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955 L'ENFANT PLAZA NORTH, S.W. WASHINGTON, D.C. 20024

B70 04031

SUBJECT: An Analysis of the Capability to Perform the Apollo 13 Fra Mauro Traverses - Case 320

DATE: April 6, 1970

FROM: T. A. Bottomley

ABSTRACT

The attached memorandum examines the capability of the Apollo 13 astronauts to accomplish the six EVA traverses recently developed by MSC and USGS for three landing sites at Fra Mauro.

The evaluation was based on the hypothesis that the total energy required to perform a specific task is a constant and equal to the product of task time and work rate. This rationale was applied to each EVA to determine average metabolic rate and time as boundary conditions for two modes of operation. One mode assumes the EVA is accomplished in minimum time at high work rates; the other mode assumes that task time is relaxed to permit the work to be performed at lower energy levels. The times and energy rates used are based largely on data from 1/6 g simulations and the Apollo 11 and 12 mission results.

The EVA requirements were compared with the consumables capacity of the -6 PLSS and the following conclusions were reached:

1) The initial traverse (EVA I) can be performed at any of the three landing locations provided that oxygen leakage and heat leak in are near zero.

2) The second planned traverse (EVA II) appears feasible at Landing Site #3, may be feasible with zero margin at Landing Site #1 and does not appear to be feasible at Landing Site #2 assuming no oxygen leakage or heat leak in occurs. This finding also assumes deletion of the alternate science locations included on EVA II at Landing Site #1.

3) It does not appear feasible to accomplish any of the EVA's as planned if oxygen leakage and heat leak in approach maximum specification values.

The planned EVA traverses are ambitious and, if executed with due consideration to the apparent marginality in life support consumables, will return data which will be very useful in planning future missions.

(NASA-CR-112716) AN ANALYSIS OF THE CAPABILITY TO PERFORM THE APOLLO 13 FRA MAURO TRAVERSES (Bellcomm, Inc.) 26 p

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MEMORANDUM FOR FILE

INTRODUCTION

The Apollo 13 EVA traverses developed by USGS and MSC for the three potential LM landing locations at Fra Mauro have been reviewed to assess the LM crew's capability to accomplish all of the scientific objectives of the mission. The traverse maps and activities planned during each EVA are covered in Attachment A.(1)

This review was made with two specific purposes in mind. One was to assess the -6 Portable Life Support Systems' consumables margins for each Apollo 13 EVA based on data obtained from ground-based tests and the Apollo 11 and 12 missions. The other was to lay groundwork for determining if the application of a limited set of quantitative guidelines is good enough to predict EVA time and energy requirements with sufficient accuracy to plan future mission traverses. Comparison of these predictions with the actual Apollo 13 results will be made subsequent to the mission.

METHOD OF ANALYSIS

The rationale used in making the analysis is based on the following hypotheses:

(1). The total energy required to perform a given task is essentially constant.

(2) The energy expenditure rate for performing tasks will be between the nominal self-paced limits of 900 and 1200 Btu/hr.

From (1) above, it follows that the time required to perform a given task will vary inversely with the energy expenditure rate. Finally, it is assumed that any task performed at a metabolic rate higher than 1200 Btu/hr will be followed by rest. In this case, the time and energy rate for rest are included in the energy cost of the task.

The rationale was applied to the Apollo 13 traverses in the following manner:

(a) Each traverse was broken down into the major activities of overhead, travel, ALSEP deployment (EVA I only) and science.

(b) Science was further sub-divided into four main tasks. The tasks were (1) selected and documented sampling, (2) panoramic photography, (3) core sampling and (4) the outpost activities detailed on the astronauts' cuff checklists. All other activities, including rest, are assumed to be covered implicitly in these designated activities.

(c) Each traverse was then evaluated in a two-step manner to establish the upper and lower bounds for total time and workload for each EVA as follows:

1) The astronaut is assumed to expend energy at a rate near the upper limit for self-paced work (i.e. 1200 Btu/hr) in order to complete the travel and scientific tasks in the minimum allotted time.

2) Using the total energy cost computed for the minimum-time EVA as a base, the time required for travel and performance of scientific tasks is relaxed by 20% in order to derive the total time and average metabolic rate which would result from a more leisurely EVA.

Complete details of the rationale, including the time and energy allocations and the bases for these allocations, are provided in Attachment B.

DISCUSSION OF RESULTS

Six traverses (two for each landing site) were evaluated to provide estimates of the total metabolic energy and time required to perform the Apollo 13 EVA's. Detailed breakdowns of the estimated time and energy requirements are shown on Tables 1, 2 and 3 for the three landing sites, respectively. The results of the analyses are summarized in Table A and discussed in the paragraphs below.

TABLE A

SUMMARY OF RESULTS

	Time (Hrs)		Btu's	
LANDING SITE #1	Min.	Max.	Req'd*	Margin**
EVA I (nom.)	4.1	4.9	4070	+730
EVA I (alt.)	4.5	5.4	4610	+190
EVA II (nom.)	4.4	5.3	5000	-200
EVA II (alt.)	4.9	5.9	5610	-810
LANDING SITE #2				
EVA I	4.1	4.9	4100	+700
EVA II	4.7	5.7	5360	-560
LANDING SITE #3				
EVA I	4.2	5.1	4240	+560
EVA II	4.2	5.0	4740	+ 60

*Includes 20 minutes (400 Btu's) reserve
**Based on -6 PLSS metabolic energy capacity of 4800 Btu's.

Comparison of total energy requirements for a traverse with the allocated metabolic capacity of the -6 PLSS indicates that more consumables margin will be available than actually is the case if the average metabolic rate approximates 1200 Btu/hr and the EVA duration exceeds four hours. This result is because the oxygen and water quantities are sized to satisfy specified maximum fixed costs for oxygen leakage and heat in-leak for a nominal four-hour excursion in addition to requirements for metabolic energy expended at the rate of 1200 Btu/hr. If oxygen leakage and heat leak in are below specification limits (0.0354 lbs/hr and 250 Btu/hr, respectively) the extra consumables can be added to the 4800 Btu metabolic allocation. Conversely, if the actual metabolic rate average is below the design value of 1200 Btu/hr, the surplus oxygen and water can be reassigned to

fixed cost supplies. The existence of either situation, or both at the same time, will permit extending EVA duration beyond the nominal 4-hour design goal.

Figures 1, 2 and 3 show the estimated requirements and margins for the EVA's at Landing Sites 1, 2 and 3, respectively, with respect to the total consumables in the -6 PLSS for both zero and specification leakage cases. Interestingly, the results for the no-leak case are almost identical to those obtained when requirements were weighed against the -6 PLSS metabolic allocation.

Of more interest (and concern) is that none of the planned EVA's appear to be feasible if oxygen leakage and heat leak in approach specified maximum limits.* The probability that these conditions will exist is much greater on the second EVA due to wear and soiling of the EMU as the mission progresses.

Finally, since the rationale assumes a linear inverse relationship between task time and metabolic rate, and the oxygen and water consumption curves are non-linear, some of the negative-margin EVA's appear feasible if the astronaut works either very hard or very little. Neither of these approaches is recommended since, in the former case, fatigue effects would shift the actual relationships and, in the latter case, the time in the pressurized suit would be excessive.

CONCLUSIONS

Based on the rationale which was used to make the analyses, and assuming no oxygen leakage and no heat leak in, the following specific conclusions were reached.

1) All of the first EVA's (EVA I) currently planned for each of the three potential landing sites appear feasible including travel to the Star rim (location w), designated as an alternate for EVA I at Landing Site #1. Estimated times for completion of all EVA I's, not including the alternate leg, range from approximately 4 hours (minimum) to 5 hours (maximum).

2) The second EVA's (EVA II) from Landing Sites #1 and #2 do not appear to be feasible if the alternate legs at Site #1 are not deleted. If the alternate legs are deleted, EVA II from Landing Site #1 appears feasible with zero PLSS margin. EVA II from Landing Site #3 appears feasible.

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*The times and metabolic rates developed by the program for EVA I and II at Landing Site #1[5] lead to the same conclusion. The data are provided in Table 4 and plotted on Figure 1.

In general, all EVA's should plan for traversing slopes circuitously (e.g., zig-zag or spiral path) to avoid inclinations steeper than 10°. In addition, deletion of alternative science and travel legs from the traverse plans carried by the crew may be desirable to avoid confusion between the crew and the ground.

It was found also that all of the EVA analyses are much more sensitive to the time required for scientific tasks than for travel. This factor may make the actual Apollo 13 EVA II excursion "time-line driven". That is, the pace may be forced by the times allotted for the tasks in order to stay on schedule. As a result, energy rates for specific tasks may actually be higher than anticipated and observations and documentation are likely to be less thorough as the EVA progresses.

While the planned traverses are very ambitious, they should return data which are more meaningful for planning future lunar landing EVA's than the data obtained on Apollo 11 and 12. Therefore, except for deletion of the alternate legs as suggested above, the Apollo 13 astronauts should attempt to follow the traverses as planned. Certain activities scheduled after completion of the tasks at the outpost locations, however, should be pre-designated as specific candidates for deletion in realtime if time and energy expenditures approach the margin required for safe return.

T. A. Bottomley

2032-TAB-tla

T. A. Bottomley

Attachments
A & B
Tables I, II & III

REFERENCES

1. Traverse Maps for the Apollo 13 Fra Mauro Site, USGS/MSC, March, 1970.

2. Preliminary Apollo 13 Lunar Surface Procedures, MSC/FCSD, January 30, 1970.

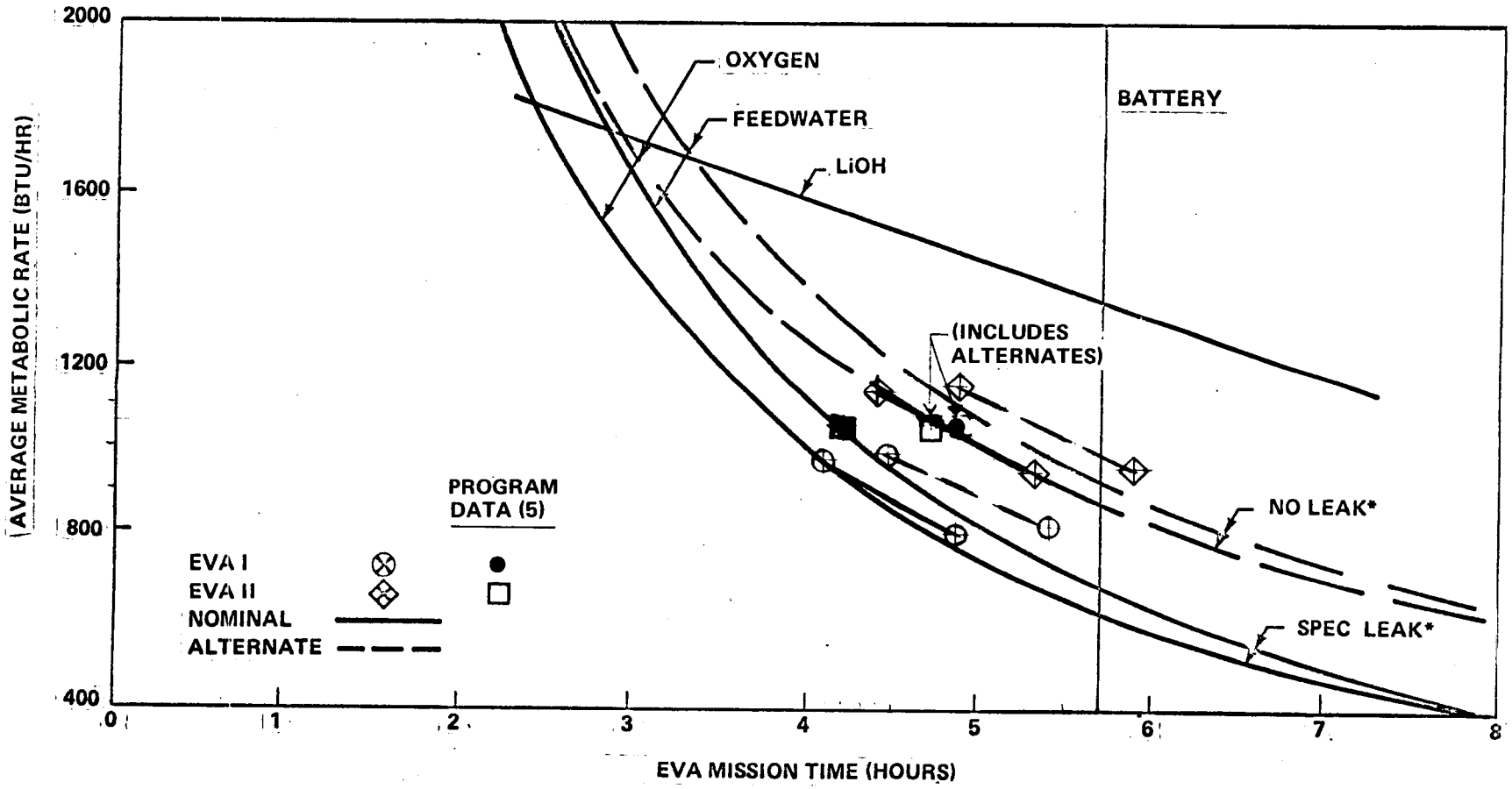
3. Robertson, W. G. and Wortz, E. C., Evaluation of the Metabolic Cost of Locomotion in an Apollo Space Suit, AiResearch Report 69-5909, January, 1970.

4. Apollo EMU Metabolic Assessment - Apollo 12, MSC/MROD (not dated).

5. Informal Communication from P. Benjamin on March 30, 1970.

6. MSC Presentation to CCB - EVA Performance Envelopes, February 13, 1970.

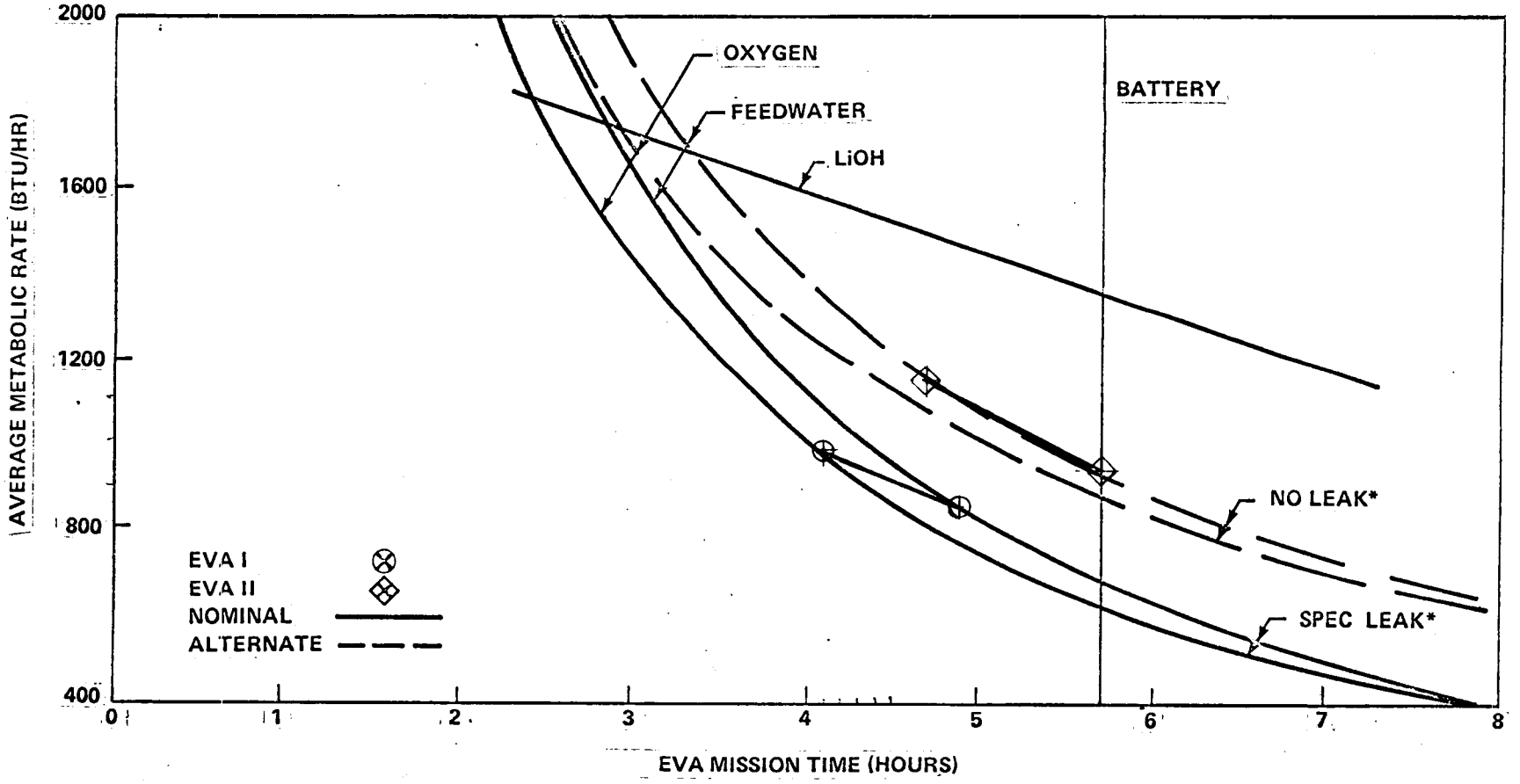
FIGURE 1. APOLLO 13 FRA MAURO MISSION - LANDING SITE # 1



- 6 PLSS EXPENDABLES DURATION

*O_2 LEAKAGE OUT AND HEAT LEAKAGE IN FROM REF 6

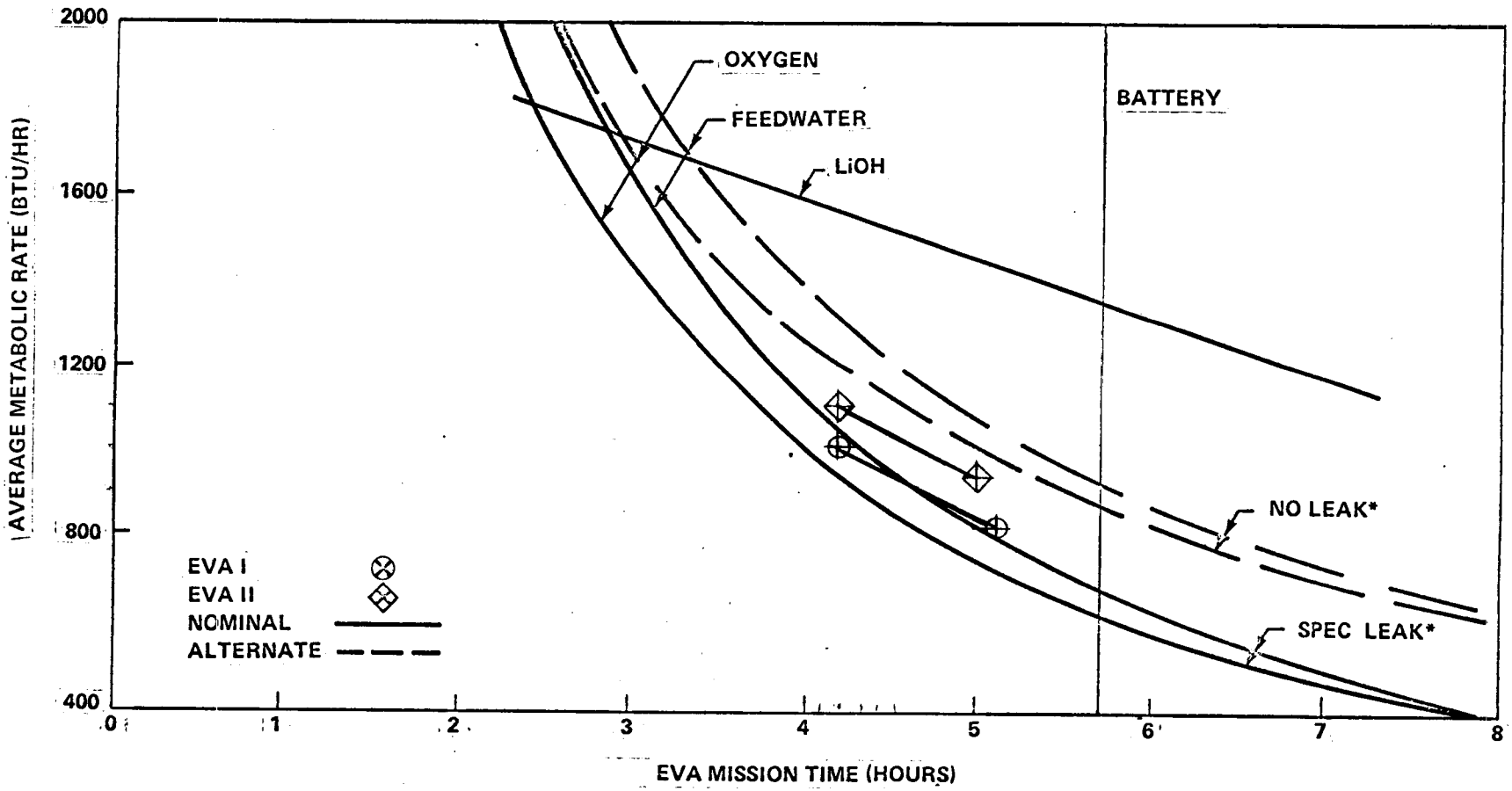
FIGURE 2. APOLLO 13 FRA MAURO MISSION - LANDING SITE # 2



- 6 PLSS EXPENDABLES DURATION

*O_2 LEAKAGE OUT AND HEAT LEAKAGE IN FROM REF 6

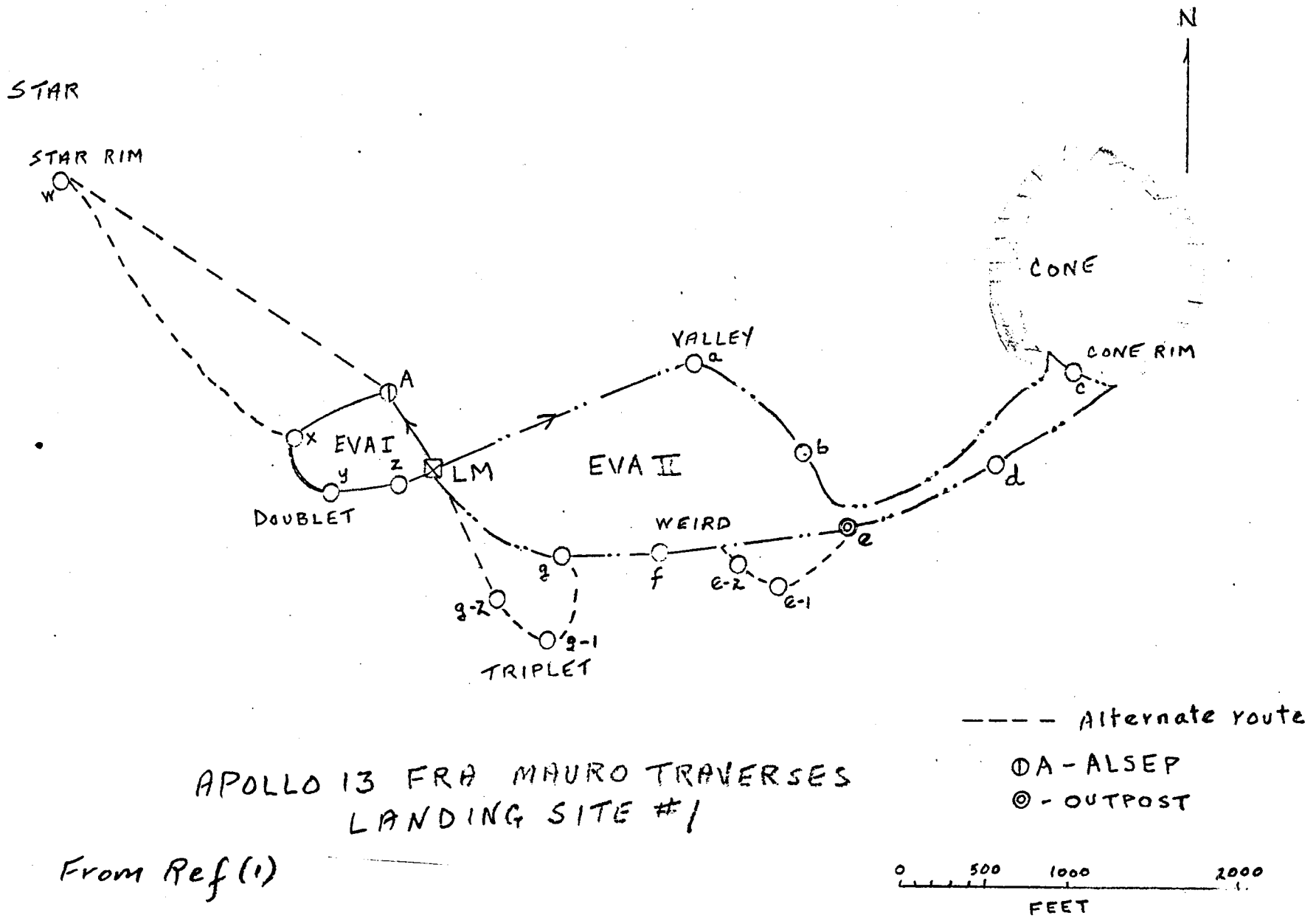
FIGURE 3. APOLLO 13 FRA MAURO MISSION - LANDING SITE # 3



- 6 PLSS EXPENDABLES DURATION

*O_2 LEAKAGE OUT AND HEAT LEAKAGE IN FROM REF 6

Attachment A



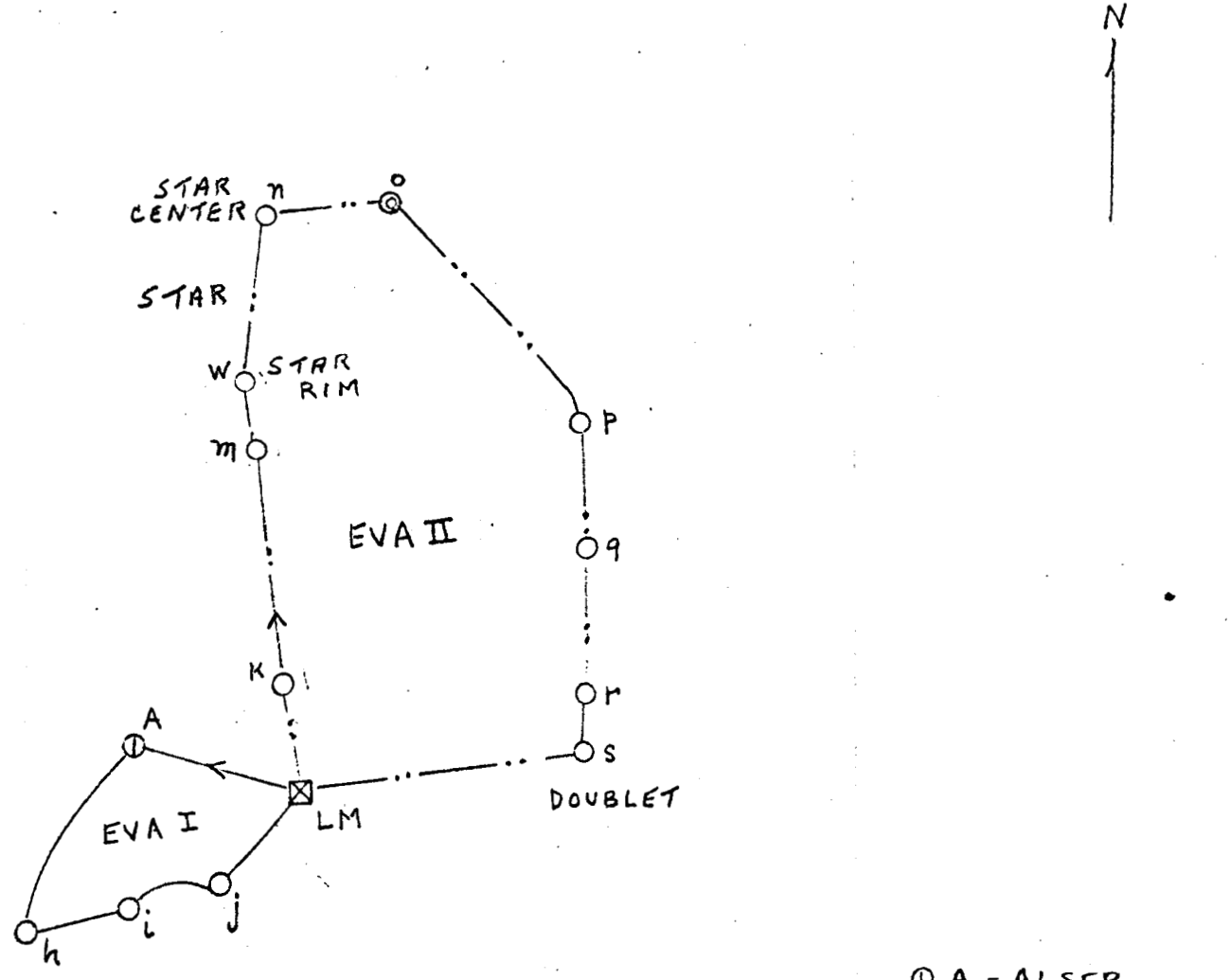
APOLLO 13 FRA MAURO TRAVERSES
LANDING SITE #1

From Ref (1)

STATION	TASKS	ADDITIONAL INFORMATION
A	•ALSEP deployment •Do cuff checklist	•On intercrater area underlain predominantly by older regolith between Copernican craters
w Star rim	•Selected sample •Pan	•Rim of large older (#1) crater. Probably penetrated regolith into Fra Mauro unit of subdued ridge •Most likely site on traverse to collect possible Fra Mauro samples
x Doublet (N)	•Selected sample	•On rim of #1 crater--crater may penetrate through regolith into underlying Smooth unit
y Doublet (S)	•Selected sample	•On rim of younger (#3) crater •Intermediate exposure age--penetrates into or through older crater ejecta
z	•Selected sample	•Relatively undisturbed regolith •Possible samples with older exposure ages

STATION	TASKS	ADDITIONAL INFORMATION
a. Valley	•Documented sample •Pan •Observe characteristics of surface	•Ejecta from (#1) crater on Smooth unit •Smooth unit; to be compared with Ridgey unit next station •Next traverse crosses contact between Smooth and Ridgey units
b. Slope (south of Slope crater rim)	•Documented sample •Single core in patterned ground •Compare with surface at Valley	•Patterned ground in Ridgey unit •Comparison of Ridgey unit and Smooth unit
c. Cone Rim	•Examine, describe, photograph boulders •Collect rock and soil samples •Two pans on rim ≥ 300 ft. baseline •Polarized pictures f:5.6, 1/125; across cone, and of sample area •Roll boulder, take 24 fps movie, crew movement, pan west, pan crater •Look for boulder tracks inside and outside	•Large boulders may be from Fra Mauro •Contacts may be visible in crater wall •Panoramas with wide base stereo
c-d	•Watch for radial variations in materials	
d. Flank	•Documented sample •Pan •Contrast rock types, sizes, shapes with Cone	•#4 crater may penetrate Cone ejecta
e. Outpost-1	•Do cuff checklist •Sample radially, SW of Outpost, 3 documented soil samples at 10 ft. intervals •Collect documented football rock on return	•#4 crater near buried contact •Crater may penetrate either Ridgey or Smooth unit
	Alternate traverse part e	
e.-1	•Documented samples	•#2 crater near buried contact
e.-2	•Documented samples •Contrast rock types at previous stations to establish contact	•#2 crater near buried contact
f. Weird	•Double core through multiple ejecta blanket •Pan •Documented sample of material from superposed craters •Observe elongate shape #3 crater for origin	•#3 crater may penetrate into Smooth unit materials •Elongate shape of #3 crater may reflect structure or composite of multiple craters
g. Triplet	•Documented sample •Pan •Observe patterned ground	•Large #2 crater may penetrate into underlying Smooth unit, either Fra Mauro breccia or younger volcanic rock •Largest crater sampled in Smooth unit
	Alternate traverse part g	
g.-1	•Documented samples •Pan	
g.-2	•Documented sample	

Attachment A (cont'd)



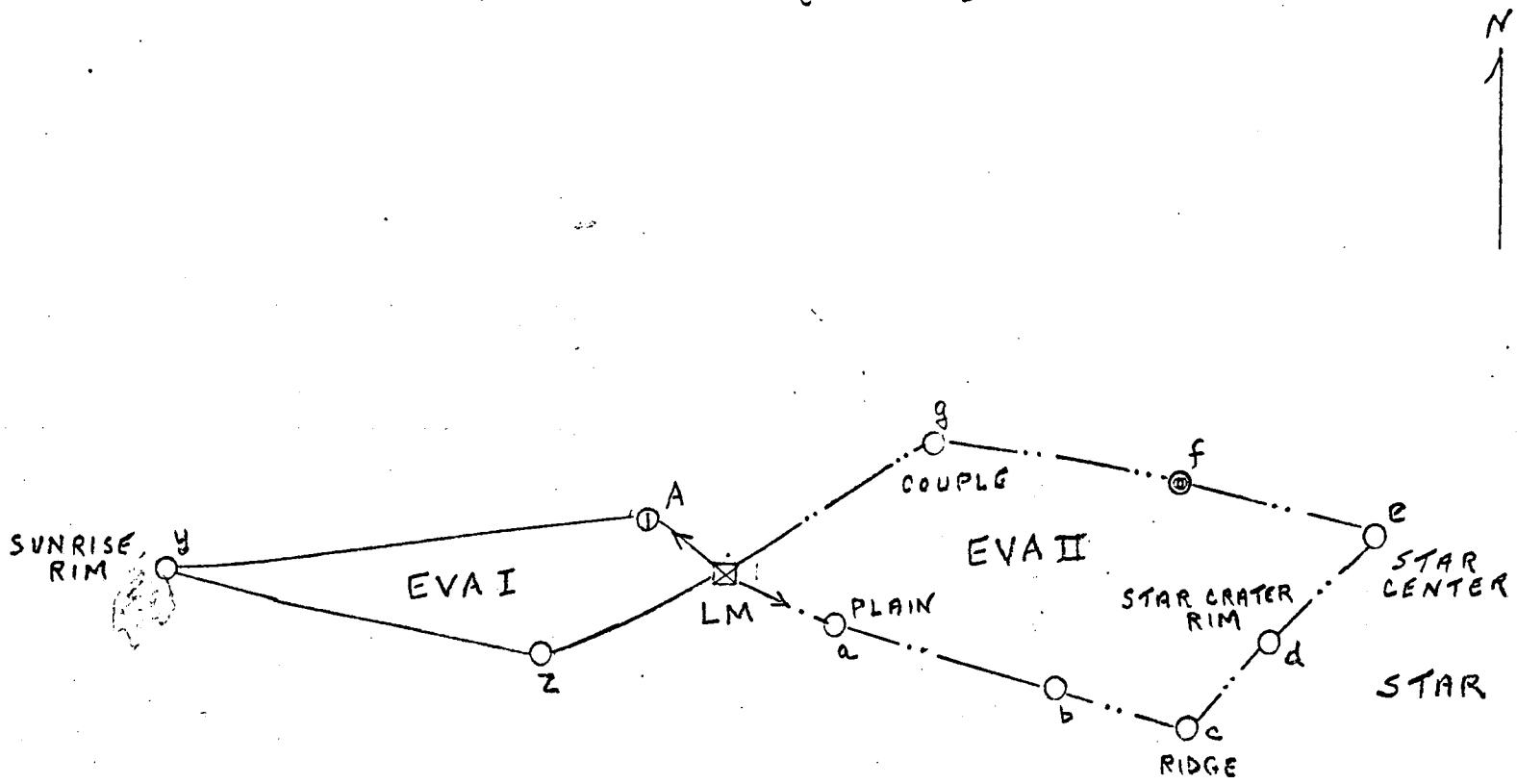
APOLLO 13 FRA MAURO TRAVERSES
LANDING SITE #2

From Ref (1)

STATION	TASKS	ADDITIONAL INFORMATION
A	•Deploy ALSEP	
h	•Selected sample	•#4 crater may excavate material from Smooth unit, beneath regolith
i	•Selected sample	•#1 crater may excavate material from ridge unit, beneath regolith
j	•Selected sample	•Cluster of moderately young (#3) craters

STATION	TASKS	ADDITIONAL INFORMATION
k	•Documented sample •Pan •Core	•Small younger (#4) crater in Ridgey unit on margin of larger older (#1) crater. May sample blanket of deeper ejecta •Good opportunity to observe possible patterned ground on irregular ridge slopes
k-m	•Observations on character relative to slope of patterned ground	
m	•Documented sample •Pan	•Small (#4) crater in cluster of #4 craters which may cut through ejecta blanket of Star crater
w Star rim	•Documented sample •Double pan ≥ 300 ft. between points •Core	•Rim of major deep older crater superimposed on approximate location of contact between Ridgey unit and smooth unit •Possible sample site of Fra Mauro materials •Ejecta may be different on east rim of crater than on west rim due to superposition of crater on Ridgey-Smooth unit contact
n Star center	•Documented sample on rim of young crater •Polarized pictures f:5.6, 1/125; to N wall of Star, and of sample area •Observe characteristics of surface	•Fresh young crater (#6) in bottom of major older crater (Star) which may penetrate to Fra Mauro
n-o	•Look for surface changes that may be related to approximate contact between Ridgey and Smooth units	•Ejecta on east side may be different than on west side of Star crater
o Outpost-2	•Do cuff checklist •Document sample •Pan •Sample radially, SE of Outpost crater, 3 documented soil samples at 25 ft. intervals •Compare surface materials with those of Star •Collect documented football rock on return	•Well-defined crater (#4) in Smooth unit with good younger ejecta blanket overlying older regolith of Smooth unit •Material may be different from that at Star
p Halfway	•Documented sample •Pan	•Prominent younger (#4) crater well out into Smooth unit •May provide good sample of excavated Smooth unit
q	•Documented sample •Core •Observe possible patterned ground, compare with any patterned ground on traverse leg from LM to Star	•Relatively undisturbed older regolith on Smooth unit •May provide samples with older exposure ages
r Doublet (N)	•Documented sample	•Small crater (#3) superimposed on rim of larger older (#1) crater •Possible deep sample of Smooth unit
s Doublet (S)	•Documented sample •Pan •Bulk sample, especially rock fragments, if sample yield has been small. Collect from as large an area as practical	•Superimposed craters in Smooth unit •Possible deep sample of Smooth unit •Next leg of traverse will cross approximate contact between Ridgey and Smooth unit

Attachment A (Cont'd)



APOLLO 13 FRA MAURO TRAVERSES
LANDING SITE #3

① A - ALSEP
◎ - OUTPOST

0 500 1000 2000
FEET

From Ref (1)

STATION	TASKS	ADDITIONAL INFORMATION
A	•Deploy ALSEP	
y Sunrise rim	•Selected sample	•Blocky rim of fresh, large crater--penetrates below fine fragmental layer probably excavated material from Smooth unit; possibly from under Smooth unit •Note: Sunrise rim very high priority--if time does not permit adequate sampling during first EVA, EVA 2 traverse should be adjusted to include Sunrise rim
z	•Selected samples #3 crater rim and in smooth areas back to LM	

STATION	TASKS	ADDITIONAL INFORMATION
a. Plain	•Documented samples •Pan •Look for patterned ground	•Subdued older (#1) crater in Smooth unit; may have excavated Smooth unit materials from depth •Smooth unit; to be compared with Ridgey unit next two stations
a-b Traverse	•Look for surface changes that may be related to geologic contact	•Traverse crosses approximate contact between Smooth unit and possible Fra Mauro unit
b. Contact	•Documented samples •Core •Pan •Compare with surface at Plain	•Small crater (#3) superimposed on rim of older crater (#1) •Core sample may penetrate through #3 into #1 ejecta •Comparison of Smooth unit with Ridgey unit
c. Ridge	•Documented samples •Pan •Patterned ground, fillet development, fragment rounding	•Rim of subdued (#1) crater •May penetrate regolith into Fra Mauro unit •Comparison of regolith surface with that of previous stations
d. Star crater rim	•Documented samples •Pan •Patterned ground, fillet development, fragment rounding	•Rim of large old (#1) crater which may penetrate into Fra Mauro unit •Superimposed small craters may reexcavate and invert rim deposits of large crater
d-e Traverse	•Look for changes in fragments, fillets, and patterned ground	•Patterned ground, fillet and fragment distribution may change on traverse down into crater
e. Star Center	•Documented sample •Core •Stereo pan with 100 ft. baseline •Polarimetry sequence	•Small bright crater (#16) in center of old Star crater •#6 crater excavates old crater fill, possibly including Fra Mauro •Possible large difference in exposure ages between #6 ejecta and underlying materials
f. Outpost-3	•Do cuff checklist activities •Pan from rim •Watch for football size rock; collect and document	•Pans at Star rim and Outpost-3 provide wide-base stereo at good vantage points
g. Couple	•Documented samples •Pan •Sample radially, SE of #4 crater, 3 soil samples at 10 ft. intervals	•Radial sample may determine horizontal zonation of different materials around small crater

RATIONALE FOR TRAVERSE ANALYSIS

The following assumptions provide the bases for evaluating the Apollo 13 EVA traverses:

1. The energy cost for each EVA task is a constant. Therefore, work time can be traded off against work rate.

2. The astronaut's actual average energy expenditure over the EVA mission will be between 900 and 1200 Btu/hr.

3. Task activities are broken down into four major categories:

   (1) Overhead at the LM

   (2) Travel (including ALSEP traverse)

   (3) ALSEP deployment

   (4) Science tasks at the traverse stations

I. Overhead

4. Overhead time and energy are computed as follows and include 20 minutes (400 Btu) reserve.

	Time	Rate	Total
EVA 1	2.2 hrs (2)	1000 Btu/hr	2200 Btu's
EVA 2	1.5 hrs (2)	1000 Btu/hr	1500 Btu's

II. Travel

5. The relationship between energy rate and walking speed is linear over the velocity range 2 to 5 km/hr. (3)

   a) The minimum cost is 400 Btu/km traveled. (3)

   b) The maximum cost (adjusted for wander, slope <10°, and load) is assumed to be 500 Btu/km traveled.

   c) The assumed velocity is 3 km/hr (1.8 mph) in all cases. (3)

6. All slopes can be traversed at an inclination $\leq 10°$. Therefore travel distance is arbitrarily increased for slope exceeding 10°.

III. ALSEP Deployment

7. ALSEP deployment does not include deployment travel. The time and energy costs are fixed at

Time	Rate	Btu's
80 min (4)	15/Btu/min (4)	1200

IV. Science

8. Science is broken down into four major tasks as follows:

(1) Sampling (S)

(2) Panoramic Photograph (P)

(3) Core sampling (C)

(4) Outpost tasks (O)

No other tasks are allotted for.

9. Time and energy costs for the four science tasks are initially allotted as follows:

	Time (min)	Rate (Btu/min)
S	5	20
P	5	20
C	5	20
O	30 (5)	20

Use of these values will provide the minimum time EVA at an average energy expenditure of 1200 Btu/hr. A maximum time (minimum energy) EVA is computed by increasing travel and science times only by 20%.

10. Time and energy costs for all tasks are assumed equal for the two astronauts; that is, both share in all tasks and the workload is equally divided over the EVA period.

TABLE I

SUMMARY OF EVA COSTS - APOLLO 13

LANDING SITE #1

A. EVA I	Time (min)	Btu's
Overhead	132	2200
ALSEP	80	1200
Travel (0.68 km)	14	270
Science (3S + 1P)	20	400
Nominal Minimum	246 (4.1)*	4070
Nominal Maximum	294 (4.9)*	4070
+ Alt. Travel	22	440
+ Alt. Science (1S)	5	100
Alternate Minimum	273 (4.5)*	4610
Alternate Maximum	326 (5.4)*	4610
B. EVA II		
Overhead	90	1500
Travel (2.75 + .75km)**	70	1400
Science (7S + 5P + 3C + O)	105	2100
Nominal Minimum	265 (4.4)*	5000
Nominal Maximum	318 (5.3)*	5000
+ Alt. Travel (0.03 km) (0.25 km)	6	110
+ Alt. Science (2S) (2S + 1P)	25	500
Alternate Minimum	296 (4.9)*	5610
Alternate Maximum	355 (5.9)*	5610

*Hours

**Increment for ascending slope >10° at Cone Rim.

TABLE II

SUMMARY OF EVA COSTS - APOLLO 13

LANDING SITE #2

A. EVA I	Time (min)	Btu's
Overhead	132	2200
ALSEP	80	1200
Travel (0.98 KM)	20	400
Science (3S)	15	300
Nominal Minimum	247 (4.1)*	4100
Nominal Maximum	296 (4.9)*	4100
Alt. Travel		
Alt. Science		
Alternate Minimum		
Alternate Maximum		
B. EVA II		
Overhead	90	1500
Travel (2.2 + 0.2km)**	48	960
Science (11S + 7P + 3C + O)	145	2900
Nominal Minimum	283 (4.7)*	5360
Nominal Maximum	340 (5.7)*	5360
Alt. Travel		
Alt. Science		
Alternate Minimum		
Alternate Maximum		

*Hours

**Adjustment for slope > 10° from Star Rim to Star Center.

TABLE III

SUMMARY OF EVA COSTS - APOLLO 13

LANDING SITE #3

A. EVA I	Time (min)	Btu's
Overhead	132	2200
ALSEP	80	1200
Travel (1.6 km)	32	640
Science (2S)	10	200
Nominal Minimum	254 (4.2)*	4240
Nominal Maximum	305 (5.1)*	4240
Alt. Travel		
Alt. Science		
Alternate Minimum		
Alternate Maximum		
B. EVA II		
Overhead	90	1500
Travel (1.95 + .2km)**	42	840
Science (9S + 7P + 2C + O)	120	2400
Nominal Minimum	252 (4.2)*	4740
Nominal Maximum	302 (5.0)*	4740
Alt. Travel		
Alt. Science		
Alternate Minimum		
Alternate Maximum		

*Hours

**Adjusted for slope >10° from Star Rim to Star Center

TABLE IV

SUMMARY OF EVA COSTS - APOLLO 13[5]

LANDING SITE #1

A. EVA I	Btu/hr	Time (min)	Btu's
Overhead		132	
ALSEP		80	
Travel		19	
Science		22	
Nominal Minimum	1050	253 (4.2)*	4400
Nominal Maximum			
Alt. Travel		30	
Alt. Science		10	
Alternate Minimum	1050	293 (4.9)*	5150
Nominal Maximum			
B. EVA II			
Overhead		90	
Travel		55	
Science		107	
Nominal Minimum	1050	252 (4.2)*	4400
Nominal Maximum		252 (4.2)*	4400
Alt. Travel		12	
Alt. Science		19	
Alternate Minimum	1050	283 (4.7)*	4940
Alternate Maximum			

*Hours

BELLCOMM, INC.

Subject: An Analysis of the Capability to Perform the Apollo 13 Fra Mauro Traverses - Case 320

From: T. A. Bottomley

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