CYCLIC VISITS TO MARS VIA ASTRONAUT HOTELS OR THE INTERPLANETARY RAPID TRANSIT (IRT) SYSTEM

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TOPICS

- Phase II Contributors
- Interplanetary Rapid Transit System (IRT) Concept Overview
- Visions, Goals, Assumptions, and Realities
- Orbital Tracks and Space Lines
- Using the Atmosphere To Put The Brakes On
- Taxi, Shuttle, Transport Hubs, and Hotel Design Concepts
- Example Transit Schedule
- Turning Planet Dirt Into Rocket Fuel and Other Useful Things
- Technologies To Build Upon
- What's The Best Architecture and How Much Will It Cost?
- Summary

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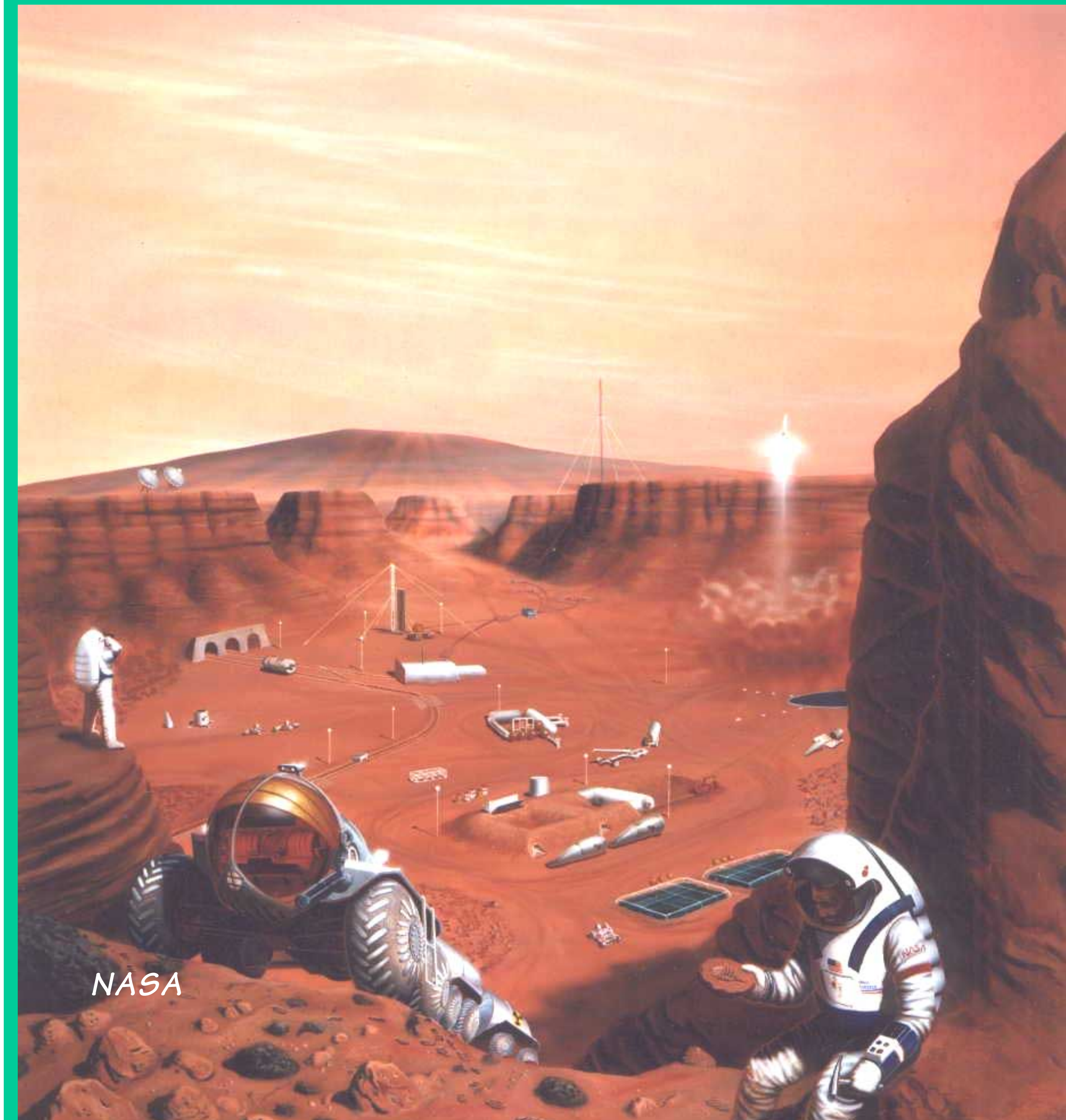
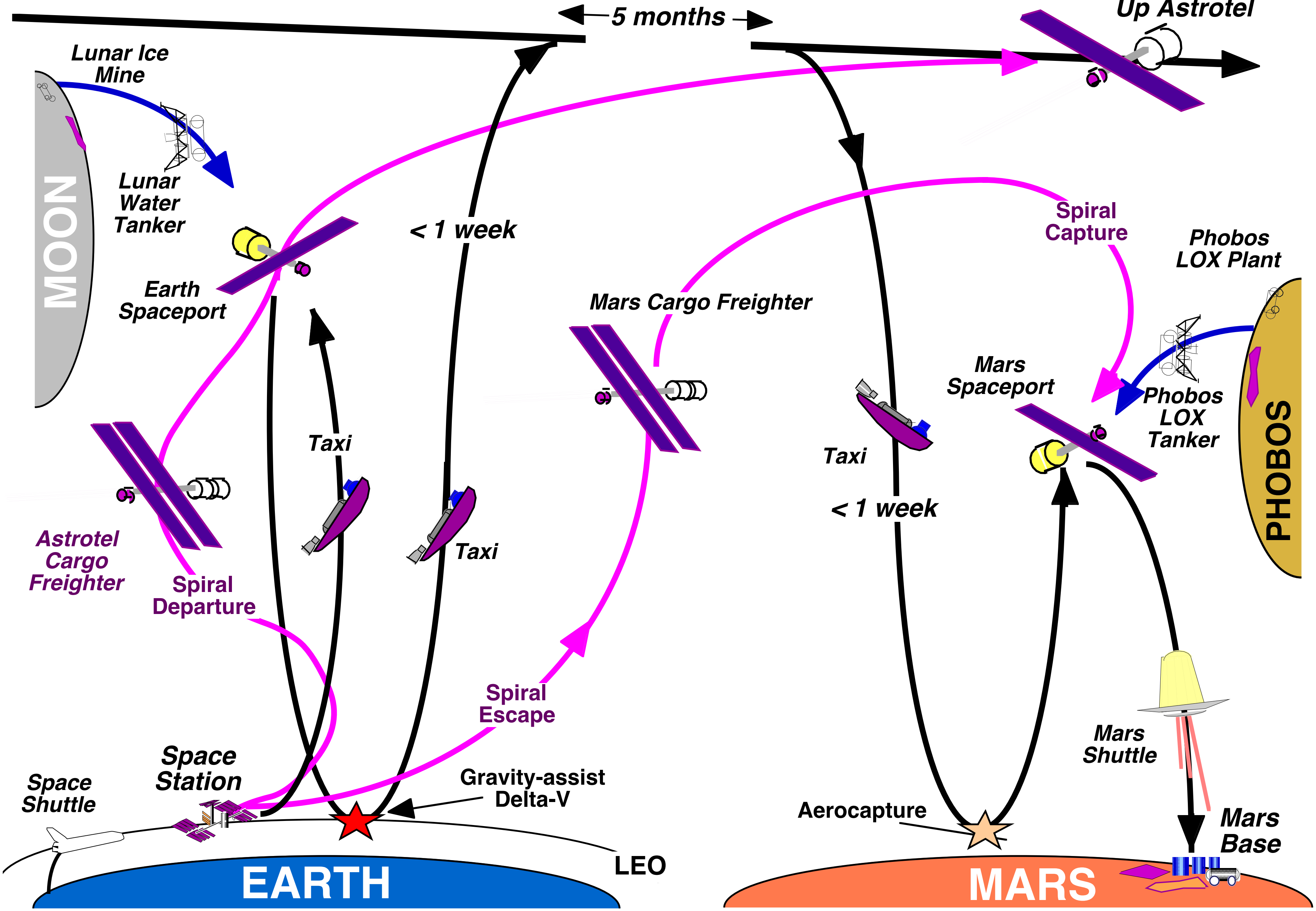
INTERPLANETARY RAPID TRANSIT (IRT) SYSTEM CONCEPT

MARS BASE



Mars Base Systems	# of Units	Unit Mass, mt	Total Mass, mt
Life Critical Systems			
Habitat	4	38.5	154.0
Washdown facility	2	0.9	1.8
			155.8
Mission Support Systems			
120 kW Power Source (solar array @100W/kg)	2	1.2	2.4
Power Management, Distribution and Maintenance	2	0.3	0.6
Energy Storage (NRFC packages)	2	1.1	2.2
Suitup/Maintenance Facility	2	1.8	3.6
Pressurized Transporter	3	9.1	27.3
Open Rovers	3	1.0	3.0
Inflatable Shelter w/Airlock	10	0.5	5.0
Communication Satellites	3	0.8	2.4
Crane	2	5.0	10.0
Trailer	2	2.0	4.0
			60.5
Science and Exploration Systems			
Base Laboratory	2	13.6	27.2
Mobile Laboratory	3	9.1	27.3
200 m Drill	1	2.3	2.3
10 m Drill	3	0.1	0.3
UAV	3	0.3	0.9
Robotic Rovers	10	0.2	2.0
Weather Station	5	0.2	1.0
Survey Orbiters	2	0.8	1.6
			62.6
Total			**278.9**

IRT ROUTE MAP



VISIONS, GOALS, ASSUMPTIONS AND REALITIES

A VISION OF THE FUTURE

- Permanent inhabitation of Mars by scientists and explorers occurs as quickly as financially feasible
- Earth-Mars transit system is created providing safe, frequent and affordable travel
- Reduced reliance on Earth for space activities
- Pathways are opened for exploration beyond Mars

SUGGESTED DEVELOPMENT GOALS OF A FUTURE TRANSIT SYSTEM

- Demonstrate physiologically feasible travel to and from Mars (zero-g, radiation protection)
- Minimize transit system life cycle costs
- Maximize use of natural resources
- Establish context for future human space exploration and development, space technology advance, and robotic missions
- Incorporate advanced technology to lower costs and make trips safer

KEY ARCHITECTURE STUDY ASSUMPTIONS

- Sustained Mars Base of 20 people that is self sufficient except for hardware
- Earth launch costs are $2,000 per kg to low Earth orbit
- Use solar energy for space and surface power
- Use space resources to make rocket fuels
- Use currently and clearly foreseeable technologies
- Transport crews and cargo in efficient steps with specialized vehicles

REALITIES

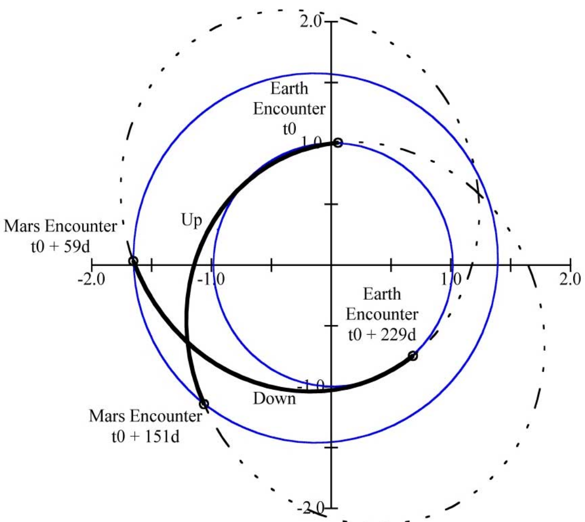
- An Earth-Mars transportation system will be expensive and will require
  - imagination to minimize costs,
  - significant and sustained political leadership and
  - international collaboration
- If used, space nuclear reactor system costs will be very expensive without DOD and/or commercial applications
- Launch costs will be an order of magnitude less when they are

ORBITAL TRACKS AND SPACE LINES

The Interplanetary Rapid Transit (IRT) System

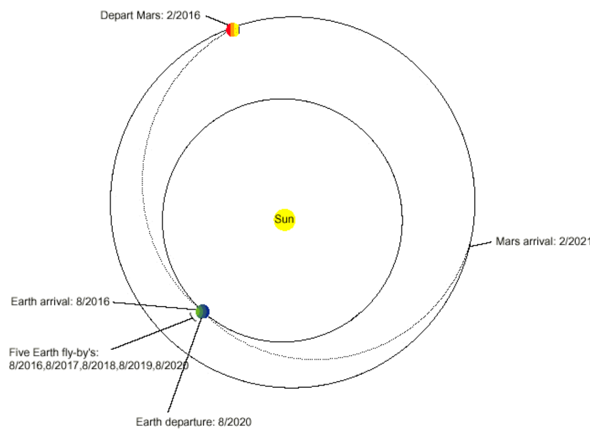
CYCLIC ORBIT OPTIONS

Low-thrust Aldrin Cyclers



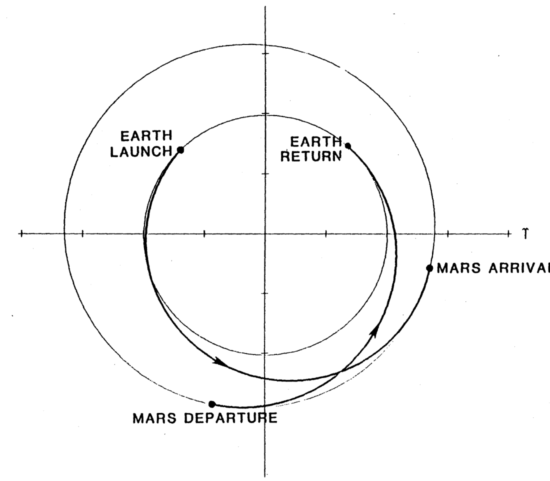
- Up and Down Cyclers, two Astrotels
- Gravity assist to rotate orbits to achieve 15-year repeating sequence
- Low-thrust guidance maneuvers
- 5 month trips to and from Mars
- High Taxi ΔV to leave Mars

Semi-Cyclers



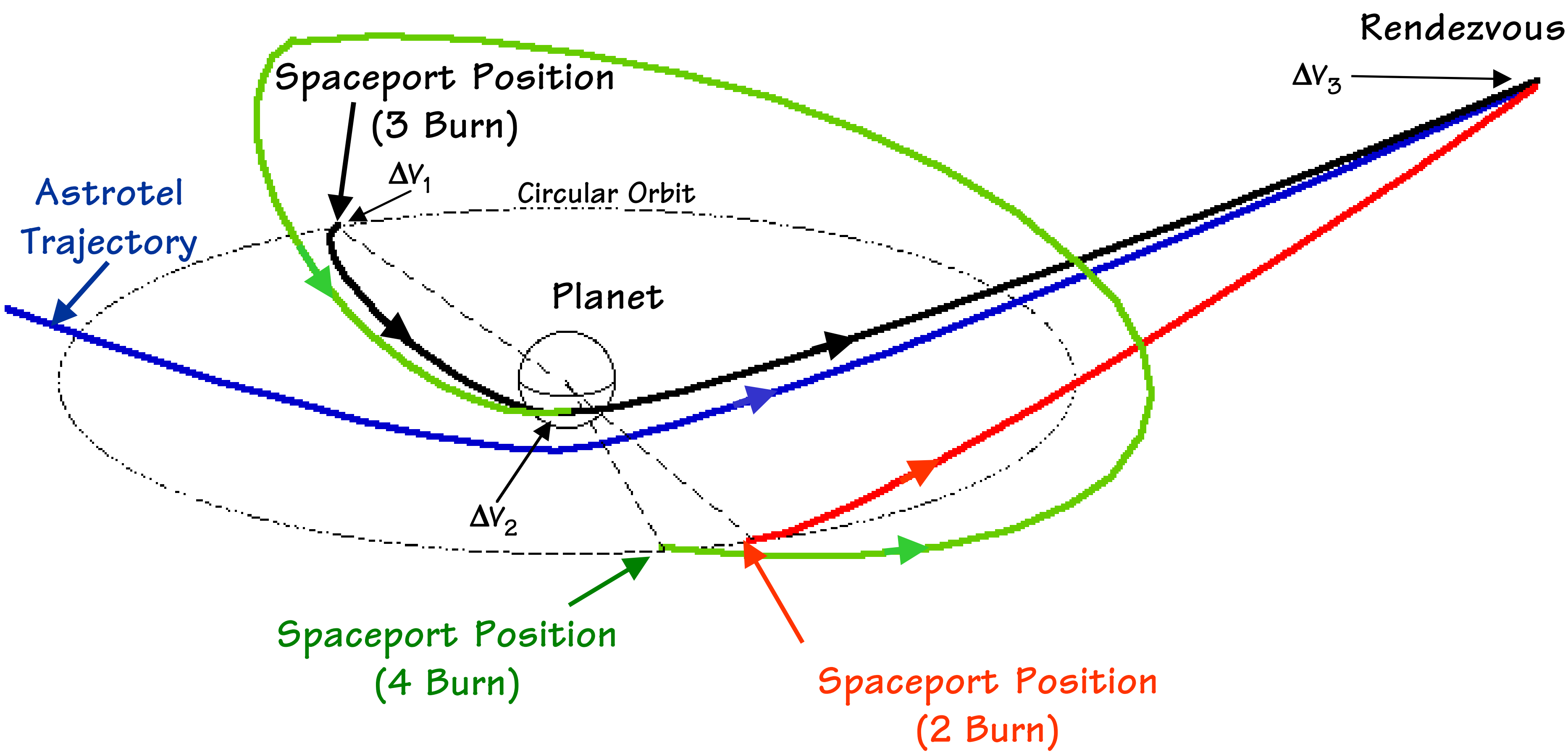
- Three Astrotels on 78 month trips between Mars arrival and departure
- High-thrust Mars escape / capture
- Five Earth flybys between Mars departure and arrival
- 6 month crew trips to / from Mars
- 1.5 year Astrotel stay time at Mars

Stopover Cyclers



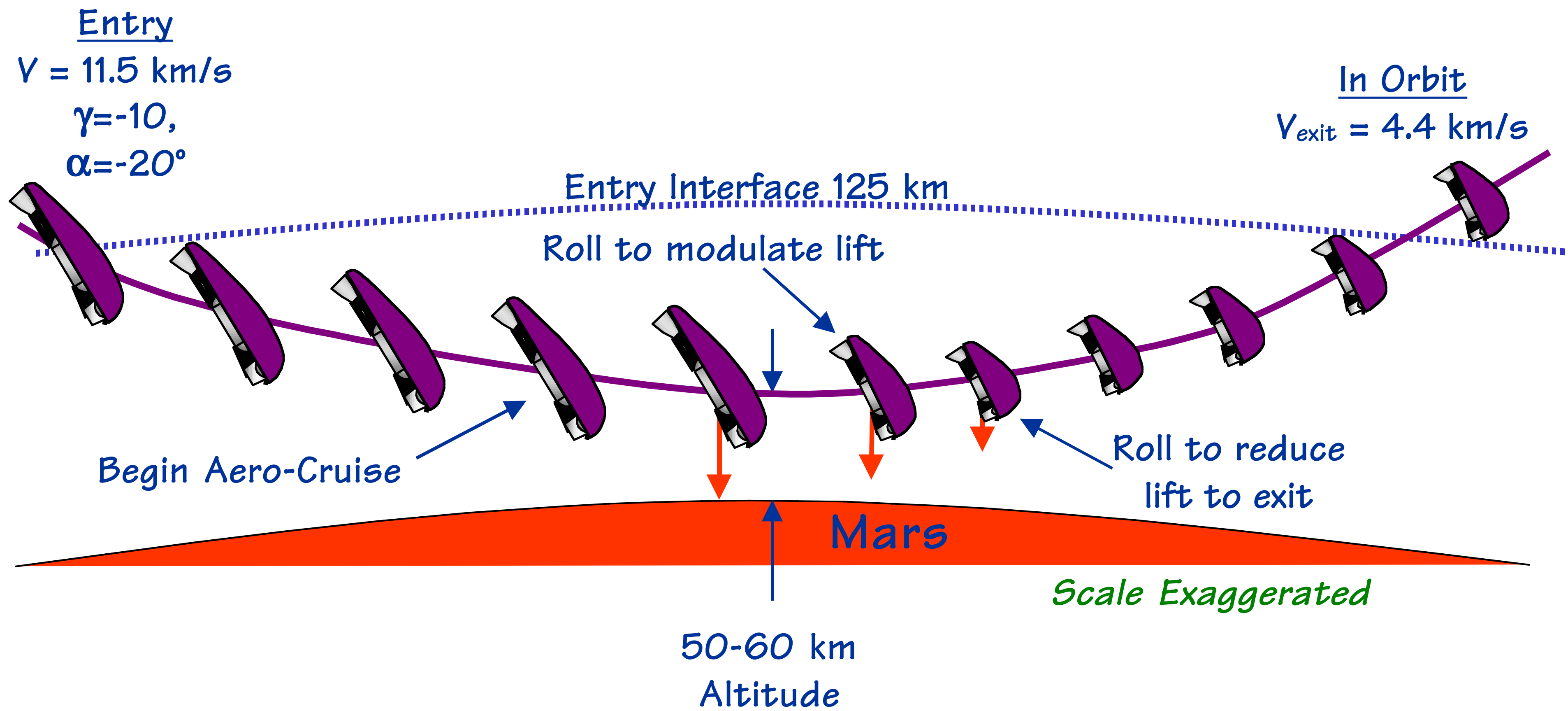
- Two Astrotels on near-minimum energy orbits
- Stops at Earth and Mars
- High-thrust escape/capture
- 4-7 month trips depending on opportunity and fuel loading
- 1.5 year Astrotel stay time at Mars

HYPERBOLIC RENDEZVOUS TRAJECTORY GEOMETRY



USING THE ATMOSPHERE TO PUT THE BRAKES ON

MARS AEROCAPTURE PROFILE

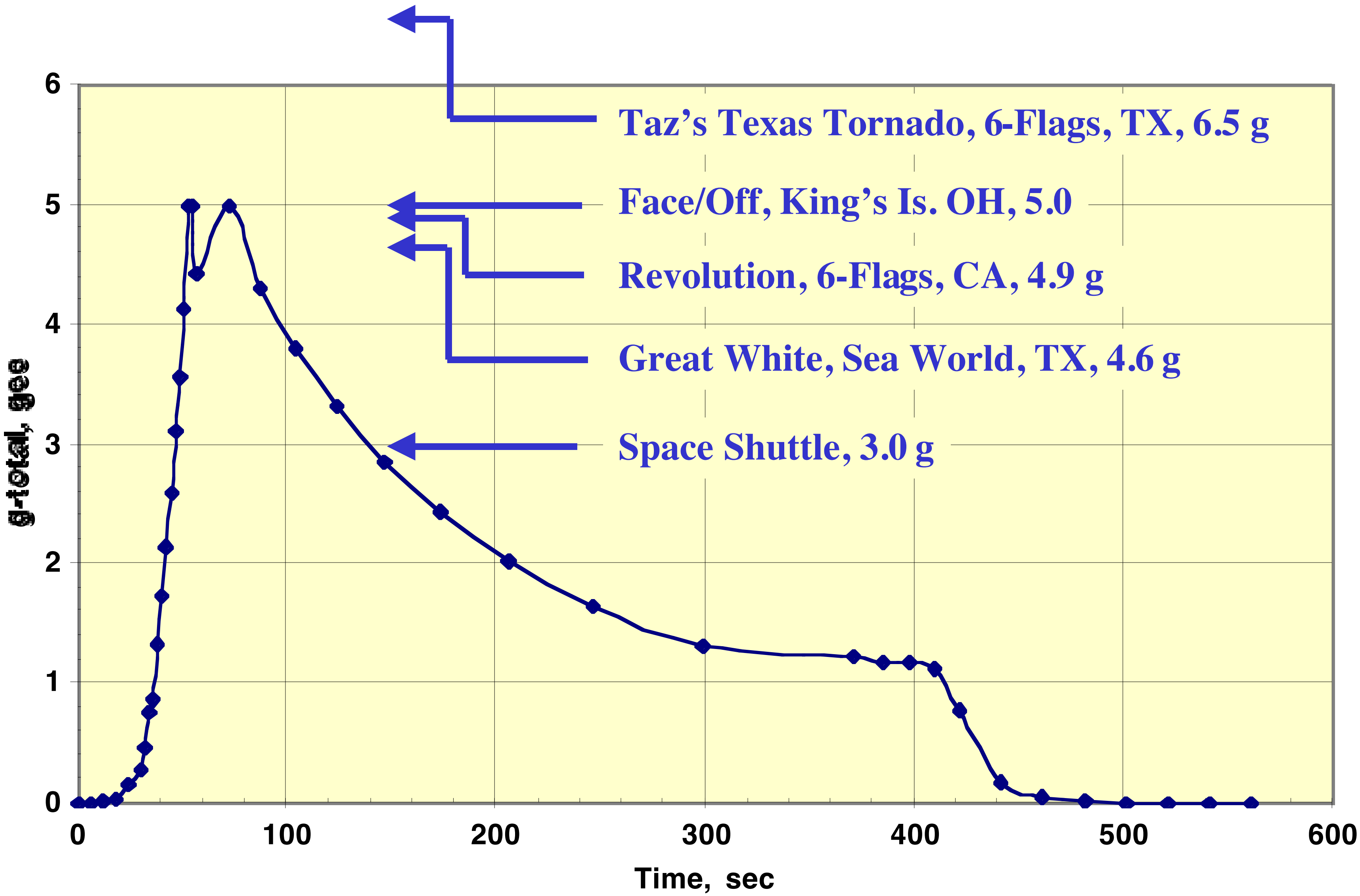


Aerocapture at Mars saves about 83 mt of fuel

TAXI IN AEROCRUISE OVER MARS

10 crew, Earth / Mars aerocapture, 12 m diameter aeroshell (Elliptical Raked Cone), 16.1 mt vehicle dry

TAXI AEROCAPTURE G-LOAD

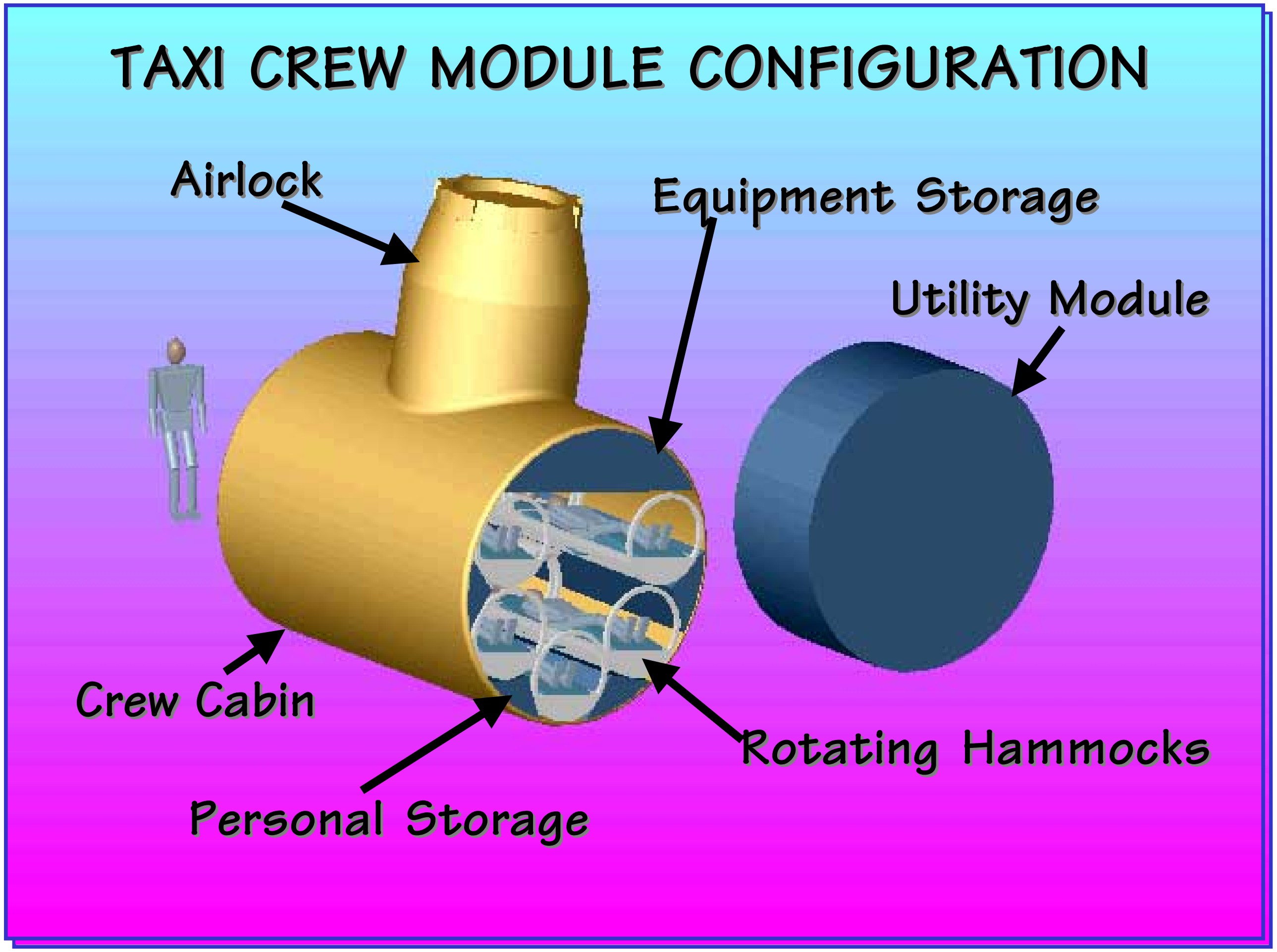


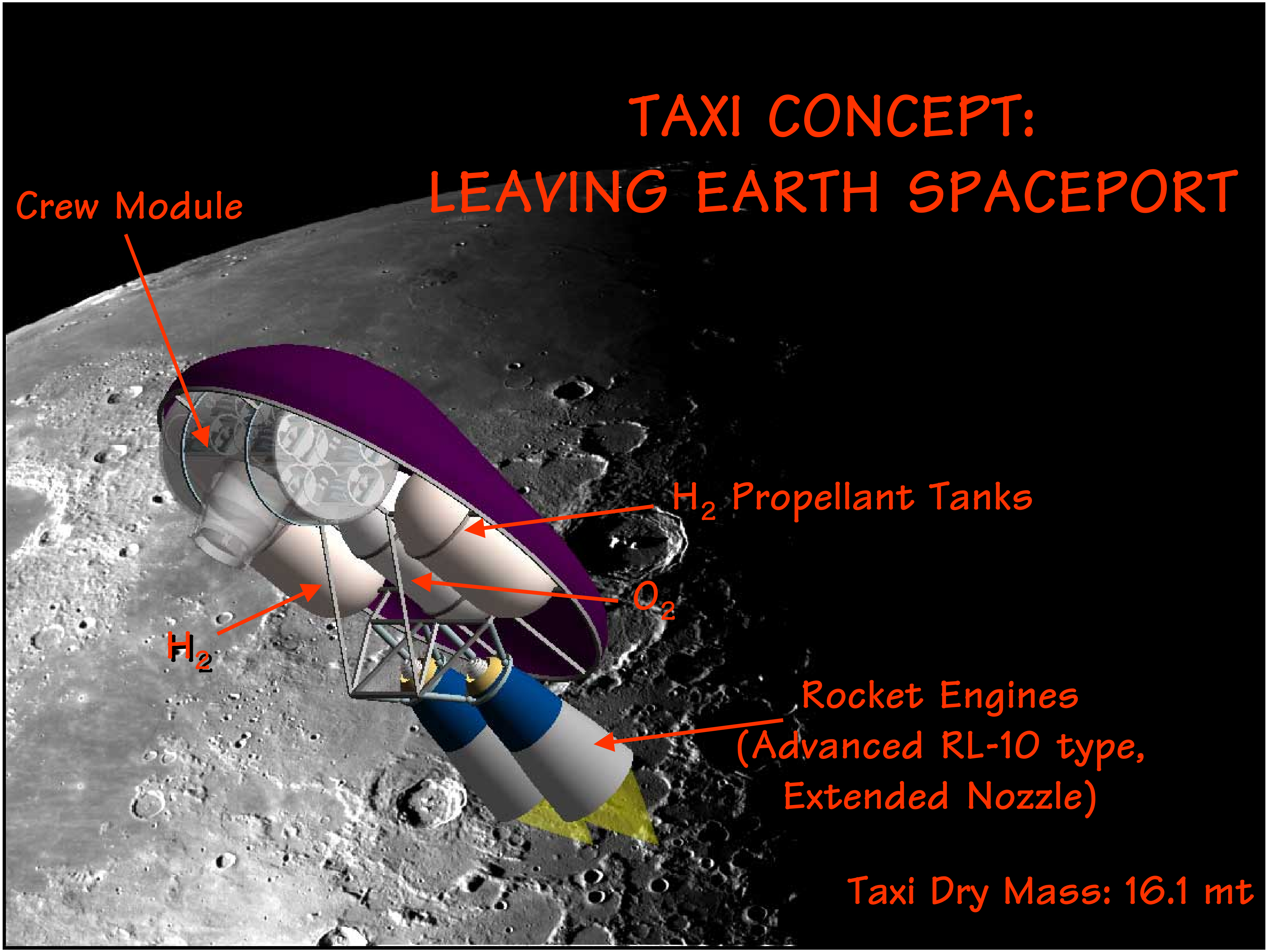
TAXI, SHUTTLE, TRANSPORT HUBS, AND HOTEL DESIGN CONCEPTS

CREW MODULE

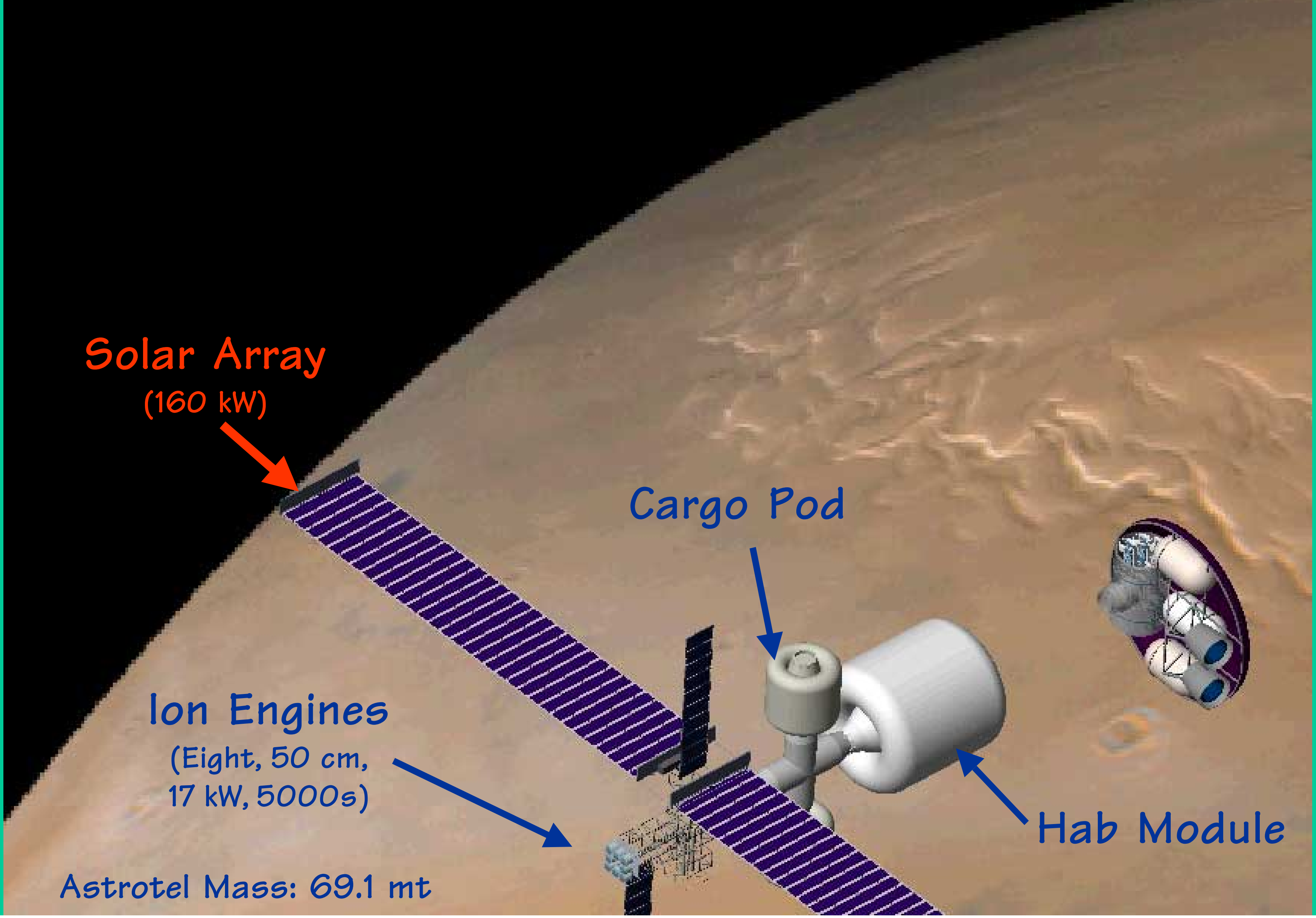
KEY FEATURES

- Supports crew of 10 for 7d
- Apollo accommodations
- G-aligned crew hammocks
- 7.2 mt including life support and power
- Taxi and Mars Shuttle vehicle versions
  - Mars Shuttle: No radiation shielding and minimal energy storage for <3 hour flights, add second airlock for Mars surface access
  - Taxi: Energy storage for 7 days, minimal radiation shield, single airlock




TAXI CONCEPT:
LEAVING EARTH SPACEPORT
Crew Module
H_2 Propellant Tanks
O_2
H_2
Rocket Engines
(Advanced RL-10 type,
Extended Nozzle)
Taxi Dry Mass: 16.1 mt

TAXI DOCKING TO ASTROTEL

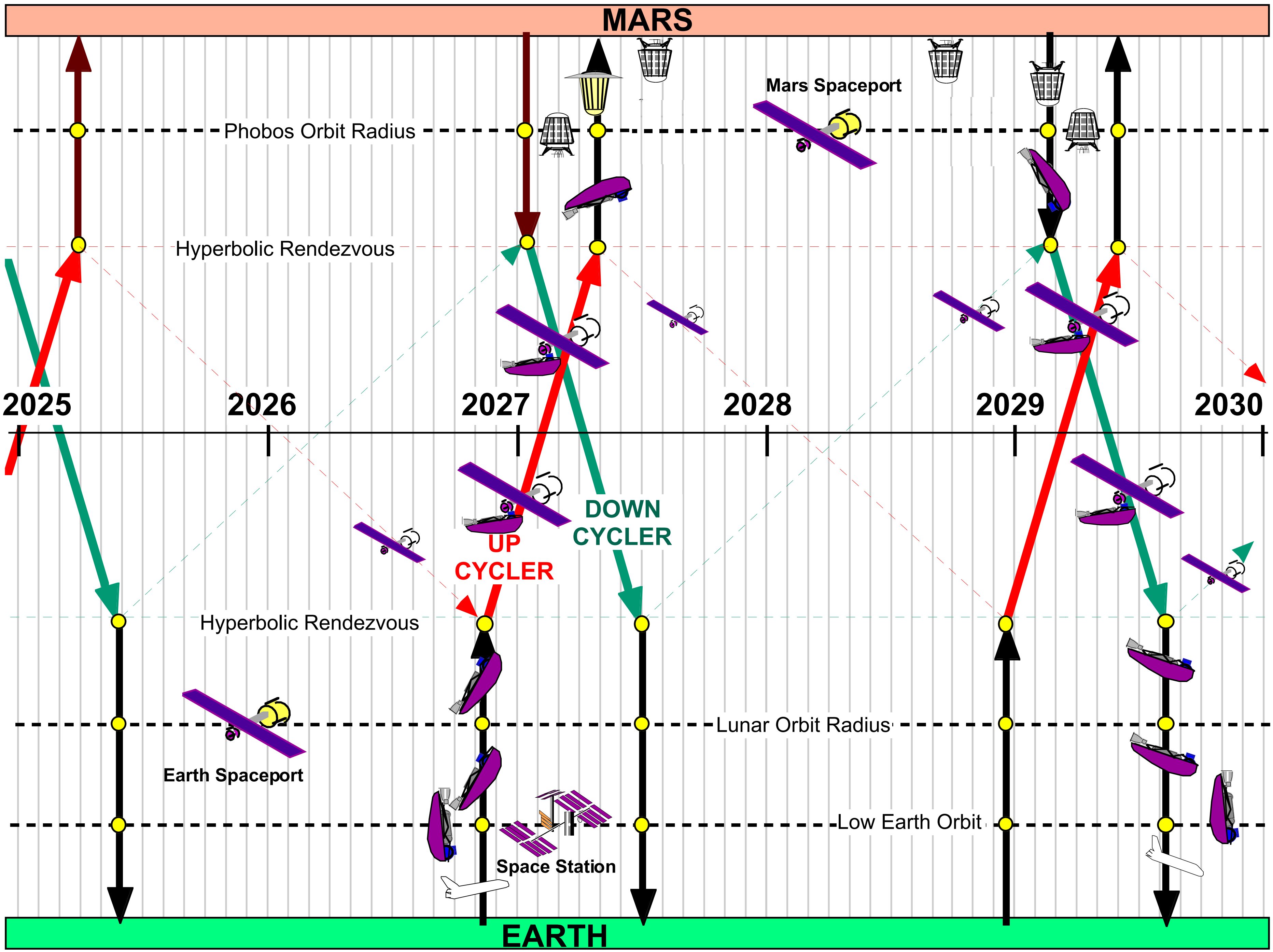



MARS SHUTTLE AT ENTRY
KEY FEATURES
10 crew
Direct entry from Phobos orbit
10 mt cargo
17.9 mt vehicle (dry)
LH Tank
LOX Tank
Common Crew Module
Cargo Containers
AEROBRAKE DESIGN
• 20 m diameter, Viking aeroshell shape, open back
• 30 deployable and stowable segments
• Al structure & honeycomb substrate, STS-type TPS
• Deployed at the Mars Spaceport
• Stowed before departure from Mars surface

MARS SHUTTLE LANDING

MARS SHUTTLE AFTER LAUNCH

IRT TRANSIT SCHEDULE



MARS
Mars Spaceport
Phobos Orbit Radius
Hyperbolic Rendezvous
2025
2026
2027
2028
2029
2030
DOWN CYCLER
UP CYCLER
Hyperbolic Rendezvous
Lunar Orbit Radius
Earth Spaceport
Low Earth Orbit
Space Station
EARTH

KEY ADVANTAGES OF ALDRIN CYCLERS

- Astrotels can take advantage of ion propulsions system (IPS) technology
- Astrotels never stop
- With IPS, one can incrementally increase the Astrotel capability over time with very little propulsion cost
  - Increase radiation shielding thickness
  - Incorporate artificial gravity if needed
  - Add redundant Taxi and/or escape vehicles
  - Grow a cache of repair hardware, propellants and consumables

TURNING PLANET DIRT INTO ROCKET FUEL AND OTHER USEFUL THINGS

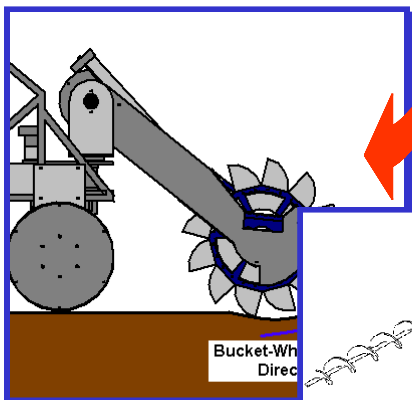
TURNING NATURAL RESOURCES INTO ROCKET FUEL

- Moon --> Water from Polar ice
- Phobos --> O_2-bearing regolith
- Mars Surface --> Water-bearing regolith
- Spaceports --> Electrolysis of water to and/or storage of LH and LOX using solar energy

SPACE RESOURCE PROPELLANT PRODUCTION SYSTEMS

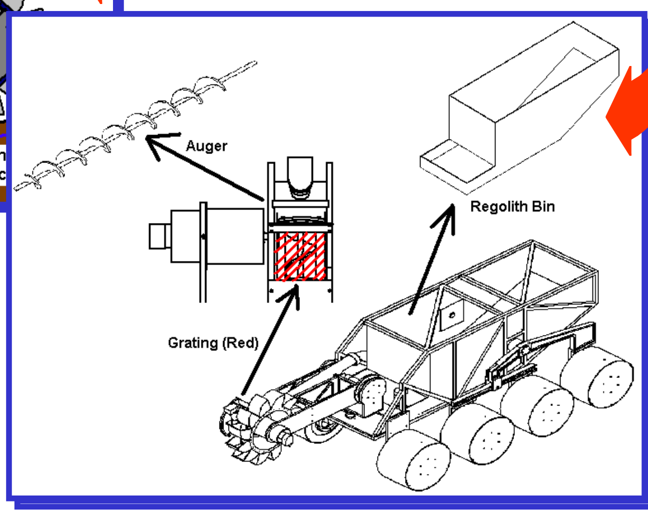
Excavator

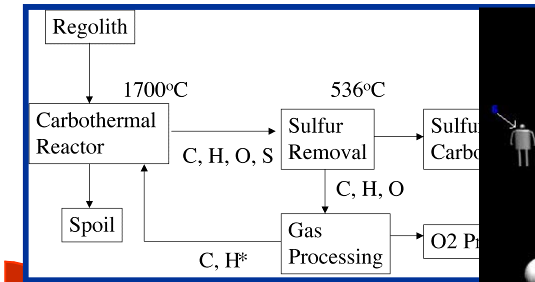
- Bucket wheel
- Scraper



Transporter

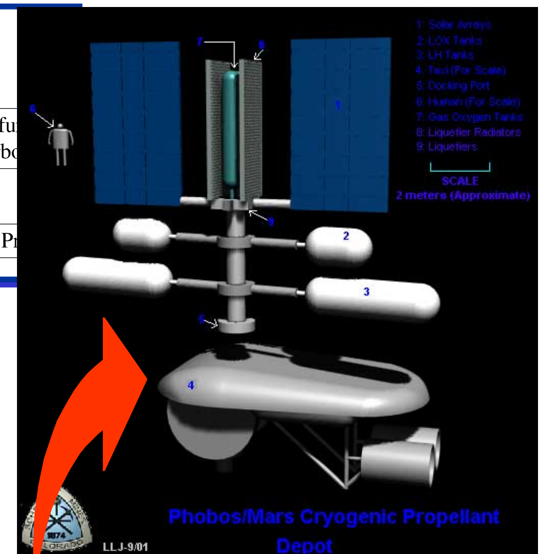
- Integrated with excavator
- Separate vehicle





Reactor

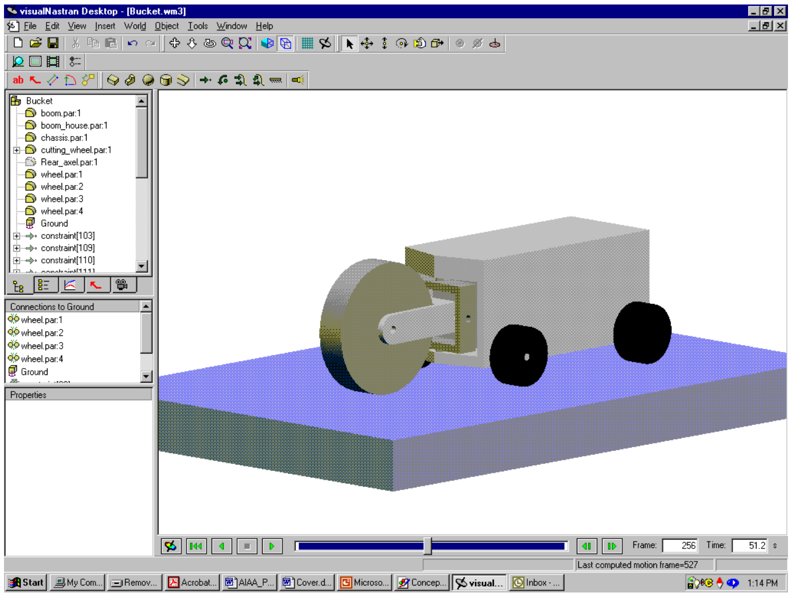
- Thermal extraction
- Carbothermal reactor
- Electrolysis
- Liquefaction

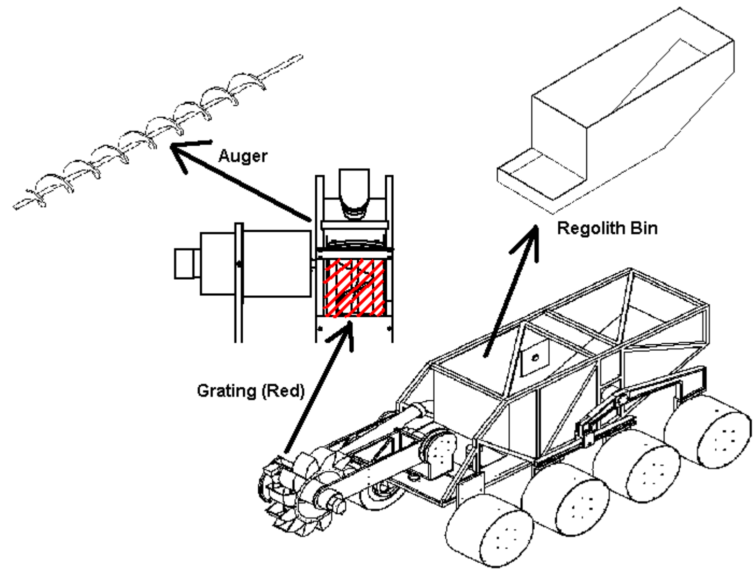


Storage

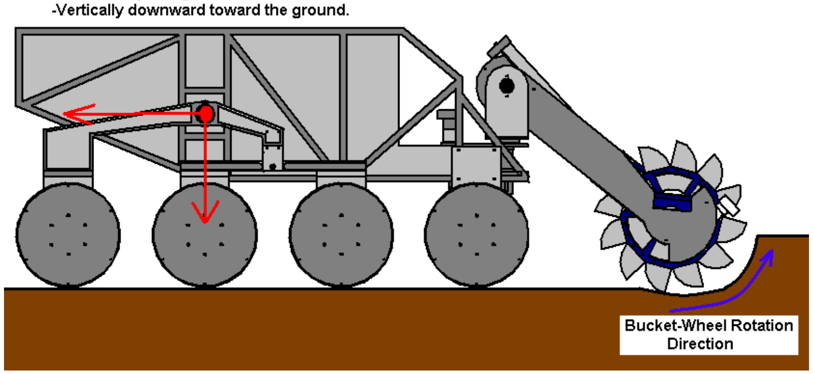
- Cryogenic
- Transfer

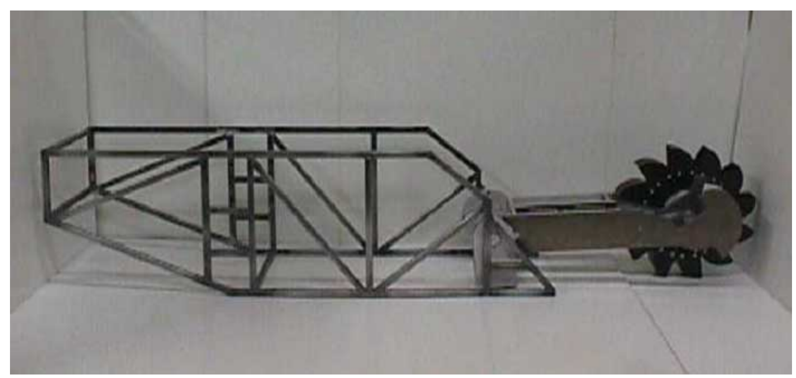
PHOBOS/MARS BUCKET WHEEL EXCAVATOR SYSTEM DEVELOPMENT



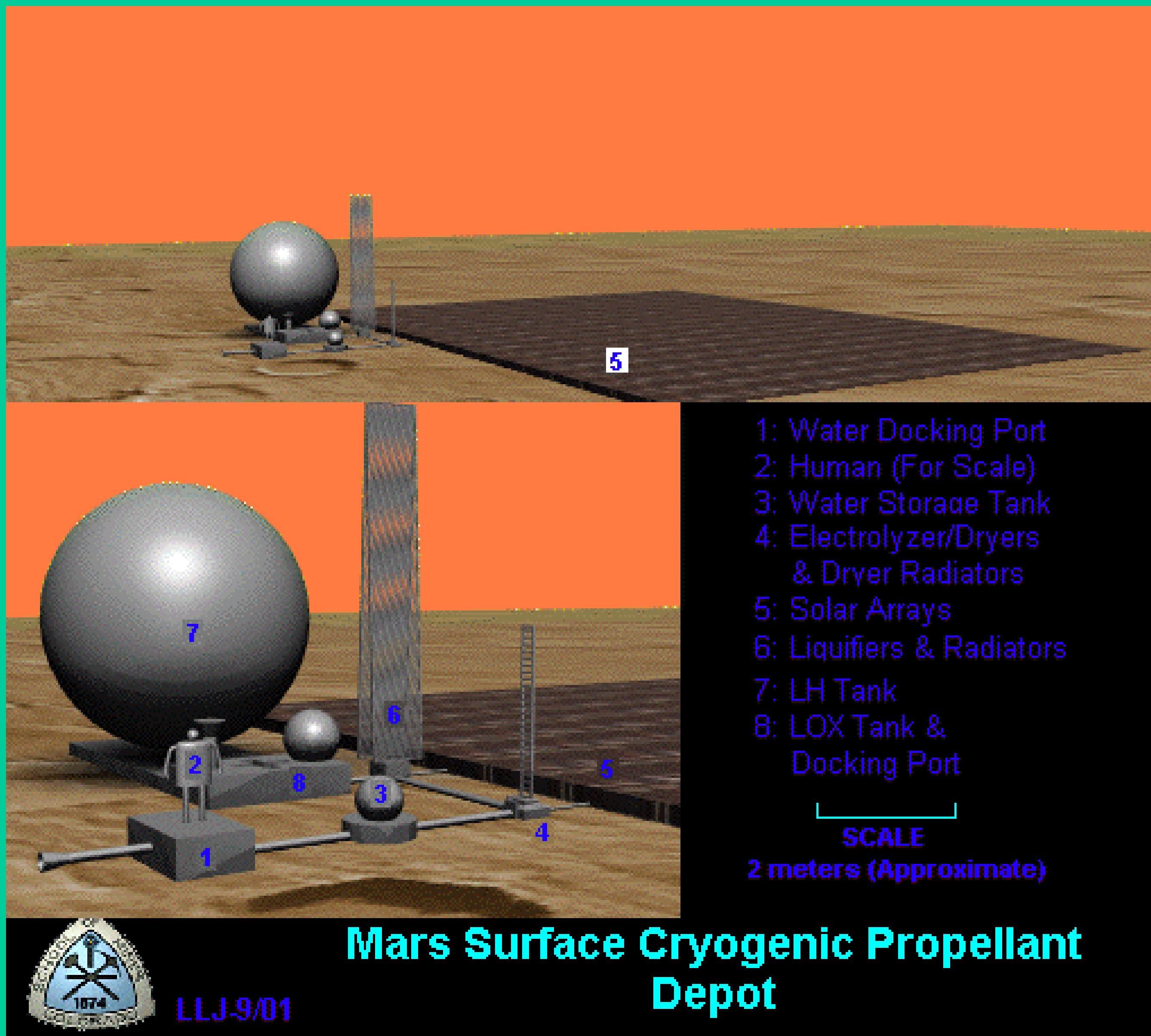


Resultant Forces on Excavator
-Horizontally along the boom axis
-Vertically downward toward the ground.





MARS PROPELLANT PRODUCTION AND STORAGE FACILITY CONCEPT



TECHNOLOGIES TO BUILD UPON

TECHNOLOGIES TO BUILD UPON

- Human physiology and life support in space
- Automation and robotics
- Assembly and operations in space
- Aero-assist
- Ion propulsion systems
- Space resource mining, processing and manufacture
- Photovoltaic energy generation
- Fuel cell energy storage
- High-strength, lightweight structures
- Advanced Computers
- High-bandwidth interplanetary communications

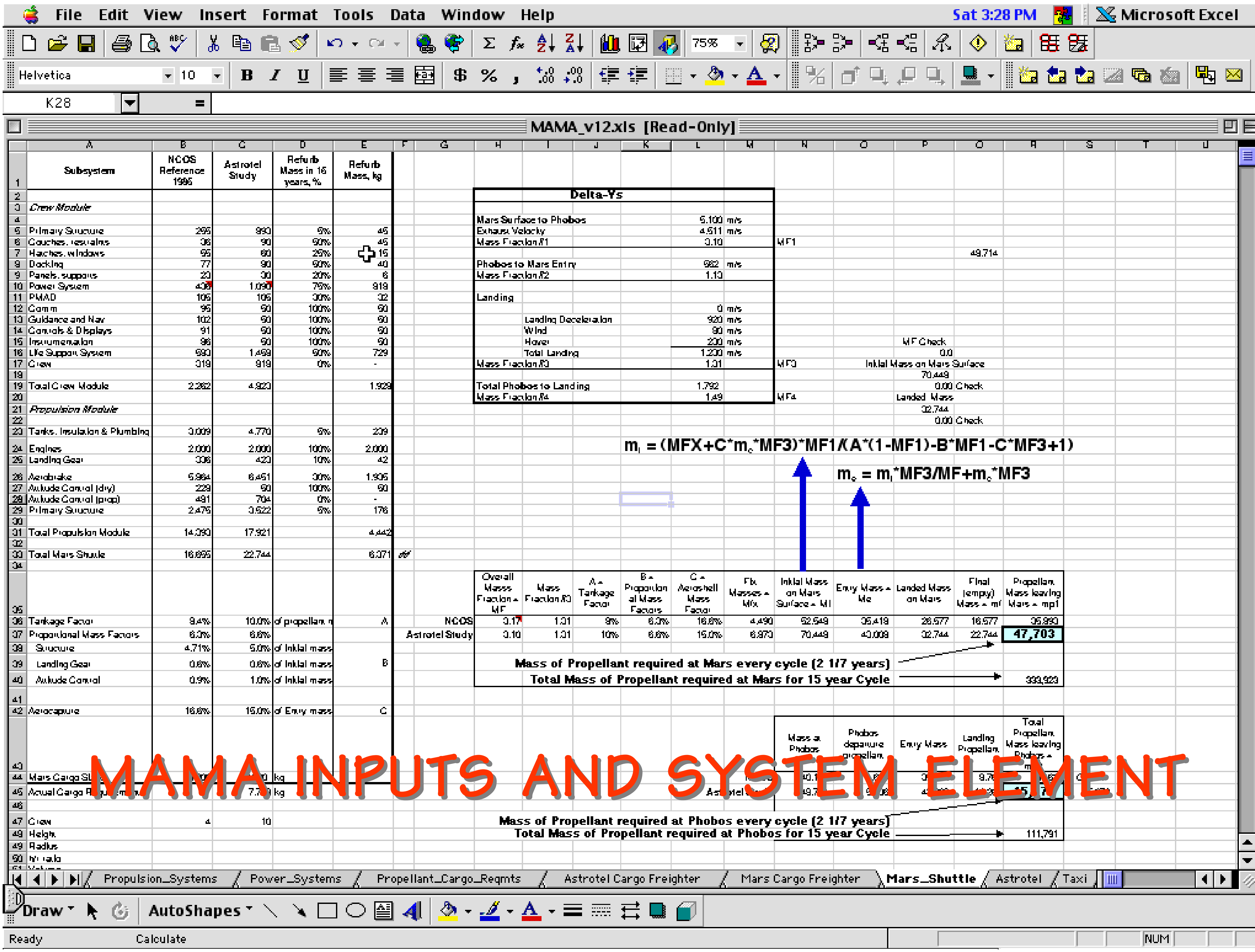
WHAT'S THE BEST IRT DESIGN AND HOW MUCH WILL IT COST?

MISSION ARCHITECTURE MODEL AND ANALYZER (MAMA) DESCRIPTION

- MAMA is a tool to support trade study analyses of Mars Astrotel Concepts
- MAMA integrates multiple lower-level models enabling assessment of technology selection/definition impacts on an overall Mars Astrotel scenario's life cycle requirements
- MAMA maintains a database of past runs to allow comparison of features from different Astrotel scenarios
- MAMA will use a multi-level approach for collecting inputs

MAMA is better for comparing different options than generating absolute cost estimates

MAMA INPUTS AND SYSTEM ELEMENT


MAMA_v12.xls [Read-Only]

	Subsystem	NCOS Reference 1996	Astrotel Study	Refurb Mass in 15 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
8	Docking	77	90	50%	40
9	Panels, supports	20	30	20%	6
10	Power System	408	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	990	1,459	50%	729
17	Crew	319	919	0%	-
18					
19	Total Crew Module	2,262	4,920		1,929
20					
21	*Propulsion Module*				
22					
23	Tanks, Insulation & Plumbing	3,009	4,770	5%	239
24	Engines	2,000	2,000	100%	2,000
25	Landing Gear	308	420	10%	42
26	Aerobrake	5,984	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	14,390	17,921		4,442
32					
33	Total Mars Shuttle	16,895	22,744		6,371
34					
35					
36	Tankage Factor	9.4%	10.0%	of propellant m	A
37	Proportional Mass Factors	6.3%	6.8%		
38	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	16.8%	15.0%	of Entry mass	C
43					
44	Mars Cargo S[illegible]	[illegible]	[illegible]	kg	
45	Actual Cargo R[illegible]		7,7[illegible]	kg	
46					
47	Crew	4	10		
48	Height				
49	Radius				
50	Wetted				

Delta-Ys

Mars Surface to Phobos	5,100	m/s	
Exhaust Velocity	4,511	m/s	
Mass Fraction #1	3.10		MF1
Phobos to Mars Entry	582	m/s	
Mass Fraction #2	1.13		
Landing			
	0	m/s	
Landing Deceleration	920	m/s	
Wind	90	m/s	
Hover	200	m/s	
Total Landing	1,200	m/s	
Mass Fraction #3	1.31		MF3
Total Phobos to Landing	1,792		
Mass Fraction #4	1.49		MF4

49,714

MF Check 0.0

Initial Mass on Mars Surface 70,449

0.00 Check

Landed Mass 32,744

0.00 Check

m_i = (MFX+C*m_c*MF3)*MF1/(A*(1-MF1)-B*MF1-C*MF3+1)

m_e = m_i*MF3/MF+m_c*MF3

	Overall Mass Fraction - MF	Mass Fraction #3	A - Tankage Factor	B - Proportional Mass Factors	C - Aeroshell Mass Factor	Fix Masses - Mfx	Initial Mass on Mars Surface - Mi	Entry Mass - Me	Landed Mass on Mars	Final (empty) Mass - mf	Propellant Mass leaving Mars - mp1
NCOS	3.17	1.31	9%	6.3%	16.8%	4,490	52,549	35,419	26,577	16,577	35,990
Astrotel Study	3.10	1.31	10%	6.8%	15.0%	6,970	70,449	40,008	32,744	22,744	**47,703**

Mass of Propellant required at Mars every cycle (2 1/7 years)

Total Mass of Propellant required at Mars for 15 year Cycle → 333,923

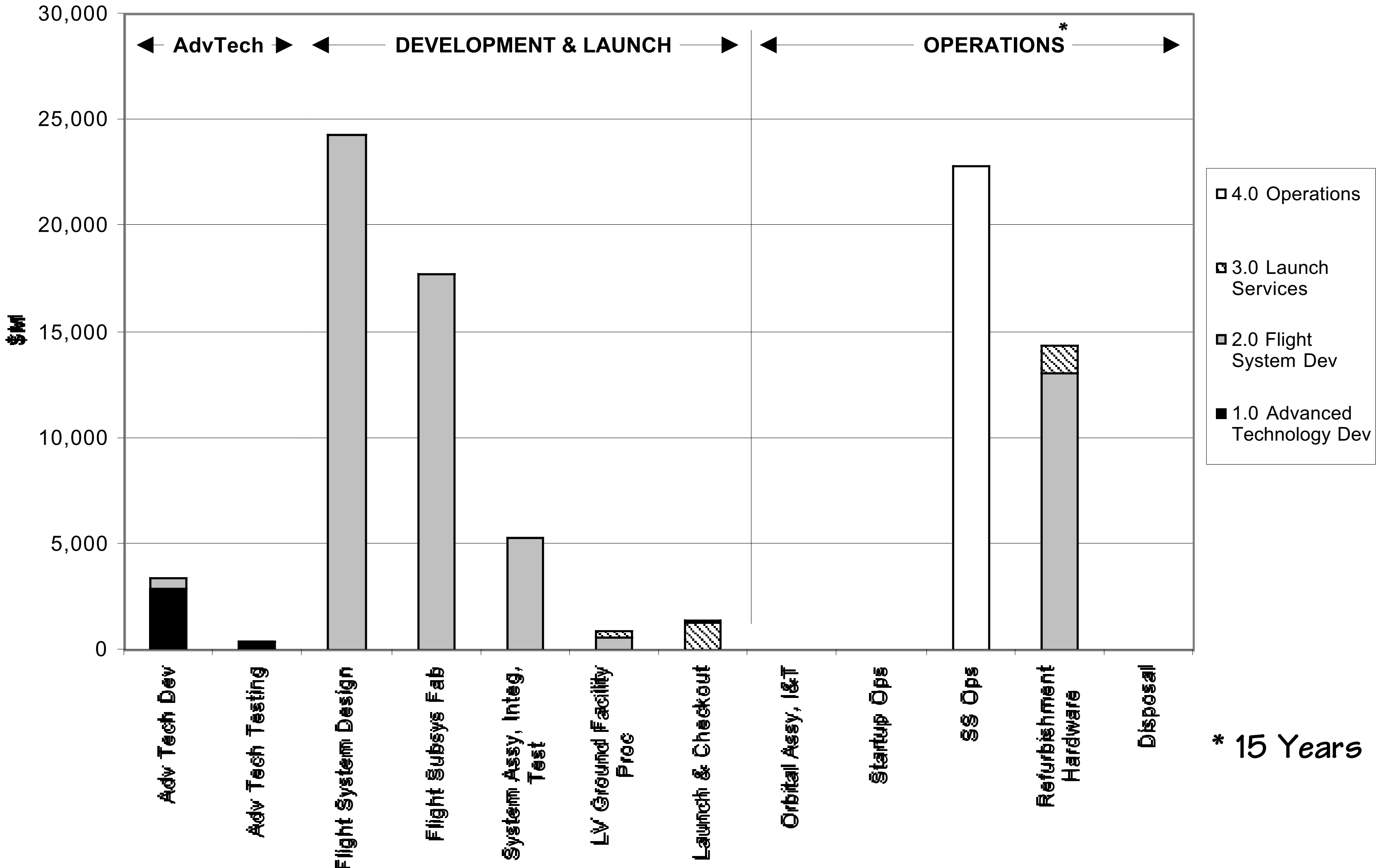
	Mass at Phobos	Phobos departure propellant	Entry Mass	Landing Propellant	Total Propellant Mass leaving Phobos - m
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Astrotel [illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

Mass of Propellant required at Phobos every cycle (2 1/7 years)

Total Mass of Propellant required at Phobos for 15 year Cycle → 111,791

Propulsion_Systems / Power_Systems / Propellant_Cargo_Reqmts / Astrotel Cargo Freighter / Mars Cargo Freighter / **Mars_Shuttle** / Astrotel / Taxi

MAMA LIFE CYCLE COST OUTPUT



* 15 Years

SUMMARY OF EARLY, ROUGH MAMA COST ESTIMATES

Development: ~$5B/yr for 10 years

Operations: ~$3B/yr

Assumes:

- Advanced Technology Development
- Flight System Development
- Launch (specific launch vehicle cost of $2000/kg)
- Operations (includes repair, refurbish, upgrade hardware & propellants/consumables)
- FY 2000 dollars

ADVANCED MAMA INFORMATION FLOW

Select Architecture
- Low thrust Aldrin
- Semi Cycler
- Stopover

MAMA provides defaults for all inputs

Modify Level 1 Defaults
Sample Input Categories:

NODES
- Transportation Nodes
- Transportation Node Locations

ISRU
- ISRU Propellant Production
- Lunar Hydrogen?
- Lunar ISRU Location
- Phobos Water or Oxygen?
- Mars Surface Water?
- Mars ISRU Location
- Orbital Propellant Depot(s)

POWER GENERATION & ENERGY STORAGE
- Large Surface Systems
- Mobile Surface Systems
- Space (zero-g) Systems

PROPULSION
- Ion Systems
- LOX/LH2 Systems
- Nuclear Thermal
- Others(?)

INTER-NODE TRANSPORT
- Earth/LEO
- LEO/Earth Spaceport
- Lunar ISRU/Earth Spaceport
- Phobos ISRU/Mars Propellant Depot
- Earth Spaceport/Astrotel
- Mars Spaceport/Astrotel
- Mars Spaceport/Mars Surface
- Earth Spaceport /Earth Surface

CREW ACCOMMODATION
- Radiation Shielding
- Artificial Gravity
- Air/Water
- Food
- Crew Volume
- Habitation Module

AERO-ASSIST
- Aeroshell Shape
- Structure/TPS

View Results
- Details for Current Architecture Scenario
- Comparison of Multiple Scenarios from MAMA Database

Modify Lower-Level Inputs
- Provides visibility to lower-level model inputs and allows modification of selected inputs
- For more experienced users only

POSSIBLE MAMA STUDIES

- Different cyclic orbit options
- Alternative transportation nodes
- Solar vs nuclear reactor power
- No use of natural space resources
- Higher/lower launch costs
- ISRU aerobrakes
- Impact of cyclic orbit option on increased Astrotel mass for artificial gravity, increased radiation shielding, hardware & consumable reserves

SUMMARY

SUMMARY

- The Astrotel interplanetary rapid transit system architecture:
  - Is cost effective because it reuses transit system elements
  - Uses natural space resources to produce low-cost propellants
  - Enhances human health and performance due to short trips
  - With Aldrin cyclers, can easily expand Astrotel to enhance system, and
  - Can rely entirely on solar power systems
- Concepts have been developed that could be utilized in robotic pathfinder exploration, high Earth orbit operations missions, and expedition phases of Mars exploration
- The tools developed during this study can be used to analyze and compare future technology and system options