal control surfaces. However, Reference 14 contains an analytical approach for computing such accumulation. Unfortunately, however, the complexity of this analysis was beyond the scope of this study. Consequently, this portion of the analysis was based solely upon geometrical considerations and elementary reasoning.
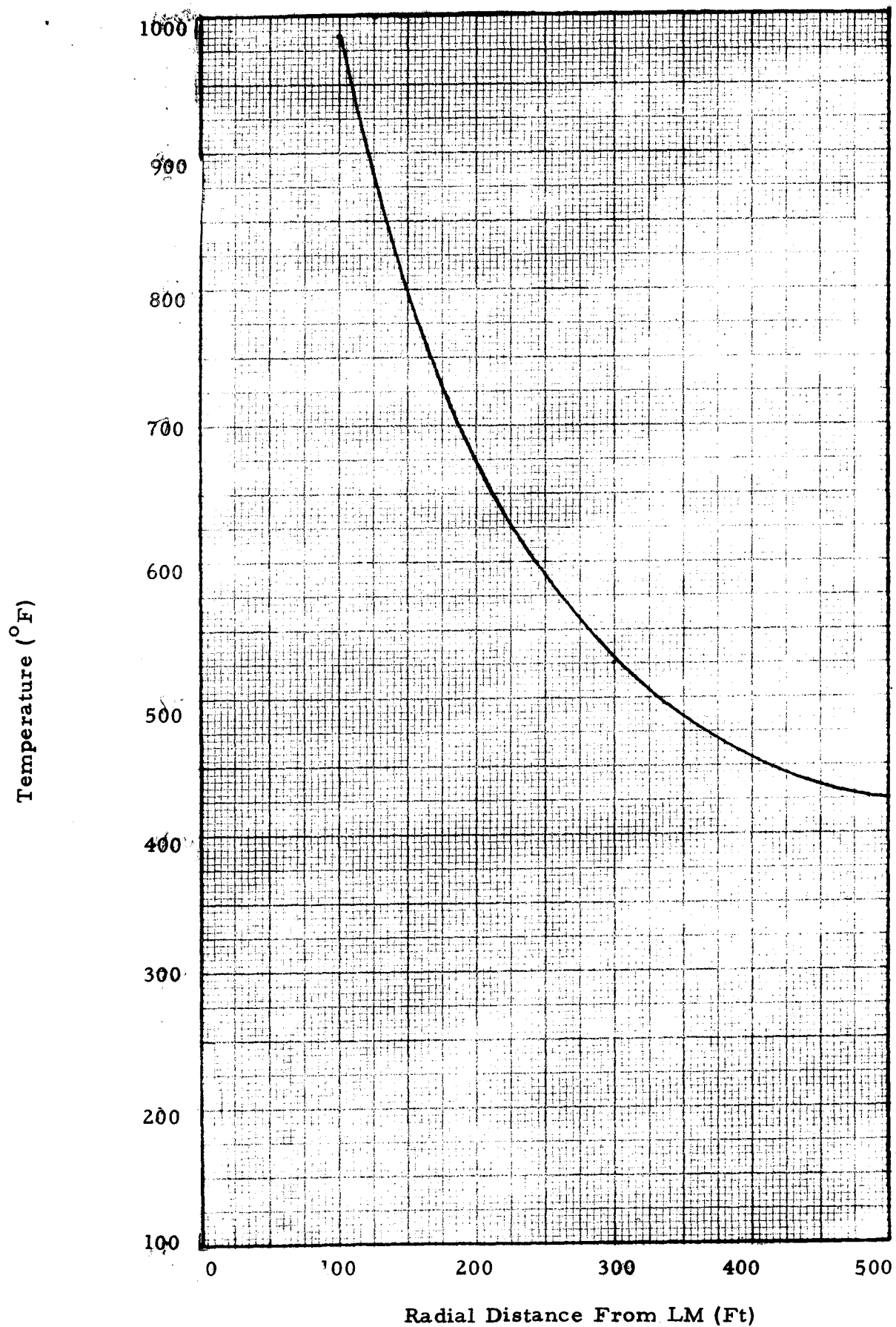
Figure 8-4 Peak ALSEP Surface Temperature Vs. Distance From LM

For the present ALSEP design, it appears that the most effective means for keeping LM-raised dust off the radiator surfaces is to align the package so that a normal to the plane of the side curtains intersects the centerline of the LM ascent stage nozzle. If this is done, the side curtain which faces the LM would protect the radiator from any dust which is blown radially outward by the ascent stage exhaust gases.

The central station design presently requires that a normal to the plane of the side curtains be nominally oriented in the east-west direction. If the side curtain is to provide dust protection for the radiator, it follows that the ALSEP must be deployed either directly east or directly west of the LM. It is recommended that the other implications of such deployment be investigated in a more detailed study.

The present central station thermal design allows for a maximum angular misalignment in the horizontal plane of $\pm 5^\circ$. The effect of such misalignment on the dust protection offered by the side curtains is illustrated in Figure 8-5. This figure shows a top view of the angular relationship between the LM and the ALSEP central station. For clarity, the central station sunshield and reflector are not shown. This figure indicates that when the central station alignment is perfect, particles of dust traveling radially cannot strike the radiator due to the presence of the side curtain. When the central station is angularly misaligned by an angle θ, however,

Bendix

Aerospace Systems Division

ALSEP Emplacement Study

LM CENTERLINE

DUST PARTICLE TRAJECTORIES

r

ℓ

RADIATOR

RADIATOR MASKS

PERFECT ALIGNMENT

SIDE CURTAIN

θ

w

β

ANGULAR MISALIGNMENT

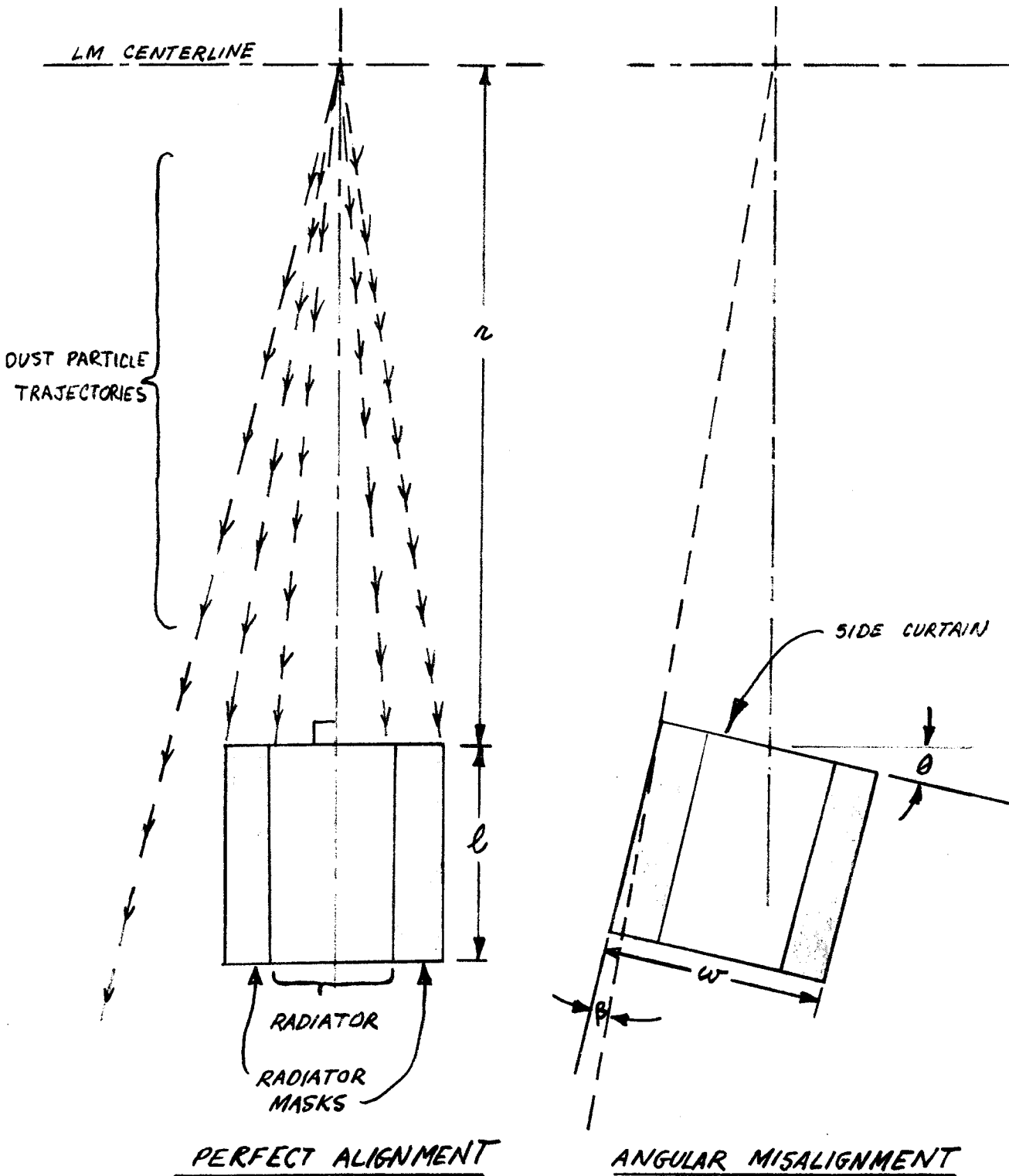Figure 8-5 Effects of Angular Misalignment of ALSEP
Upon Dust Deposition

Bendix

Aerospace Systems Division

ALSEP Emplacement Study

NO.	REV. NO.
ATM-762	

PAGE ___60___ OF __73__

DATE 1 June 1968

a dust particle which just misses the leading edge of the curtain can pass over the thermal plate. From Figure 8-5 it can be concluded that the maximum distance inward from the edge of the thermal plate that the particle can penetrate is $\ell \tan \beta$.

Now,

$$\beta = \theta - \alpha$$

if we assume:

$\ell = 26$ inches

$w = 24$ inches

$r = 300$ feet

then because $r \gg w$

$$\alpha \cong \tan^{-1}\left(\frac{w/2}{r}\right) = \tan^{-1}(.00333) \cong 0.2^{\circ}$$

Hence for maximum misalignment,

$$\theta = 5^{\circ}$$

and

$$\beta \cong 5^{\circ} - 0.2^{\circ} = 4.8^{\circ}$$

then the maximum particle penetration is:

$$\ell \tan \beta = 26 \tan 4.8^{\circ} \cong 2.18$$

or approximately 2.2 inches from the edge of the thermal plate. According to Reference 22, the minimum radiator mask width being considered is 6

inches. Consequently, this angular alignment would result in direct deposition of dust only on the mask and not on the radiator itself. Also according to Reference 22, the effect of dust deposition on the mask is small, and presents no special thermal control problems.

From the preceding discussion we tentatively conclude the total dust thickness on the central station radiator must be kept below .001 inch. Because it was not possible to compute actual accumulation levels in a study as limited as this one, it was assumed that the dust raised by LM ascent must be blocked by suitable orientation of the central station side curtains. The recommended orientation is based upon the assumption of radial flow of the dust particles, which is questionable for anything other than an ideally flat lunar surface covered by a uniform layer of homogeneous dust. Also, only direct impingement of the dust particles was considered, and possible "trapping" in the enclosure formed by the side curtains, the radiator, and the reflector was ignored.

All of the above idealizations indicate the need for a thorough study of the effects of LM-raised dust on the ALSEP thermal control systems. This study should include the following steps:

1. Compilation of a model describing the thermophysical and mechanical properties of dust (based on latest results from Surveyor and recent theoretical work)

2.   Establishment of a probable dust flow pattern;

3.   Calculation of dust accumulation on thermally significant

ALSEP surfaces as a function of orientation and distance

from the LM;

4.   Calculation of the temperature effects of this dust accumulation

and an analysis of the effect of these temperatures on the per-

formance of ALSEP.

Bendix

Aerospace Systems Division

NO.	REV. NO.
ATM-762	

ALSEP Emplacement Study

PAGE __63__ OF __73__

DATE   1 June 1968

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Bendix

**Aerospace
Systems Division**

ALSEP Emplacement Study

NO.	REV. NO.
ATM-762	

PAGE __64__ OF __73__

DATE   1 June 1968

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	NO.	REV. NO.
	ATM-762	

Bendix Aerospace Systems Division

ALSEP Emplacement Study

PAGE __65__ OF __73__

DATE 1 June 1968

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	NO.	REV. NO.
Bendix	ATM-762	
	PAGE 66 OF 73	
Aerospace Systems Division		

ALSEP Emplacement Study

DATE 1 June 1968

APPENDIX A

COMPUTATION OF ALTITUDE OF LM ASCENT STAGE
VERTICAL RISE TERMINATION

Figure A-1 shows the LM Ascent Stage and the forces working upon it during ascent. For purposes of this calculation, since the duration under consideration is small, W may be considered a constant with no appreciable error.

W is therefore taken to be 10,600 lb and T, the motor thrust, 3500 lb.

$$F = ma \tag{A-1}$$

where;

$$F = T - \frac{W}{6}$$

and,

$$M = \frac{W}{6}$$

therefore:

$$T - \frac{W}{6} = \frac{W}{32.2} \quad \text{(a)} \tag{A-2}$$

or;

$$a = \frac{1735}{329} = 5.28 \text{ ft/sec}^2$$

Bendix

Aerospace Systems Division
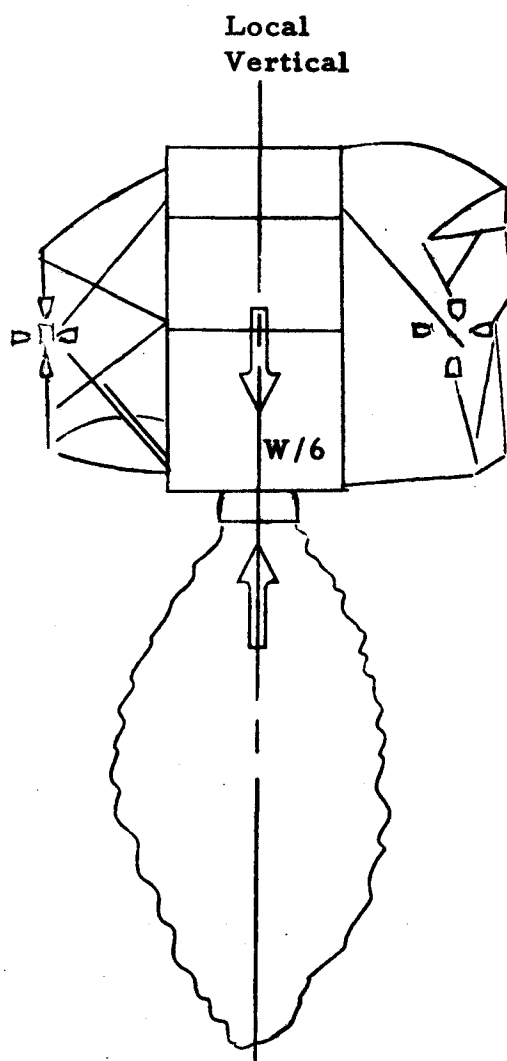
Figure A-1. LM Ascent Forces

The rapid pitch over from vertical rise begins when the velocity equals 50 ft/sec. The time from lift-off to this even is thus computed:

$$t = \frac{V}{a} = \frac{50}{5.28} = 9.48 \text{ sec} \qquad\qquad (A\text{-}3)$$

and the altitude of the pitch over commencement

$$h_{po} = \frac{1}{2} a t^2 = \frac{5.28 \, (9.48)^2}{2} = 237 \text{ feet.} \qquad (A\text{-}4)$$

APPENDIX B

DYNAMIC PRESSURES AS A FUNCTION OF ALSEP RANGE
AND
LM ALTITUDE FOR LM VERTICAL ASCENT

The following plots are derived from Equation 7-3.

Figure B-1   Dynamic Pressure vs. LM Altitude
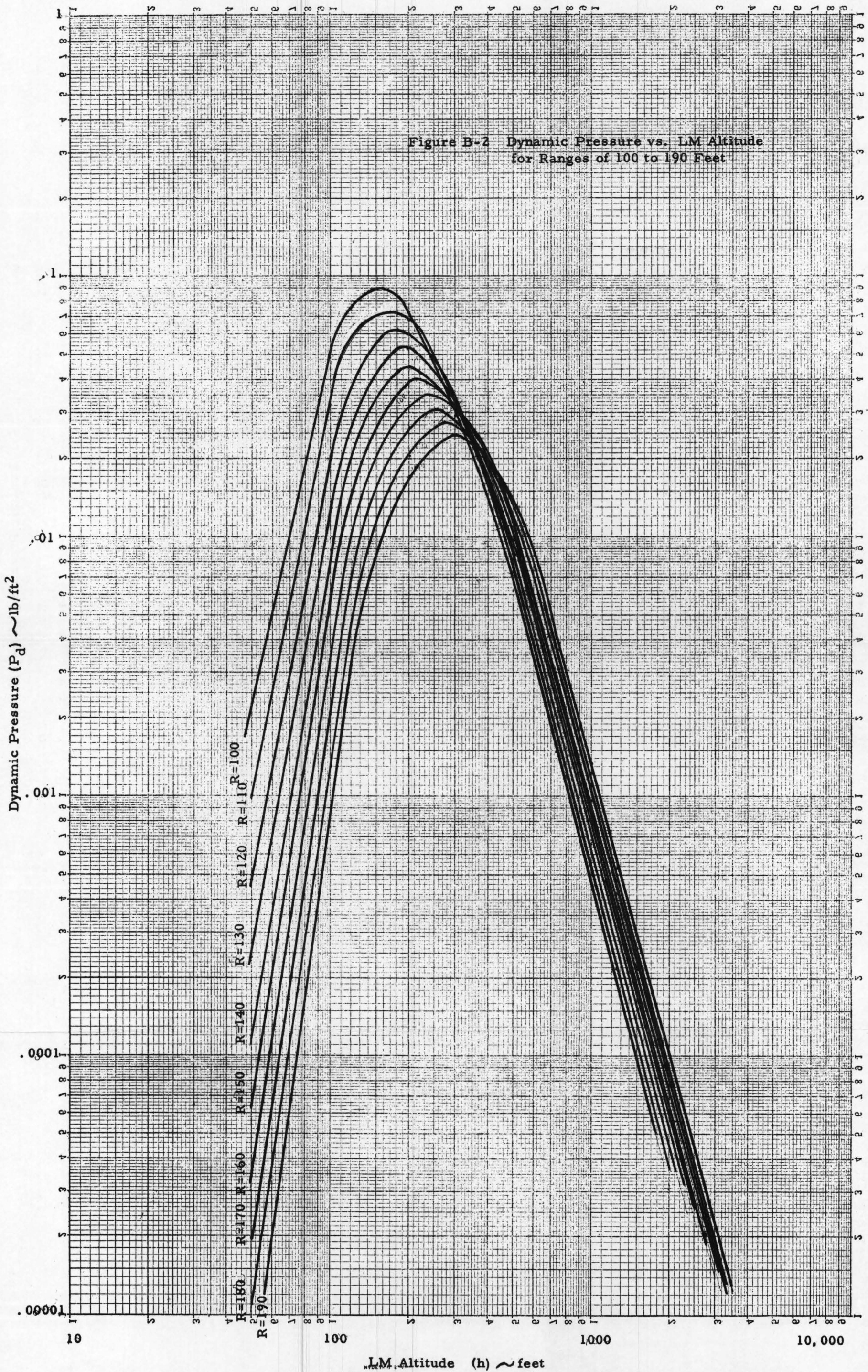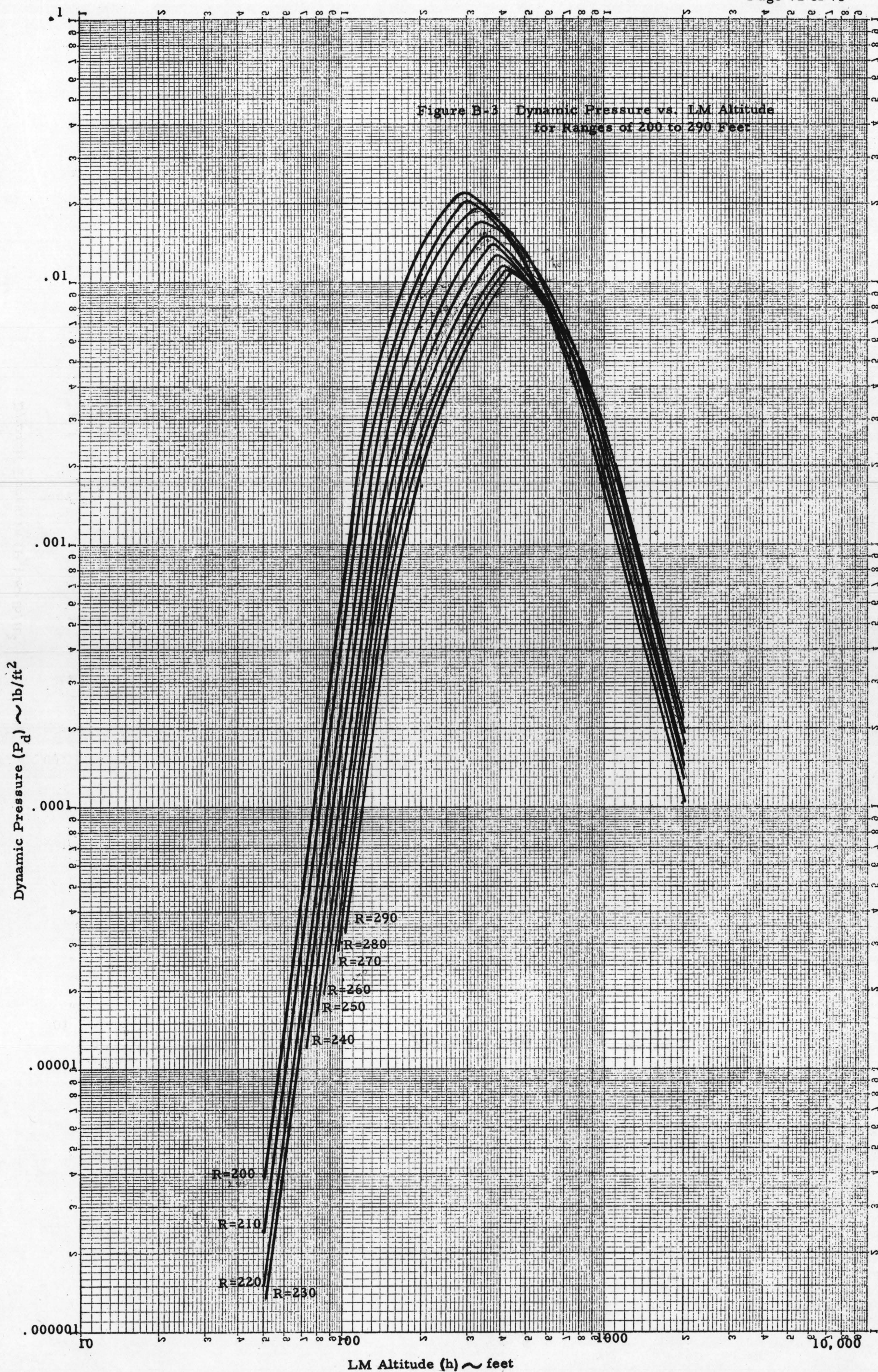for Ranges of 10 to 90 Feet

Figure B-2   Dynamic Pressure vs. LM Altitude
for Ranges of 100 to 190 Feet
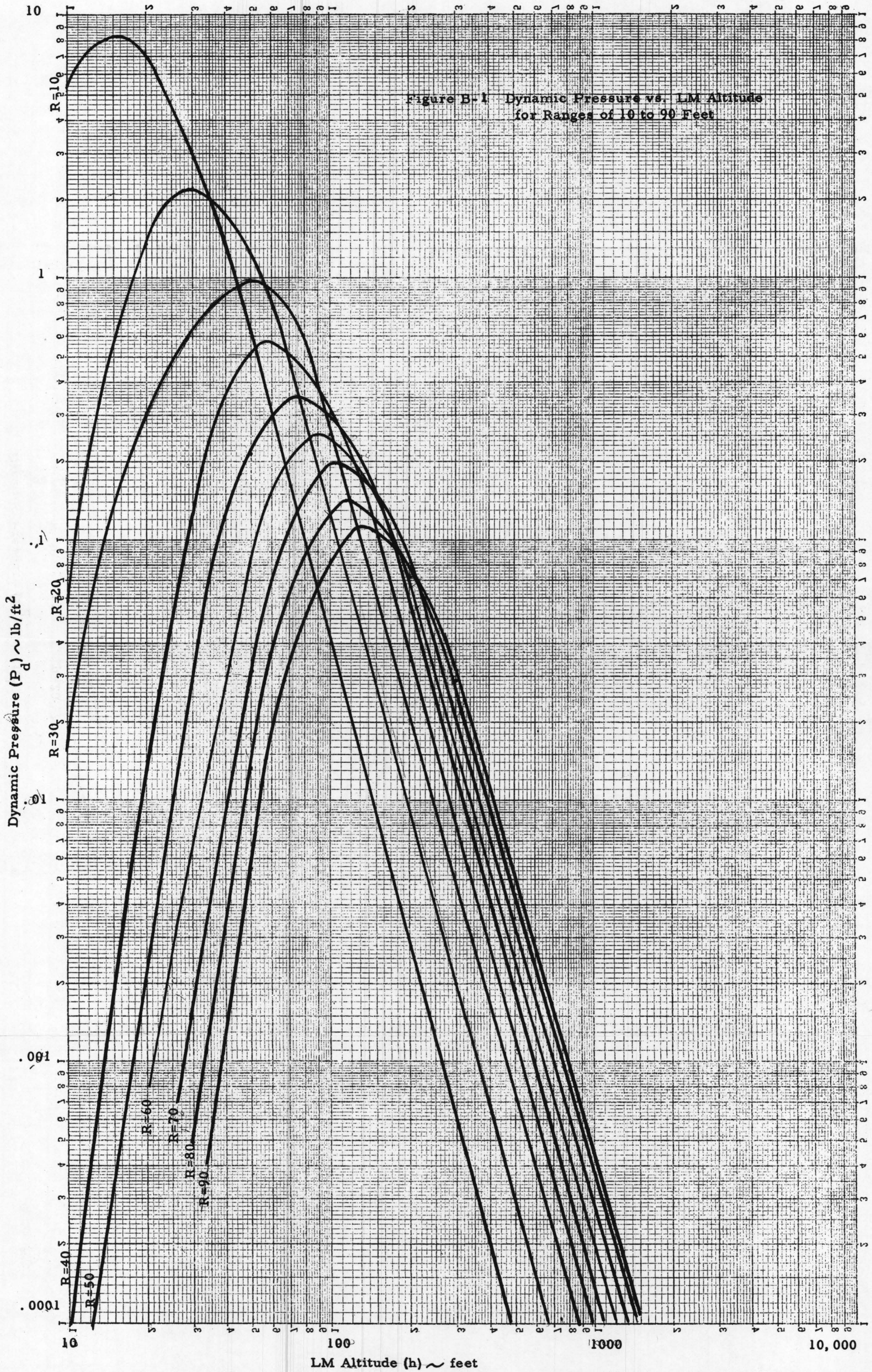
Figure B-3 Dynamic Pressure vs. LM Altitude
for Ranges of 200 to 290 Feet

Dynamic Pressure (P_d) $\sim$ lb/ft^2

LM Altitude (h) $\sim$ feet

R=290
R=280
R=270
R=260
R=250
R=240
R=200
R=210
R=220
R=230

Figure B-4. Dynamic pressure vs. LM altitude for ranges of 100-190 feet.

R = 300

R = 310

R = 320

R = 330

R = 340

R = 350

R = 360

R = 370

R = 380

R = 390
R = 400

LM Altitude (h)   Feet