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Large Depot to Service Manned Mars Missions

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Mission challenge

Goal:

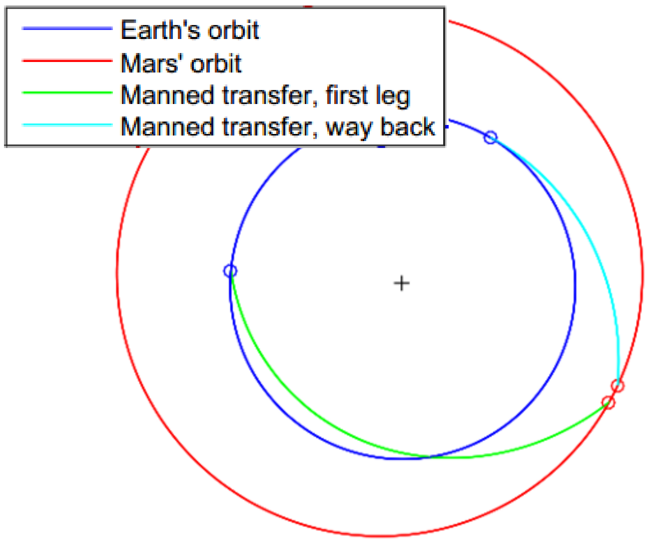
Creating an infrastructure

1) capable of supporting a recursive manned mission to Mars
2) versatile to enhance robotic exploration of the outer solar system

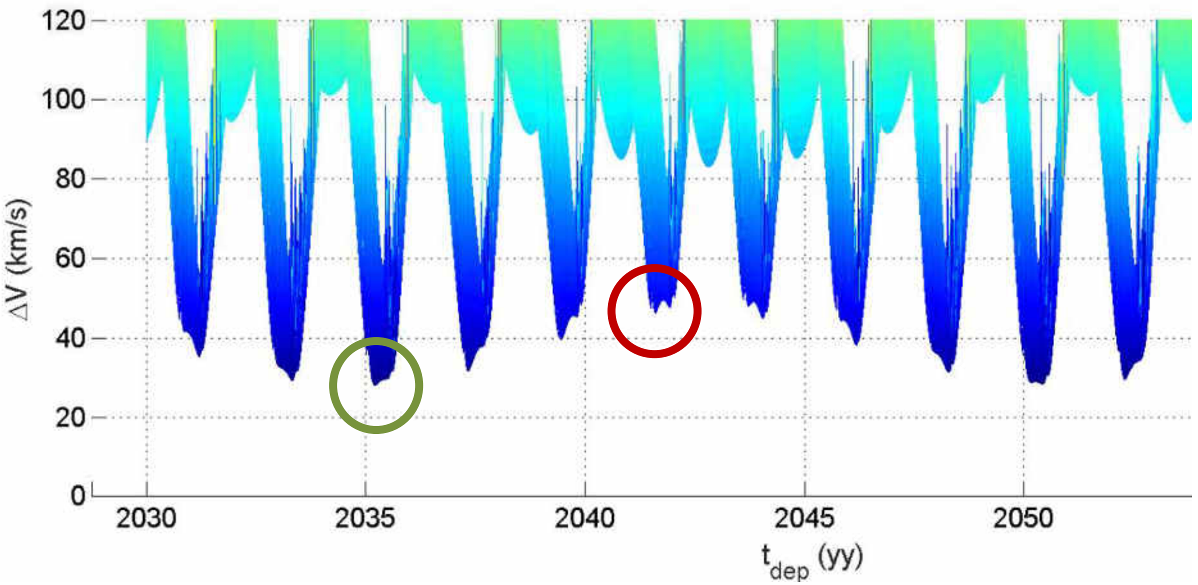
Minimum requirements:

- 250 days roundtrip to Mars
- Permanence on Mars: 7 days
- Payload: Columbus-like module: 10 tons

Main criticalities



Porkchop plot for the Mars round-trip:



Criticalities:

- **Extremely high ΔV**
- **Strongly variable ΔV**

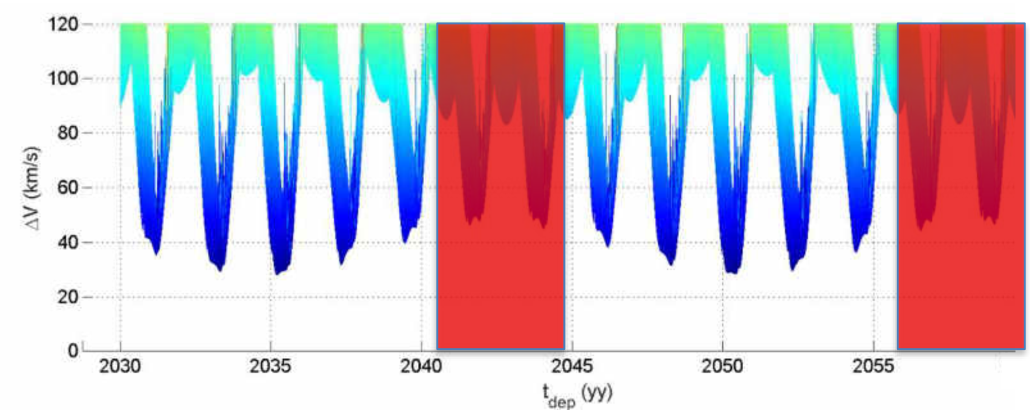
Worst case: ΔV≈47 Km/s

Best case: ΔV≈28 Km/s

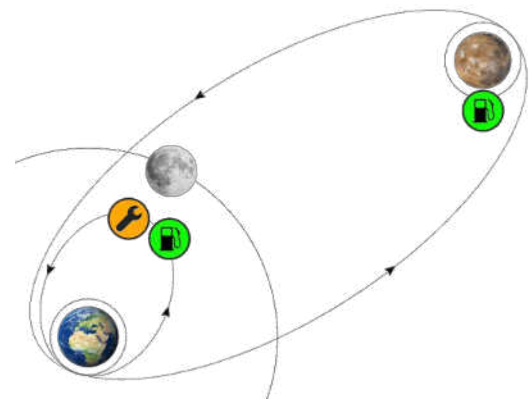
(Hohmann round trip: ΔV≈12 Km/s and TOF=520 days)

Adopted strategies

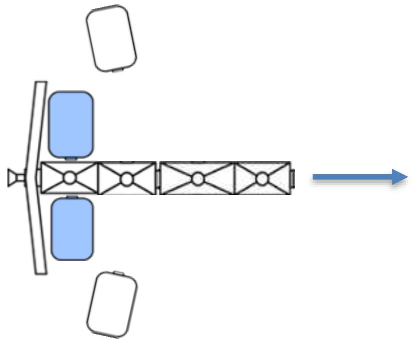
- Worst windows discarded



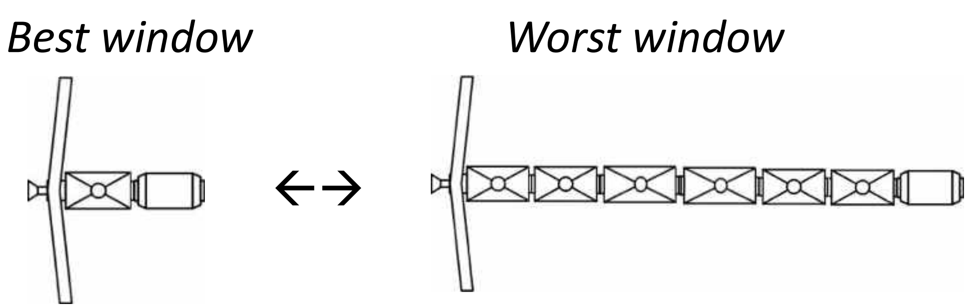
- In-space refueling: EML1 & ASO



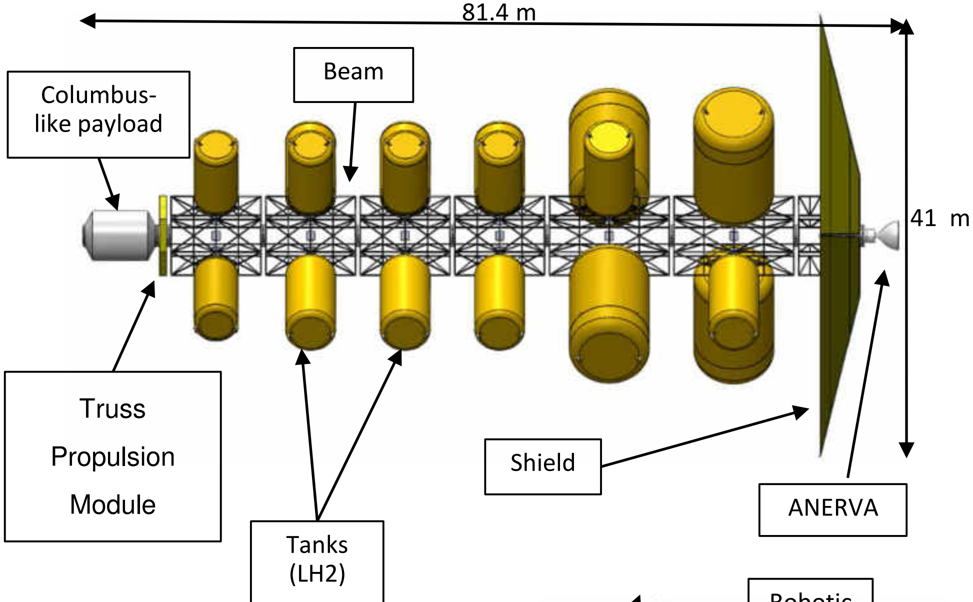
- On orbit staging



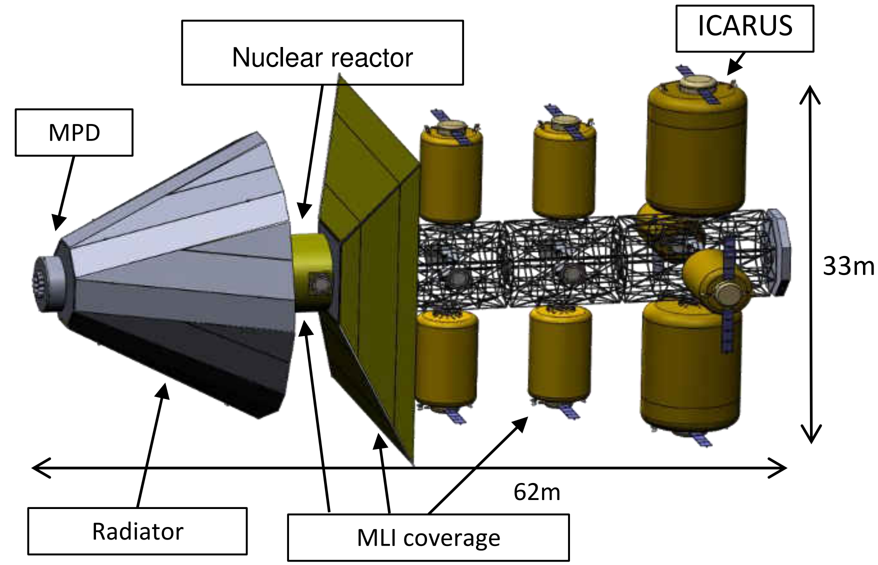
- Modular structures



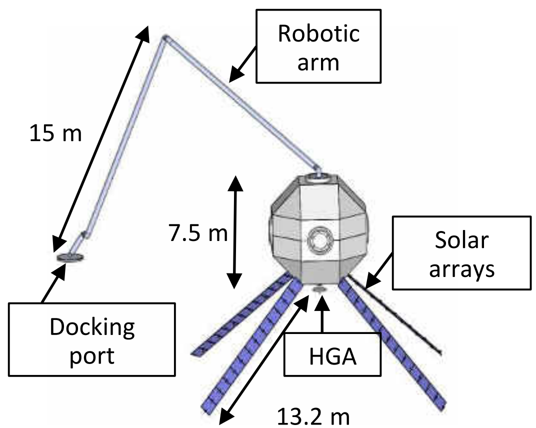
Vehicles



Diomede

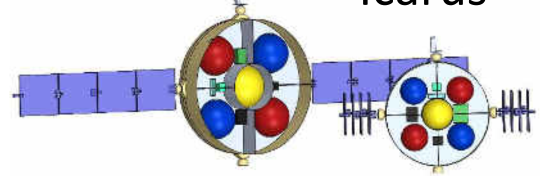


Ares

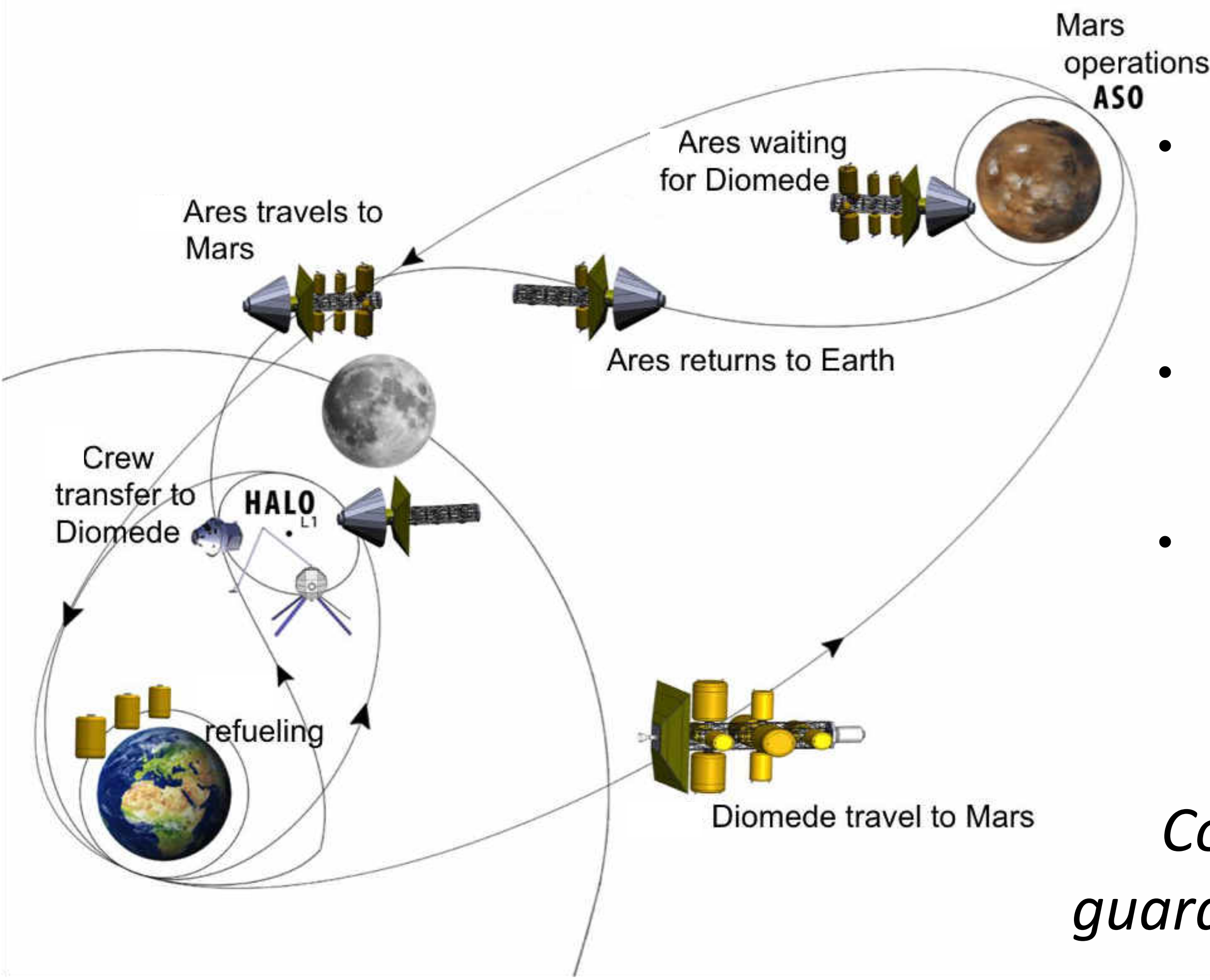


Core

Icarus



Steady state configuration



- **Assembling and re-configuration operations:**
  → EML1
- **Refueling operations:**
  → EML1 and ASO
- **Required vehicles for scheduling:**
  → 4 Ares *(TOF=4.6 years)*
  → 1 Diomede *(TOF=250 days)*
  → 1 Core

Configuration aimed to guarantee human crew safety

Propulsive system

Diomede

- Fast transfer → High thrust required
- Large ΔV required → High efficient propulsion

Ares

- Continuous manoeuvres
- Huge mass transportation

NTP propulsive system ANERVA[1]	
Propellant	LH2
Specific impulse	**1000 s**
Thrust	**220 kN**
Vehicle thrust-to-weight ratio	0.086
Reactor mass	1600 kg
Shield mass	3100 kg
Turbopump mass	90 kg
Total mass	7300 kg

Nuclear vs cryogenic: worst case

Propulsive system	Total fuel mass (t)	N° of launches
Nuclear	≈600	28
Cryogenic	≈8600	304

MPD propulsive system	
Propellant	LH2
Specific impulse	**5000 s**
Thrust	**120 N** (each)
Number of thrusters	12
Thruster assembly mass	3200 kg
Power consumed	9.9 MW

[1] Dual-mode reactor and ANERVA: Project M3-a study for a manned Mars mission in 2031, Taraba et al

Structural design and sizing

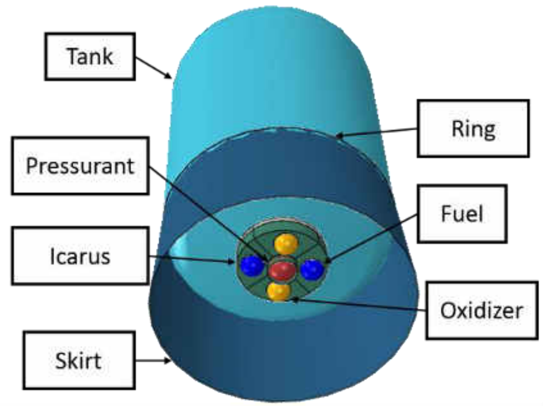
Tank structure:

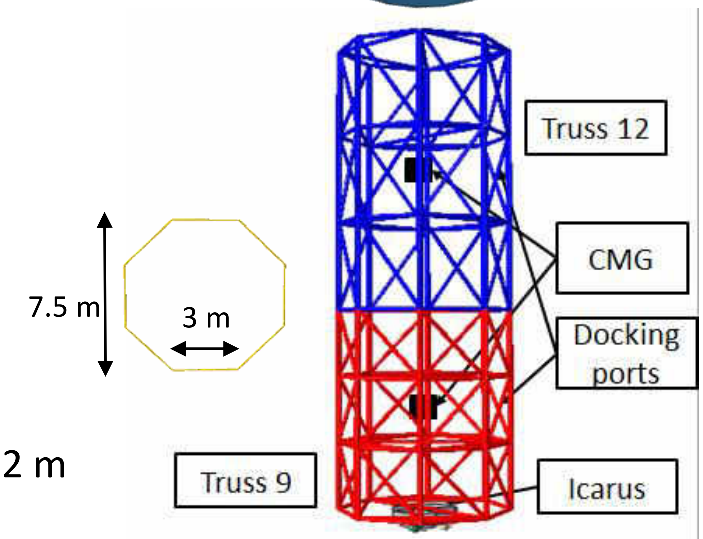
- Three sizes
- External layer: Carbon-Epoxy
- Core: Nomex
- Internal layer: Carbon-Epoxy

	D (m)	H (m)	LH2 mass (tons)
T-40	8.0	11.4	35.0
T-13	5.0	8.7	11.4
T-8	4.4	6.8	7.0

Truss structure:

- Truss member:
  - Boron/epoxy composite
  - Diameter: 40 cm
  - Thickness: 3 mm
- Launch configuration: 9 m + 12 m trusses

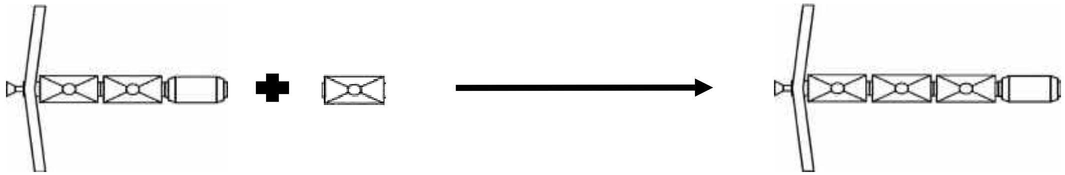


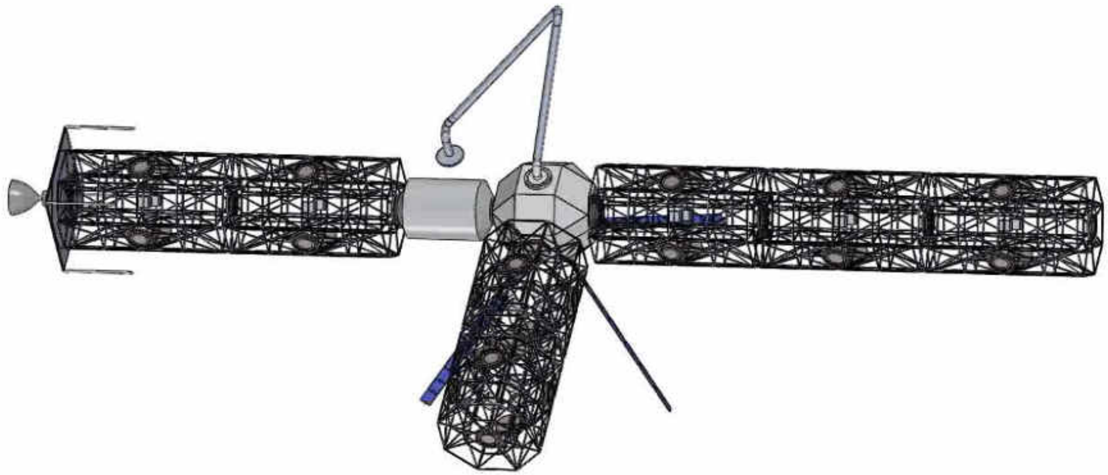


Static loads	
Maximum axial	6.0 g
Maximum lateral	2.3 g
Frequency requirements	
Bending	8 Hz
Axial	30 Hz

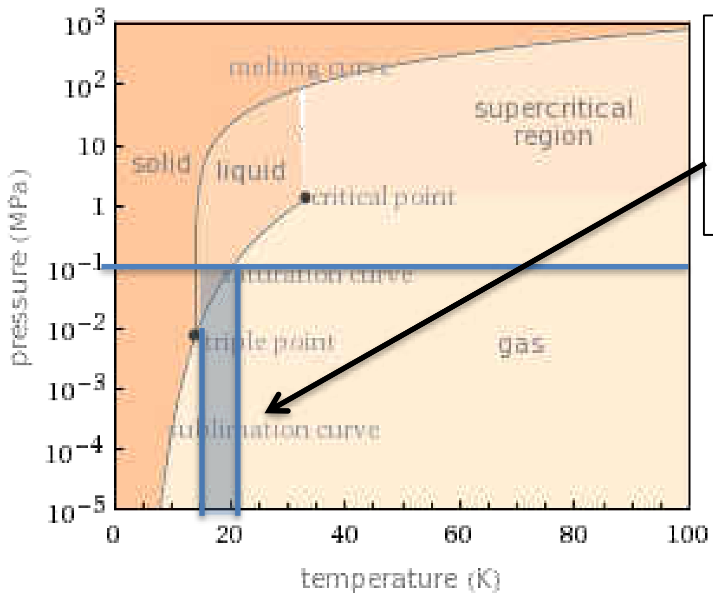
→ *Structural requirements satisfied with a factor of safety of 2*

Vehicles assembly and re-configuration



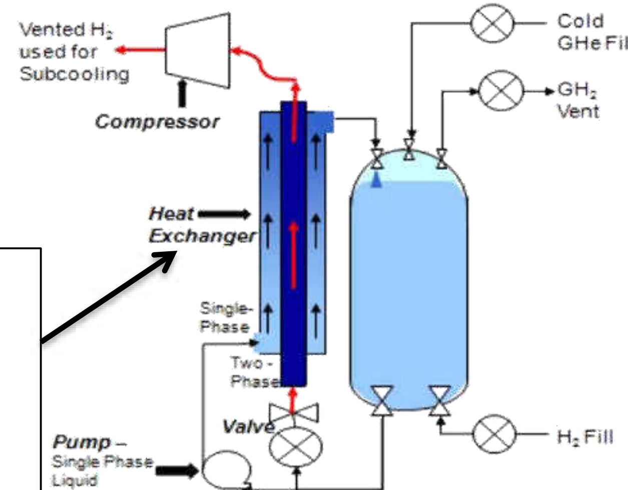


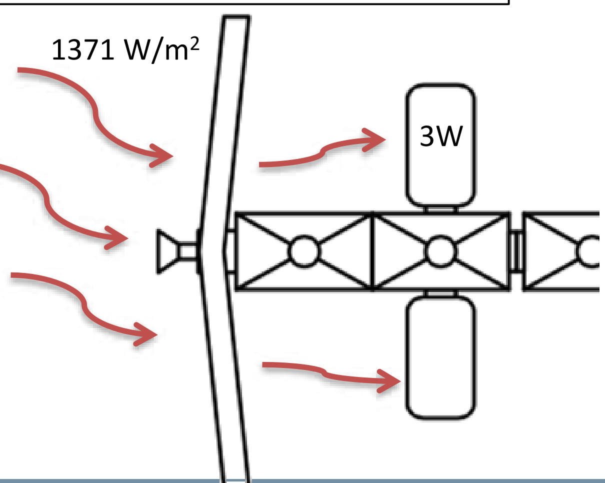
LH_2: Thermal control strategy



Sub-cooled-region:
T=15k P=1atm
Boiling point
T=20.29k P=1atm

Small amount of LH_2 is extracted and expanded through a J-T valve, subtracting heat during evaporation.





- **On ground sub-cooling technique**

→ Cryogenic hydrogen stored on ground at T=15k, P=1atm

- **MLI insulation**

→ Multiple MLI layers coverage (30 for small and 20 for big and medium tanks)

- **Thermal shield**

→ MLI layers shield (10 layers)

Permanence time (EML1) results:	
Big tank	5.65 years
Medium tank	3.74 years
Small tank	3.4 years

Nuclear Power generation for ARES

Requirements

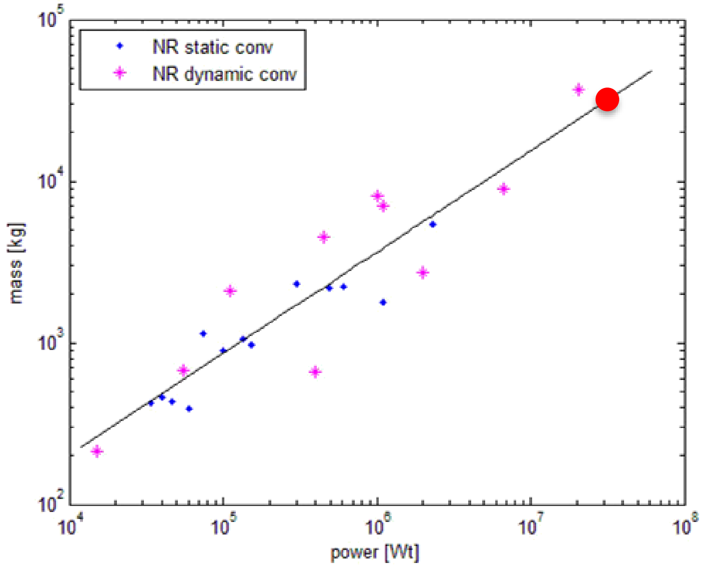
- 9.9 MW to feed MPD thrusters
- Total mass less than 40 tons

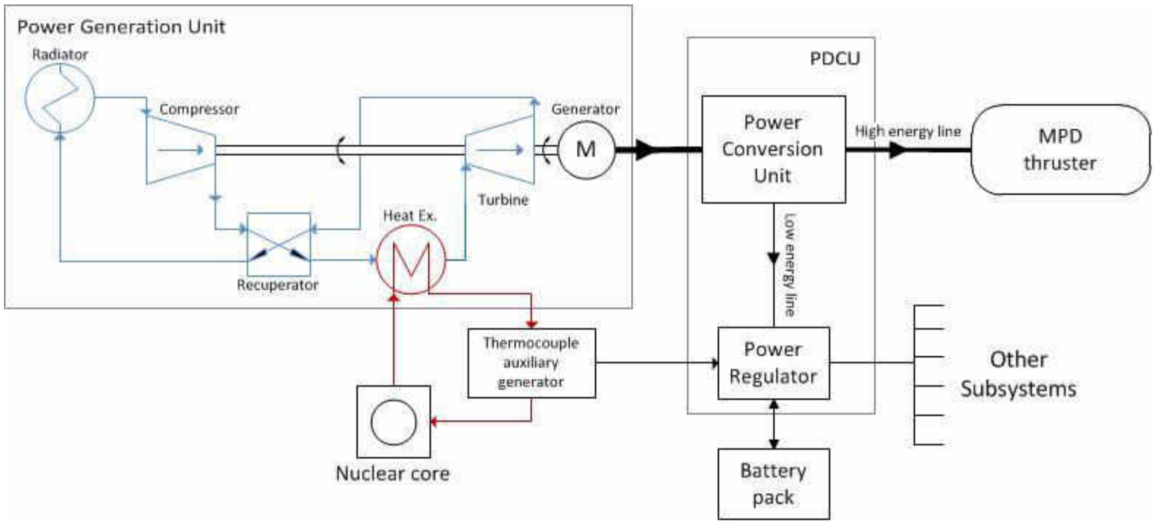
Solution

- Nuclear Power generation
- Dynamic power conversion
- Brayton cycle
- He/Xe as working fluid

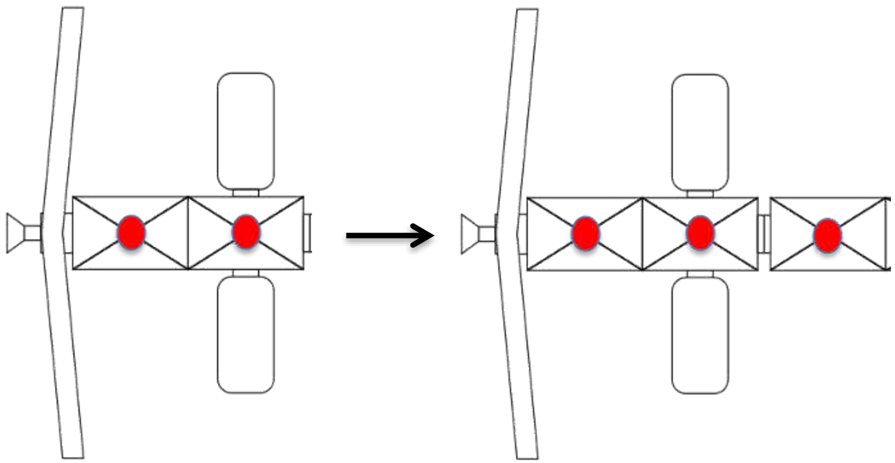
Results

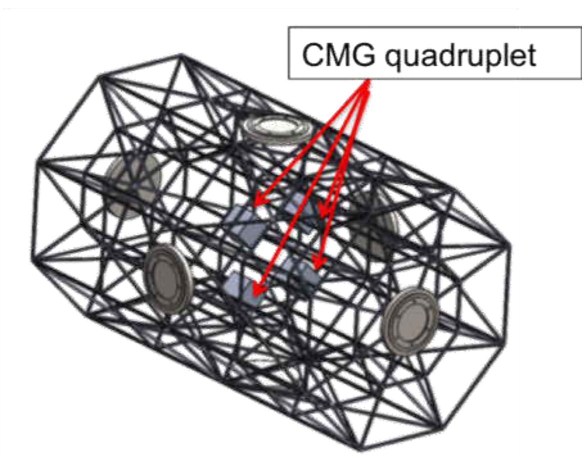
- Total mass of 39.9 tons
- Radiator area 1000 m^2
- Turbine inlet temp. 1600 K
- Brayton cycle efficiency 31 %
- Oversizing margin 12 %





ADCS: large structures of variable size control strategy





CMGs

- 4 (Tetrahedron configuration) for each piece of beam
- **Incremental configuration:** control authority augments when Diomede/Ares size increases

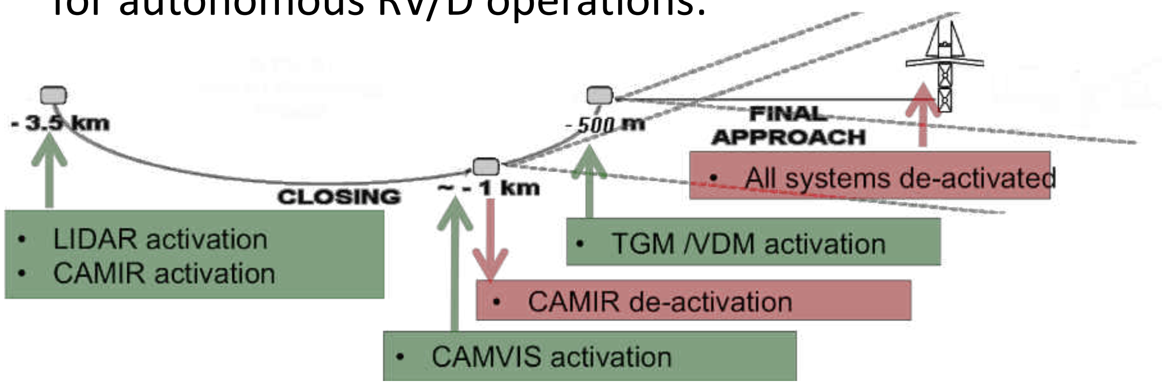
Thrusters

- 8 thruster clusters (UDMH-N_2O_2) placed at main beam tips
- Aimed for **demanding maneuvers** and desaturations

N0. of CMGs	M_{act} (kg)	P_{req} (W)	τ_{max} (Nm)	H_s (Nms)
Single	54	30	51	971
Quadruplet	216	120	64	1295

GNC: Rendezvous & Docking phase

- **Multiple sensors systems:** working at different distances for autonomous RV/D operations:

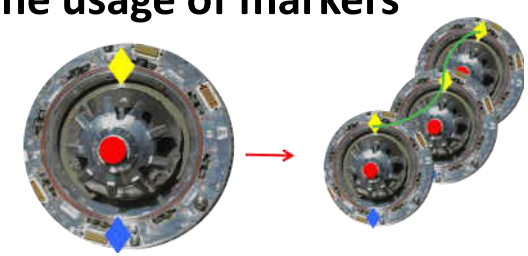


Visual sensors	
CAMVIS	visible camera
CAMIR	Infra-red camera
LIDAR	Laser imaging aperture and ranging
Optical sensor (proximity)	
VDM	Vide-meters
TGM	Tele-goniometers

- Computational requirements estimated by analogy with military rocket guidance software*
- Guidance algorithm by iterative comparison of 10 images in ±1°

Estimated SW size		
MIPS	MFLOPS	RAM
100	80	32

SW's accuracy and reliability enhanced by the usage of markers



*Wookey, Cathy; Nicholson, Bruce, "A/RD imaging processing" (1996)

TMTC Phases and Link Budget

Phases	Event	Data rate(kbps)	Antenna type
1.Launch	-		Launcher antenna
2.Post Launch and Cruise	1. ICARUS- a)Near earth b)Far earth 2. ARES	 10 10 25	 LGA MGA HGA
3. Orbit Insertion	ARES Orbit Insertion	25	HGA
4.Orbital motion	ARES Orbit (ASO)	25	HGA
5. Docking	a)ICARUS-CORE (EML1) b)CORE-ARES(EML1) c)CORE-DIOMEDE (EML1) d)ARES-DIOMEDE (ASO)	44 44 44 80	HGA HGA HGA HGA

X band

- Modulation and coding – QPSK
- Downlink – BER of 10^{-6}
- Antenna Efficiency- 0.7
- Line Losses – 2dB
- Implementation Losses- 3dB

LINK	Pt dBW	G_{Tx} dBi	G_{Rx} dBi	EIRP dBW	L_{TOT} dB	E_b/N_o dB	Margin dB
ICARUS-DSN	13.01	16.8	46	29	220	14.62	4.03
CORE-DSN	13.01	40	65	51	222	47.32	33.33
ARES-DSN	14.77	41.2	65	53.95	243	26.68	12.68

Conclusions

1. **Cycling and recursive configuration**
   capable to support many fast round trip to Mars

2. **Versatile and modular design**
   to support robotic program to explore Solar System and beyond

3. **Permanent structure in EML1**
   useful for many other different purposes

A feasible solution can be achieved in few decades

Thank you for your attention!