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Analysis and Design of Cargo Transport Architectures for Manned Mars Missions Using Electric Propulsion

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What are we intending to do?

- Cargo delivery for manned Mars missions

What cargo modules are required?

- Habitat (Complex)
- Nuclear Reactors
- Mars Ascent Vehicle (MAV)
- Eearth Retrun Vehicle (ERV)

How to send the cargo modules to Mars?

Introduction

NRM Data:

- Nuclear Thermal Propulsion, I_{sp} = 900s
- Two 80t launches to LEO, Cargo + Propulsion
- Payload to surface fraction of 33%

Reference Scenario Hohmann-Transfer:

- Chemical Propulsion, I_{sp} = 450s
- TMI by Ariane 5 SH
- Direct re-entry
- Surface payload 27.6t (or 27.6%)

Reference Mission

The Idea:
•Use of Solar Electric Propulsion

Parameter variations:
•Different thruster types
•Initial acceleration 0.2-1.0 mm/s²
•TMI 400km & 6000km LEO
•Target relative velocity 3-5km/s

Two Scenarios:
•Dispensable
•Reusable

	I_{sp} [s]	P_{max} [kW]
Arcjet	480	750
Hall	1650	1500
RIT-22-Lo	3714	4020
RIT-22-Me	4762	6209
RIT-22-Hi	6605	11100

Scenario Design

Trajectory Optimization:
- DLR tool InTrance
- Evolutionary algorithm
- Neurocontrol
- Superior by combination

EDL Subsystem Optimization:
- DLR software developed by co-author

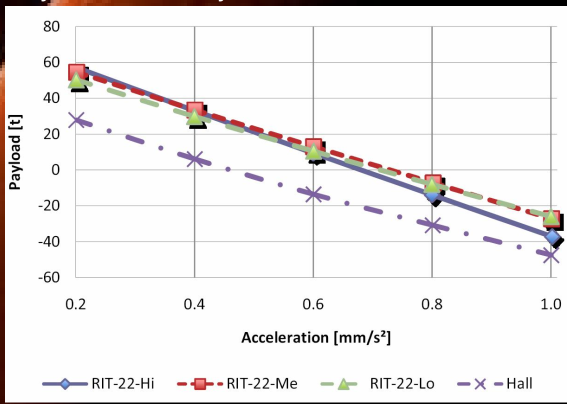
Optimization Software

Dispensable Scenario:
- Launch
- Earth escape
- Interplanetary transfer
- Direct entry

Launch:
- Ariane 5 Super-Heavy (A5SH)
- 100t payload to 400km circular LEO

Dispensable Scenario – 1/2

Payload at re-entry :



- Hi: 57t, Me: 55t, Lo: 50t, Hall: 28t → discarded
- Low acc. → high I_{sp}, high acc. → low I_{sp}

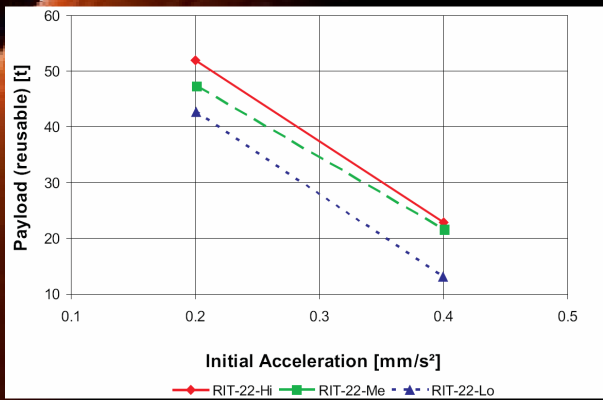
Dispensable Scenario – 2/2

Reusable Scenario:

- Two Ariane 5SH launches to 400 km LEO
- Hohmann Transfer to 6000 km HEO
- Assembly in HEO
- Earth Escape from HEO, m_0 = 100t
- Outbound flight
- Payload detachment
- Gravity assist
- Return flight
- Capture at Earth to HEO

Reusable Scenario – 1/2

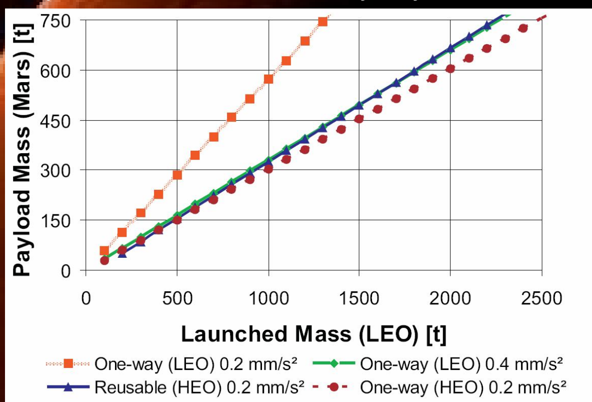
Payload Reusable Scenario:



- Higher payload with high I_{sp} engines
- Payload capability of 43 to 52t

Reusable Scenario –2/2

Dispensable vs Reusable Entry Payload:



- Dispensable also better for the fast transfer
- Reusable better at 2300t launched → 15 flights

Comparison

Entry: L/D=0.18

- Inflatable Heatshield → SP Heat Flux 25W/cm^2
- 7.5m is chosen → bc = 66.3kg/m^2
- Entry angle: 13.4° → a = -6.8g$_E$, Q = 1625J/cm^2

Descent:

- 30m supersonic parachute (700m^2)
- 80m subsonic parachute (5000m$^{2)}$ → unavailable today

→ Four 42m subsonic parachute cluster, 90% efficiency

Landing:

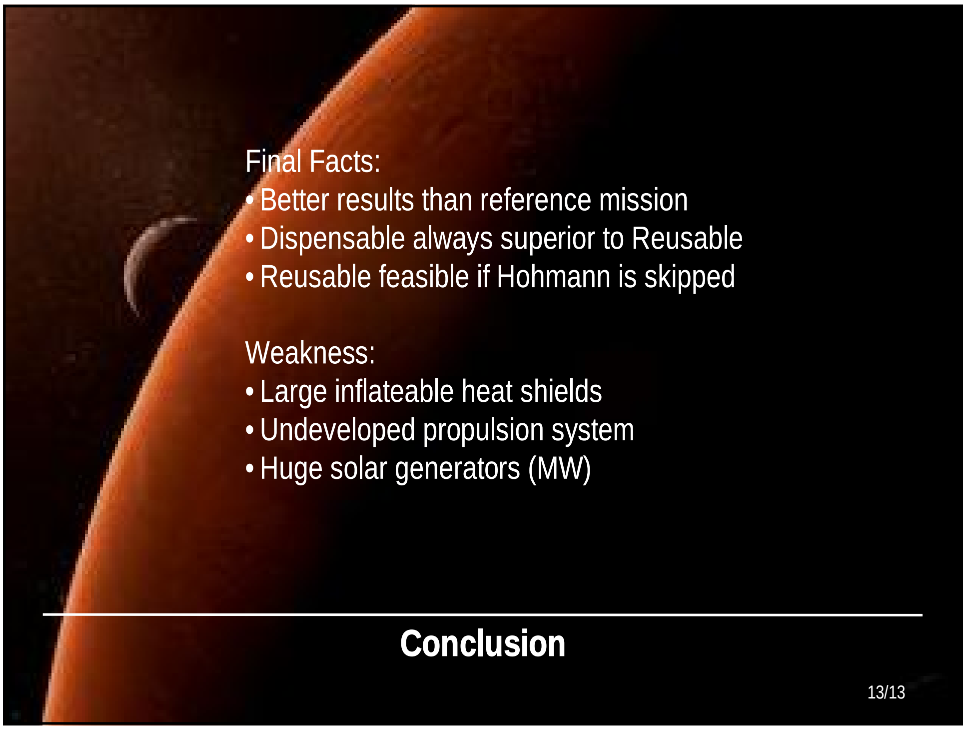
- 500kN LOX/CH4 thruster chosen
- Thrust as burn time – propellant consumption trade off

Entry mass	**25000 kg**	**35000 kg**
Total EDL mass	3880 kg	5210 kg

Entry, Desent, Landing – 3/3

Scenario	**Thruster**	**a**	**Payloa**	**T [a]**
Disp. LEO	RIT-22-Me	0.4	28.4%	1.14
Disp. LEO	RIT-22-Hi	0.2	47.4%	1.95
Disp. HEO	RIT-22-Hi	0.2	25.6%	1.55
Reusab. 1st	RIT-22-Hi	0.2	20.9%	1.55/2.50
Reusab. ff.	RIT-22-Hi	0.2	31.7%	1.55/2.50
NRM	NTP	-	33.0%	-
Reference	Chem.	-	27.6%	-

Summary


Final Facts:
• Better results than reference mission
• Dispensable always superior to Reusable
• Reusable feasible if Hohmann is skipped
Weakness:
• Large inflateable heat shields
• Undeveloped propulsion system
• Huge solar generators (MW)
Conclusion
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