MID-POINT ORAL STATUS REPORT

AN ENGINEERING STUDY and PRELIMINARY DESIGN of a ONE MAN PROPULSION DEVICE for LUNAR and FREE-SPACE ENVIRONMENTS

(Contract NAS 9-2065)

PRESENTED TO: NASA, MANNED SPACECRAFT CENTER, HOUSTON, TEXAS
BY: HAMILTON STANDARD
DIVISION OF UNITED AIRCRAFT CORPORATION
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HAN STD. Jim Smith - Program Mgt.
Bob Turek Research Control
Dick Kolb - Advance Analysis

MSC - Dick Hergert - MSC -
David Middleton - Langley
Art Vogeley - Langley

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PRESENTATION CONTENT

- **PROGRAM SCOPE**
- **LUNAR SURFACE LOCOMOTION**
  - LUNAR SURFACE OPERATIONS
  - OMLS MISSIONS
  - PROPULSION IN THE LUNAR GRAVITY FIELD
  - PILOTING AND CONTROL
  - LUNAR SURFACE PROPULSION DEVICE CONCEPTS
- **FREE- SPACE LOCOMOTION**
  - FREE-SPACE OPERATIONS
  - OMLS MISSIONS
  - NAVIGATION AND PILOTING
  - PROPULSION IN ZERO-G
  - FREE- SPACE PROPULSION DEVICE CONCEPTS
- **SUMMARY**
  - PROGRESS TO DATE
  - REMAINING PROBLEMS
  - BALANCE OF WORK TO BE PERFORMED

PROGRAM SCOPE

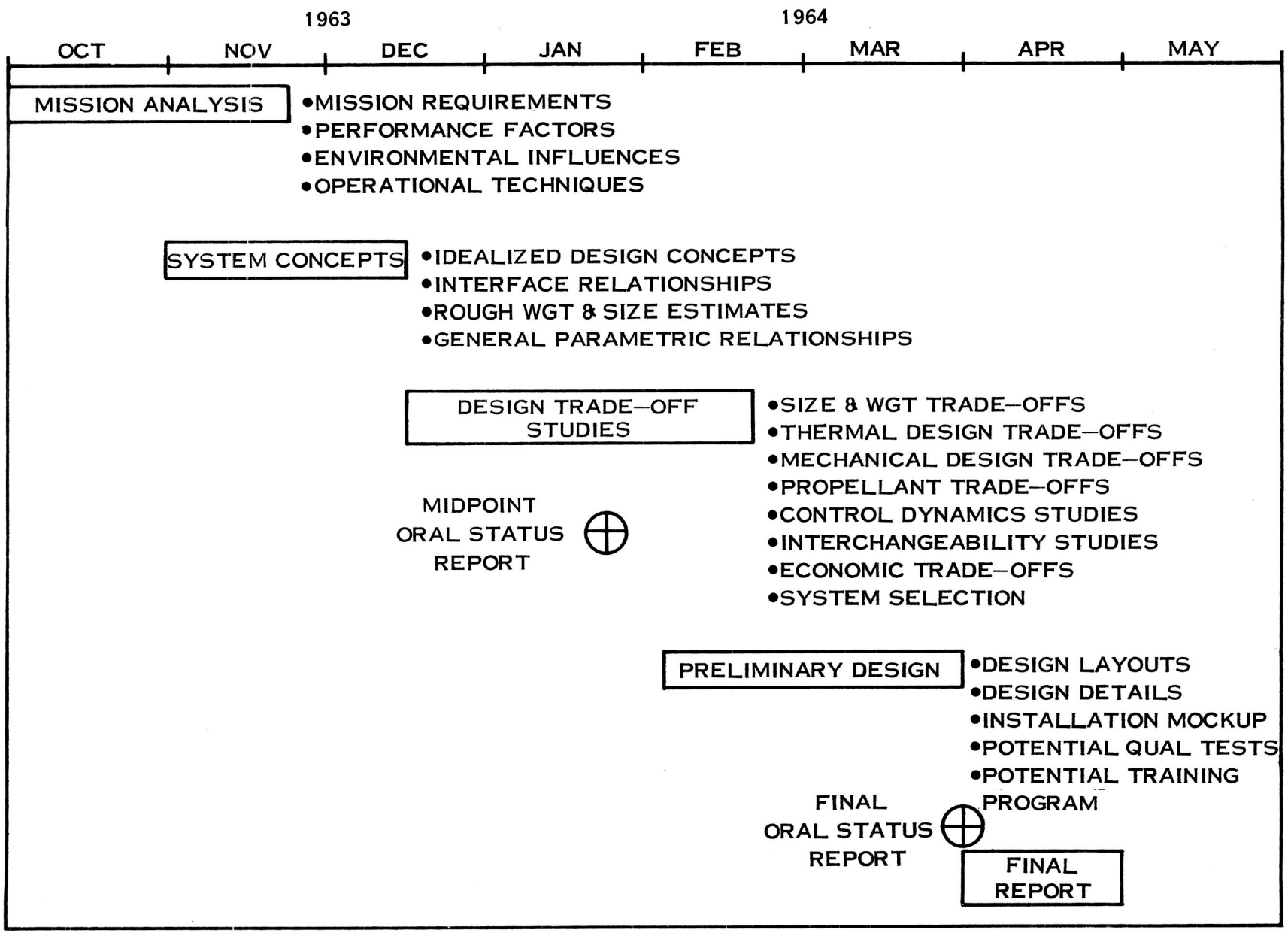
ENGINEERING STUDY

- LUNAR SURFACE ONE-MAN PROPULSION REQUIREMENTS
- FREE-SPACE ONE-MAN PROPULSION REQUIREMENTS
- DESIGN CONCEPTS FOR ONE-MAN PROPULSION DEVICES
- DEFINITION OF SYSTEMS INTERFACE RELATIONSHIPS
- MARRIAGE OF DEVICE CONCEPTS TO PROPULSION REQUIREMENTS
- SELECTION OF SYSTEM FOR PRELIMINARY DESIGN

PRELIMINARY DESIGN

- SYSTEM LAYOUT
- DESIGN DETAILS
- CONSTRUCTION OF INSTALLATION MOCKUP
- RECOMMENDATIONS FOR METHODS OF
  - SYSTEM QUALIFICATION
  - CREW TRAINING

PROGRAM SCHEDULE



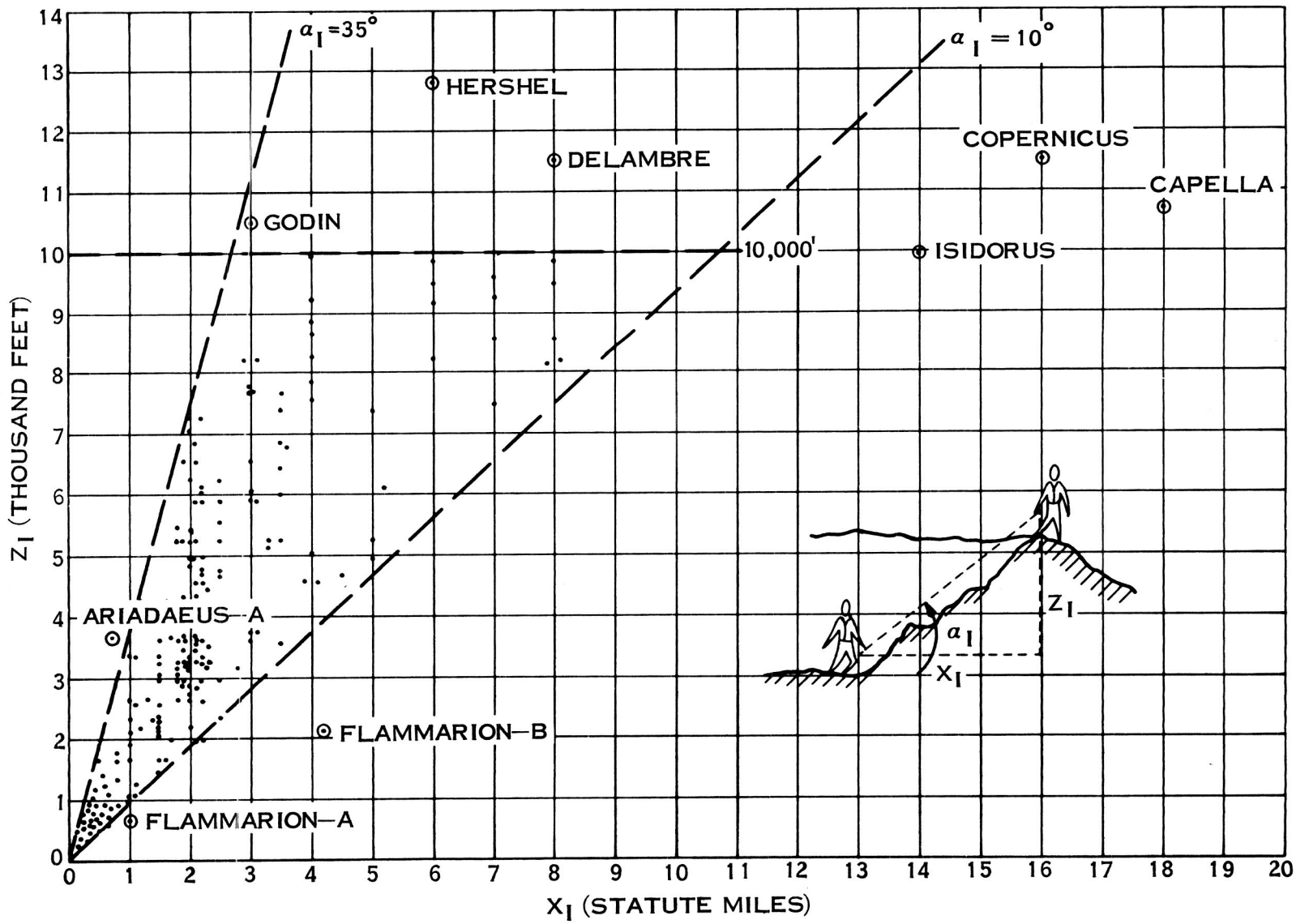
LUNAR MISSION ANALYSIS CONSIDERATIONS

- POTENTIAL LUNAR MISSIONS
  - 4 HR. LEM
  - 24 HR. LEM
  - 1 WEEK LEM
  - LUNAR BASES
- POSSIBLE LANDING SITES AND TOPOLOGY
- EXPLORER'S WALKING CAPABILITY AND PORTABLE LIFE SUPPORT SYSTEM CAPACITY
- LUNAR ROVER
- EMERGENCY CONSIDERATIONS
- SINGLE FAILURE CONCEPT

LUNAR TOPOGRAPHICAL MODELS

	GENERAL SLOPES	OBSTACLES
● MARIA	– 2°–4° LOCALLY	– GENERALLY ~ 4 INCHES – CAN BE AS HIGH AS 24–30 INCHES
● HIGHLANDS	– 10°–15° LOCALLY	– FREQUENTLY 4–24 INCHES LOCALLY – CAN BE AS HIGH AS 10–20 FEET LOCALLY – MOUNTAIN HEIGHTS 15,000–25,000 FEET
● RILLES	– ~ 10° ON APPROACHES – 45°–90° ON WALLS – ~ 6° ON FLOORS	– FREQUENTLY 4–24 INCHES LOCALLY ON APPROACHES AND FLOORS – DEPTHS 300–1200 FEET – WIDTHS 1/2–1 MILE – LENGTHS 10–300 MILES
● FAULTS	– ~ 5° ON APPROACHES – 45°–90° ON WALLS	– FREQUENTLY 4–24 INCHES LOCALLY ON APPROACHES – WALL HEIGHTS LESS THAN 1200 FEET – LENGTHS LESS THAN 70 MILES
● CRATERS	– ~ 10° ON APPROACHES – 5–45° ON WALLS – ~ 6° ON FLOORS	– FREQUENTLY 4–24 INCHES LOCALLY ON APPROACHES AND FLOORS – GENERALLY 2–10 FEET LOCALLY ON WALLS – CAN BE AS HIGH AS ~ 1,000 FEET ON WALLS – RIM TO FLOOR VERTICAL DISTANCE UP TO ~ 13,000 FEET – RIM TO FLOOR HORIZONTAL DISTANCE UP TO ~ 18 MILES – DIAMETERS UP TO 60 MILES

LUNAR CRATERS
(± 10° LAT., ± 50° LONG.)



SUITED ASTRONAUT MODEL

• WALKING SPEED

	4,24 HR LEM	168 HR LEM	LUNAR BASE
– AVERAGE, ON LEVEL SURFACE	.7 – 1 MPH	1 – 1.5 MPH	1.3 – 2 MPH
– MAXIMUM (FOR 10 MINUTES)	2 MPH	3 MPH	3 MPH

• OBSTACLE CLEARANCE

– HEIGHTS (WIDTH NEGLIGIBLE)	12 INCHES
– WIDTHS (OVER A 5 INCH HIGH OBSTACLE)	12 INCHES

• WEIGHTS

– 50TH PERCENTILE MAN	160 LBS.
– SUIT AND PLSS	80 LBS.
– ACCESSORY EQUIPMENT	20 LBS
TOTAL (EARTH WEIGHT)	260 LBS

• TIME FACTORS

– NORMAL SITUATIONS

	DESIGN	25 % RESERVE
– RESTING	4 HRS.	3 HRS.
– INTEGRATED MISSION PROFILE	4 HRS.	3 HRS.
– WALKING	3.2 HRS.	2.4 HRS.

– EMERGENCY SITUATIONS

– PLSS FAILURES	5–120 MINUTES
– SOLAR FLARES	60 MINUTES

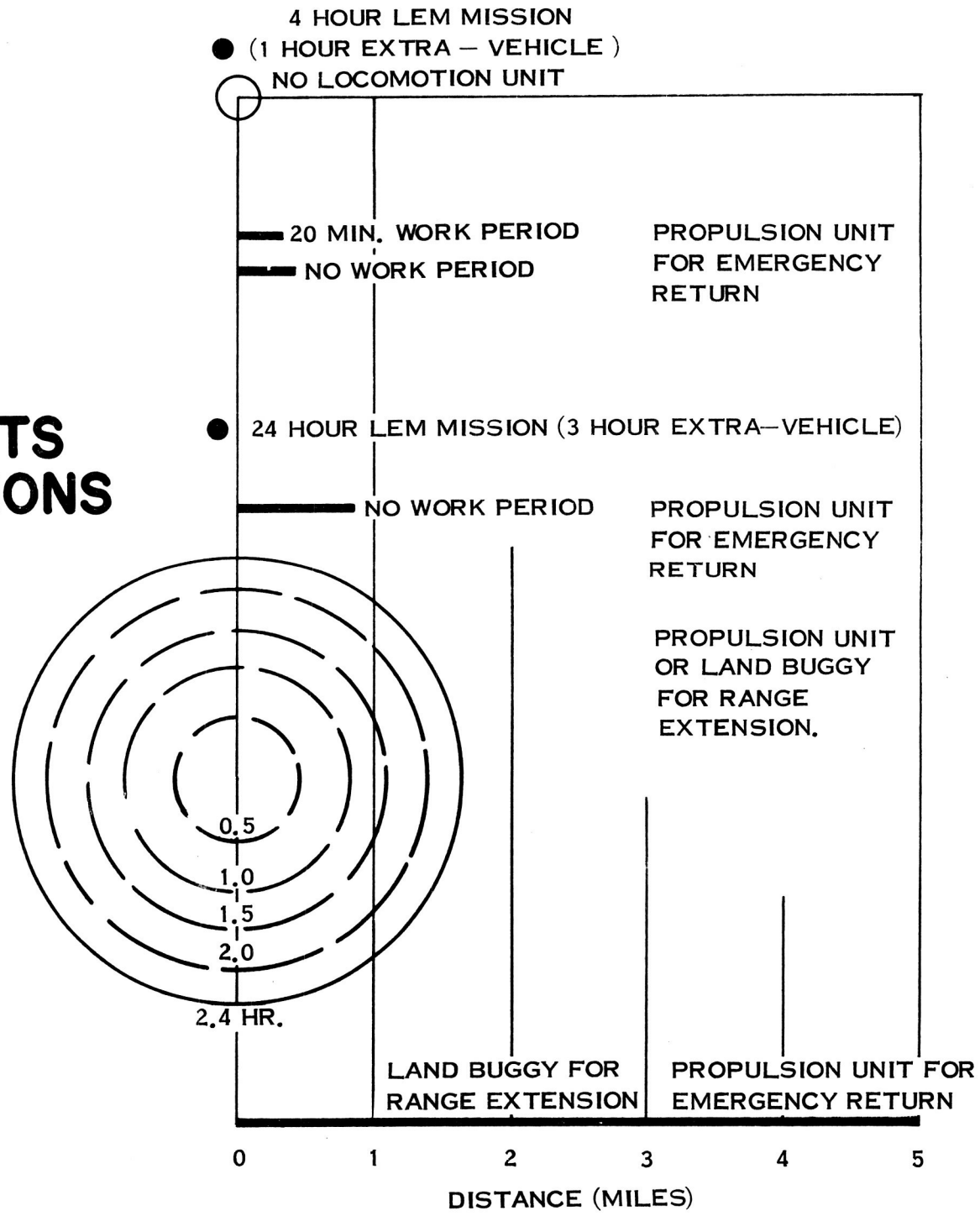
LUNAR ROVER MODELS

	MODEL – 1	MODEL – 2	MODEL – 3	MODEL – 4
• MISSIONS	EARLY LEM–168	LATER LEM–168	EARLY LUNAR BASE	LATER LUNAR BASE
• CREW SIZE	1	2	2	3
• CABIN	OPEN	CLOSED	CLOSED	CLOSED
• ECS	LRV OUTLET FOR SUIT	LRV	LRV	LRV
• MISSION DURATION	1 DAY	2 DAYS	7 DAYS	28 DAYS
• WEIGHT (EARTH LBS.)	1,500 LBS	3,000–4,000 LBS	6,000–8,000 LBS	11,000–23,000 LBS
• POWER	1 KW	1 1/2 KW	3–6 KW	14–31 KW
• SPEED CAPABILITIES				
– AVERAGE	2.5 MPH	2.5 MPH	5 MPH	5 MPH
– MAXIMUM	5 MPH	5 MPH	10 MPH	10 MPH
• SLOPE CAPABILITIES	10°–40°	10°–40°	45° MAX.	45° MAX.
• OBSTACLE CAPABILITIES				
– HEIGHTS	7–40 INCHES	7–40 INCHES	> 3 FEET	> 3 FEET
– CREVICE WIDTHS	45–60 INCHES	45–60 INCHES	45–60 INCHES	45–60 INCHES
• RANGE	20–60 MILES	60–100 MILES	200 MILES	300 MILES
• VEHICLES PER MISSION	1	1	1–2	≥ 2

LUNAR MISSION MODELS

MISSION	RANGE (MILES)	OMLS EQUIPMENT
● 4 HOUR LEM, 1 HOUR EXTRA-VEHICLE		
● EXPLORATION OF AREA WITHIN 5 MINUTE WALK–BACK RADIUS	1/6	NONE
● EXPLORATION ALONG PATH WITH A 1 HOUR WALKING RANGE	.41	PROPULSION UNIT FOR EMERGENCY RETURN IN 5 MINUTES
● OBSTACLE CLEARING		NONE–NO LARGE OBSTACLES EXPECTED ON ABOVE MISSIONS
● 24 HOUR LEM, 3 HOUR EXTRA-VEHICLE		
● EXPLORATION ALONG PATH WITH A 3 HOUR WALKING RANGE	.83	PROPULSION UNIT FOR EMERGENCY RE–TURN IN 5 MINUTES
● EXPLORATION OF AREA WITHIN SAFE WALK–BACK RADIUS	1.65	• PROPULSION UNIT FOR RANGE EXTENSION • LAND BUGGY FOR RANGE EXTENSION • LAND BUGGY FOR PLUS PROPULSION UNIT FOR EMERGENCY RETURN
● OBSTACLE CLEARING		NONE
● EXPLORATION ALONG PATH WITH A RANGE EXCEEDING WALKING CAPABILITY	5	LAND BUGGY PLUS PROPULSION UNIT
● 168 HOUR LEM AND BASES		
● GO TO SHELTER AND RETURN	1	PROPULSION UNIT FOR EMERGENCY RETURN
● EXPLORATION OF ROUGH TERRAIN		PROPULSION UNIT
● EMERGENCY RETURN–ROVER TO SHELTER		PROPULSION UNIT
• 168 HOUR LEM	3–50	
• LUNAR BASES	4–100	

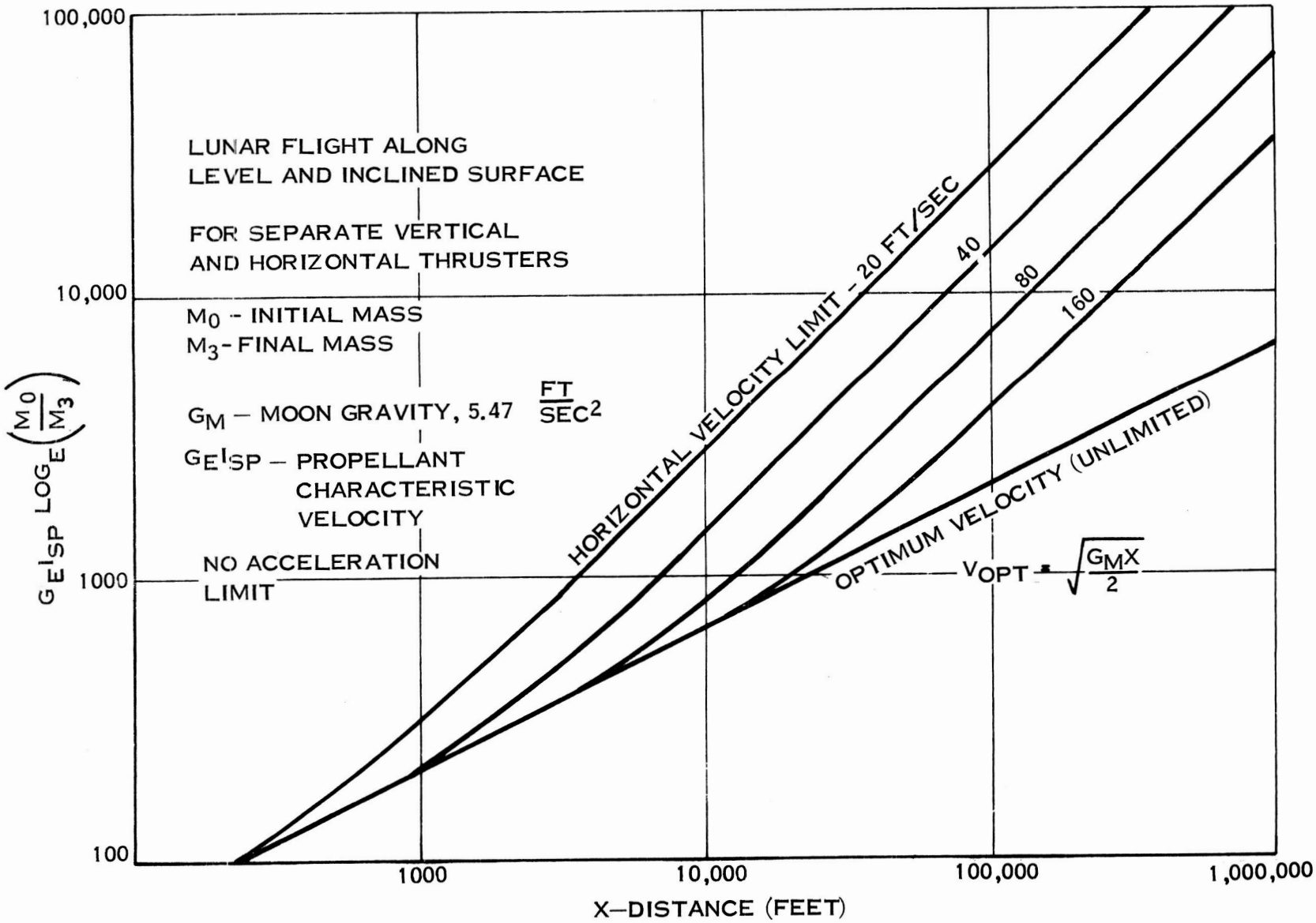
EXPLORATION LIMITS FOR VARIOUS MISSIONS



PROPELLANT REQUIREMENT VS RANGE
NO ACCELERATION OR VELOCITY LIMIT

FLIGHT MODE	FUEL FACTOR $\frac{g_e I_{sp} \log_e\left(\frac{\text{initial weight}}{\text{final weight}}\right)}{\sqrt{g_m X}}$
• BALLISTIC • ANGLED THRUSTER-45° (OPT)	2.0
• FLYING	
• SINGLE ANGLED THRUSTER	
• CONSTANT HORIZONTAL ACCELERATION-45° (OPT)	2.828
• VARIABLE HORIZONTAL ACCELERATION	2.46-2.63
• SEPARATE VERTICAL AND HORIZONTAL THRUSTERS	
• IMPULSE HORIZONTAL ACCELERATION (OPT)	2.828
• CONSTANT HORIZONTAL ACCELERATION-g_m (OPT)	4.0
• CONSTANT HORIZONTAL ACCELERATION-g_m WITH CONSTANT VELOCITY MID-FLIGHT	3.48

MASS RATIO VS RANGE



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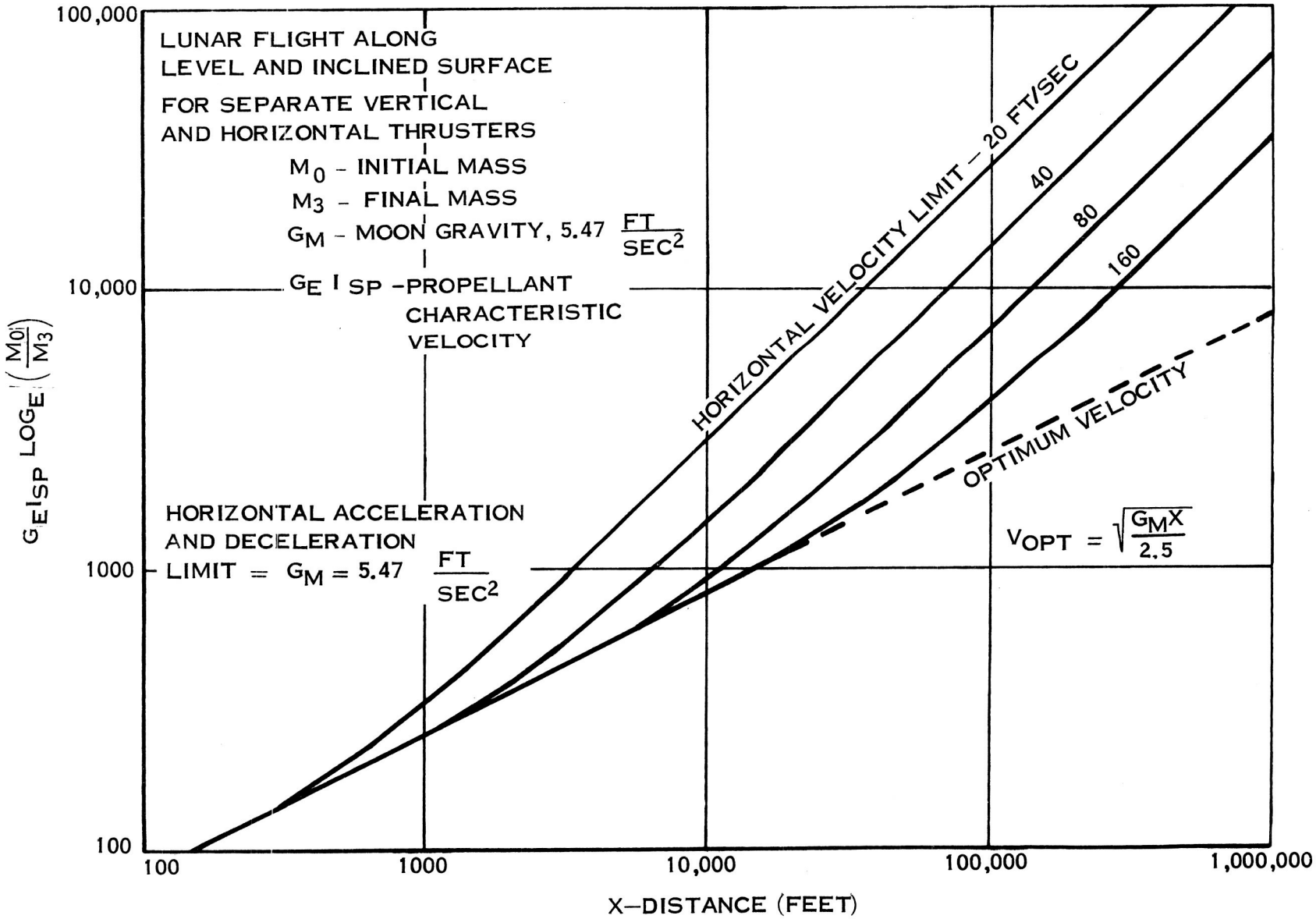
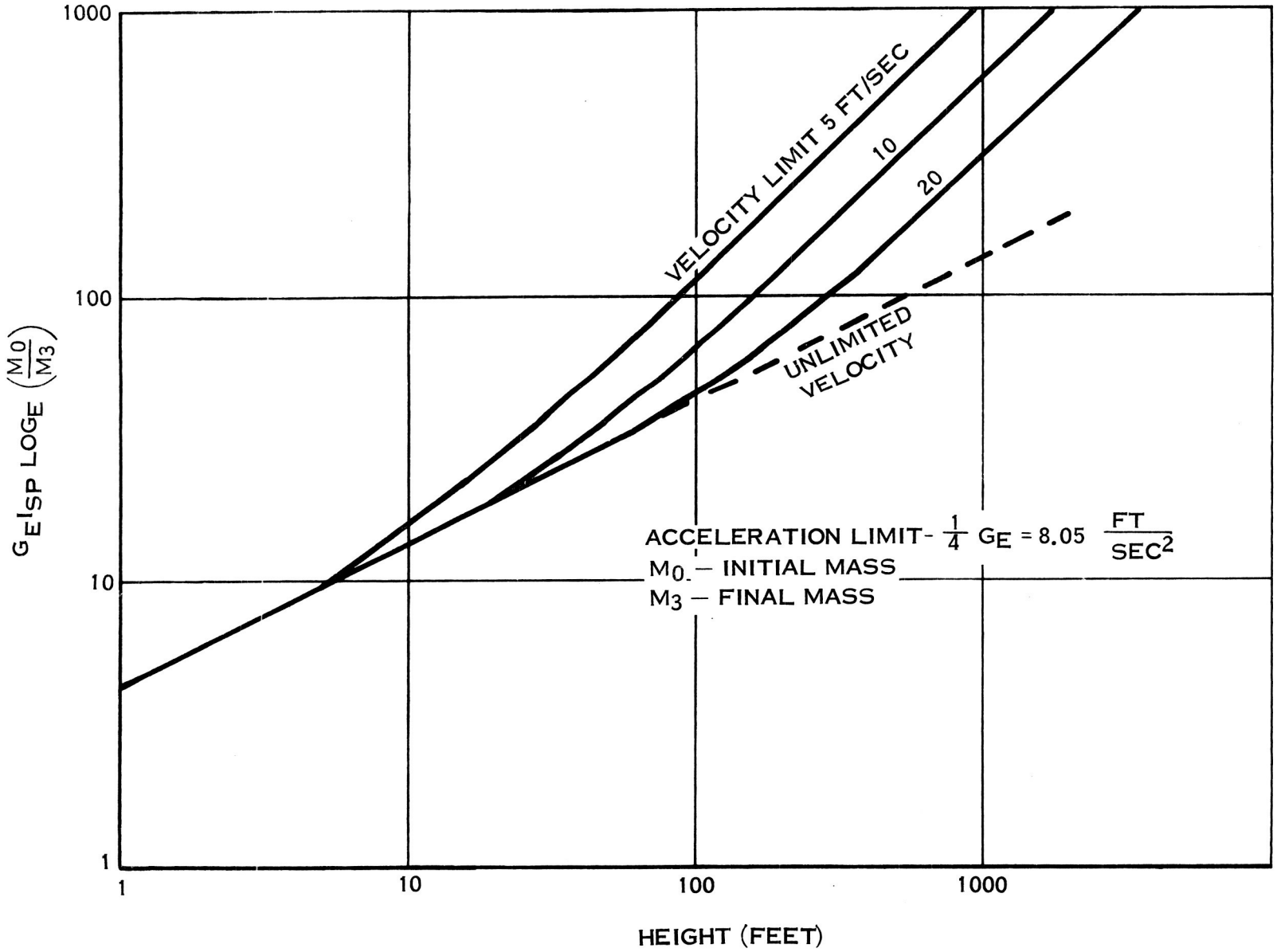
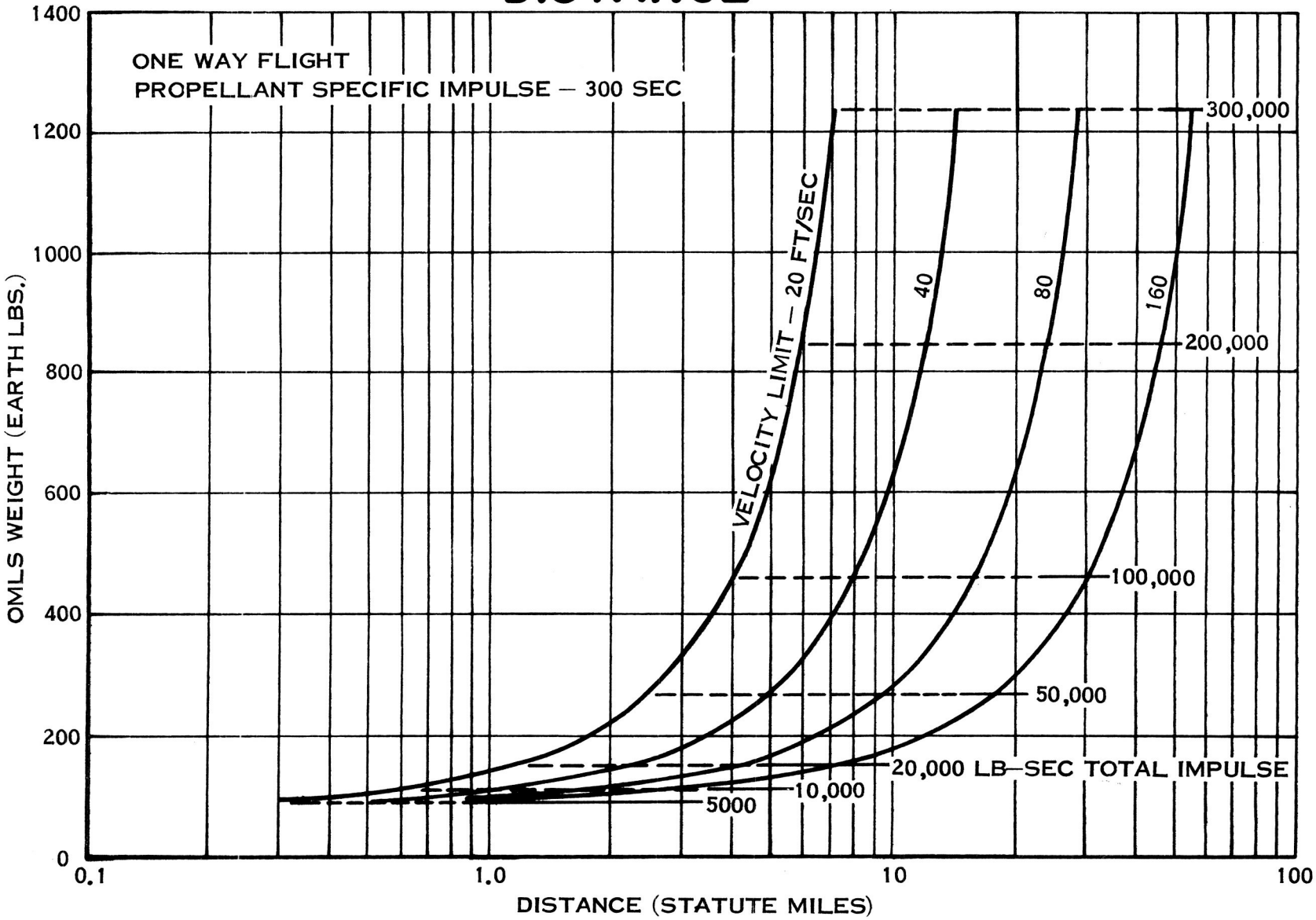


MASS RATIO VS HEIGHT
LUNAR SURFACE



WEIGHT OF ONE MAN LOCOMOTION SYSTEM
VS
DISTANCE



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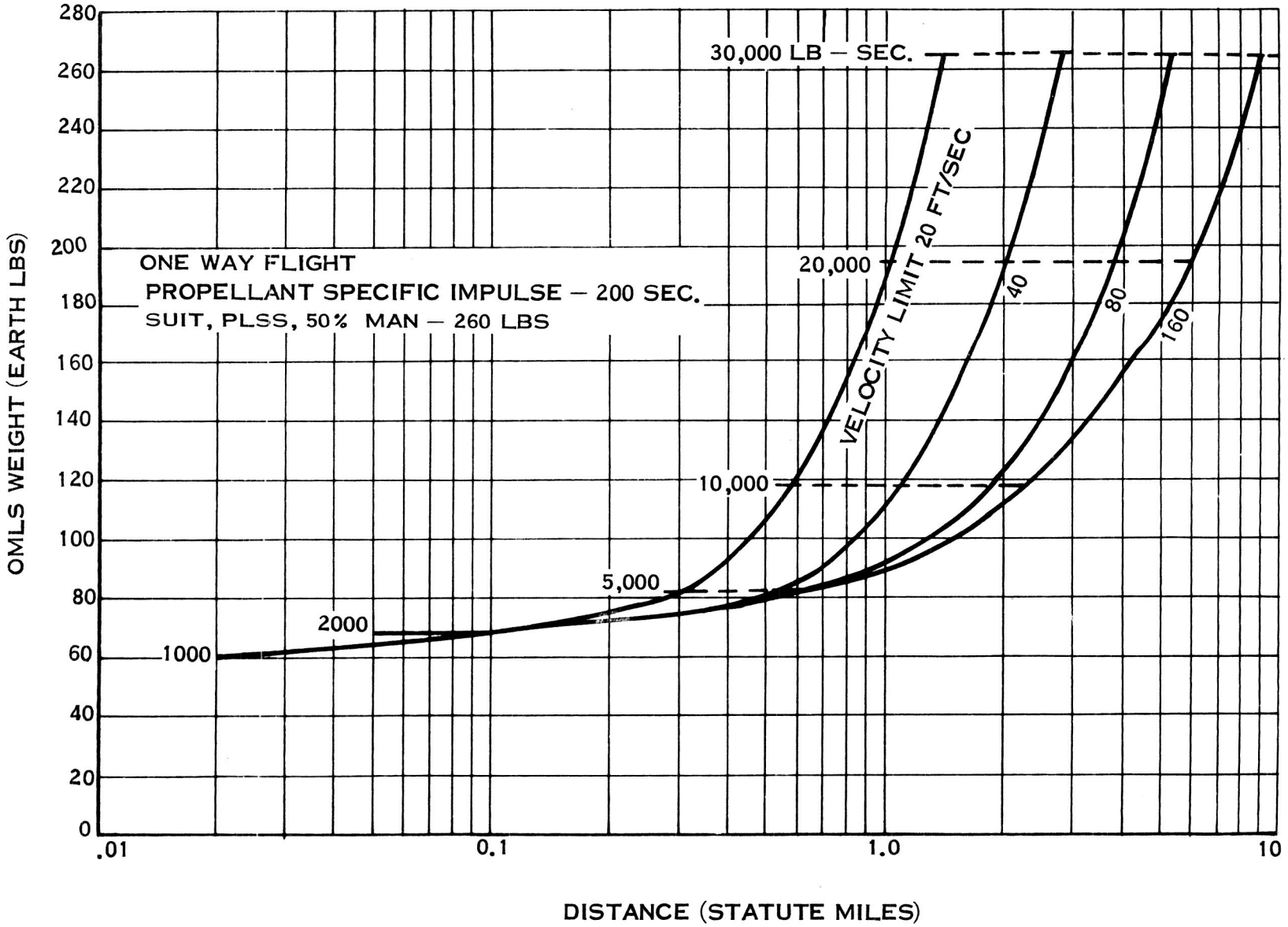
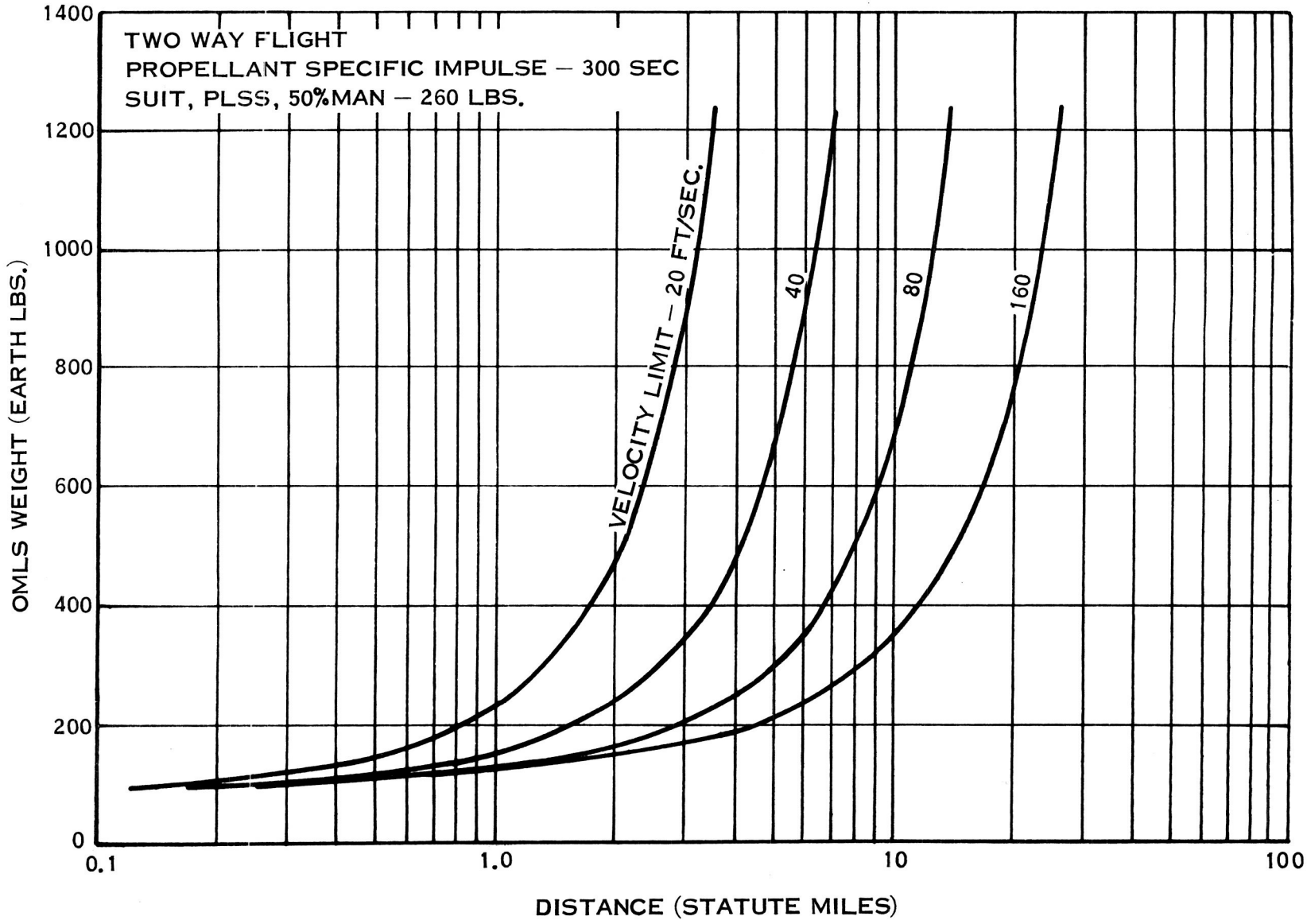


WEIGHT OF ONE MAN LOCOMOTION SYSTEM VS DISTANCE ONE WAY



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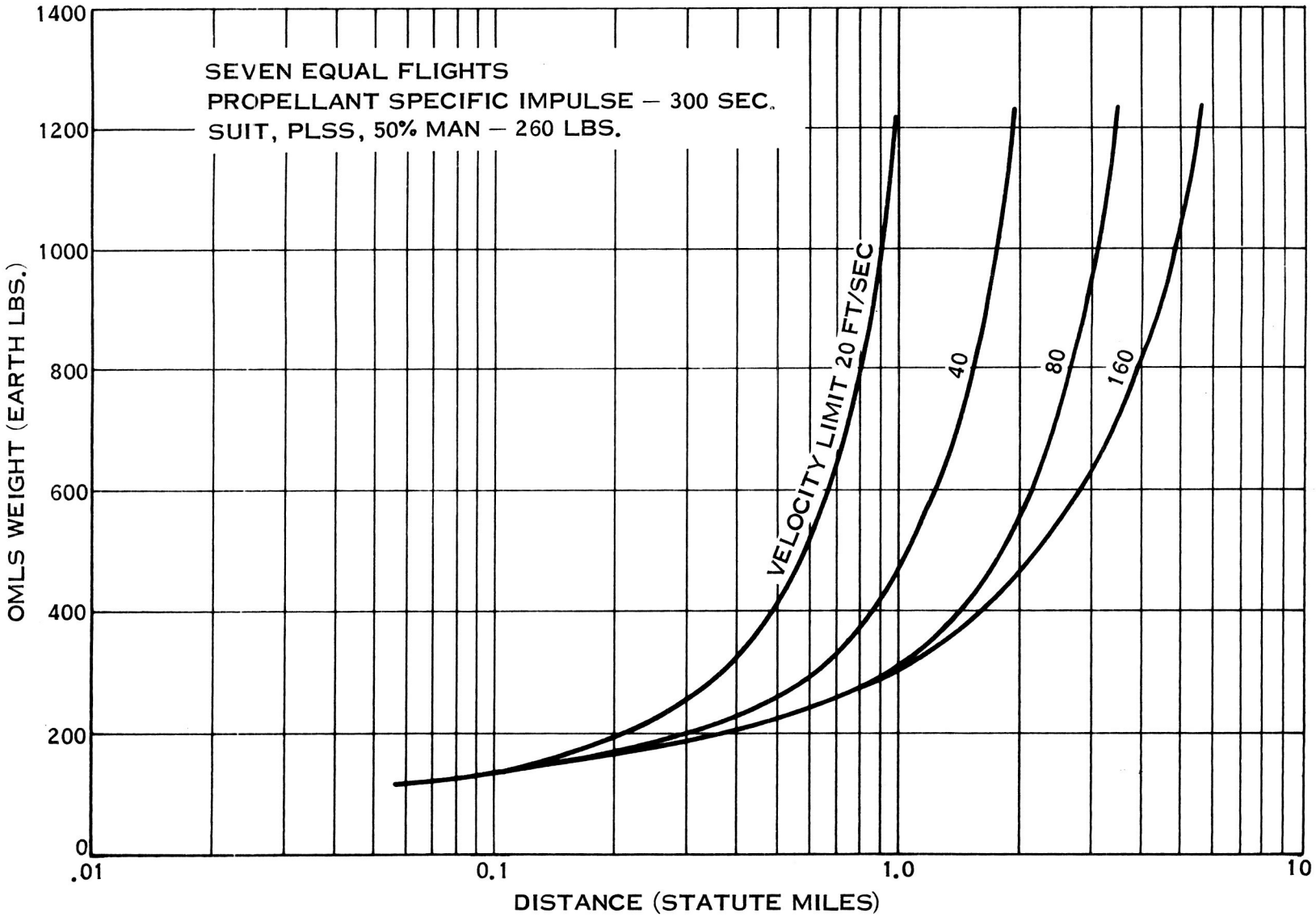
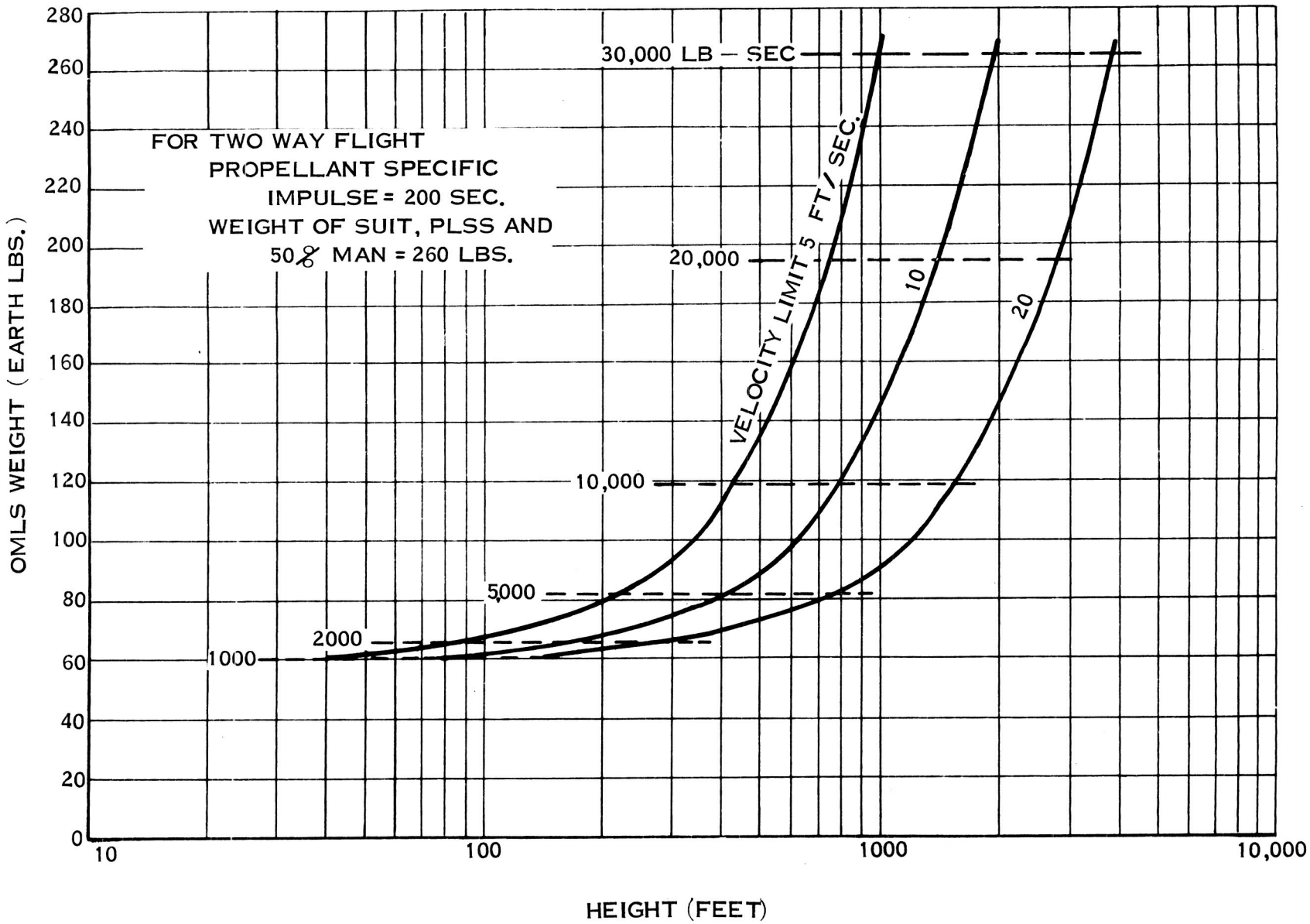


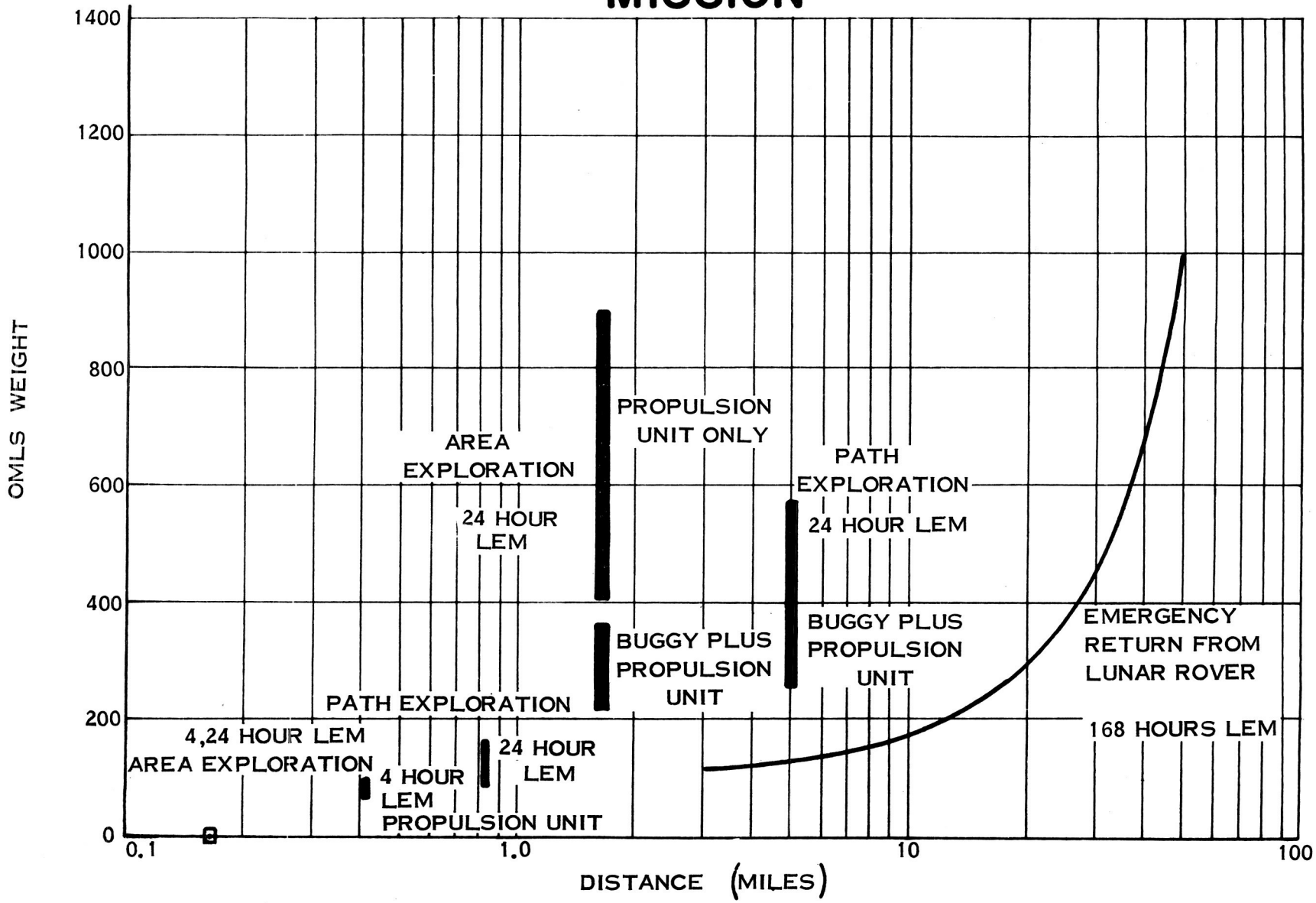
WEIGHT OF ONE MAN LOCOMOTION SYSTEM VS HEIGHT



LAND BUGGY

- SMALL VEHICLE - OPEN CONSTRUCTION - TRACK DRIVE
- AVERAGE SPEED 3-5 MPH
- MAXIMUM SPEED 7-10 MPH
- SLOPE CAPABILITY 15 DEG
- OBSTACLE CLEARING CAPABILITY
  - STEP 1 FT
  - CREVICE 3.5 FT
- POWER (MAXIMUM) 1.23 KW
- SIZE
  - DRIVE WHEEL RADIUS 1 FT
  - TRACK LENGTH - GROUND CONTACT 6.5 FT
- DRAW BAR PULL 70 LB
- WEIGHT ESTIMATE 120-200 LB

WEIGHT SUMMARY VS MISSION



PROPELLANTS SURVEYED FOR OMLS APPLICATION

LIQUID BI-PROPELLANTS

FUEL	OXIDIZER
B_5H_9	H_2O_2
B_5H_9	N_2O_4
B_5H_9	ClO_3F
N_2H_4	ClF_3
N_2H_4	ClO_3F
N_2H_4	N_2O_4
AEROZINE - 50	N_2O_4
UDMH	ClO_3F
MMH	N_2O_4
B_5H_9	ClF_3
MMH	ClF_3
AEROZINE - 50	ClF_3
UDMH	N_2O_4
N_2H_4	H_2O_2
UDMH	H_2O_2
N_2H_4	RFNA
MMH	H_2O_2
AEROZINE - 50	H_2O_2
MMH	RFNA
AEROZINE - 50	RFNA
UDMH	ClF_3
UDMH	RFNA
C_4N_2	N_2O_4
C_4N_2	H_2O_2

MONO PROPELLANTS

LIQUIDS

CAVEA - B
N_2H_4 - $N_2H_5NO_3$
N_2H_4
AEROZINE - 50
ETHYL NITRATE - PROPYL NITRATE
ETHYLENE OXIDE
PROPYL NITRATE
H_2O_2

GASES

HYDROGEN
HELIUM
NITROGEN
ARGON
FREON

HYBRIDS

FUEL	OXIDIZER
PMM	GO_2
B_5H_9	NH_4ClO_4
PMM	H_2O_2
PMM	N_2O_4
N_2H_4	NH_4ClO_4
UDMH	NH_4ClO_4
PMM	RFNA

SOLIDS

METALLIZED SOLIDS
NON-METALLIZED SOLIDS

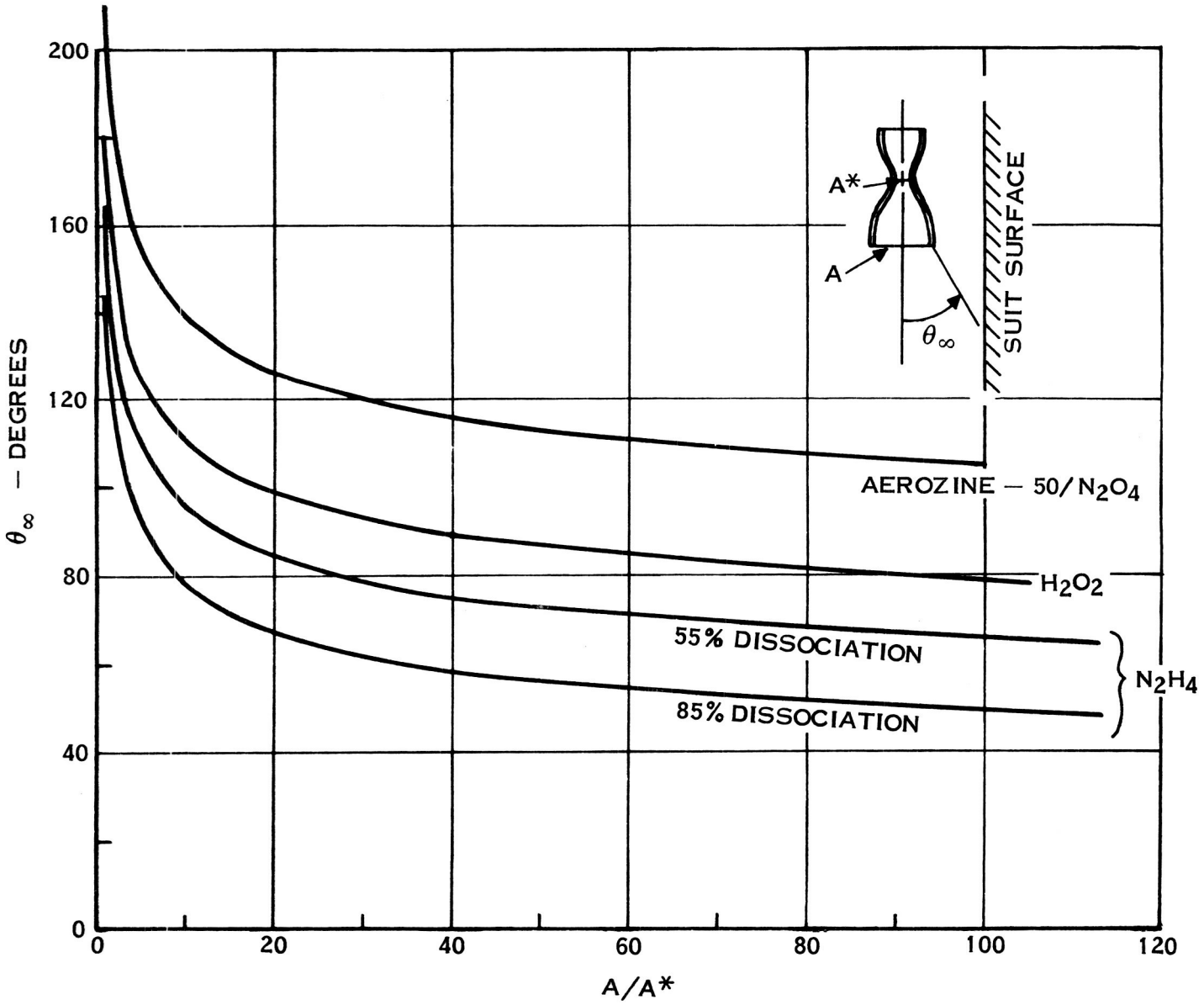
PROPELLANTS ELIMINATED IN INITIAL SCREENING

PROPELLANTS ELIMINATED	REASONS FOR ELIMINATION: SOLIDS IN EXHAUST	SERIOUS HAZARDS	SEVERE STORAGE PROBLEMS	"STATE OF THE ART" QUESTIONABLE	I_{SP} TOO LOW
B_5H_9/NH_4ClO_4	X	X	X	X	
B_5H_9/H_2O_2	X	X	X		
B_5H_9/N_2O_4	X	X	X		
B_5H_9/ClO_3F	X	X	X		
N_2H_4/ClF_3		X	X		
N_2H_4/ClO_3F		X	X		
$UDMH/ClO_3F$		X	X		
B_5H_9/ClF_3	X	X	X		
MMH/ClF_3		X	X		
$AEROZINE-50/ClF_3$		X	X		
$UDMH/ClF_3$		X	X		
C_4N_2/N_2O_4	X			X	
C_4N_2/H_2O_2	X			X	
CAVEA - B		X			
ETHYLENE OXIDE	X				
ARGON GAS					X
FREON GAS					X
N_2H_4/NH_4ClO_4				X	
$UDMH/NH_4ClO_4$				X	

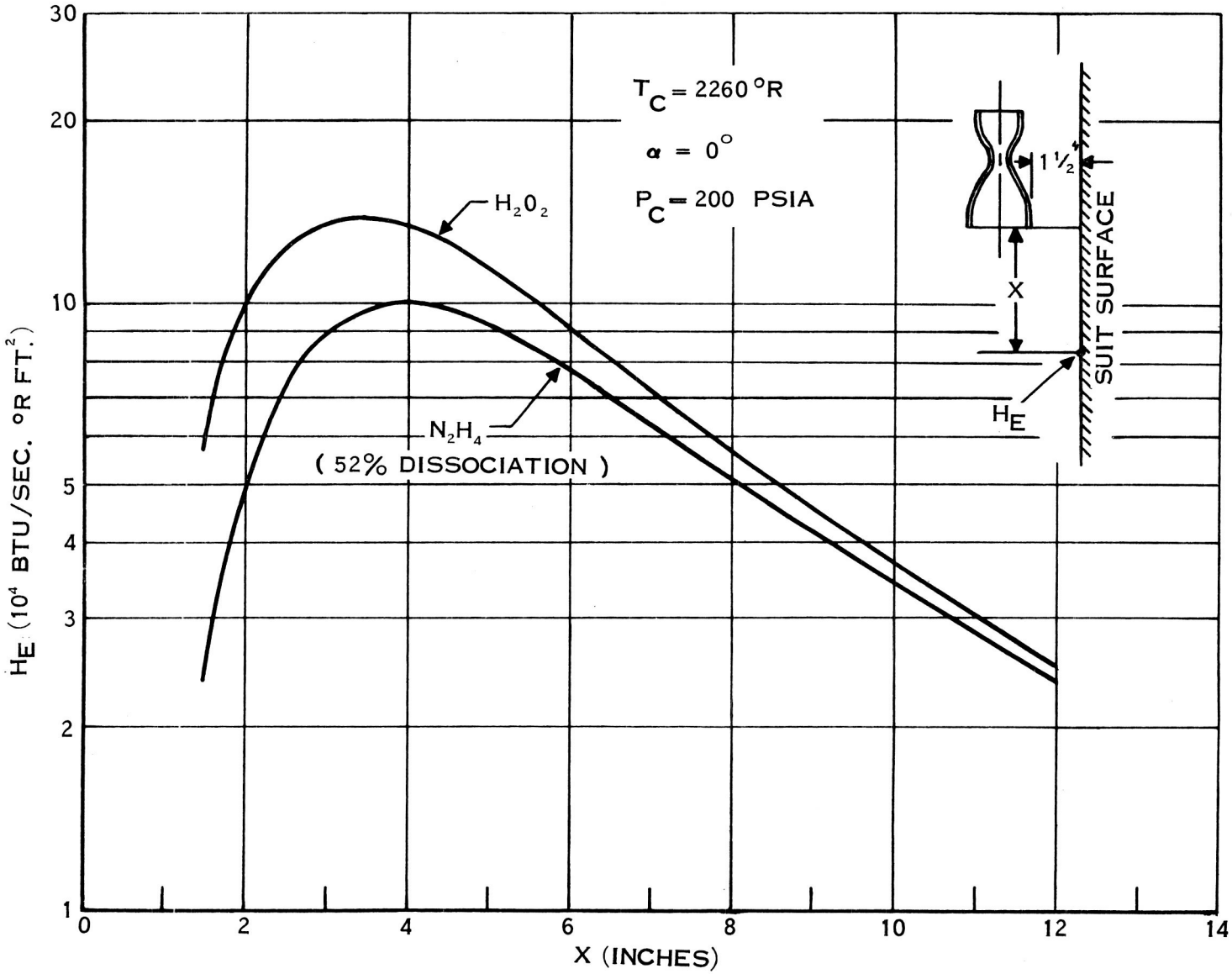
TYPICAL CHAMBER TEMPERATURES AND IMPULSE DATA

POTENTIAL PROPELLANTS	T_C (°R)	ESTIMATED DELIVERED VACUUM I_{SP} @ ε=50 : 1 $\left(\frac{LB_F\text{-SEC.}}{LB_M}\right)$	TYPICAL TOTAL IMPULSE PER UNIT VOLUME $\left(\frac{LB_F\text{-SEC.}}{FT^3}\right)$
PMM/GO_2	6,570	329	7,050
PMM/N_2O_4	6,210	298	23,100
UDMH/N_2O_4	6,172	333	24,750
MMH/N_2O_4	6,100	335	33,500
AEROZINE - 50/N_2O_4	6,049	337	25,600
AEROZINE - 50/H_2O_2	6,040	323	25,250
PMM/RFNA	5,900	267	20,650
N_2H_4/N_2O_4	5,864	338	26,200
UDMH/RFNA	5,800	318	25,050
MMH/RFNA	5,740	267	25,250
AEROZINE - 50/RFNA	5,710	323	25,600
UDMH/H_2O_2	5,403	327	25,700
PMM/H_2O_2	5,382	304	23,150
MMH/H_2O_2	5,320	323	25,600
N_2H_4/H_2O_2	5,272	331	26,450
N_2H_4/$N_2H_5NO_3$	2,660	269	18,500
PROPYL NITRATE	2,440	197	13,150
H_2O_2	2,282	169	15,450
AEROZINE - 50	1,980 - 2,856	235 - 258	13,150 - 14,450
N_2H_4	1,620 - 2,790	228 - 241	14,400 - 15,250
G H_2	540	292	390
G He	540	207	670
G N_2	540	78	1,630

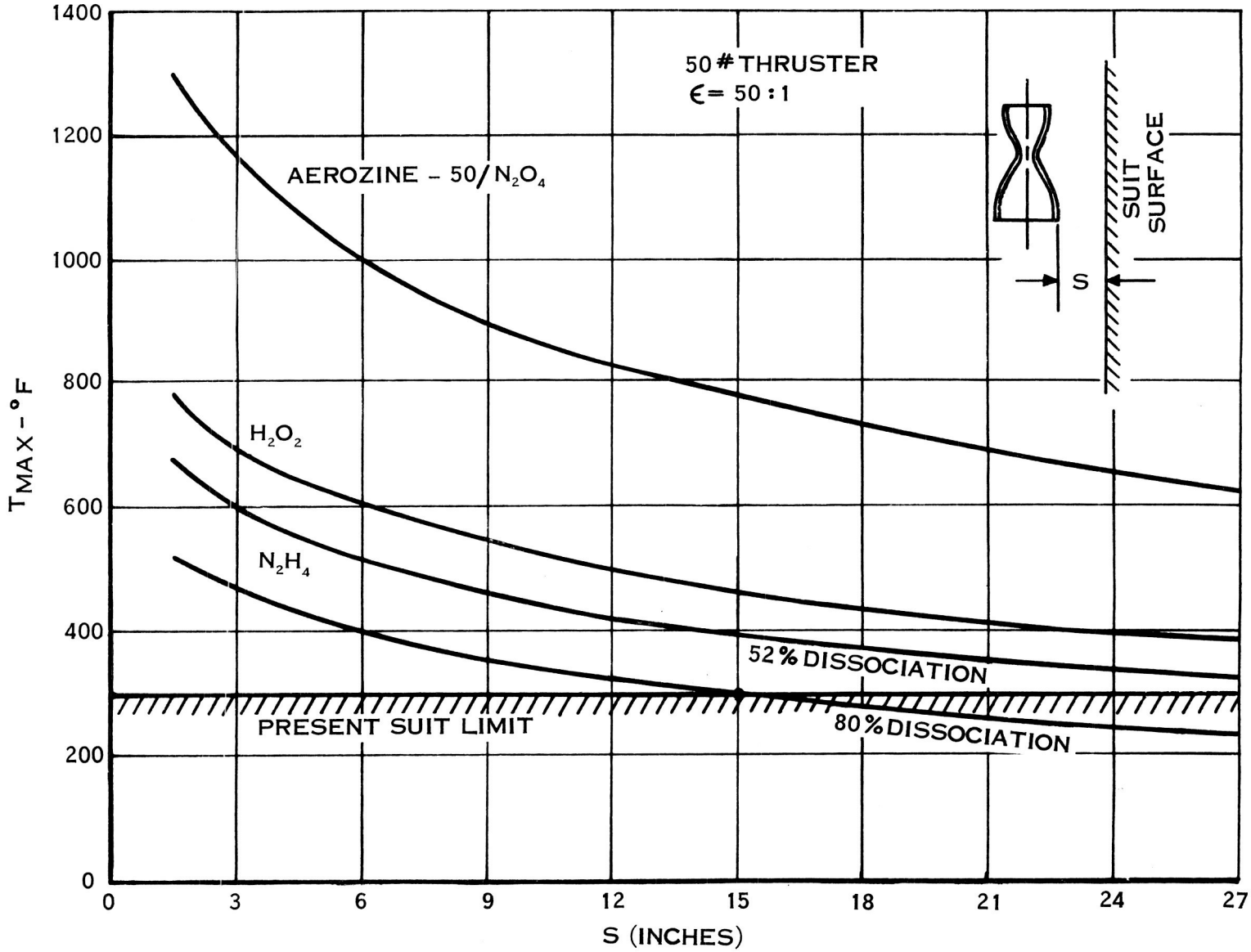
ROCKET NOZZLE EXHAUST PLUME ANGLES



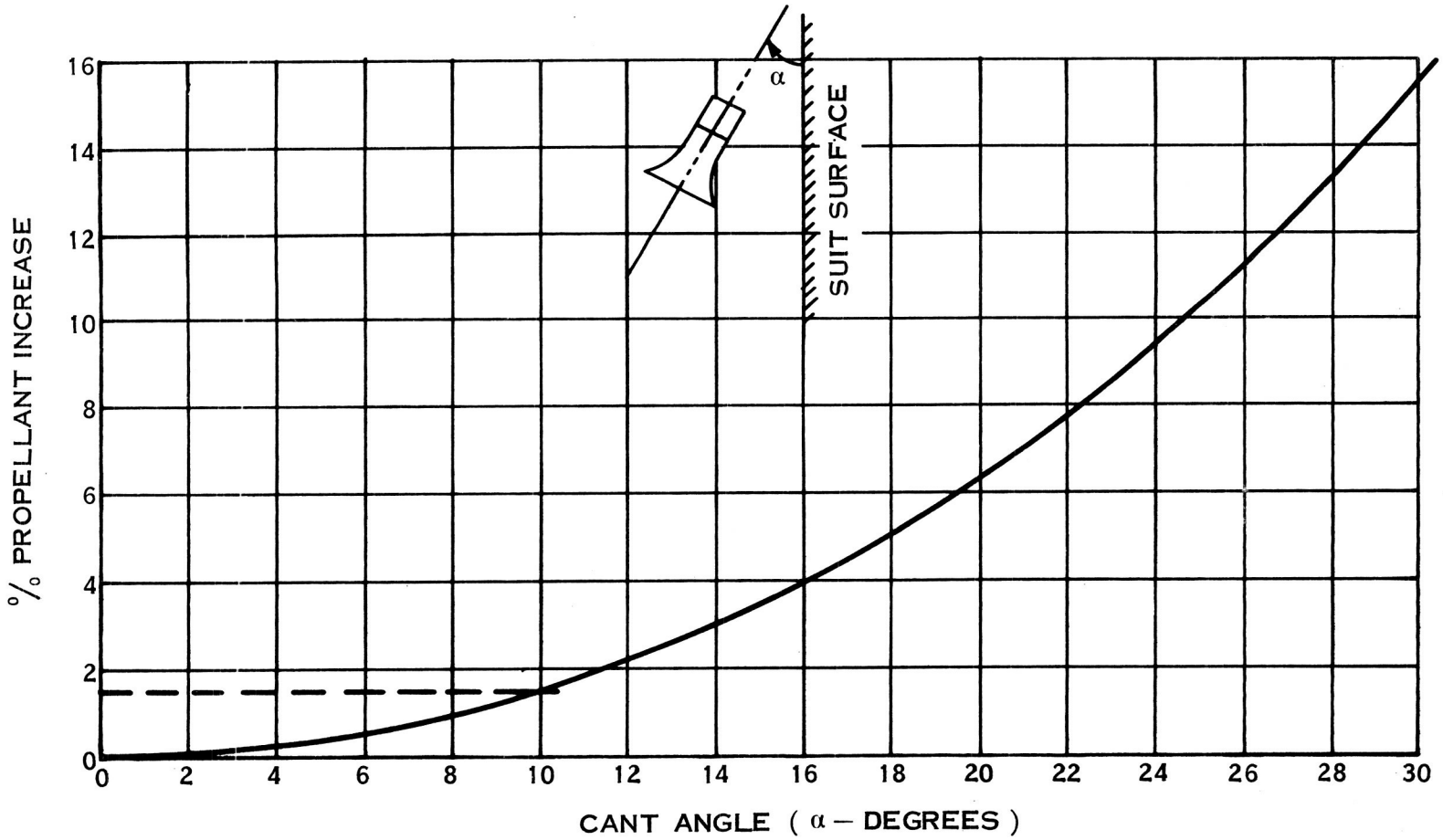
COMPARISON OF FILM COEFFICIENTS
HYDROGEN PEROXIDE VS HYDRAZINE



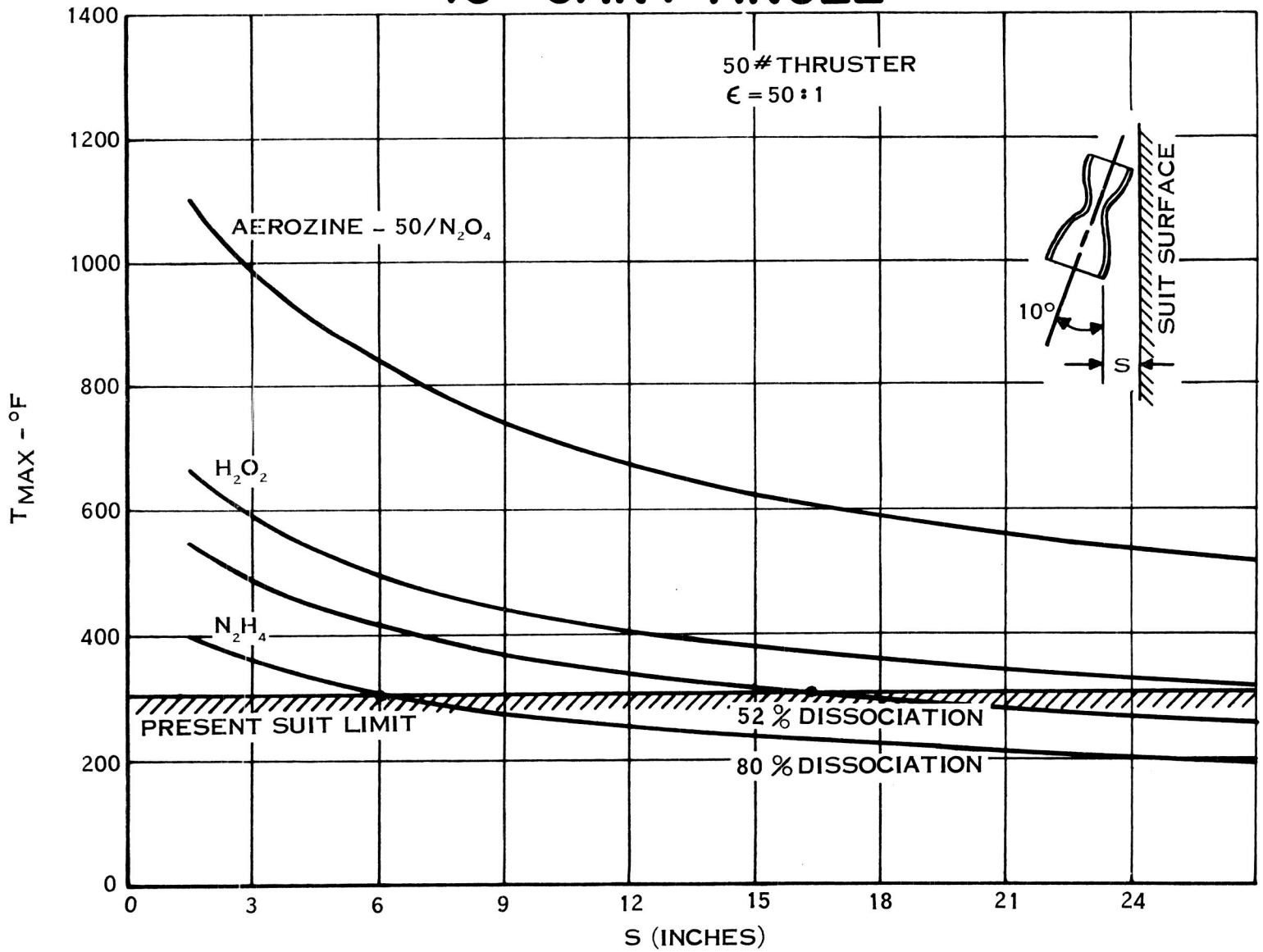
CALCULATED MAXIMUM SUIT SURFACE TEMPERATURE DUE TO EXHAUST PLUME

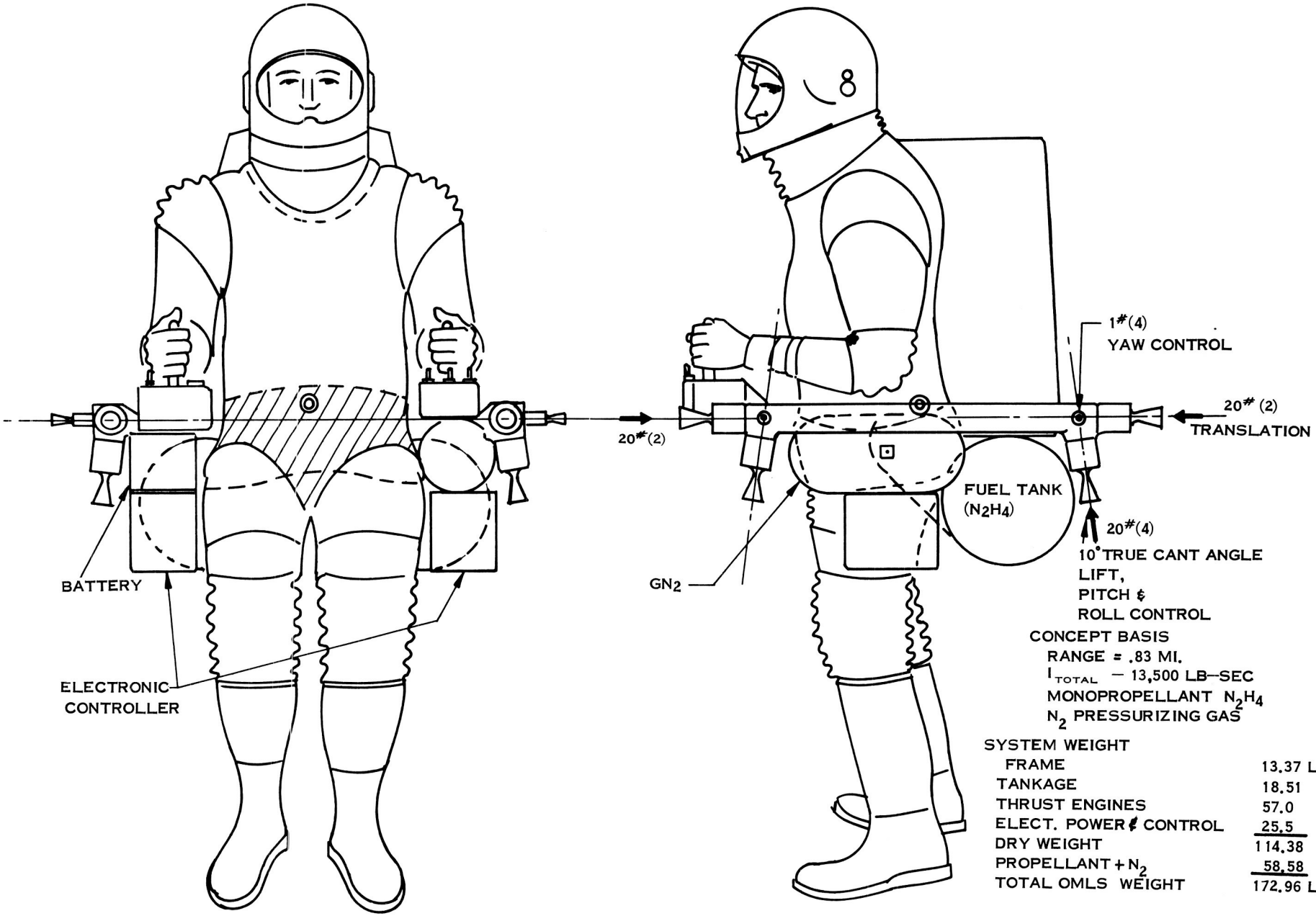


EFFECT OF NOZZLE CANT ANGLE ON PROPELLANT REQUIREMENTS



CALCULATED MAXIMUM SUIT SURFACE TEMPERATURE DUE TO EXHAUST PLUME 10° CANT ANGLE





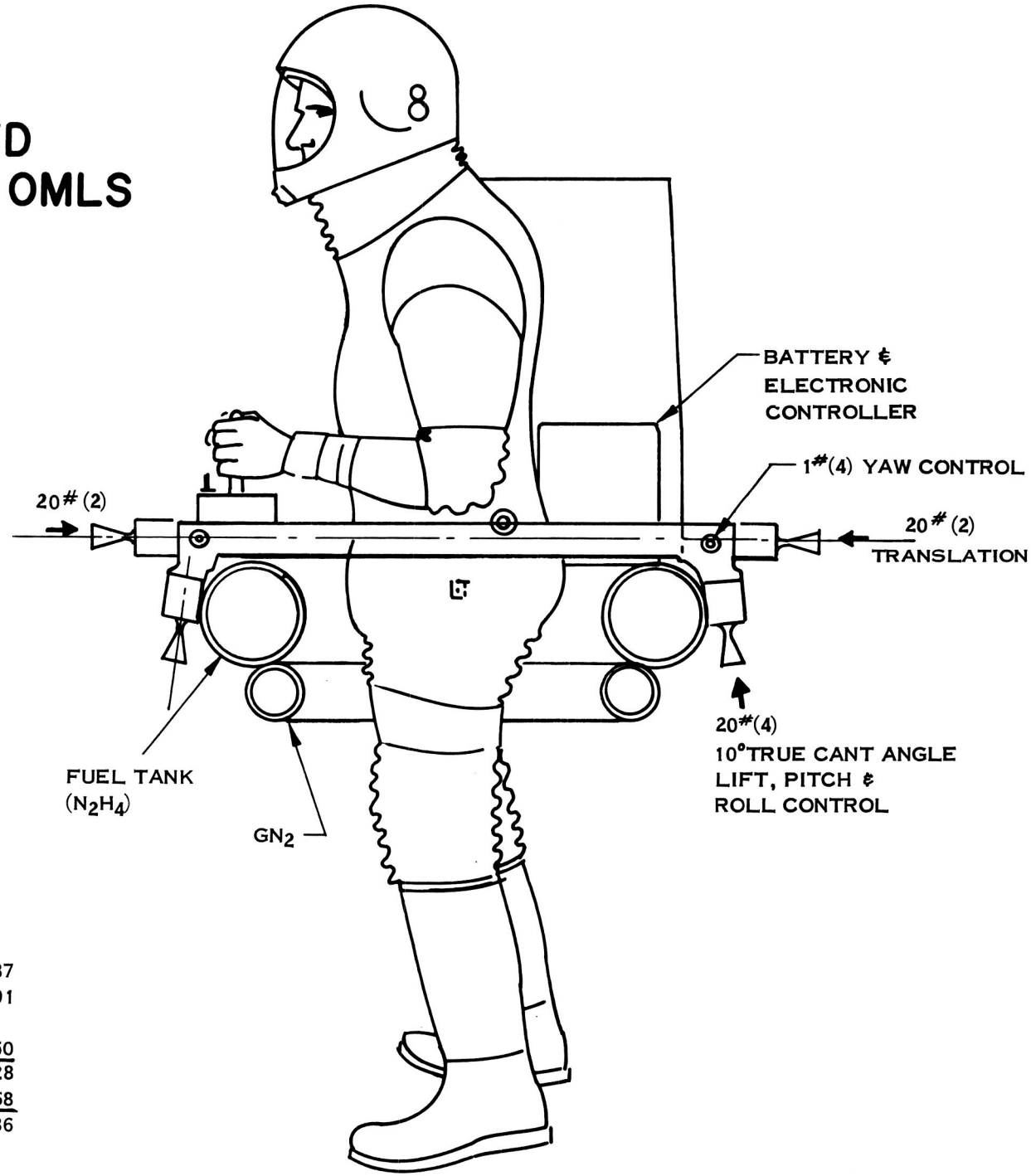
CONCEPT BASIS
- RANGE = .83 MI.
- I_{TOTAL} — 13,500 LB–SEC
- MONOPROPELLANT N_2H_4
- N_2 PRESSURIZING GAS

SYSTEM WEIGHT

FRAME	13.37 LBS
TANKAGE	18.51
THRUST ENGINES	57.0
ELECT. POWER & CONTROL	25.5
DRY WEIGHT	114.38
PROPELLANT + N_2	58.58
TOTAL OMLS WEIGHT	172.96 LBS

BODY-MOUNTED LUNAR SURFACE OMLS

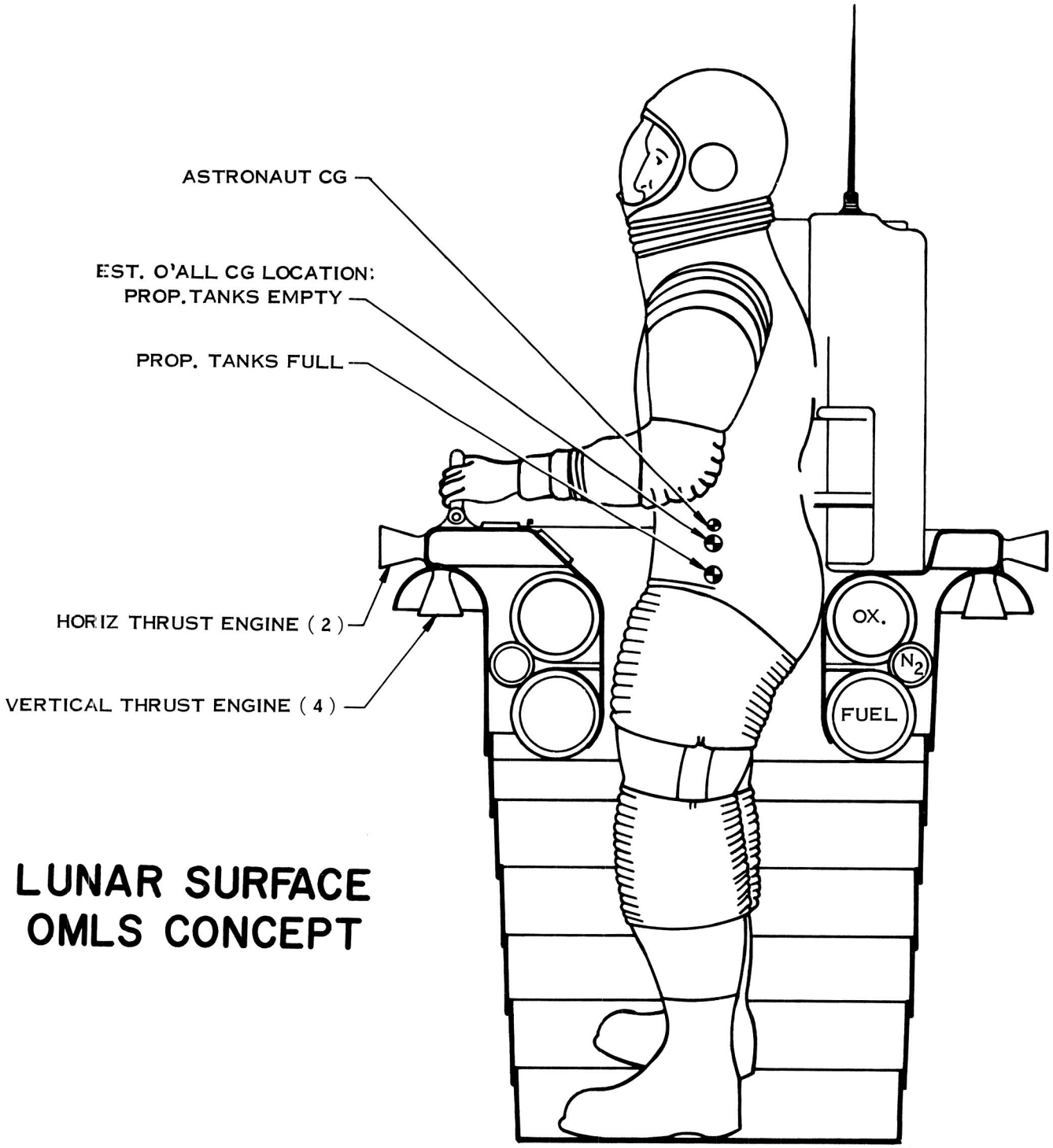
BODY-MOUNTED LUNAR SURFACE OMLS



CONCEPT BASIS
- RANGE = .83 MI.
- I_{TOTAL} – 13,500 LB–SEC
- MONOPROPELLANT N_2H_4
- N_2 PRESSURIZING GAS

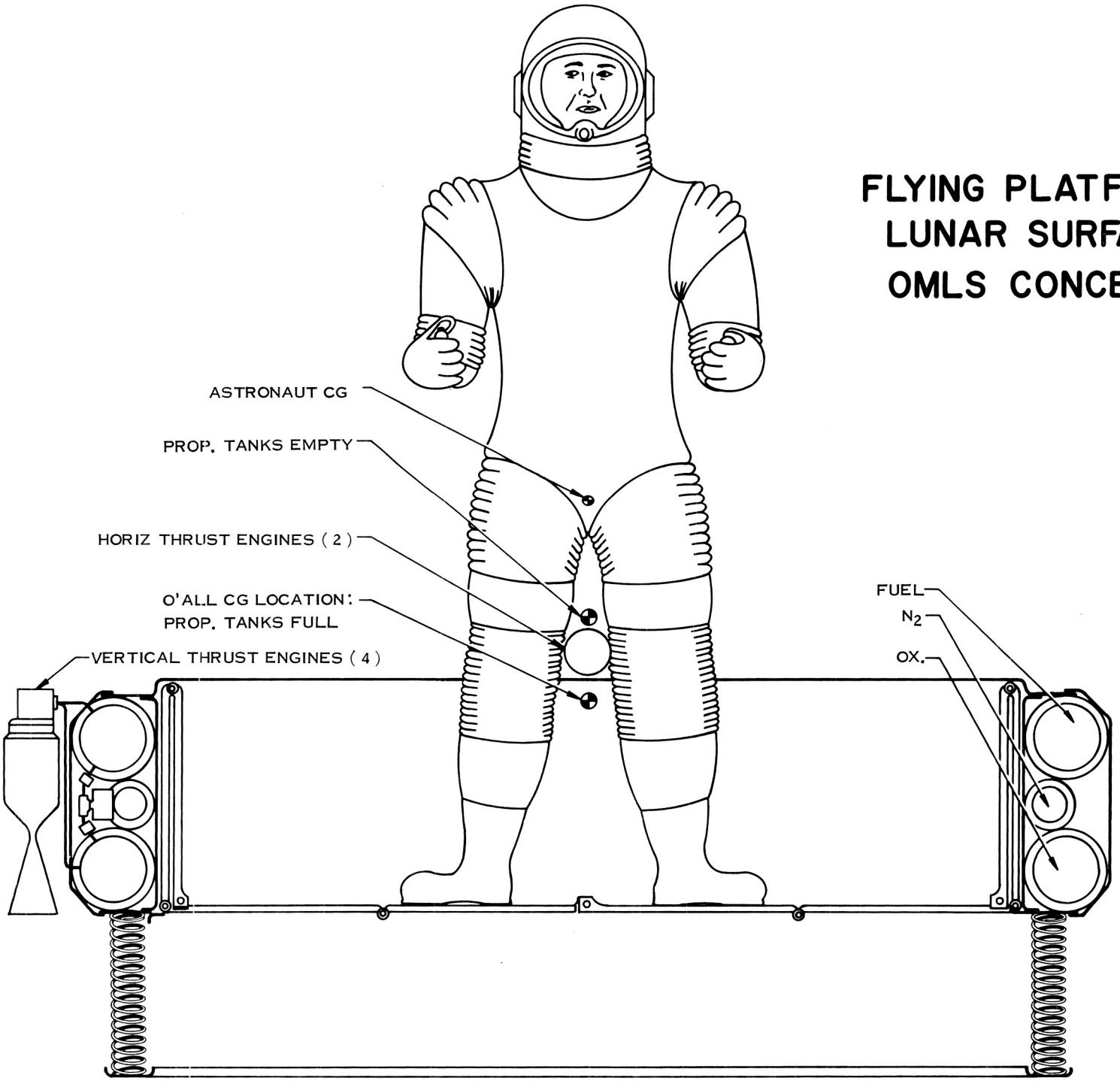
SYSTEM WEIGHT

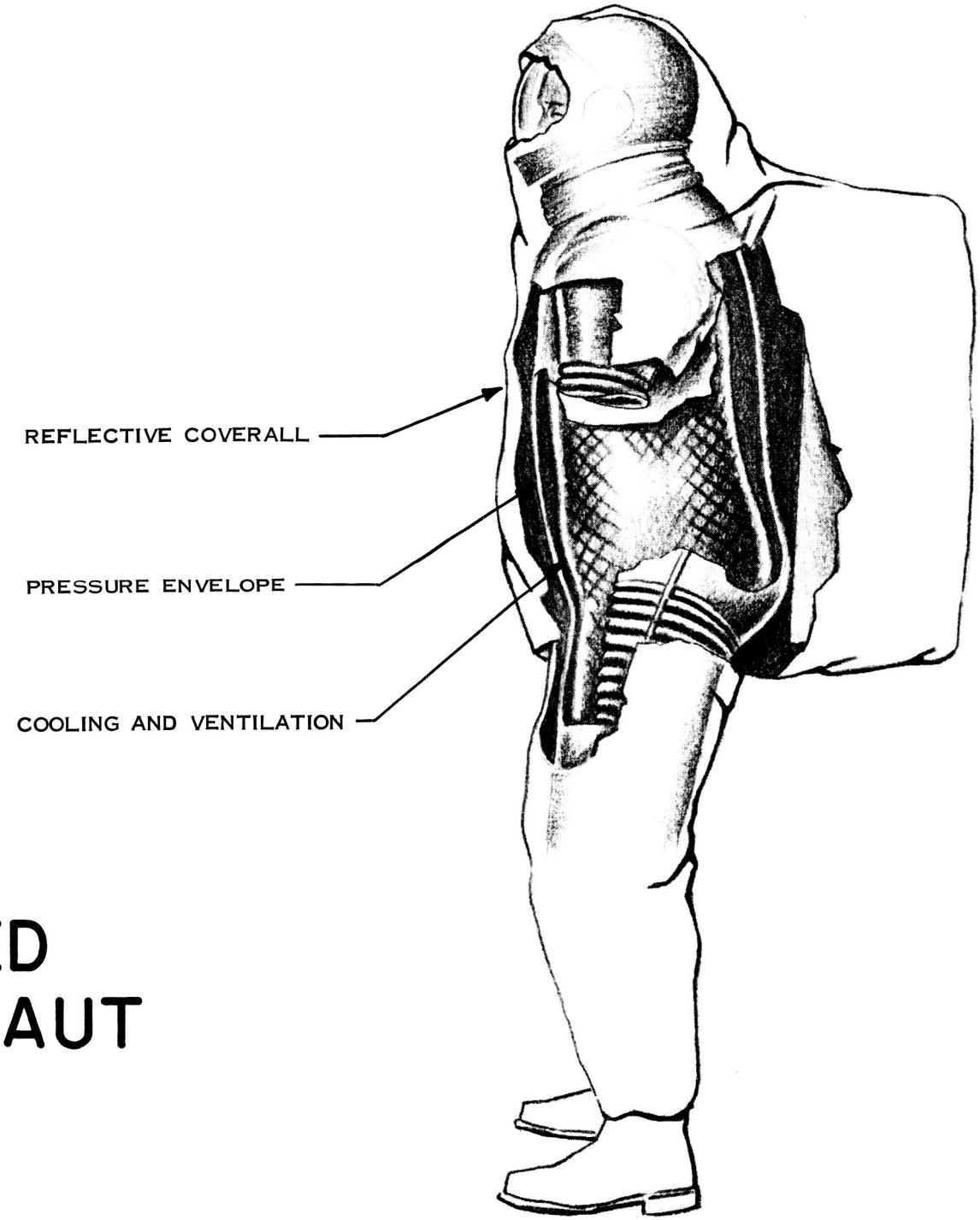
FRAME	12.87
TANKAGE	17.91
THRUST ENGINES	57.
ELECT POWER & CONTROL	25.50
DRY WEIGHT	113.28
PROPELLANT + N_2	58.58
TOTAL OMLS WEIGHT	171.86



LUNAR SURFACE OMLS CONCEPT

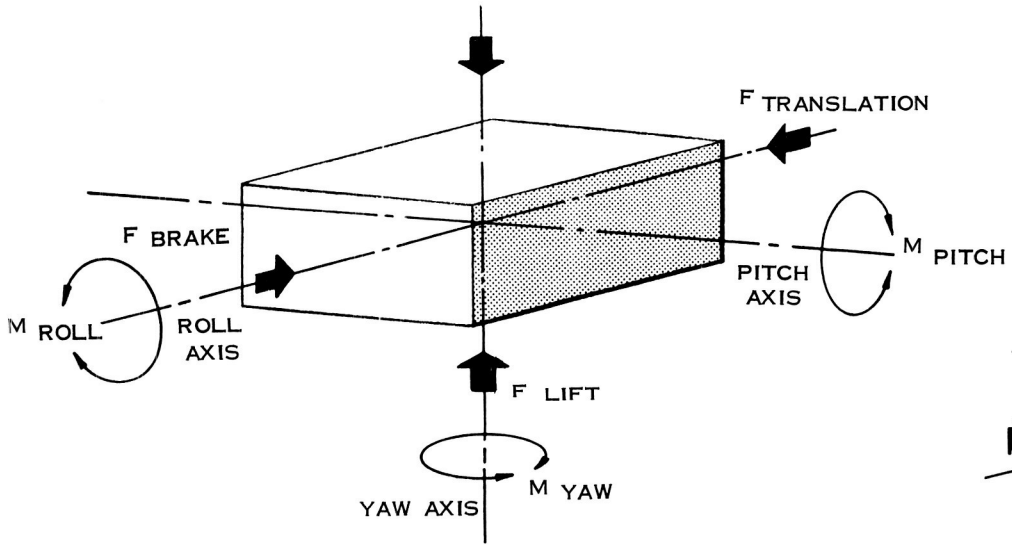
FLYING PLATFORM LUNAR SURFACE OMLS CONCEPT

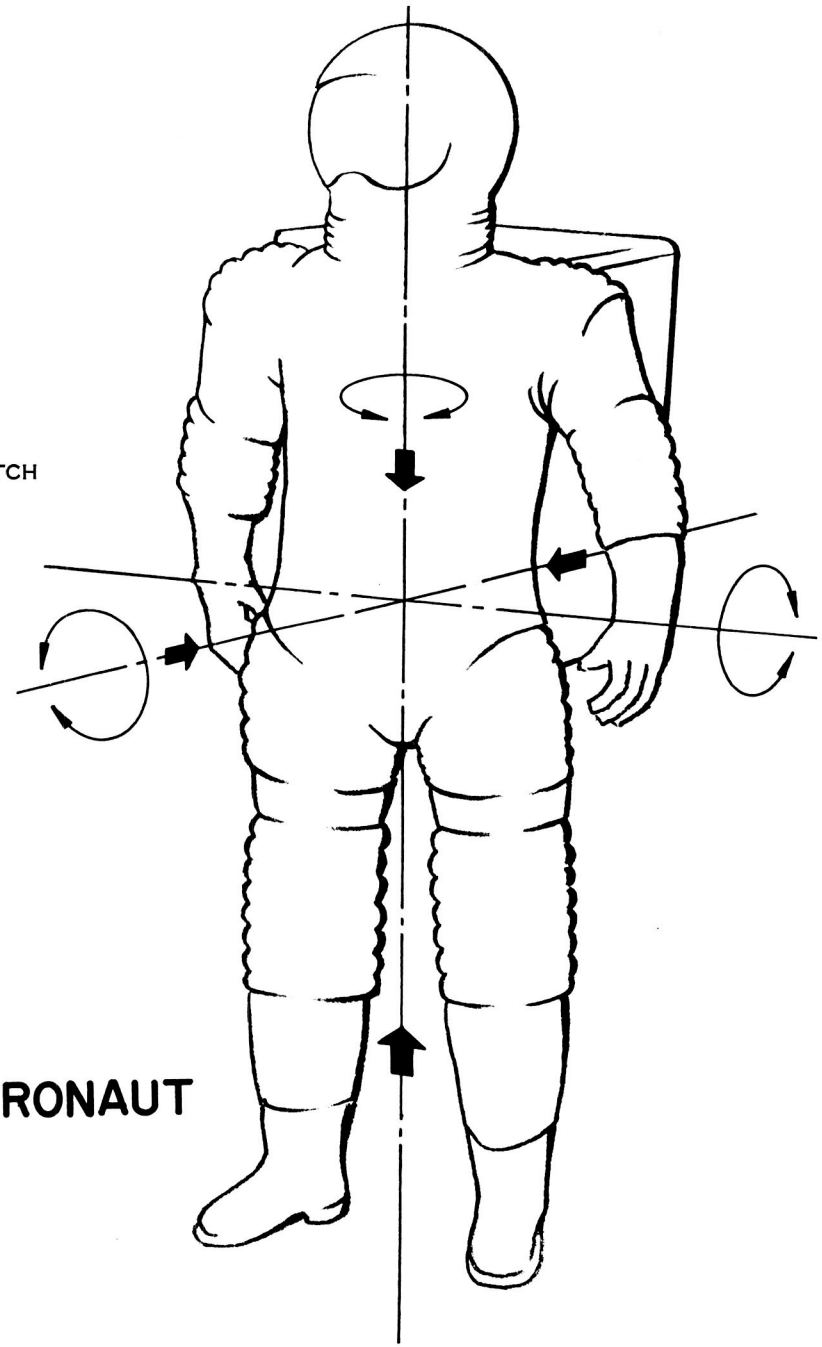




SUITED ASTRONAUT

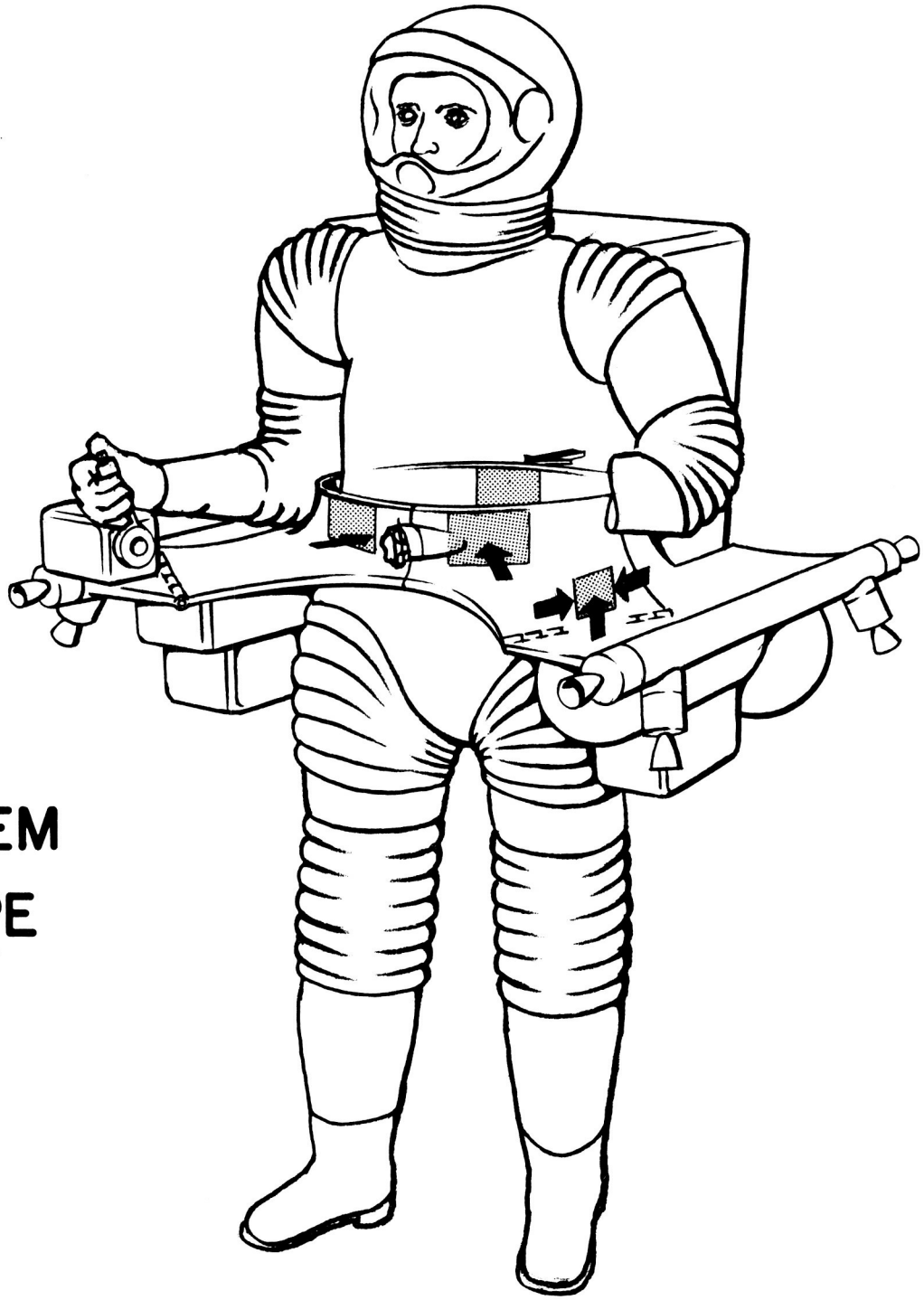
IDEALIZED RESULTANT FORCES and MOMENTS DURING LOCOMOTION



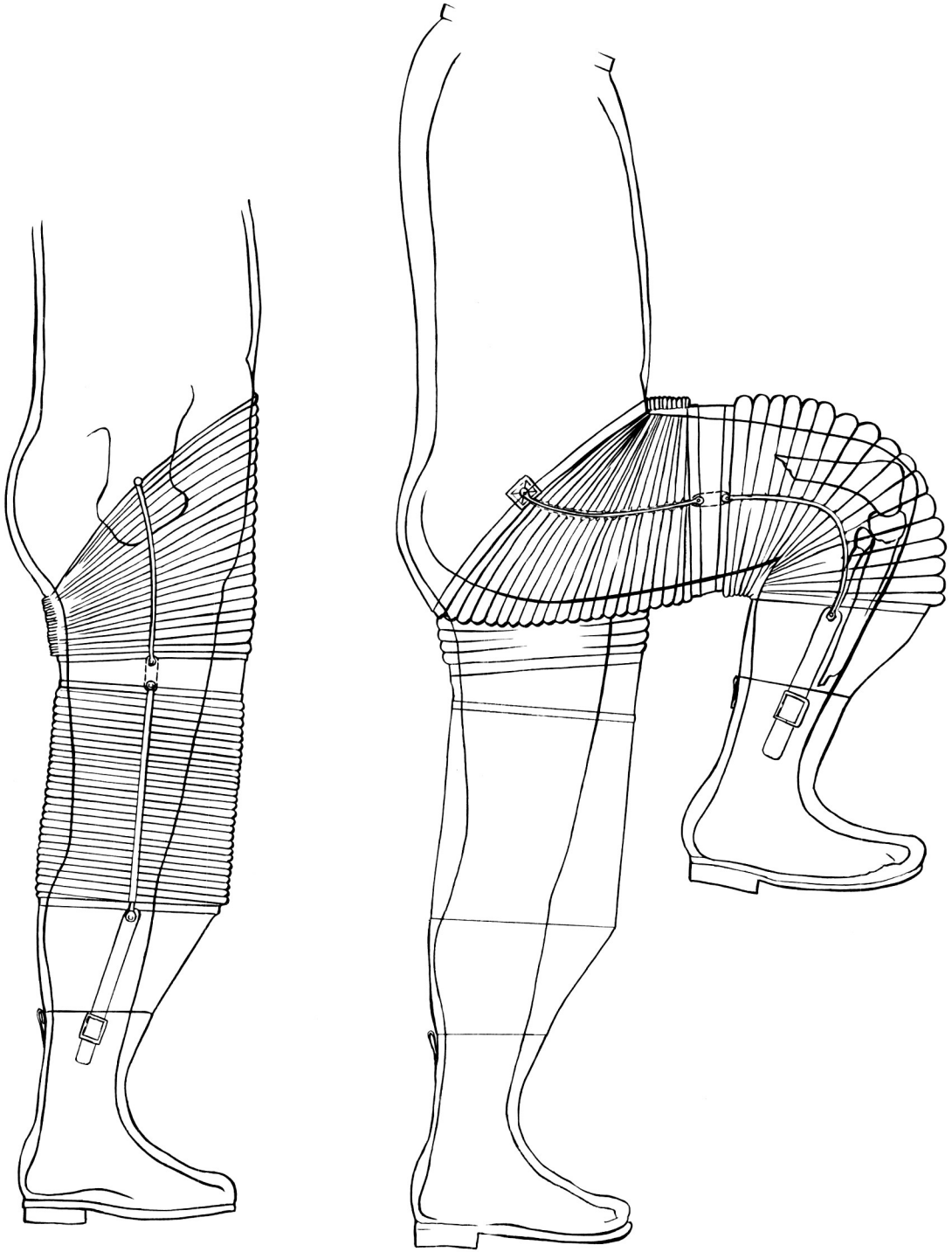


FORCE SYSTEM APPLIED TO SUITED ASTRONAUT

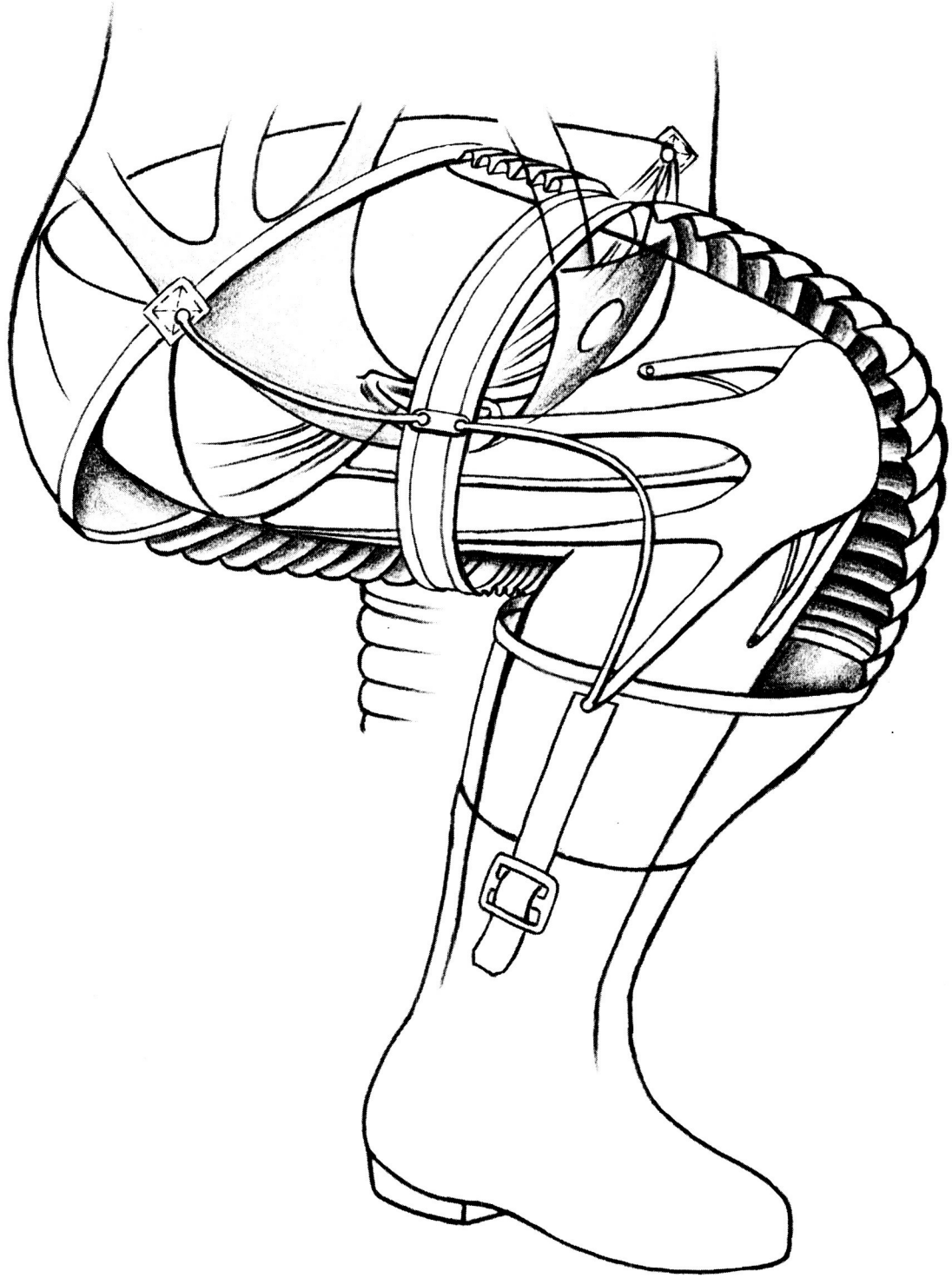
APPLYING FORCE SYSTEM
TO PRESSURE ENVELOPE

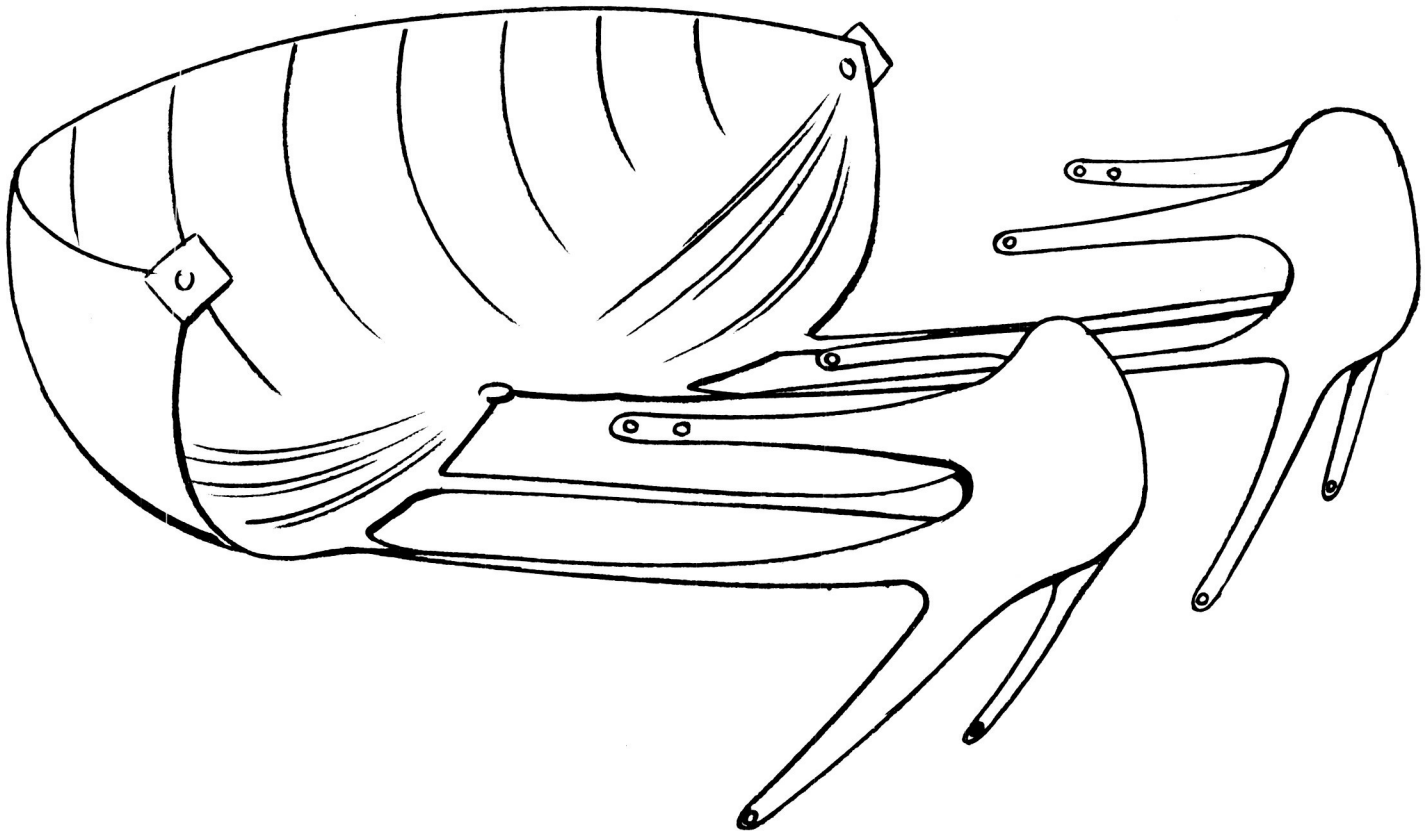


CRITICAL SUIT CLEARANCE



POSSIBLE SUIT MODIFICATIONS





SEAT and KNEE HARNESS

FREE-SPACE MISSION ANALYSIS CONSIDERATIONS

- THE USE OF A ONE-MAN LOCOMOTION SYSTEM IN CONJUNCTION WITH PRESENTLY KNOWN APOLLO MISSIONS IS OF PRIMARY INTEREST
- USES ASSOCIATED WITH SPACE STATIONS AND INTERPLANETARY MISSIONS ARE OF INTEREST MAINLY WITH REGARD TO POTENTIAL FUTURE OMLS NEEDS
- STOWAGE OF OMLS SHOULD BE INTERIOR OF THE SPACECRAFT TO PROVIDE READY ACCESSIBILITY BY CREW MEMBERS
- SPACECRAFT EGRESS AND INGRESS WITH OMLS IS OF PARAMOUNT IMPORTANCE
- DONNING AND DOFFING IN ZERO-G ENVIRONMENT MUST BE CONSIDERED
- WHEN USED IN EXTRA-VEHICULAR ACTIVITIES THE OMLS IS NOT BACKED UP BY ANY REDUNDANT FORM OF LOCOMOTION

POSSIBLE APOLLO FREE-SPACE OMLS USES

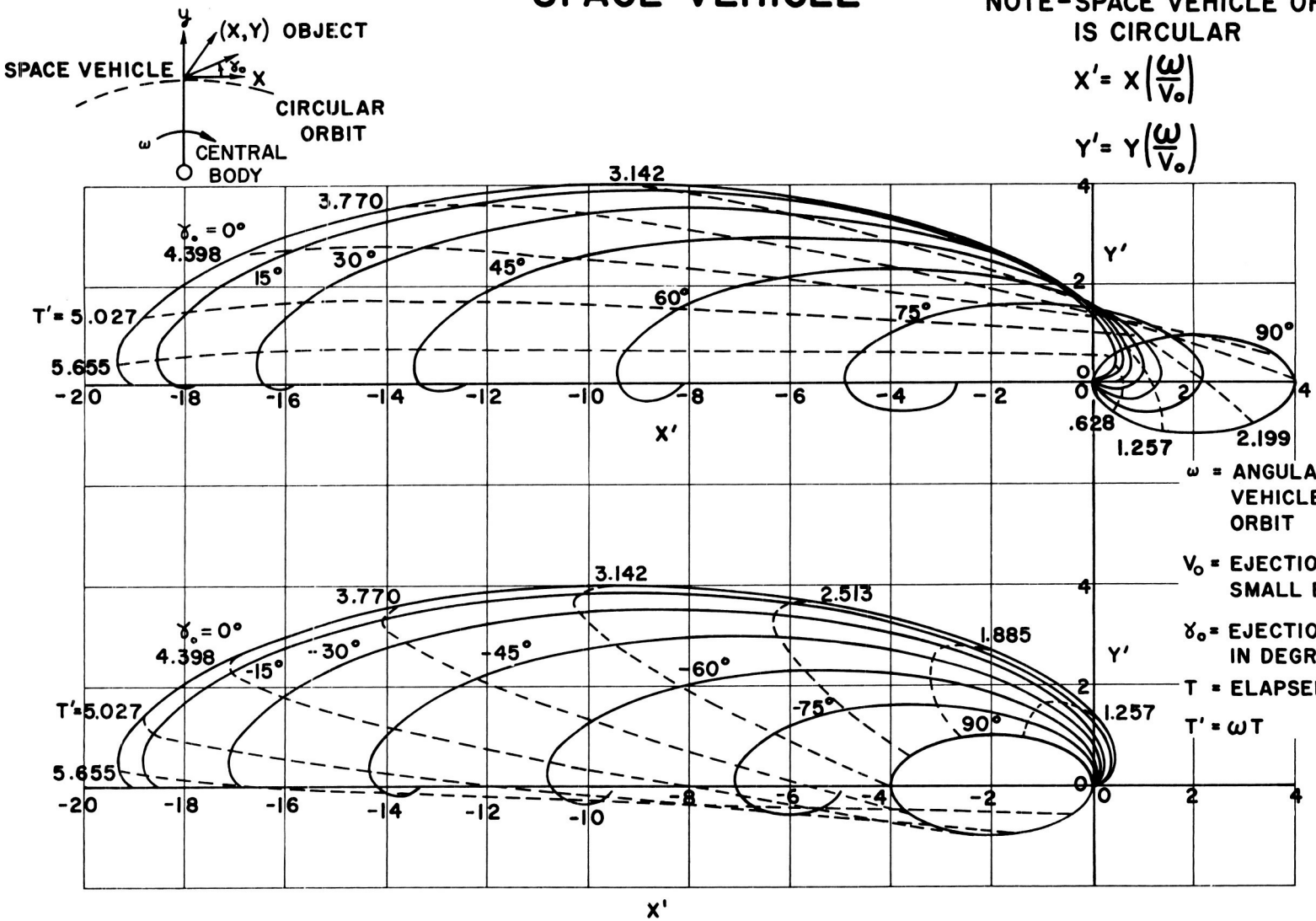
PHASE OF APOLLO PROFILE	DESCRIPTION OF POSSIBLE OMLS MISSION	PRIMARY MISSION	SECONDARY MISSION	OMLS MISSION DURATION	OMLS RANGE NEEDED
LAUNCH TRAJECTORY	—	—	—	—	—
EARTH ORBIT	1) POST-MORTEM OF VEHICLE PRIOR TO ABORTING FLIGHT	NO	PERHAPS	1 - 4 HRS.	~100 FT.
TRANSLUNAR TRAJECTORY					
A) TRANSPOSITION OF APOLLO	1) ASSIST IN UNCOUPLING OR RECOUPLING	NO	PERHAPS	1 - 4 HRS.	~100 FT.
	2) ASSIST IN RENDEZVOUS AND DOCKING	NO	PERHAPS	1 - 4 HRS.	100 - 1,000 FT.
B) LEM CHECKOUT	1) EMERGENCY RETURN FROM LEM	NO	YES	1 HR.	100 - 1,000 FT.
LUNAR ORBIT					
A) LEM SEPARATION	1) EMERGENCY RETURN FROM LEM	NO	YES	1 HR.	100 - 1,000 FT.
B) LEM ABORT RENDEZVOUS	1) EMERGENCY ESCAPE FROM LEM AND RETURN TO APOLLO	NO	YES	1 - 2 HRS.	100 - 1,000 FT.
C) LEM ASCENT	1) EMERGENCY RENDEZVOUS WITH APOLLO	NO	YES	1 - 4 HRS.	100 - 1,000 FT.
	2) EMERGENCY CREW TRANSFER	NO	YES	1 HR.	~100 FT.
EARTH-RETURN TRAJECTORY	1) ASSIST IN UNCOUPLING LEM	NO	PERHAPS	1 HR.	~100 FT.
	2) EXTERIOR CHECK OF RE-ENTRY VEHICLE	NO	PERHAPS	1 - 4 HRS.	~100 FT.

NORMALIZED TRAJECTORIES OF A SMALL BODY EJECTED IN THE ORBITAL PLANE OF A SPACE VEHICLE

NOTE-SPACE VEHICLE ORBIT IS CIRCULAR

$X' = X\left(\frac{\omega}{V_o}\right)$

$Y' = Y\left(\frac{\omega}{V_o}\right)$



ω = ANGULAR RATE OF SPACE VEHICLE IN CIRCULAR ORBIT

V_o = EJECTION VELOCITY OF SMALL BODY

γ_o = EJECTION ANGLE IN DEGREES

T = ELAPSED TIME - SECONDS

$T' = \omega T$

PILOTING AND VELOCITY REQUIREMENTS

- PILOTING LAW
  - LINE UP TARGET DEAD AHEAD
  - APPLY VELOCITY INCREMENT
  - HOLD HEADING CONSTANT, WHEN RELATIVE BEARING (β) EQUALS SELECTED VALUE, RE-ALIGN WITH TARGET AND APPLY ANOTHER VELOCITY INCREMENT

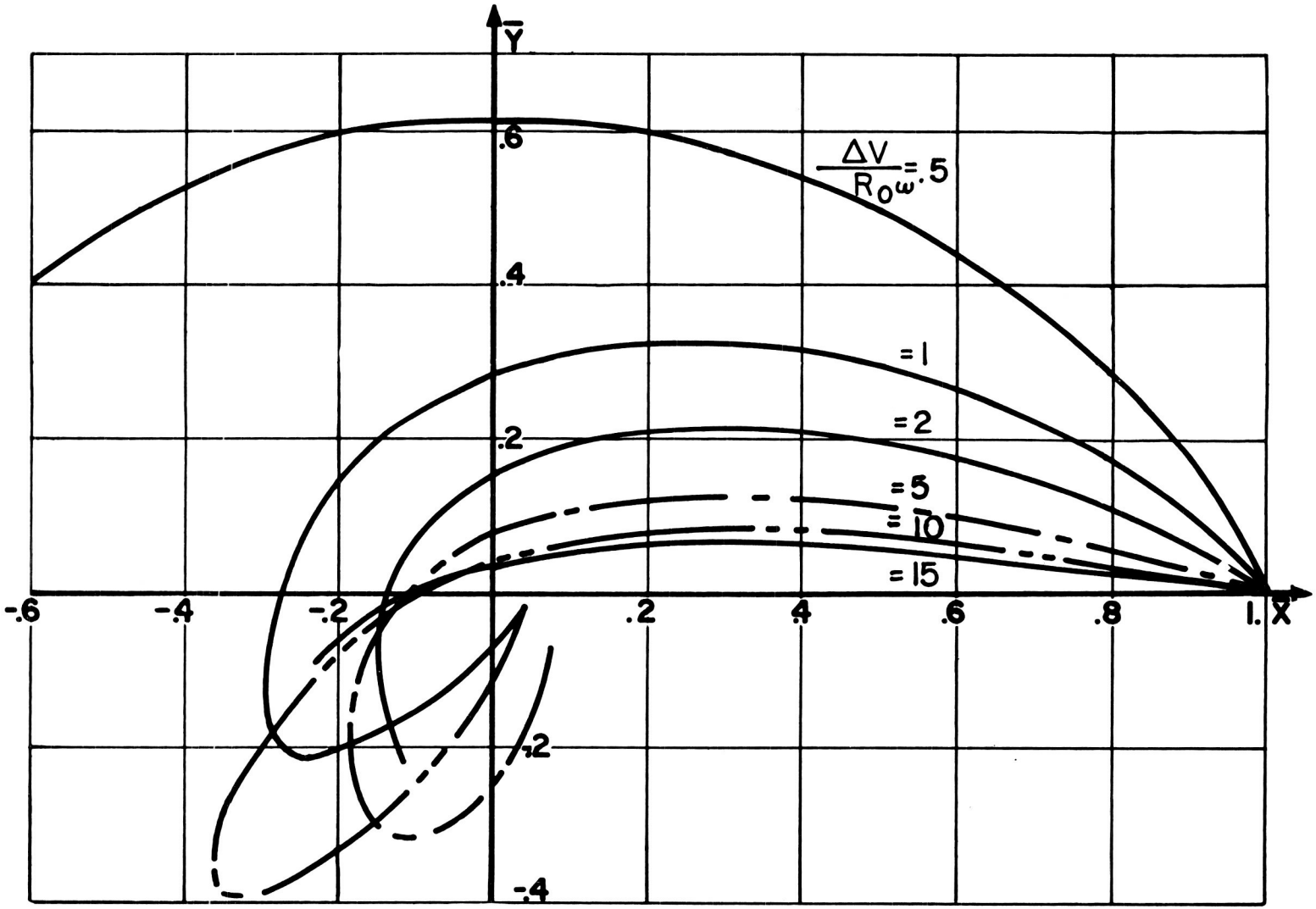
- TOTAL VELOCITY INCREMENT TO APPROACH WITHIN 5% OF ORIGINAL DISTANCE VARIES WITH α THE ANGLE FROM HORIZONTAL

$$\frac{\Delta V}{r_0 \omega} = 26 \text{ TO } 92$$

WHERE r_0 = INITIAL DISTANCE

ω = ORBIT FREQUENCY

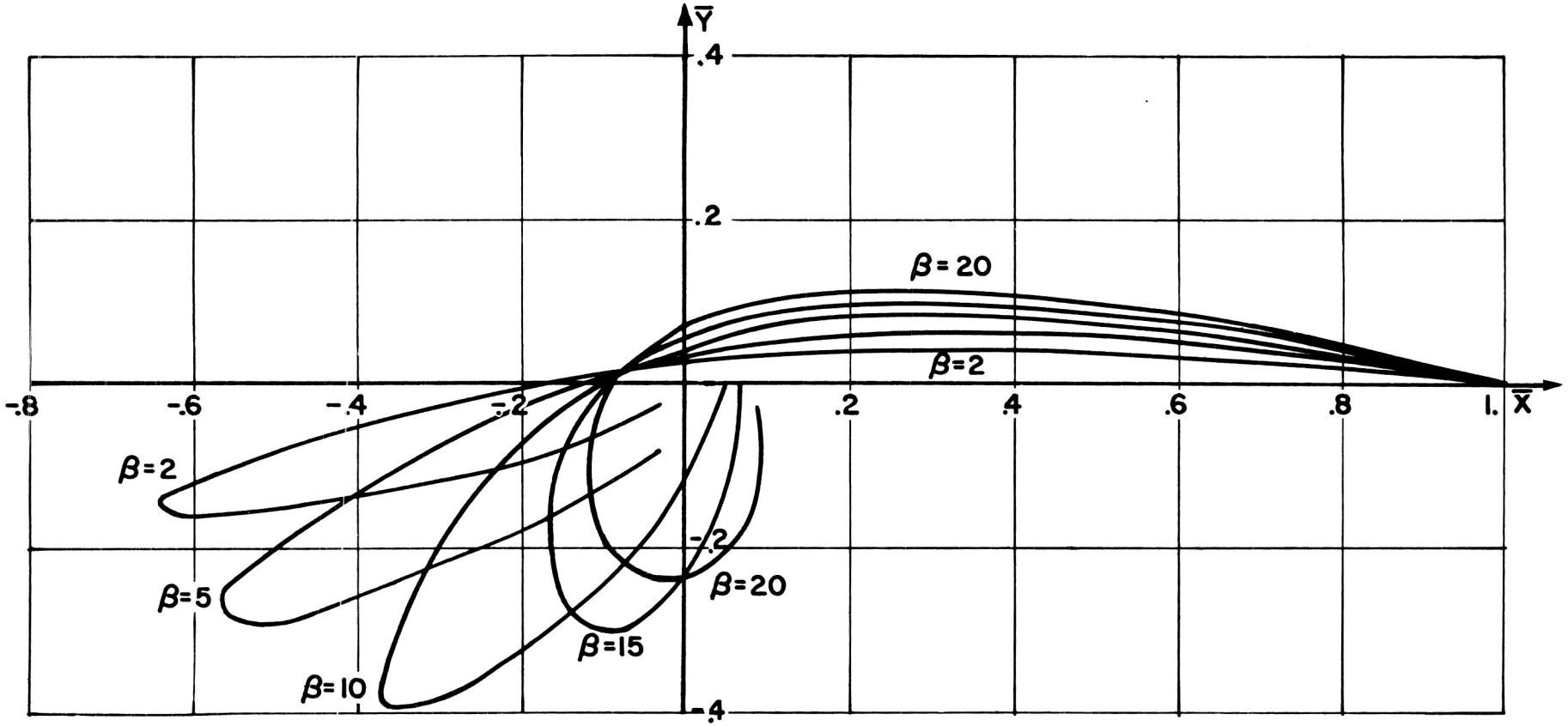
NORMALIZED TRAJECTORIES FOR CIRCULAR ORBIT TRANSFERS



$\beta = 10°$ $\epsilon = 0°$

VARIABLE; $\frac{\Delta V}{R_o \omega}$

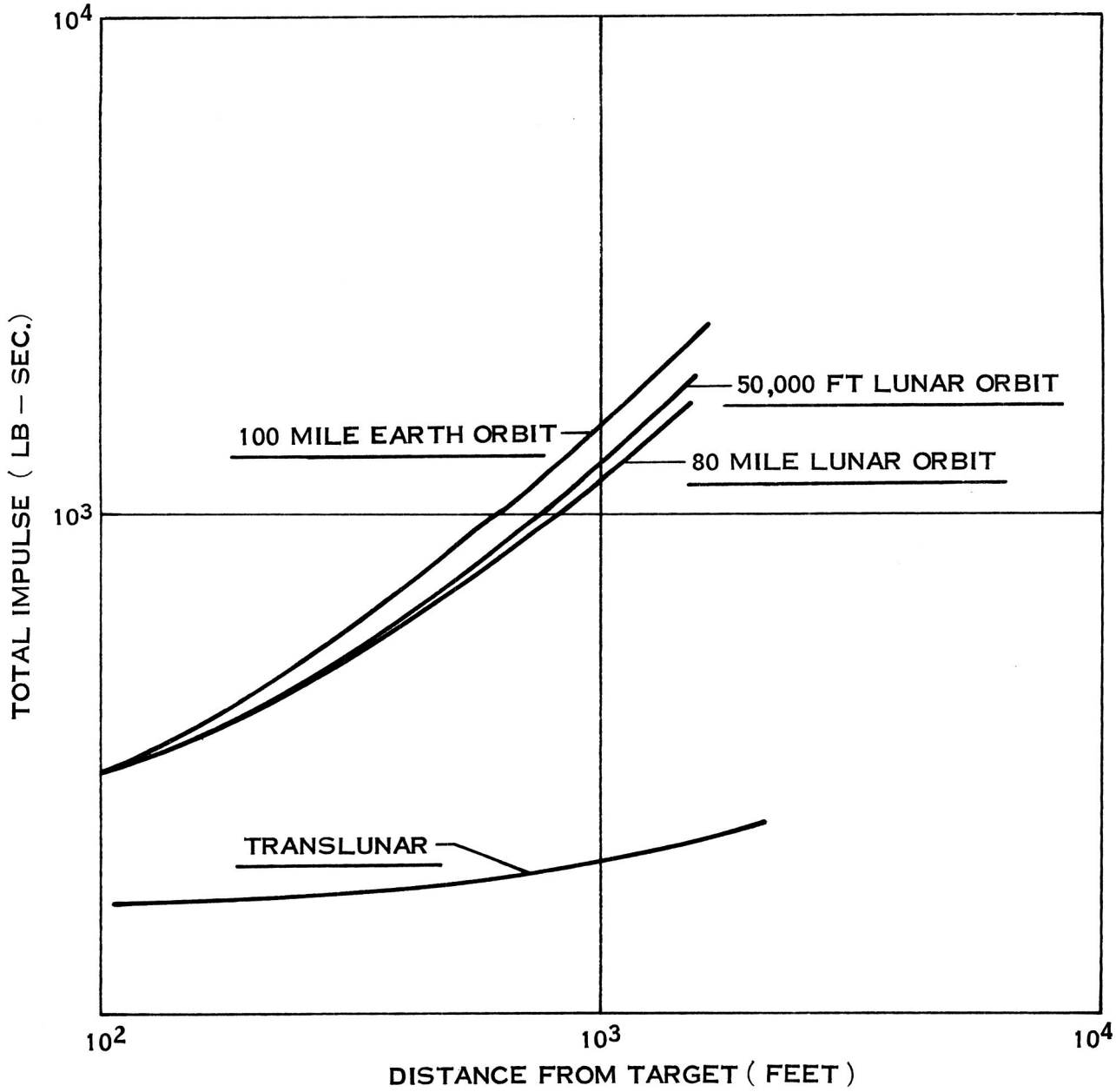
NORMALIZED TRAJECTORIES FOR CIRCULAR ORBIT TRANSFERS



$\frac{\Delta V}{R_o \omega} = 10 \quad \epsilon = 0_o$

VARIABLE; β

FREE SPACE TOTAL IMPULSE REQUIREMENTS VS INITIAL DISTANCE FROM TARGET

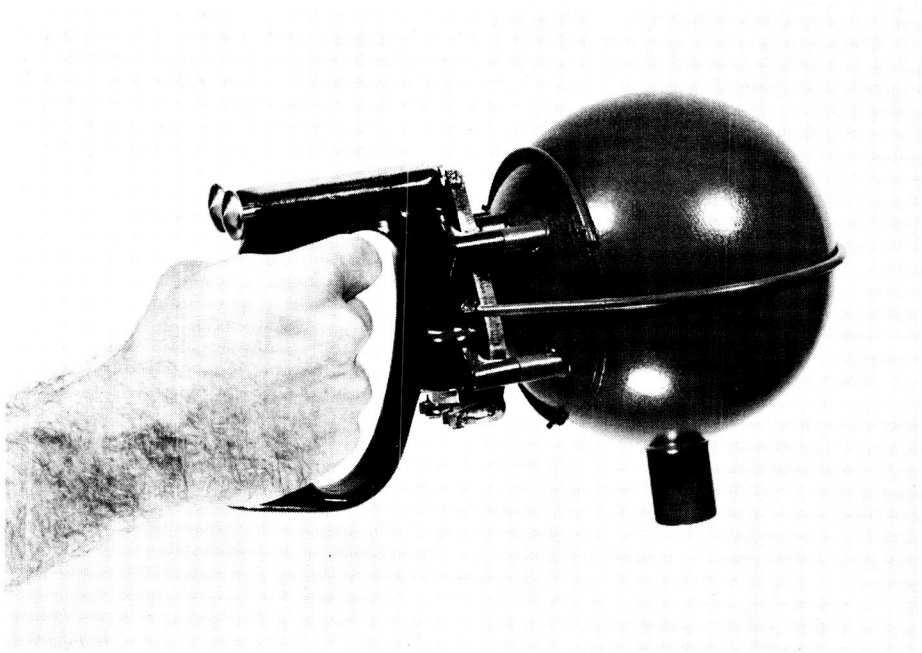


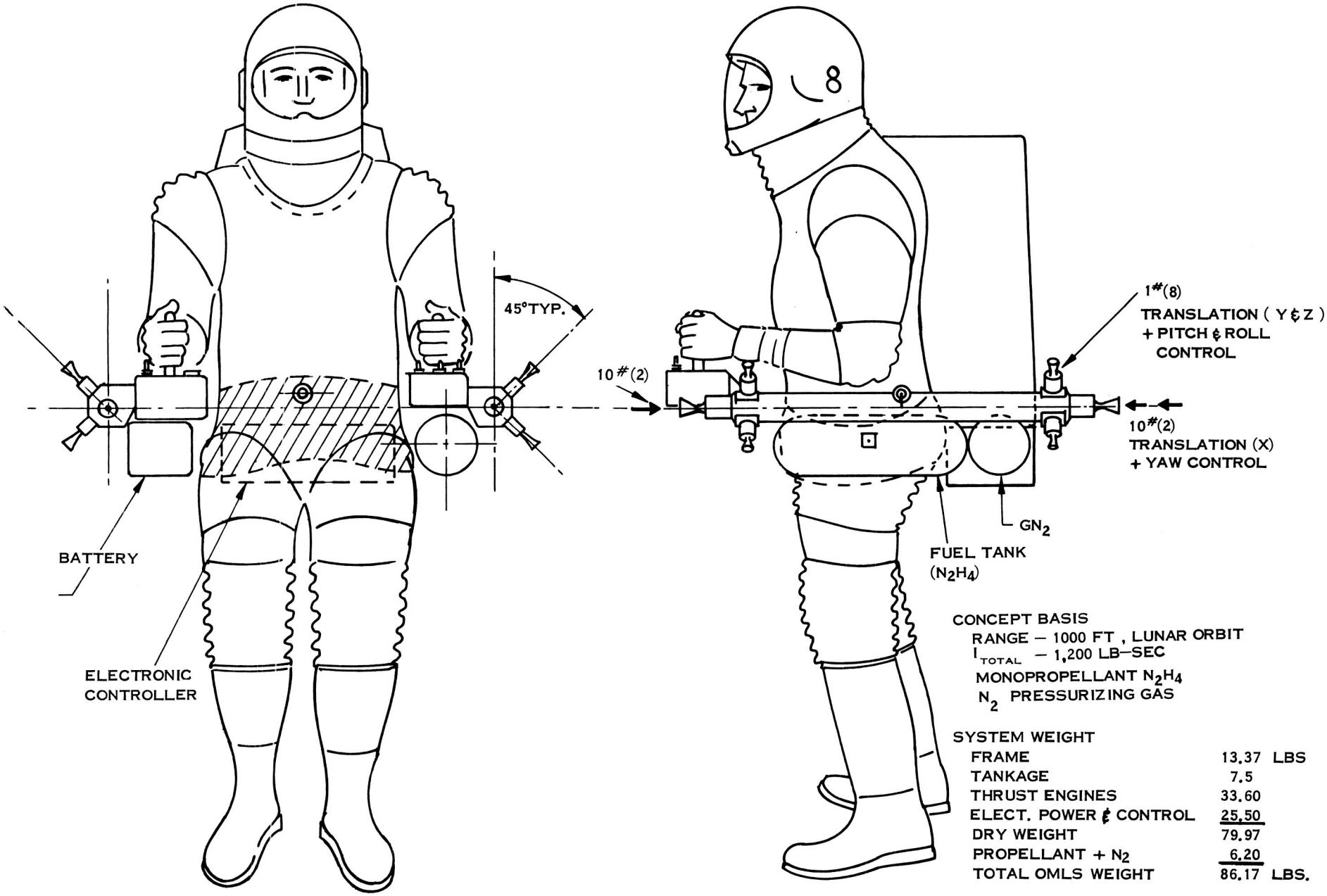
HAND-HELD UNIT

PROPELLANT - NITROGEN (COLDGAS)

I_t - 125 LB-SEC

SYSTEM WGT - 9.7 LBS (ON EARTH)





CONCEPT BASIS

RANGE – 1000 FT , LUNAR ORBIT

I_{TOTAL} – 1,200 LB–SEC

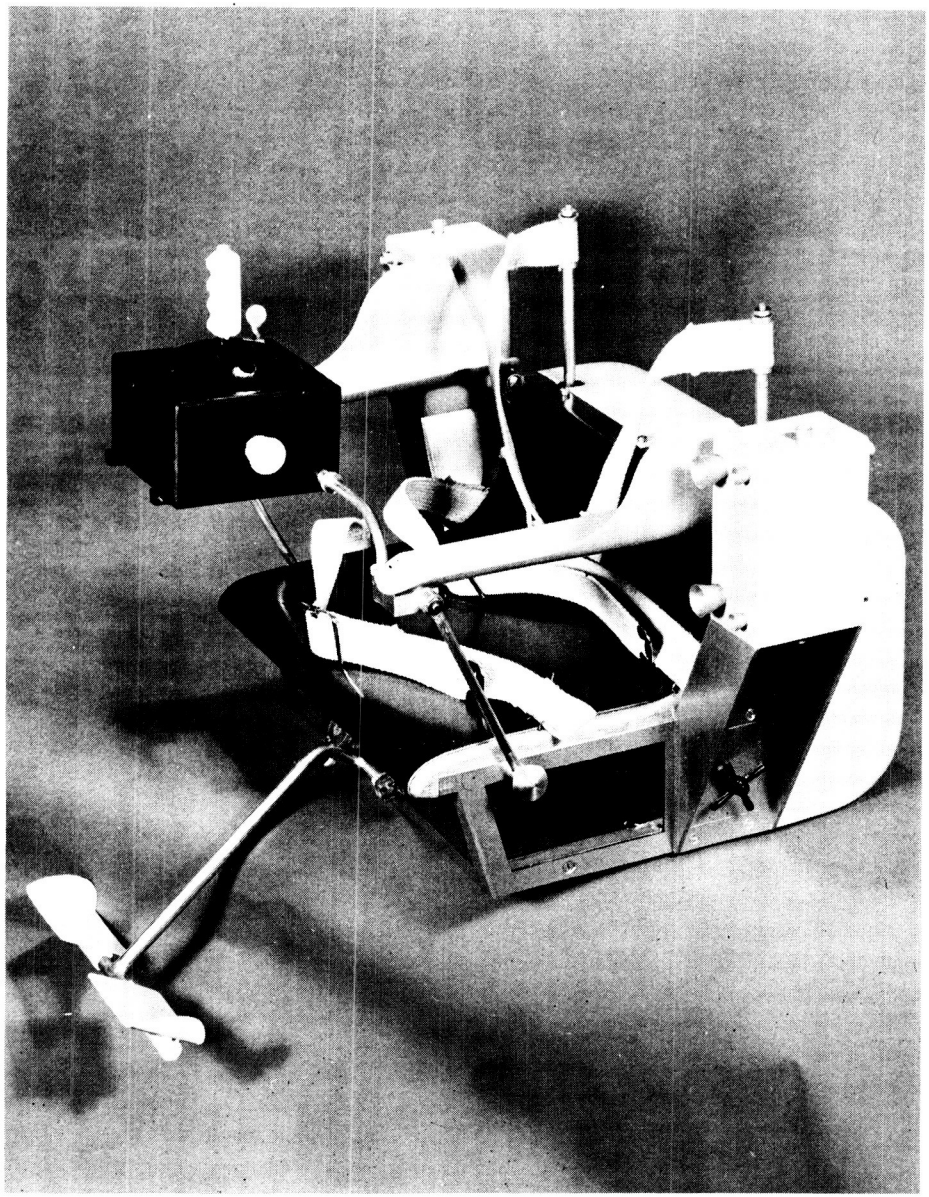
MONOPROPELLANT N_2H_4

N_2 PRESSURIZING GAS

SYSTEM WEIGHT

FRAME	13.37 LBS
TANKAGE	7.5
THRUST ENGINES	33.60
ELECT. POWER & CONTROL	25.50
DRY WEIGHT	79.97
PROPELLANT + N_2	6.20
TOTAL OMLS WEIGHT	86.17 LBS.

BODY-MOUNTED FREE-SPACE OMLS



SEAT-TYPE UNIT

PROPELLANT- HYDRAZINE MONOPROPELLANT

I_t - 12,000 LB-SEC

SYSTEM WGT - 137 LBS (ON EARTH)

PROGRESS TO DATE

- OMLS MISSION MODELS HAVE BEEN ESTABLISHED FOR LUNAR AND FREE-SPACE OPERATIONS
- PROPULSION REQUIREMENTS HAVE BEEN ESTABLISHED FOR THOSE MODELS
- PRELIMINARY PROPULSION DEVICE CONCEPTS HAVE BEEN ESTABLISHED BASED UPON THESE REQUIREMENTS
- AN INITIAL SCREENING OF POTENTIAL PROPELLANTS HAS BEEN COMPLETED
- SYSTEM INTERFACES HAVE BEEN EXAMINED
- DESIGN TRADE-OFF FACTORS HAVE BEEN ESTABLISHED
- SYSTEM SIZE & WEIGHT ESTIMATES HAVE BEEN COMPLETED FOR TYPICAL OMLS CONCEPTS
- A PRELIMINARY STUDY HAS BEEN MADE OF NAVIGATION, PILOTING AND CONTROL REQUIREMENTS
- DESIGN TRADE-OFF STUDIES OF POTENTIAL SYSTEMS CONCEPTS HAVE BEEN INITIATED

REMAINING PROBLEMS

- SUIT & PLSS INTERFACES
  - Resolution of attachment problems
  - Resolution of thermal problems
- VEHICLE INTERFACES
  - Resolution of OMLS stowage problem
- PROPELLANTS
  - Establishment of selection criteria for fine screening process
- STABILIZATION & CONTROL
  - Definition of precise effects of center of gravity shifts for specific system designs
  - Definition of limitations imposed on manual control

BALANCE OF WORK TO BE PERFORMED

- COMPLETE DESIGN TRADE-OFF STUDIES
  - — ADVISABILITY OF A COMMON SYSTEM FOR USE IN BOTH FREE-SPACE AND ON THE LUNAR SURFACE
  - — FUNCTIONAL, ECONOMIC, AND RELIABILITY EVALUATIONS
- SELECTION OF SYSTEM FOR PRELIMINARY DESIGN
  - — SYSTEM OPERATIONAL REQUIREMENTS AND DESIGN SPECIFICATIONS
- SYSTEM PRELIMINARY DESIGN
  - — SYSTEM LAYOUT
  - — DESIGN DETAILS
  - — INSTALLATION MOCKUP
  - — CREW TRAINING METHODS
  - — SYSTEM QUALIFICATION TEST METHODS
- FINAL ORAL STATUS REPORT
- FINAL REPORT