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BELLCOMM, INC.
1100 Seventeenth Street, N.W. Washington, D.C. 20036

SUBJECT: Planetary Spacecraft Weight Estimates - Case 233

DATE: September 27, 1967

FROM: D. Macchia

ABSTRACT

This memorandum estimates typical planetary spacecraft weights after departure from earth orbit. A 700 day mission, which is representative of numerous flyby and capture missions to Mars and/or Venus is assumed. The spacecraft is comprised of life support, power, mission equipment, structure, earth return capsule, payload, midcourse and attitude control propulsion. (Major propulsion stages are excluded.) Subsystem weights vary with crew size and also mission time to account for spares, redundancy, and expendables.

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MEMORANDUM FOR FILE

CONTENT

This memorandum estimates typical planetary spacecraft weights after departure from earth orbit. A 700 day mission, which is representative of numerous flyby and capture missions to Mars and/or Venus is assumed. The spacecraft is comprised of life support, power, mission equipment, structure, earth return capsule, payload, midcourse and attitude control propulsion. (Major propulsion stages are excluded.) Subsystem weights vary with crew size and also mission time to account for spares, redundancy, and expendables.

A baseline weight estimate of a Mars flyby mission (through the asteroid belt) is summarized on Table I and Figure 1. This baseline S/C is bracketed by minimum and maximum S/C weight estimates (Table II) which are a function of free volume, radiation shielding, meteoroid shielding, power and payload requirements, and the particular choice of subsystems. The weight of the mission module which includes everything except propulsion, payload, and the earth entry module is also indicated on Figure 1.

The various detailed weight estimates (see Appendix) are based on data from numerous sources which are given in the reference list and Bellcomm studies.* Only those data which are believed to be reliable and realistic were used. Gross weight estimates, without detailed breakdowns or explanation were disregarded. It is noted that the weight of payload, which accounts for a significant portion of the S/C weight, is based on assumptions by the author. However, the total payload resulting is in approximate agreement with various contractor and Bellcomm studies. The payload weight should probably be increased for dual and triple planet flyby missions.

DISCUSSION

As indicated in Table II, the major contributions to S/C weight, excluding propulsion, are life support, payload, and the earth return module. The mission module structure can also

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*Unpublished work of C. E. Johnson on meteoroid protection and mission module structure is reflected in this paper.

become heavy if it must operate through the asteroid belt or in a worst case radiation environment. Significant weight savings can be made in the life support area by using efficient means of O_2 storage (or even O_2 recovery from CO_2) and also by attempting to minimize cabin atmospheric leakage. As an example, the weight penalty for O_2 recovery is about 250-300 lb/man as opposed to 1540 lb/man for subcritical cryo storage or 3500 lb/man for gaseous O_2 storage. Weight can also be trimmed from the payload by accepting a less ambitious mission.

Each additional crewman increases the baseline mission module and spacecraft by 7000 and 16000 lbs.respectively for optimized designs. However, it is not likely that spacecraft will be optimized for varying mission crew sizes. Figure 2 illustrates the penalties for using S/C of greater crew capacity. As an example, a 6 man S/C for a 4 man mission weighs 129,000 lbs. which compares with 110,000 lbs. for the optimized S/C.

It is noted that the total S/C and mission module weights are much lower than previous estimates. This is due to elimination of arbitrary contingency factors and the use of achievable rather than conservative individual system weight estimates. Although specific estimates may well be subject to much criticism, it is believed that this memorandum gives a useful indication of the influence of crew size on S/C weight for a consistent set of assumptions. Since S/C weight has major impact on launch vehicles, facilities, cost, etc., and eventually mission acceptability it is evident that a thorough examination of all system weights is required.

D. Macchia

1013-DM-nmm D. Macchia

Attachment:
References 1 - 10

REFERENCES

1. "Mars Landing and Reconnaissance Mission Environmental Control and Life Support System Study," Vol. 2, NAS9-1701, Hamilton Standard, March, 1964.

2. "Life Support System for Space Flights of Extended Time Periods," NASA CR-614, November, 1966.

3. "Space Power Systems Advanced Technology Conference," Lewis Research Center, August 23-24, 1966.

4. "Manned Mars and/or Venus Flyby Vehicle Systems Study," NAS9-3499, North American Aviation, June, 1965.

5. "Manned Planetary Flyby Missions Based on Saturn/Apollo Systems," Vol. D, NAS8-18025, North American Aviation, February 1, 1967.

6. "Report on the Optimization of the Manned Orbital Research Laboratory (MORL) System Concept," Vols. I, XI, XVI, XVII, NAS1-3612, Douglas Aircraft Co., September, 1964.

7. "MORL Isotope Power System Briefing," NAS1-4479, Douglas Aircraft Co., February, 1965.

8. "Communications Systems Design for Manned Mars Flyby Mission," TM-66-2021-8, R. K. Chen, R. L. Selden, Bellcomm, Inc., July 29, 1966.

9. "Weight Relationships for Manned Spacecraft," (CONF.) (U), E. D. Harris, W. D. Gosch, J. R. Hiland, R. T. Oelschalger, Rand Corp., March, 1967.

10. "Comments Concerning Meteoroid/Asteroid Spacecraft Design Policy For a Manned Mars Twilight Flyby Mission," TM-67-1013-4, C. E. Johnson (to be published).

BASELINE S/C

	2 MAN	3 MAN	4 MAN	6 MAN	8 MAN
Life Support	13660	19110	24560	35460	46360
Power	3170	3790	4410	5655	6895
Mission Equip	2250	2250	2250	2250	2250
Payload	33350	36225	39100	44850	50600
MM Structure	6350	8710	10400	13510	16340
PH Structure	4650	4850	5150	5700	6100
Earth Entry Mod.	7480	11220	14960	22440	29920
Subtotal	70910	86155	100830	129865	158465
∿ Midcourse Prop	7300	8890	10400	13400	16300
∿ Attitude Control	780	940	1110	1430	1740
∿ Total S/C Wt.	78990	95985	112340	144695	176505

TABLE I

	2 MAN Min/Max	3 MAN Min/Max	4 MAN Min/Max	6 MAN Min/Max	8 MAN Min/Max
Life Support	10596/25170	14836/32490	19076/39810	27556/54450	36036/69090
Power	2099/5215	2375/5960	2651/6705	3203/8195	3755/9685
Mission Equip.	2100/2800	2100/2800	2100/2800	2100/2800	2100/2800
Payload	33350/41400	36225/44850	39100/48300	44850/55200	50600/62100
MM Structure	4320/9630	5540/12540	6580/14800	8560/19170	10360/23300
PH Structure	4650/5400	4850/5700	5150/6000	5700/6500	6100/7000
Earth Entry Mod.	7480/7480	11220/11220	14960/14960	22440/22440	29920/29920
Subtotal	64595/97095	77146/115560	89617/133375	114409/168755	138871/203895
∿ Midcourse Prop.	6600/15500	7900/18400	9200/21500	11700/27000	14300/32600
∿ Attitude Control	700/1100	900/1300	100/1500	1300/2000	1500/2400
Total S/C Weight	71900/116700	85900/135300	99800/156400	128400/198000	154700/238900

TABLE II

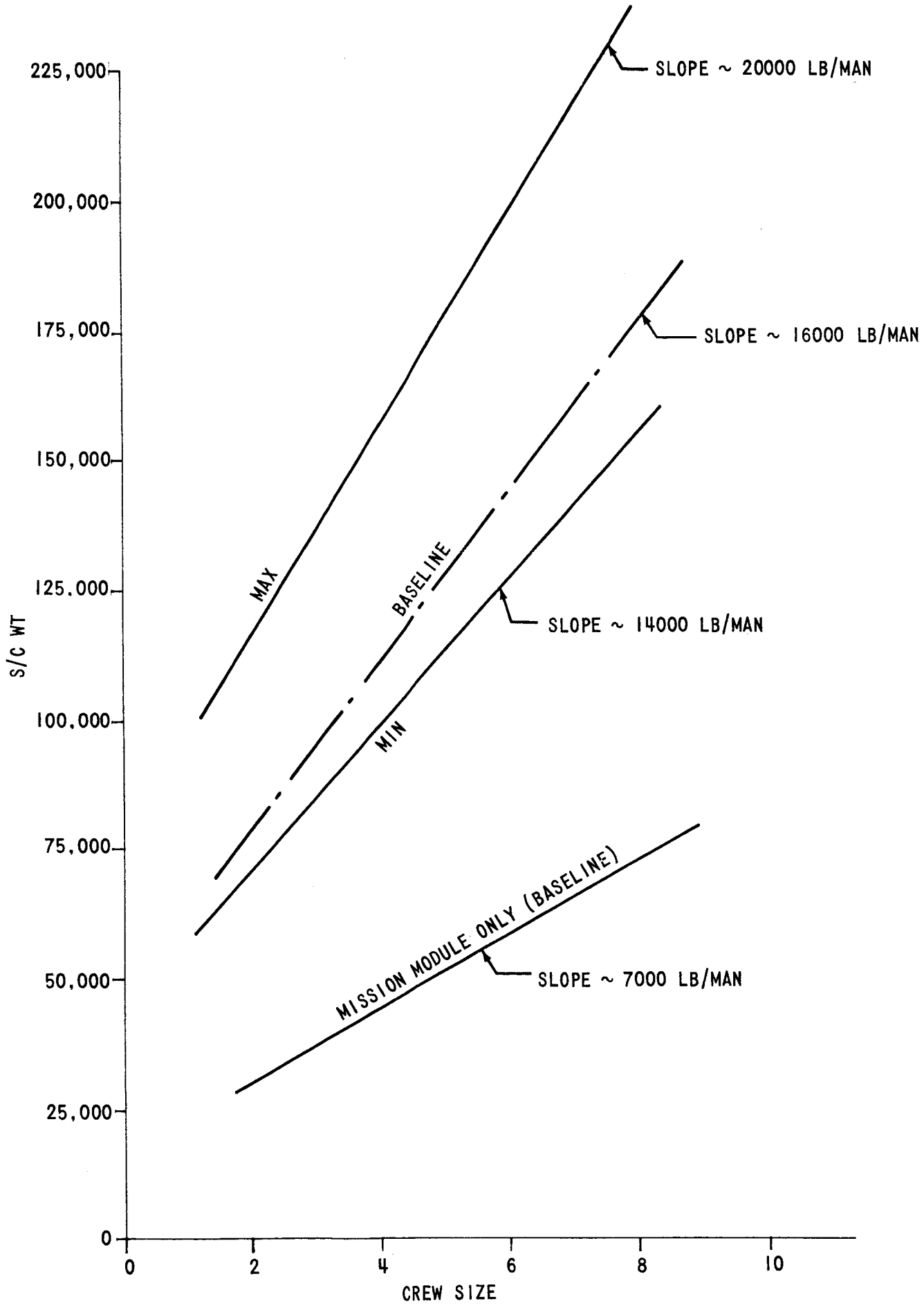
225,000
200,000
175,000
150,000
125,000
100,000
75,000
50,000
25,000
0
S/C WT
0
2
4
6
8
10
CREW SIZE
SLOPE ~ 20000 LB/MAN
SLOPE ~ 16000 LB/MAN
SLOPE ~ 14000 LB/MAN
SLOPE ~ 7000 LB/MAN
MAX
BASELINE
MIN
MISSION MODULE ONLY (BASELINE)

FIGURE 1

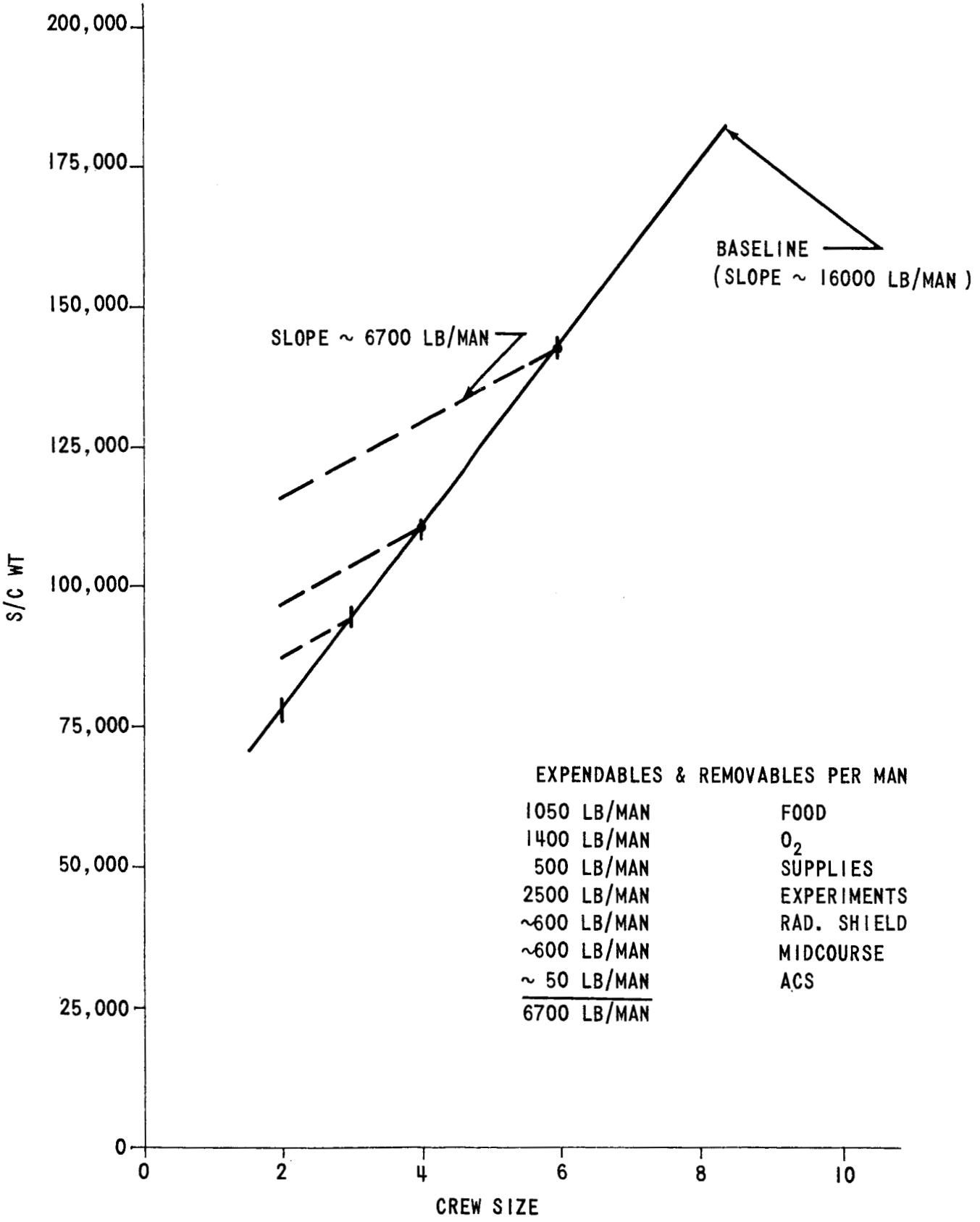
200,000
175,000
150,000
125,000
100,000
75,000
50,000
25,000
0
S/C WT
0
2
4
6
8
10
CREW SIZE
BASELINE
(SLOPE ~ 16000 LB/MAN)
SLOPE ~ 6700 LB/MAN
EXPENDABLES & REMOVABLES PER MAN
1050 LB/MAN FOOD
1400 LB/MAN O_2
500 LB/MAN SUPPLIES
2500 LB/MAN EXPERIMENTS
~600 LB/MAN RAD. SHIELD
~600 LB/MAN MIDCOURSE
~ 50 LB/MAN ACS
6700 LB/MAN

FIGURE 2

LIFE SUPPORT

Subsystems	Min (lb)	Baseline	Max (lb)
1. O_2 supply including tankage (2 lb/man-day, min. wt. for subcrit., max. wt. for gas)	1540 N	1820 N	3500 N
2. Food and packaging (1.5 lb/man-day)	1050 N	1050 N	1050 N
3. Cabin repressurization at 100 day intervals (500 - 700 ft^3/man, subcrit. or gas storage)	146 N	200 N	465 N
4. Atmos. leakage (2-5 lb/day, subcrit. or gas storage)	1540	2000	8750
5. Water recovery systems and waste management + H_2O supply	∿300 N	300 N	∿400 N
6. Atmosphere control (temp., humidity, contaminants, circulation, (O_2 removal)	∿250 N	350 N	∿350 N
7. Astronaut + supplies (clothes, bunk, galley, cabinets, space suit, back pack, exercise equip.)	∿400 N	500 N	∿600 N
8. Fixed weight for items 5-7	∿300	400	∿400

NOTES:

1) Atmosphere storage weights

1.1 lb/lb O_2 or N_2 for subcritical cryo storage

1.3 lb/lb O_2 or N_2 for supercritical cryo storage

2.5 lb/lb O_2 or N_2 for high press gas storage

Subsystems	Min (lb)	Baseline	Max (lb)
9. Sub Total	1840 + 3686 N	2400 + 4620 N	9150 + 6365 N
10. Support Struct. @ 15%	276 + 554 N	360 + 830 N	1380 + 955 N
11. Total (lbs)	2116 + 4240 N	2760 + 5450 N	10530 + 7320 N

Volume	Min (ft^3)	Baseline	Max (ft^3)
1. O_2 and N_2 supply	14 + 31 N	14 + 31 N	42 + 210 N
2. Food	42 N	42 N	42 N
3. Equipment	30 + 95 N	40 + 115 N	40 + 135 N
4. Total (ft^3)	44 + 168 N	54 + 188 N	82 + 387 N

POWER

Power Requirements	Min (kw)	Baseline	Max (kw)
1. EC/LS without CO_2 reduction	.4 N	.5 N	.5 N
2. Communications	2.0	2.0	3.5
3. G and N and Propulsion	.8	.8	1.0
4. Expmts and Instrumentation	.1 N	.4 N	.4 N
5. Subtotal	2.8 + .5 N	2.8 + .9 N	4.5 + .9 N

NOTES:

1) $\sim$.02 ft^3/lb for cryo storage

$\sim$.06 ft^3/lb for gas storage

2) $\sim$.04 ft^3/lb for food storage

3) $\sim$.10 ft^3/lb for equipment

Power Requirements	Min (kw)	Baseline	Max (kw)
6. Conversion and distribution losses @ 20%	.56 + .1 N	.56 + .18 N	.9 + .18 N
7. Total (kw)	3.36 + .6 N	3.36 + 1.08 N	5.4 + 1.08 N

Weight	Min (lbs)	Baseline	Max (lbs)
1. Power system wt. at typical specific wts. (400-600 lb/kw)	1345 + 240 N	1680 + 540 N	3240 + 648 N
2. Support Struct. @ 15%	202 + 36 N	252 + 81 N	485 + 97 N
3. Total	1547 + 276 N	1932 + 621 N	3725 + 745 N
	Min (ft^3)	Baseline	Max (ft^3)
Volume at .05 ft^3/lb	77 + 14 N	97 + 31 N	186 + 37 N

MISSION EQUIPMENT

Subsystems	Min (lbs)	Baseline	Max (lbs)
1. G and N	∿500	∿500	∿500
2. Data Management and Console	∿200	∿300	∿400
3. Communications and Antenna	∿900	∿900	∿1200
4. Probe Checkout	∿300	∿300	∿400

Subsystems	Min (lbs)	Baseline	Max (lbs)
5. Instrumentation and other checkout	∿200	∿250	∿300
6. Total	2100	2250	2800
	Min (ft^3)	Baseline	Max (ft^3)
Volume at .04 ft^3/lb	84	90	112

PAYLOAD

Payload Weights	Min (lbs)	Baseline	Max (lbs)
1. Major probes justifying mission	24000	24000	30000
2. Small Probes and en route experiments	2500 N	2500 N	3000 N
3. Subtotal	24000 + 2500 N	24000 + 2500 N	30000 + 3000 N
4. Support Struct. @ 15%	3600 + 375 N	3600 + 375 N	4500 + 450 N
5. Total (lbs)	27600 + 2875 N	27600 + 2875 N	34500 + 3450 N
	Min (ft^3)	Baseline	Max (ft^3)
Volume at .3 ft^3/lb	8300 + 860 N	8300 + 860 N	10400 + 1040 N

STRUCTURE

Mission Module Volume	Min (ft^3)	Baseline	Max (ft^3)
1. Crew free volume	300 N	500 N	600 N
2. Storm shelter volume	70 N	70 N	70 N
3. Life support	44 + 168 N	54 + 188 N	82 + 387 N
4. Power	77 + 14 N	97 + 31 N	186 + 37 N
5. Mission Equipment	84	90	112
6. Total	205 + 552 N	241 + 789 N	380 + 1094 N

Mission Module Weights	Min (lbs)	Baseline	Max (ft^3)
1. Structure and Meteoroid shield @ $\sim 24\ V^{2/3}$ for 2 yr. interplanetary space, $\sim 36\ V^{2/3}$ for 8 mos. asteroid belt	$24\ (V_{min})^{2/3}$	$36\ (V_{max})^{2/3}$	$36\ (V_{max})^{2/3}$
2. Radiation shield for storm shelter $\sim 50\text{-}100\ (70\ N)^{2/3}$	$850\ N^{2/3}$	$850\ N^{2/3}$	$1700\ N^{2/3}$
3. Support structure for storm shelter taken @ 10%	$85\ N^{2/3}$	$85\ N^{2/3}$	$170\ N^{2/3}$
4. Total	$24\ (V_{min})^{2/3} + 935\ N^{2/3}$	$36\ (V_{max})^{2/3} + 935\ N^{2/3}$	$36\ (V_{max})^{2/3} + 1870\ N^{2/3}$

NOTES:

1) Existing shielding of 10 lb/ft^2 assumed

2) 10-20 lb/ft^2 radiation shield added

Probe Hangar Weights	Min (lbs)	Baseline	Max (lbs)
Weight is estimated as $\sim 10\ V^{2/3}$	$10\ (8300 + 860\ N)^{2/3}$	$10\ (8300 + 860\ N)^{2/3}$	$10\ (10400 + 1040\ N)^{2/3}$

Earth Entry Module	Min (lbs)	Baseline	Max (lbs)
1. Weight based on Fig. A-1	3400 N	3400 N	3400 N
2. Adapter structure @ 10%	340 N	340 N	340 N
3. Total	3740 N	3740 N	3740 N

Midcourse Propulsion (See Table I)

1) 1000 fps min to 1500 fps max applied to total S.C weight ($375\ I_{sp}$ and $.85\ \lambda$)

2) Average S/C weight is much less due to expendables and probes/hanger ejection. This allows propulsion safety factor and considerable ΔV for EEM.

3) 1000 fps for baseline mission.

Attitude Control

Taken as approximately 1% total S/C weight.

APPENDIX

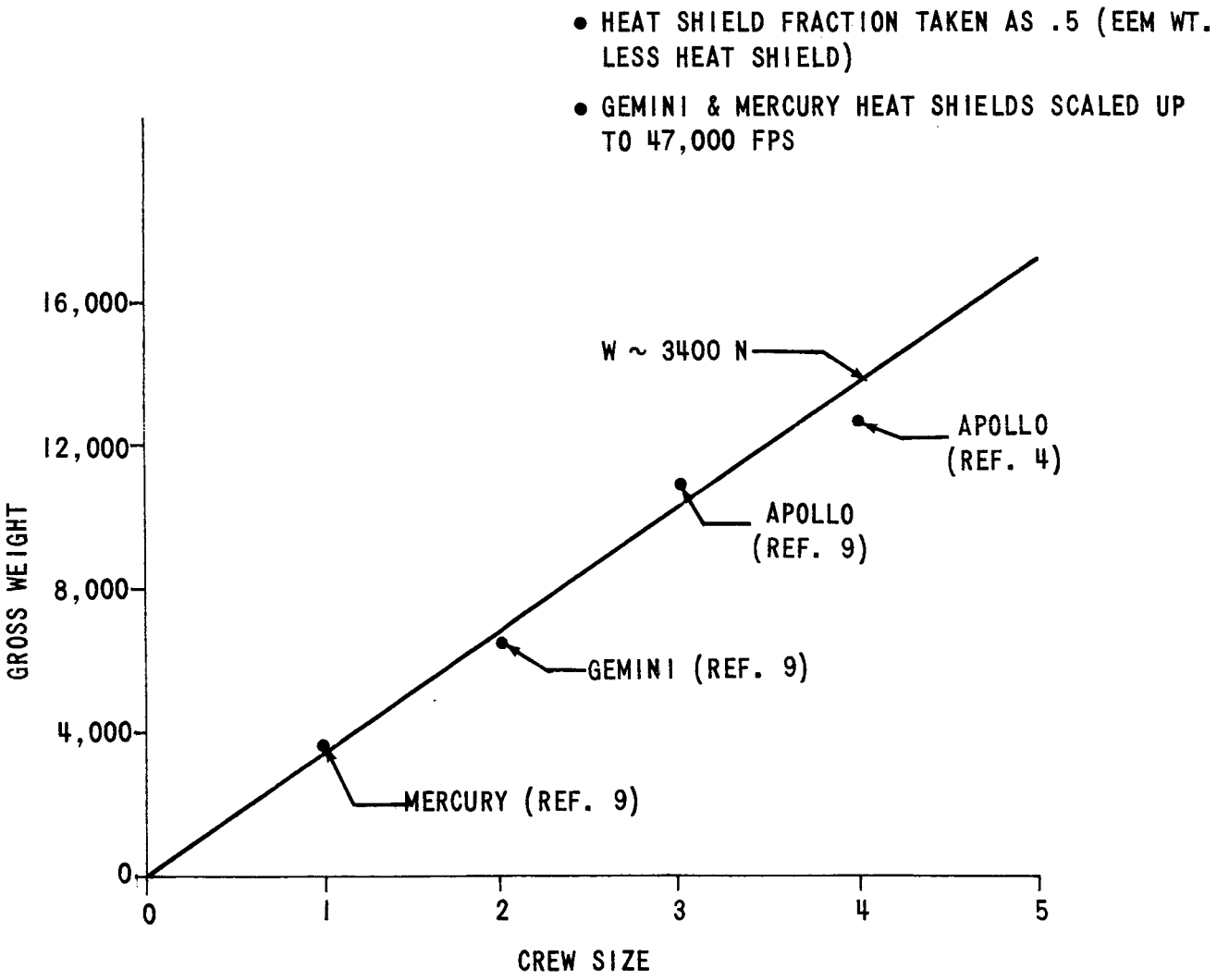

FIGURE A1 - EARTH ENTRY MODULE WEIGHT

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FROM: D. Macchia

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