CYCLICAL VISITS TO MARS VIA ASTRONAUT HOTELS

Presentation to the
NASA Institute for Advanced Concepts (NIAC)
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Visions of the Future in Aeronautics and Space

by

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TOPICS

INTRODUCTION

ORBIT ANALYSIS

TRANSPORTATION SYSTEM ARCHITECTURE

SYSTEM MODELING, ANALYSIS & COSTS

SIGNIFICANCE TO NASA

SUMMARY

INTRODUCTION

BACKGROUND

- 1985 National Commission on Space (NCOS)
  - Mars transportation infrastructure for permanent Mars base
  - Use of cyclic orbits
  - Cycling vehicles (CASTLES), spaceports and taxis
- Revolutionary NIAC concept being studied by Global Aerospace
  - Reduce crew occupation to only 5 months
  - Increase systems autonomy
  - Eliminate artificial gravity from cycling vehicles
  - Reduce cycling vehicle size
  - Use solar energy for surface and space power systems
  - Employ solar-powered ion propulsion systems (IPS) throughout
  - Significantly reduce reliance on earth propellants, consumables and refurbishment, repair and upgrade (RRU) cargo

CONCEPT MOTIVATION

- Create permanent elements of a Mars transportation system
- Take advantage of natural orbital physics to facilitate Mars transportation
- Eliminate need for new, expensive class of rockets and launchers
- Offer environmentally safe technology, without political baggage, for transportation to and from mars
- Increase reliance on in situ resources for Mars transportation architecture
- Accelerate the timeframe for permanent inhabitation of Mars

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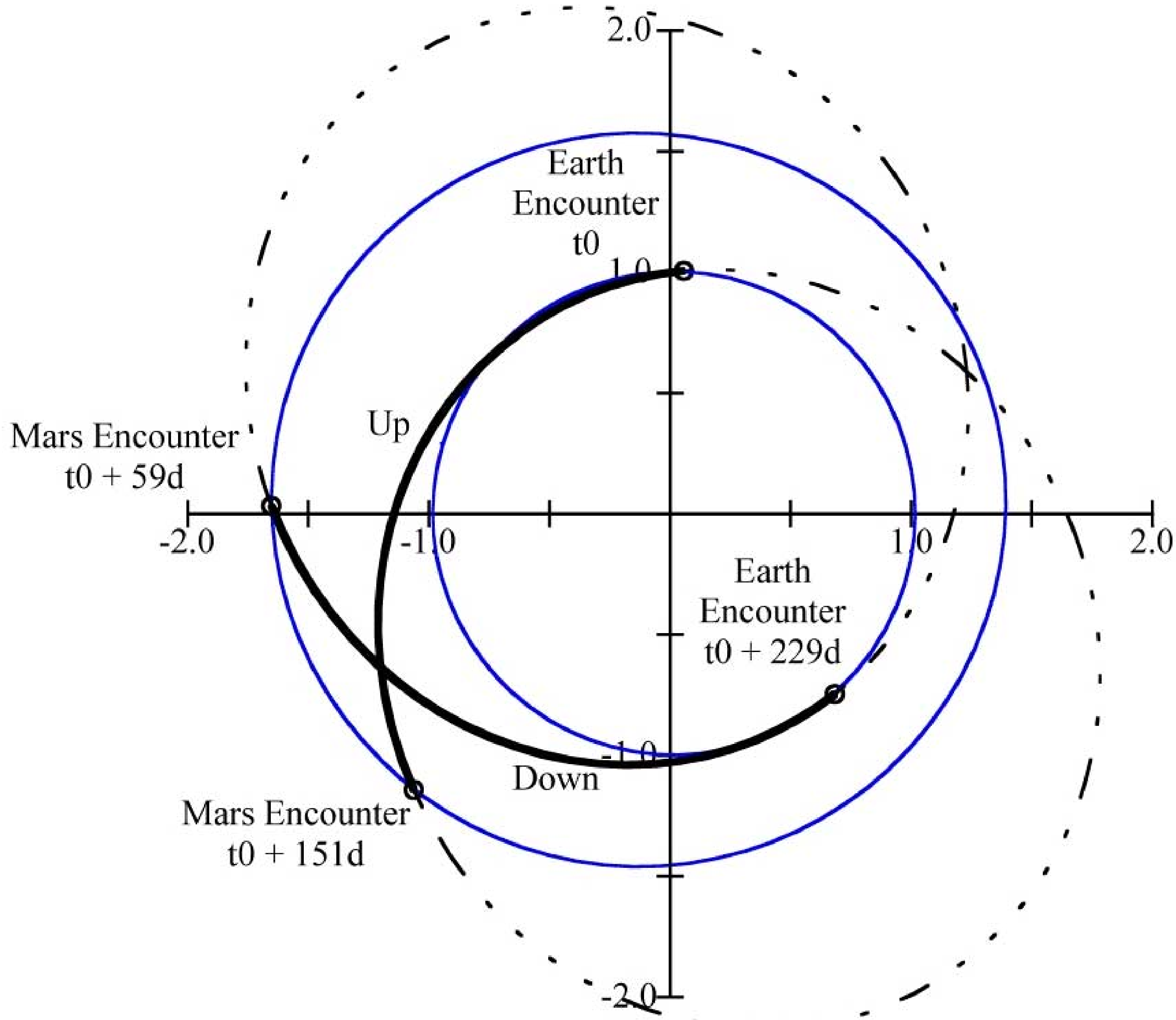
Cyclical Visits To Mars via Astronaut Hotels

KEYS TO THE CURRENT CONCEPT

- Cycler orbits between Earth and Mars that enable fast, frequent transfers between these planets
- Astronaut hotels, or Astrotels, which are small transport vehicles capable of carrying 10 people on cycling orbits between planets
- Orbital spaceports at the planets and very small, fast, hyperbolic transfer vehicles, or taxis, between spaceports and astrotels.
- Propellant and life support in situ resource manufacturing plants
- Cargo vehicles that utilize low-energy, long-flighttime orbits to transport propellant and low value cargo to and from planets
- Shuttles to and from spaceports and planetary surfaces

ORBIT ANALYSIS

ALDRIN CYCLERS



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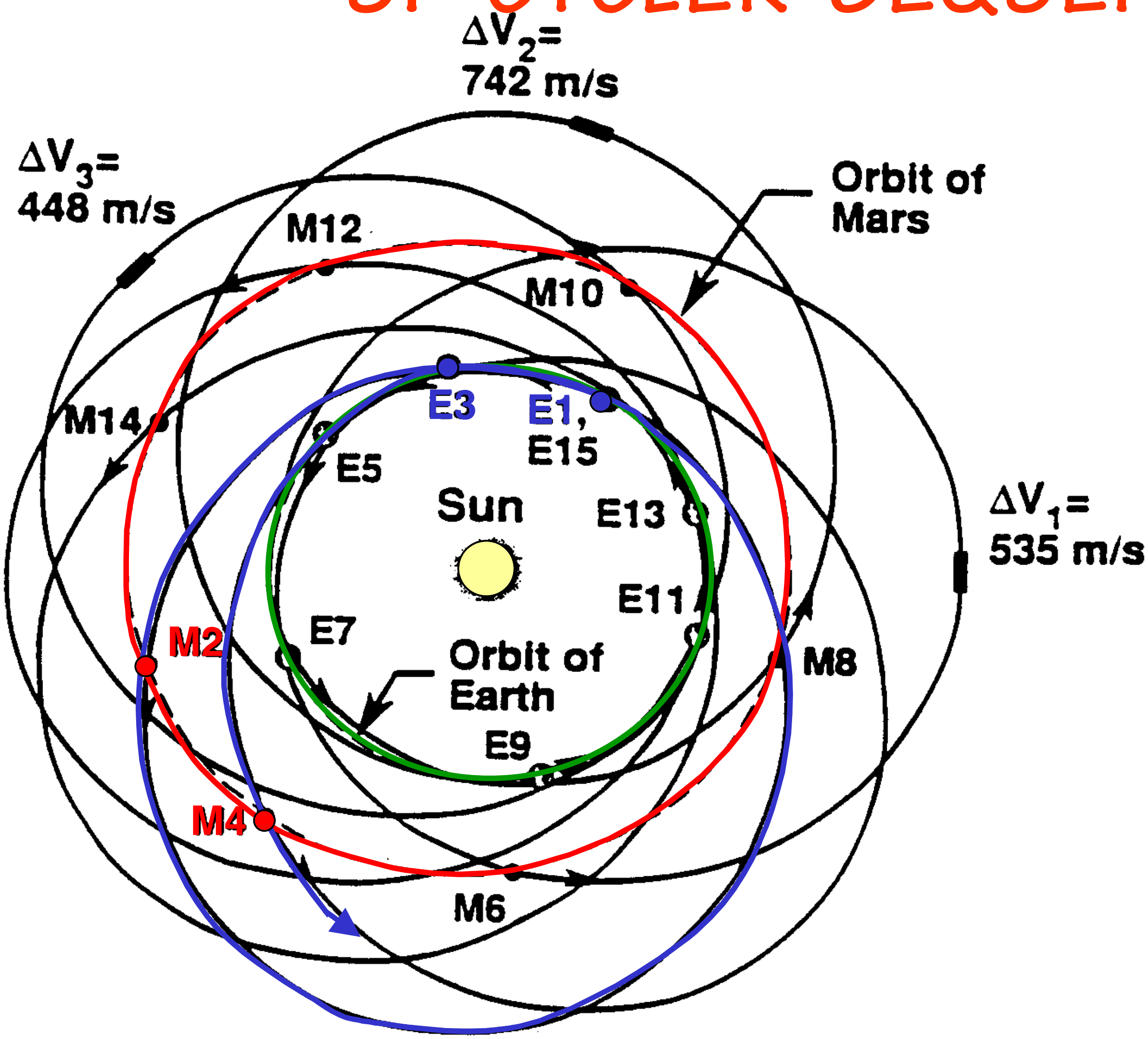
EXAMPLE ALDRIN UP-CYCLER SEQUENCE



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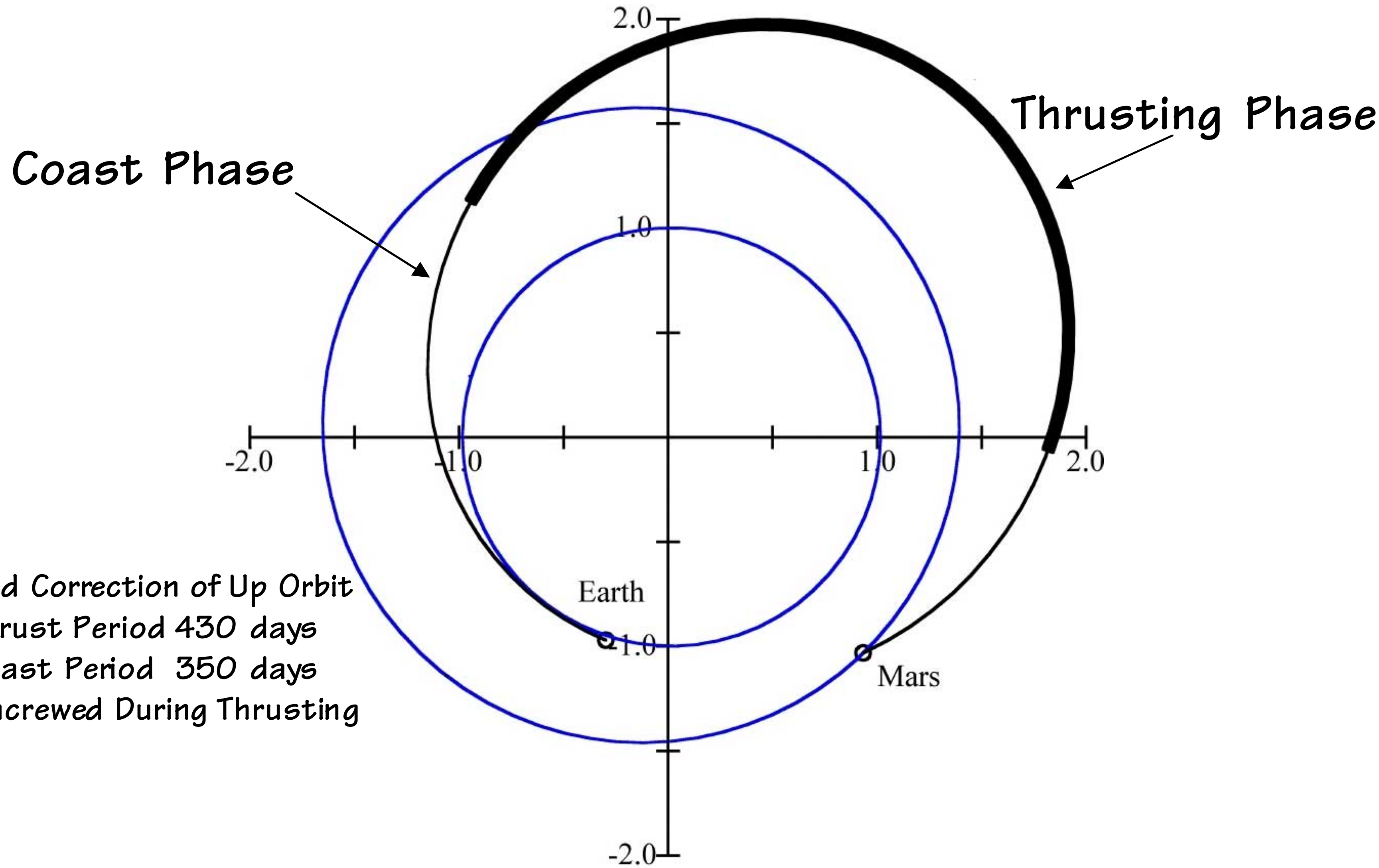
UP-CYCLER LOW THRUST TRAJECTORY SHAPING



- 2nd Correction of Up Orbit
- Thrust Period 430 days
- Coast Period 350 days
- Uncrewed During Thrusting

TRANSPORTATION SYSTEM ARCHITECTURE

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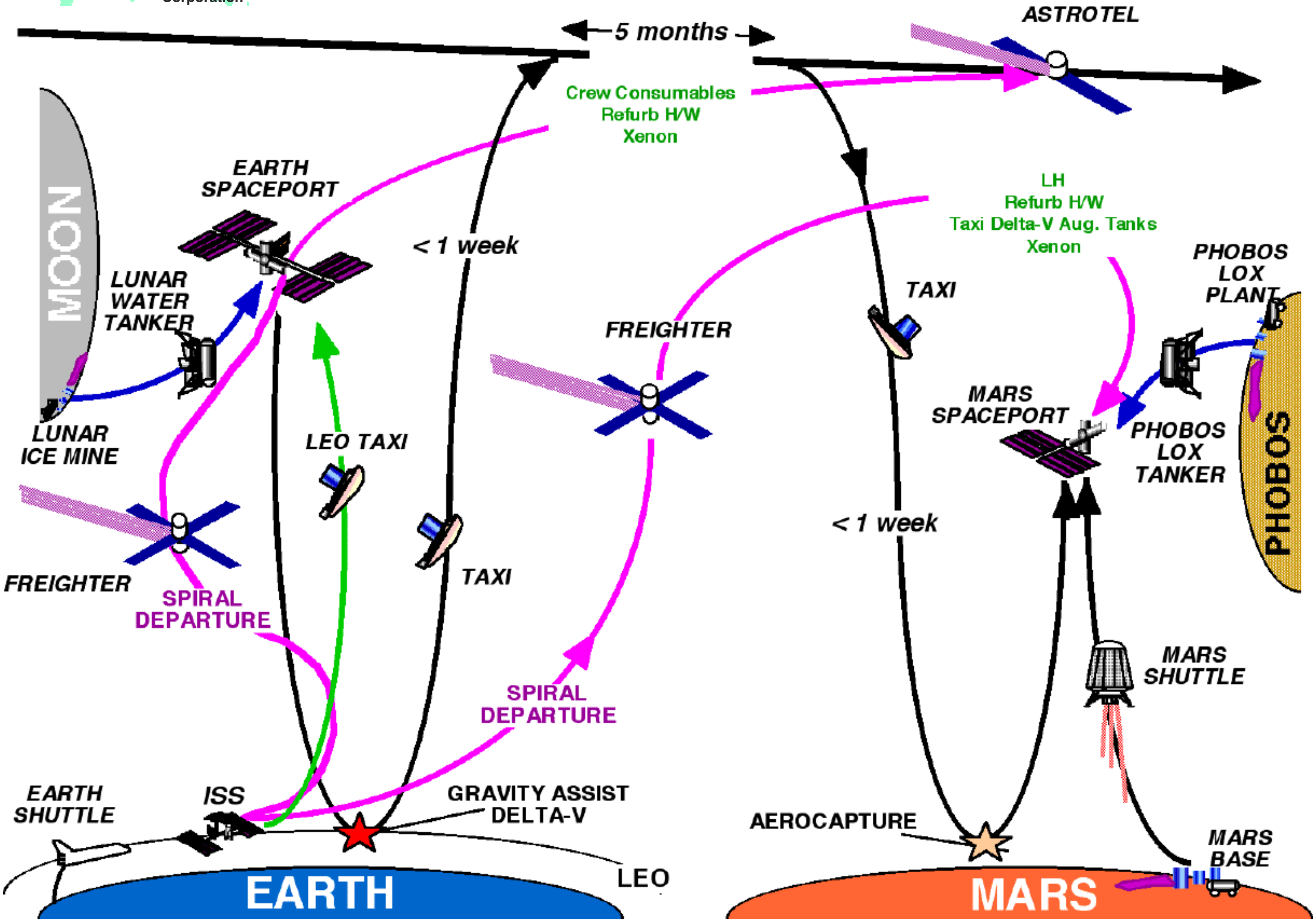
TRANSPORTATION ARCHITECTURE



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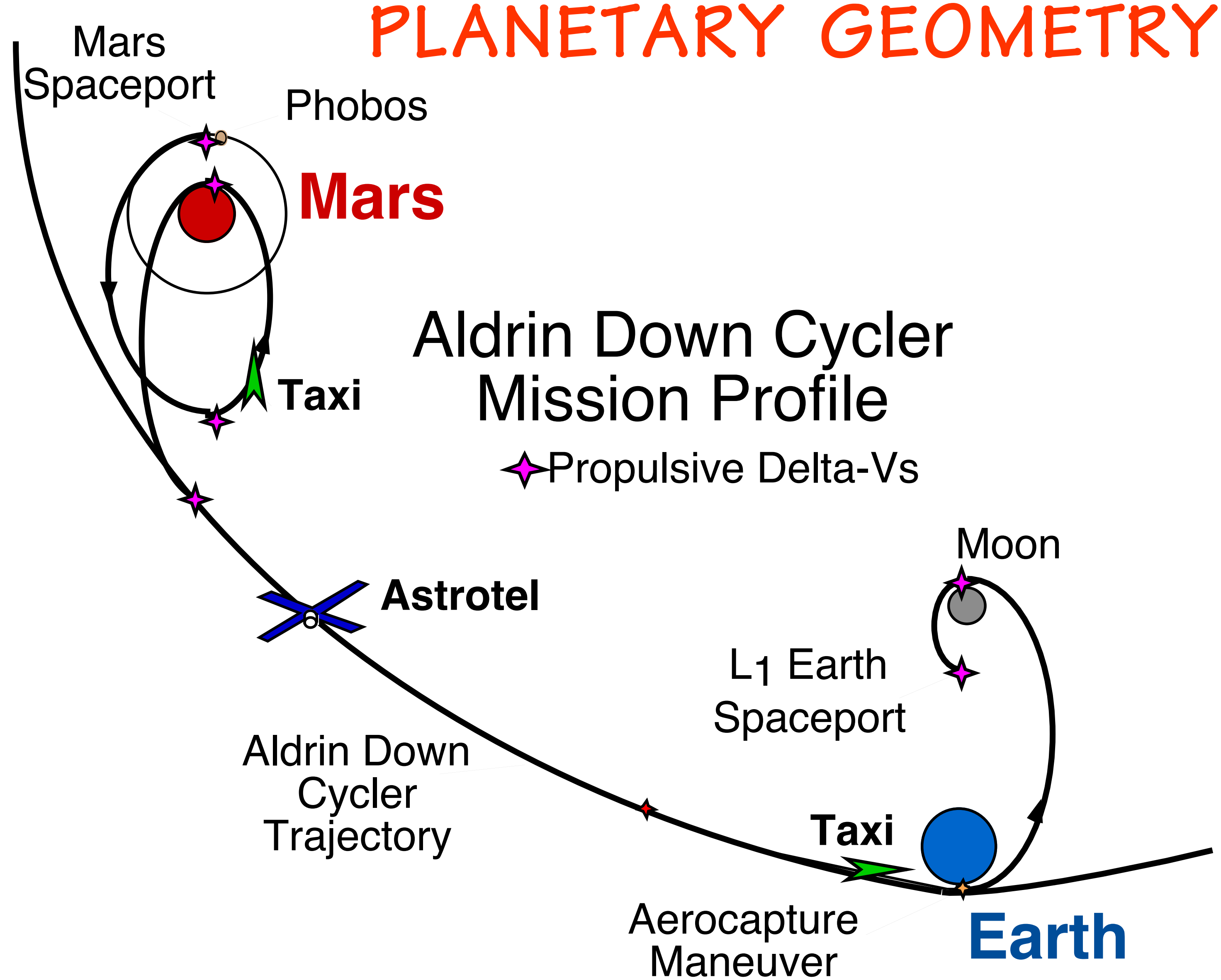
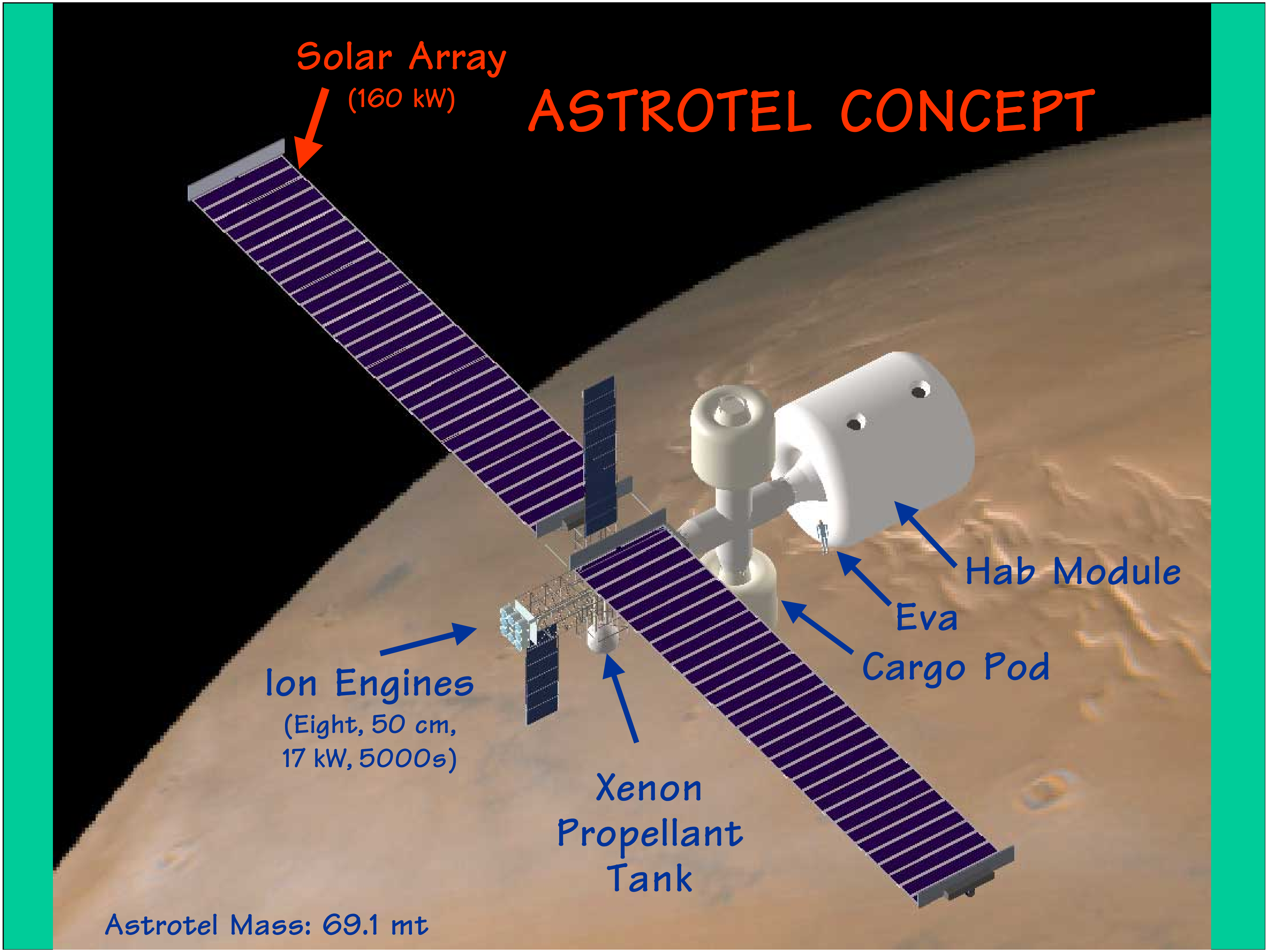
DOWN-CYCLER
PLANETARY GEOMETRY




Solar Array
(160 kW)
ASTROTEL CONCEPT
Hab Module
Eva
Cargo Pod
Ion Engines
(Eight, 50 cm,
17 kW, 5000s)
Xenon
Propellant
Tank
Astrotel Mass: 69.1 mt

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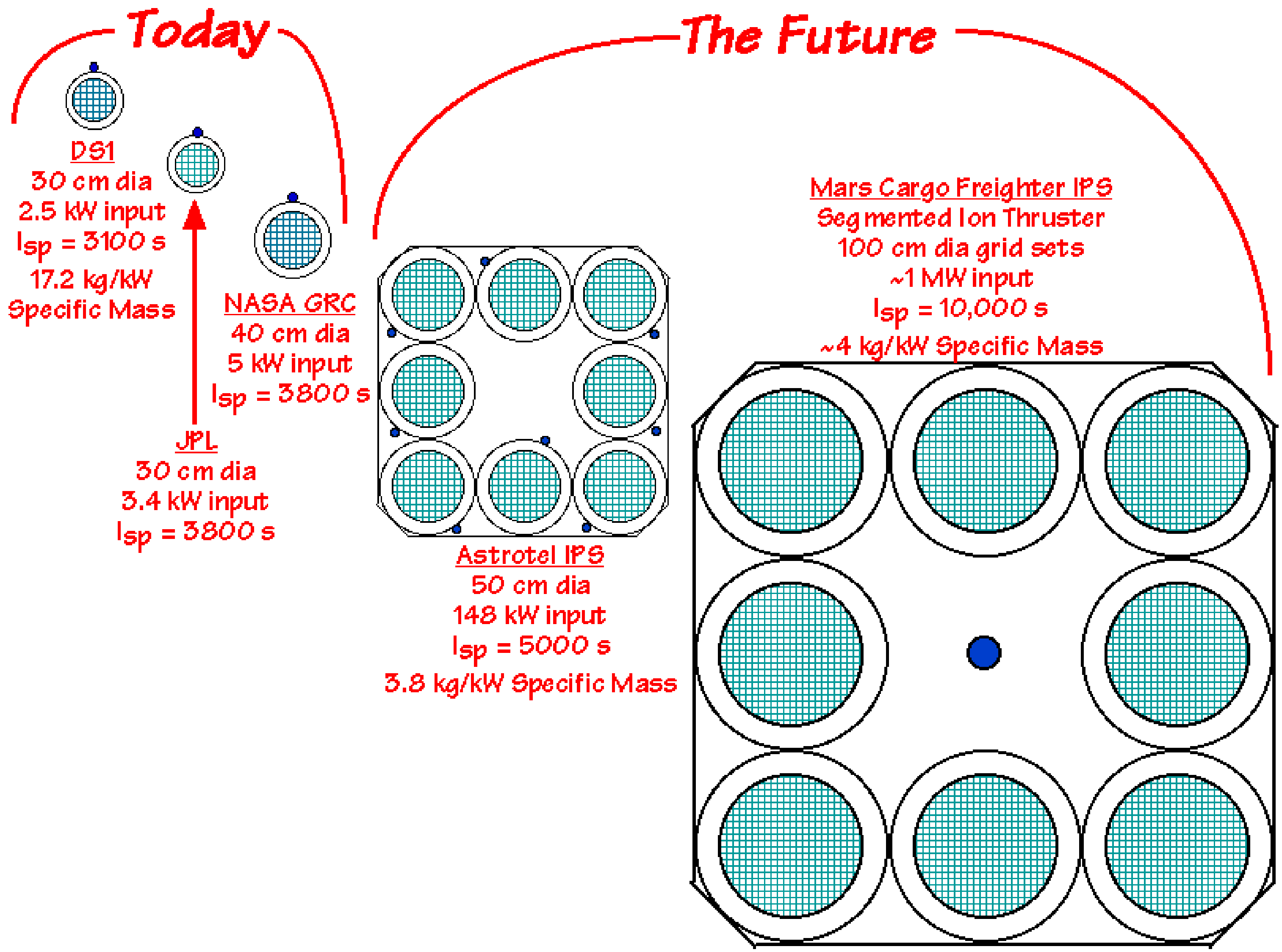
ION PROPULSION SYSTEM (IPS)



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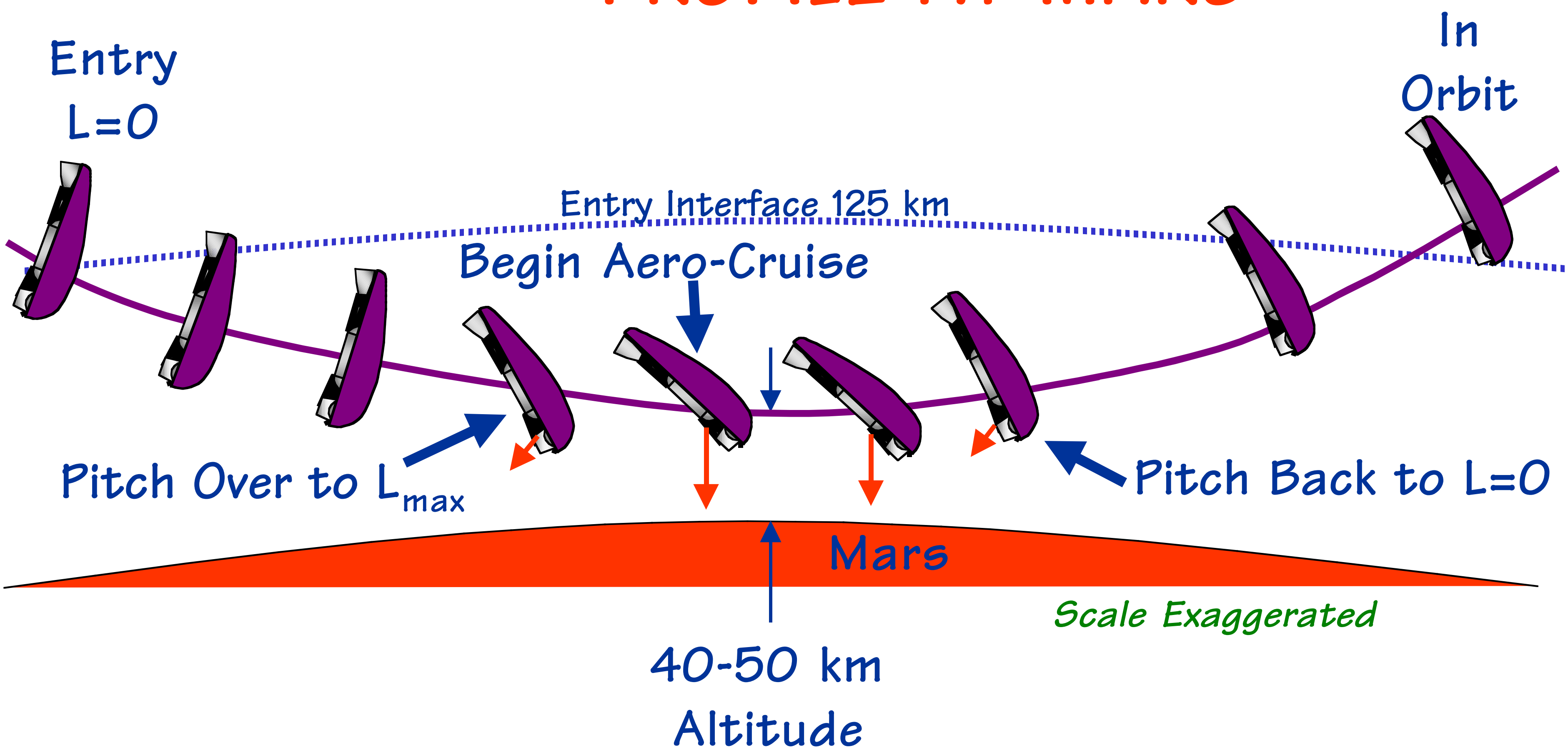
EXAMPLE AERO-ASSIST PROFILE AT MARS

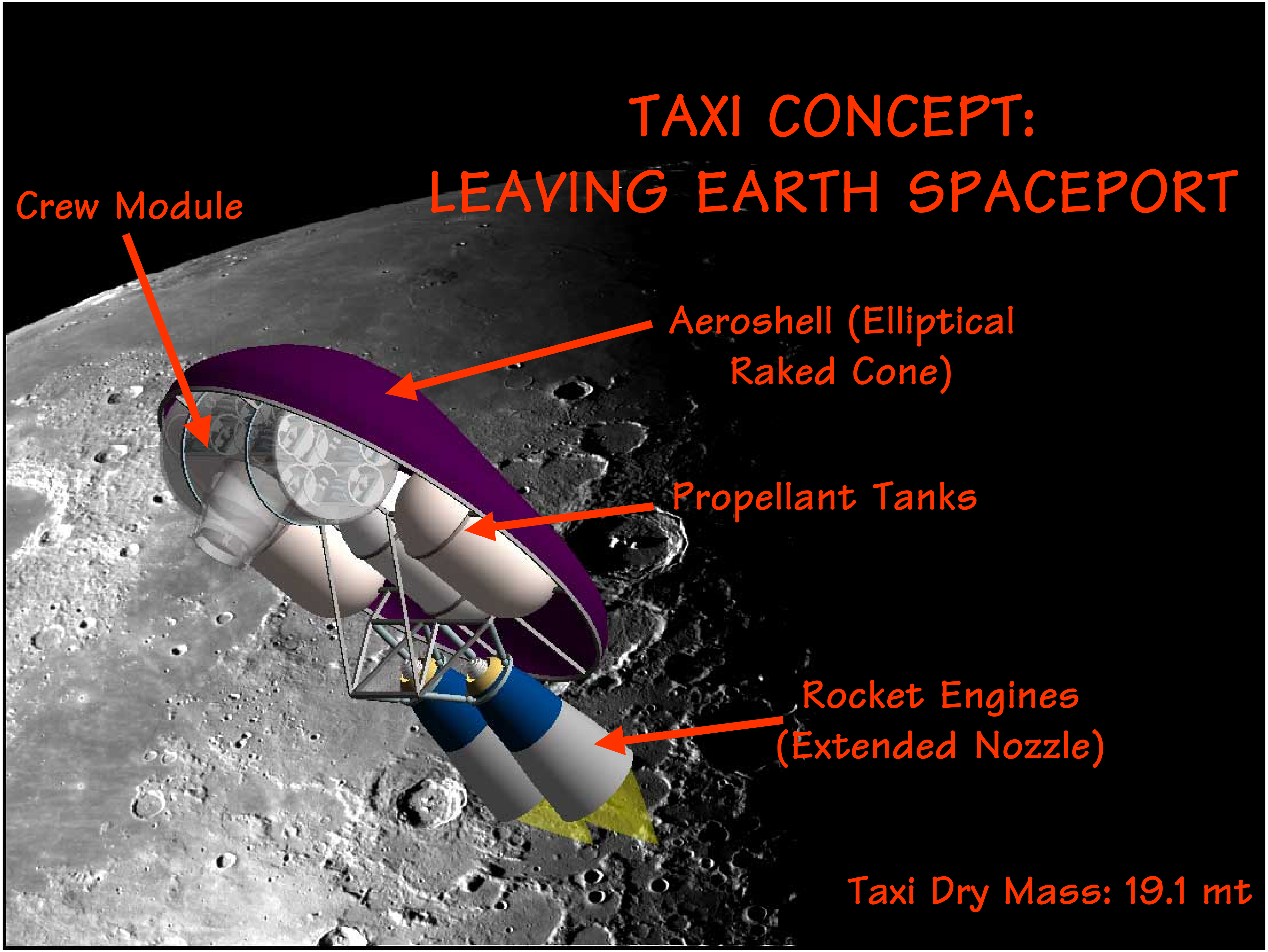


ISS TRANSHAB CONCEPT

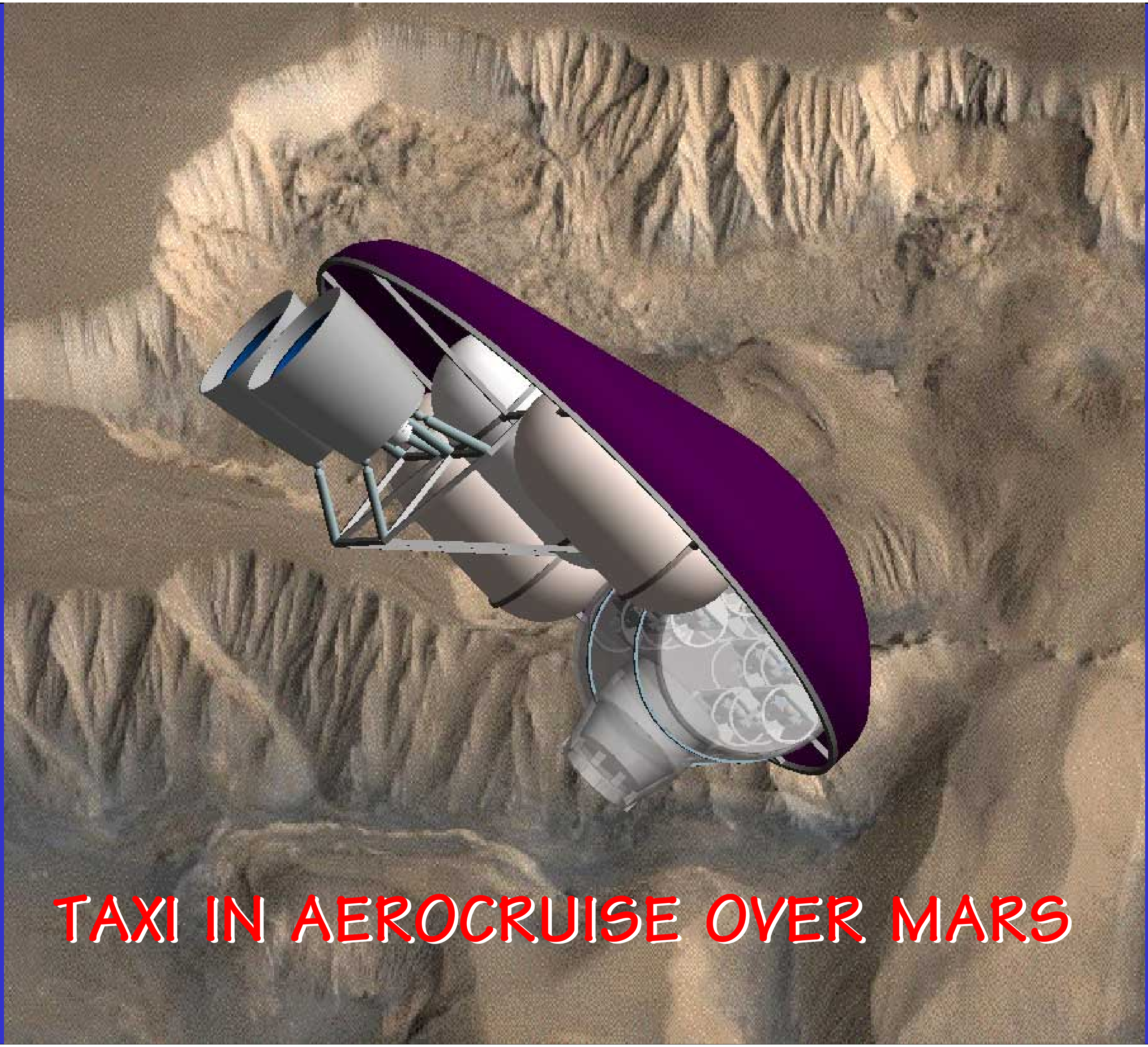
(Courtesy NASA/JSC)

Modifications

- Expansion of crew from 6 to 10
- 6-times volume/crew as STS
- Expansion of radiation protection
- Added docking port
- Include Astrotel command and control systems


TAXI CONCEPT:
LEAVING EARTH SPACEPORT
Crew Module
Aeroshell (Elliptical Raked Cone)
Propellant Tanks
Rocket Engines (Extended Nozzle)
Taxi Dry Mass: 19.1 mt


TAXI CREW MODULE
Variable
g-Vector
Seats (10)
Crew Space Equal to Apollo
Docking Port


TAXI IN AEROCRUISE OVER MARS

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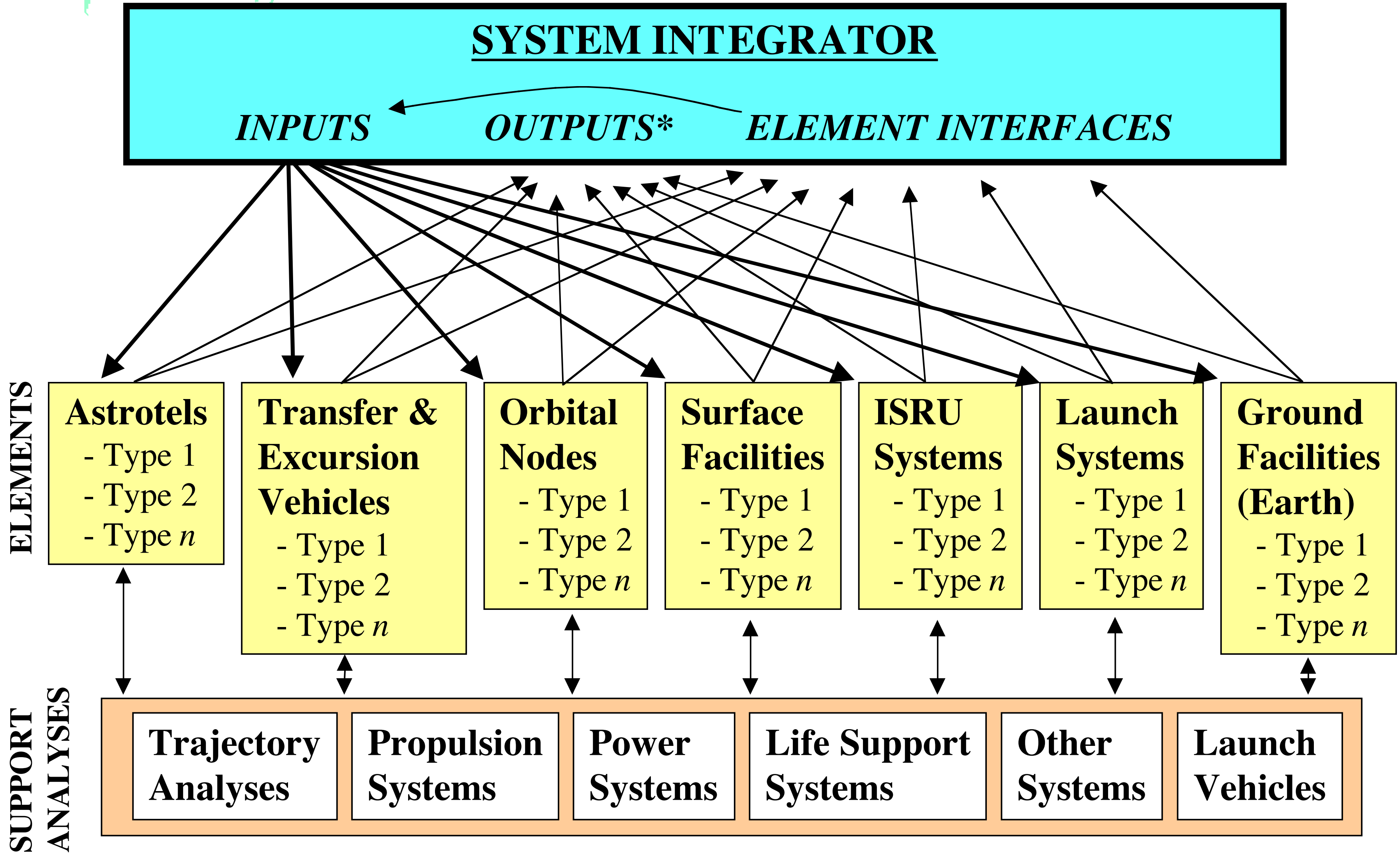
IN SITU RESOURCE UTILIZATION STRATEGIES

- Moon --> Polar Ice
  - Excavate regolith, heat and extract water (10.2 kg/hr)
  - Electrolyze some water into O_2/H_2 and liquefy to LOX/LH for lunar water tanker
  - Liquefy and transport most water to earth spaceport
- Earth Spaceport --> ~100% Sun
  - Electrolyze Lunar water Into O_2/H_2 and liquefy to LOX/LH (1.6 kg/hr)
  - LOX/LH storage for Taxi
- Phobos --> O_2-Bearing Regolith
  - Carbon reduction of regolith to produce O_2 (23.2 kg/hr)
  - Liquefy to LOX and transport to Mars spaceport for storage
- Mars Spaceport --> ~100% Sun
  - LOX/LH storage for Taxi
- Mars Surface --> Water-Bearing Regolith
  - Excavate regolith (dunes), heat and extract water (8.1 kg/hr)
  - Electrolyze water into O_2/H_2 and liquefy to LOX/LH for Mars shuttle

SYSTEM MODELING, ANALYSIS AND COSTS

Cyclical Visits To Mars via Astronaut Hotels

MAMA



* System Integrator Output includes a standard WBS-format for all architecture candidates

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MAMA_v12.xls

	Subsystem	NCOS Reference 1995	Astrotel Study	Refurb Mass in 16 years, %	Refurb Mass, kg
1					
2					
3	*Crew Module*				
4					
5	Primary Structure	295	990	5%	45
6	Couches, restraints	38	90	50%	45
7	Hatches, windows	95	60	25%	15
9	Docking	77	80	50%	40
9	Panels, supports	23	30	20%	6
10	Power System	438	1,090	75%	819
11	PMAD	105	105	30%	32
12	Comm	95	90	100%	90
13	Guidance and Nav	102	90	100%	90
14	Controls & Displays	91	90	100%	90
15	Instrumentation	98	90	100%	90
16	Life Support System	930	1,459	50%	729
17	Crew	319	819	0%	-
19					
19	Total Crew Module	2,262	4,920		1,929
20					
21	*Propulsion Module*				
22					
23	Tanks, Insulation & Plumbing	2,920	4,810	5%	200
24	Engines	2,000	2,000	100%	2,000
25	Landing Gear	308	420	10%	42
26	Aerobrake	5,790	6,451	30%	1,935
27	Attitude Control (dry)	229	90	100%	90
28	Attitude Control (prop)	491	704	0%	-
29	Primary Structure	2,475	3,522	5%	176
30					
31	Total Propulsion Module	14,222	17,760		4,434
32					
33	Total Mars Shuttle	16,484	22,584		6,363 ###
34					
35					
36	Tankage Factor	9.4%	10.0%	of propellant m	A
37	Proportional Mass Factors				
39	Structure	4.71%	5.0%	of initial mass	
39	Landing Gear	0.6%	0.6%	of initial mass	B
40	Attitude Control	0.9%	1.0%	of initial mass	
41					
42	Aerocapture	16.6%	15.0%	of Entry mass	C
43					
44	Mars Cargo Sized	10,000	10,000	kg	
45	Actual Cargo Requirement		7,720	kg	

Delta-Vs		
Mars Surface to Phobos	5,100	m/s
Exhaust Velocity	4,511	m/s
Mass Fraction #1	3.10	
Phobos to Mars Entry	562	m/s
Mass Fraction #2	1.13	
Landing		
	0	m/s
Landing Deceleration	920	m/s
Wind	80	m/s
Hover	200	m/s
Total Landing	1,200	m/s
Mass Fraction #3	1.31	
Total Phobos to Landing	1,792	
Mass Fraction #4	1.49	

$m_i = (m_p + C^*m_c^*MF4)^*MF/(A^*(1-MF)-B^*MF-C^*MF4+1)$

$m_e = m_i^*MF4/MF + m_c^*MF4$

	Overall Mass Fraction - MF	Mass Fraction #3	A - Tankage Factor	B - Proportional Mass Factors	C - Aeroshell Mass Factor	Fix Masses - Mfx	Initial Mass - Mi	Entry Mass - Me	Landed Mass	Final (empty) Mass - mf	Propellant Mass leaving Mars - mp1	Propellant Mass leaving Phobos - mp2
NCOS	3.17	1.31	9%	6.3%	16.6%	4,490	52,549	34,907	26,577	16,577	34,984	39,509
Astrotel Study	3.10	1.31	10%	6.6%	15.0%	6,970	70,449	43,008	32,744	22,744	46,098	48,714

Mass of Propellant required at Mars every cycle (2 1/7 years) — 322,670

Mass of Propellant required at Phobos every cycle (2 1/7 years) — 341,001

EXAMPLE MAMA SYSTEM ELEMENT

Propellant_Cargo_Reqmts / Astrotel Cargo Freighter / Mars Cargo Freighter / **Mars_Shuttle** / Astrotel / Taxi / Lunar Water Tanker / Escape Pod

CARGO USE PROFILE SUMMARY

Location------------->	At LEO	At Earth Spaceport	At Mars Spaceport	At Surface of Mars	At Surface of Moon	At Astrotels (2 vehicles)
Total Cargo Requirements						
LOX		122,631	1,036,348	282,339		
LH		17,519	148,050	40,334		
Water		157,669		363,007		
Xenon	245,106					5,751
Refurb Mass	149,863	37,800	80,259	54,061	567	14,692
Augmentation Tanks	107,827		107,827			
Crew Consumables	119,140					119,140
Communications Satellites						
Total Mass Required	621,935	335,619	1,372,483	739,741	567	139,583

- Cargo requirements over 15-years
- All masses in kg

CARGO DELIVERY SYSTEMS REQUIREMENTS SUMMARY

Location------------->	At LEO	At Earth Spaceport	At Mars Spaceport	At Surface of Mars	At Surface of Moon	At Astrotels (2 vehicles)
Delivery Systems						
SEP Freighter Delivered Cargo		**37,800**	**336,135**			**139,583**
Cargo Freighter Each Trip		5,400	48,019			19,940
Lunar Water Tanker Total		**157,669**			**567**	
Lunar Water Tanker Each Trip		22,524			81	
Phobos LOX Tanker Total			**1,036,348**			
Phobos LOX Tanker Each Trip			34,545			
Mars Shuttle				**54,061**		
Mars Shuttle Each Trip				7,723		

All masses in kg

NIAC / NCOS COMPARISON

Item	NCOS Study	NIAC Study	Factor
Cyclic Transport Vehicle Size, mt	460	70	7
Total 15-year Propellant and Consumables, mt	34,335	2,011	17
Lunar LOX Production Rate, kg/day	4,014	73	55
Phobos LOX Production Rate, kg/day	1066	189	6
Primary Power Generation Mode	Nuclear	Solar	--

KEY COST ASSUMPTIONS

- FY 2000 dollars
- Full cost accounting on all life cycle elements
- Major cost elements include:
  - Advanced Technology Development
  - Flight System Development
  - Launch (specific launch vehicle cost of $2000/kg)
  - Operations (15 years, includes RRU & propellants/consumables)

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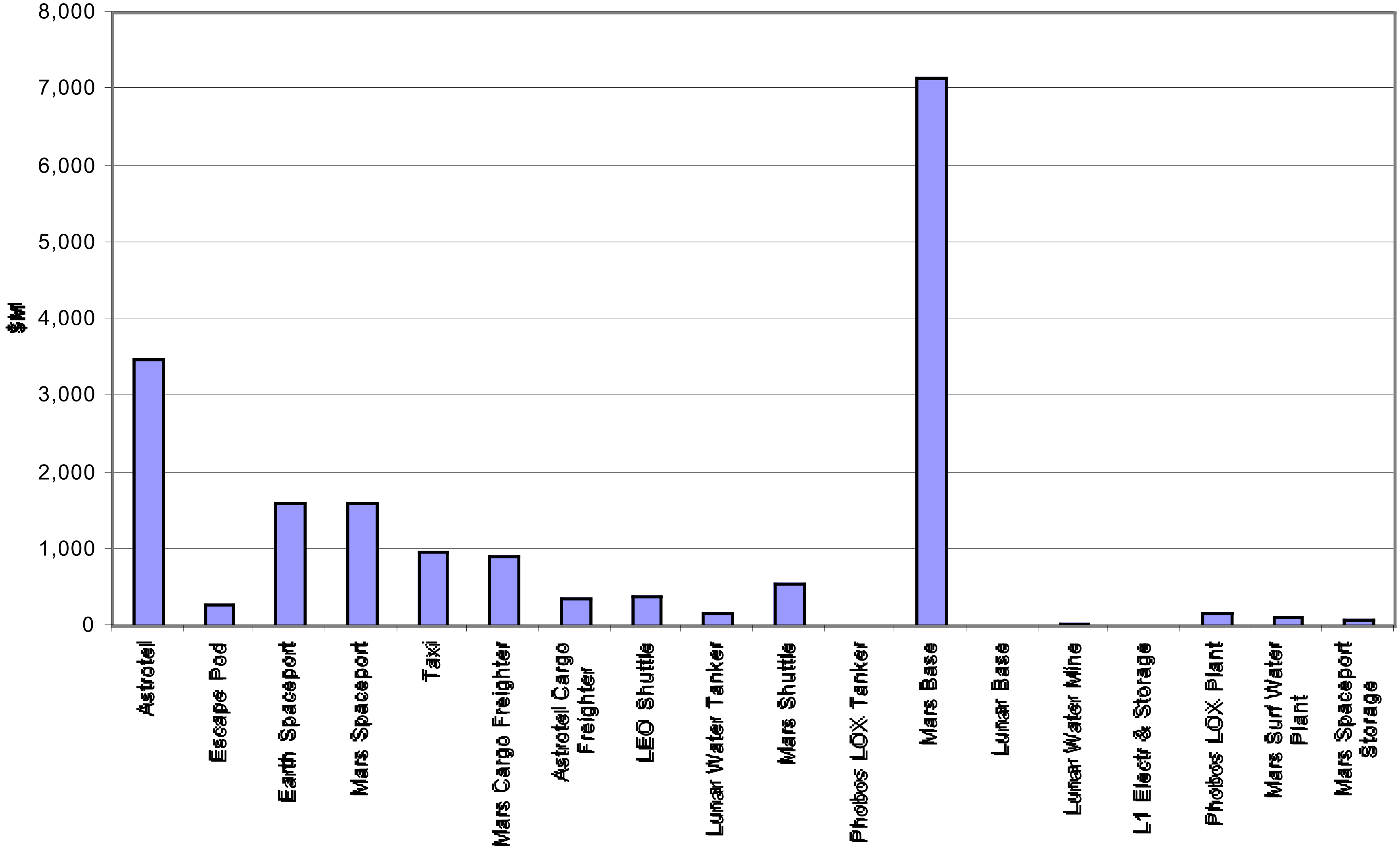
SYSTEM INTEGRATOR OUTPUT: RECURRING COSTS



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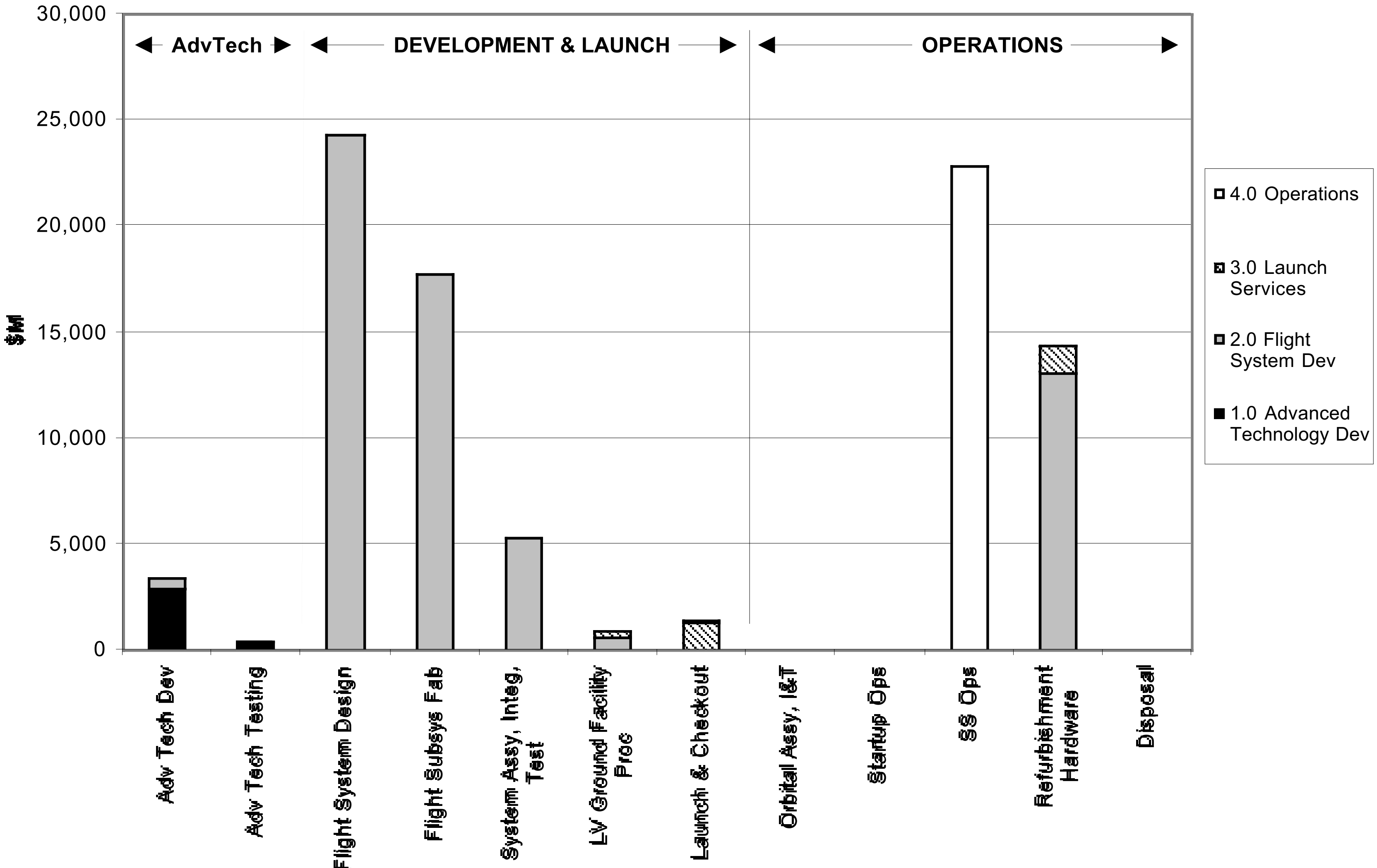
SYSTEM INTEGRATOR OUTPUT: LIFE CYCLE (15 YEARS) COSTS



SUMMARY OF COST ESTIMATES

Development	~$50B*
Operations	~$40B†
Total Lifecycle	~$90B¥

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* - ~$5B/yr for 10 years

† - ~$3B/yr for 15 years

¥ - For reference, the "90-day Study" (1989) costs for human exploration to the Moon and Mars was estimated at ~$400B and the NASA Mars Reference Mission (1997) was estimated at ~$40B.

SIGNIFICANCE OF CONCEPT TO NASA

SIGNIFICANCE TO NASA

- Facilitates human exploration to Mars and beyond
- Assists the expansion of scientific knowledge by providing ready access to Mars by scientists
- Provides safe, frequent and affordable access to Mars
- Creates a significant element of the transportation architecture thus contributing to the establishment of a permanent human presence on Mars

PHASE II

- Key Team Members
  - GAC
  - SAIC - MAMA development & costing, orbit analysis
  - Purdue (Dr. Longuski) - Orbit analysis
  - Colorado School of Mines (Dr. King) - ISRU Concepts
  - Dr. Michael Duke - ISRU
- Key Technical Tasks
  - Cyclic orbit concepts and research
  - Advanced aero-assist concepts
  - ISRU system concepts development
  - Develop and assess transportation options
  - MAMA development and costing

SUMMARY

SUMMARY

- This transportation architecture, along with Astrotels, enable low-cost, frequent access to Mars for scientists and explorers
- System concepts have been developed that could be utilized in expedition phases of Mars exploration
- This architecture provides a framework and context for future technology advance and robotic exploration
- The tools developed during this study can be used to analyze and compare future technology and system options

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