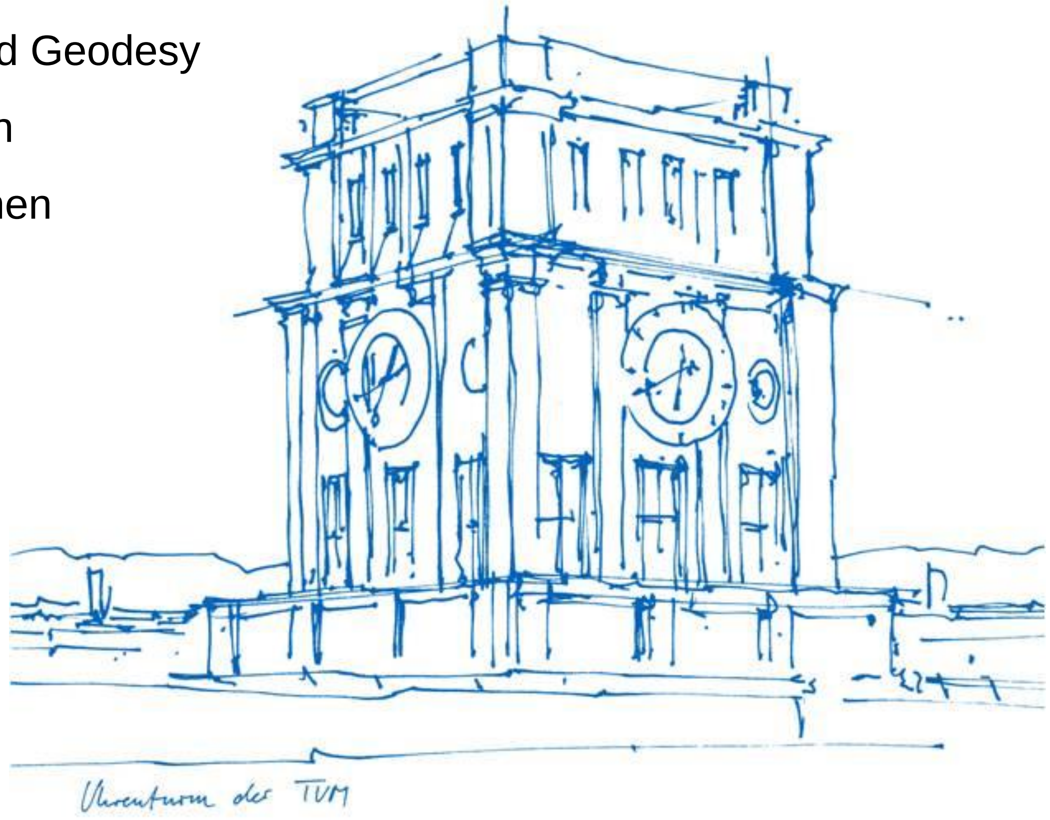
Spacecraft Propulsion II & Design Challenge
Spacecraft Propulsion System Proposal - Group 10

Technische Universität München

TUM-School of Space and Geodesy

Chair of Space Propulsion

March 23rd, 2023. München



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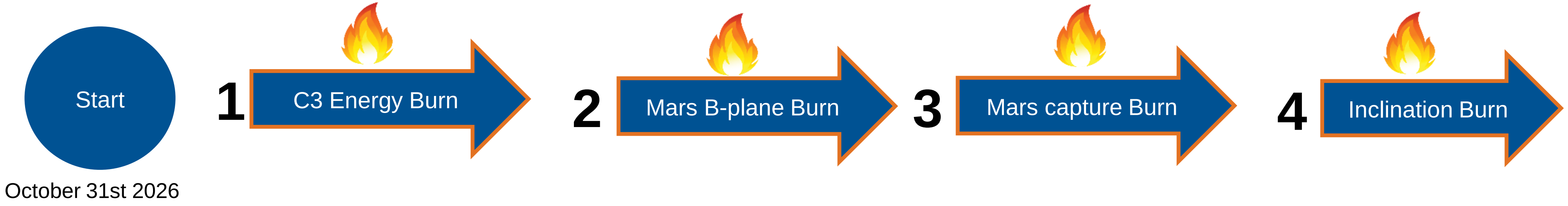
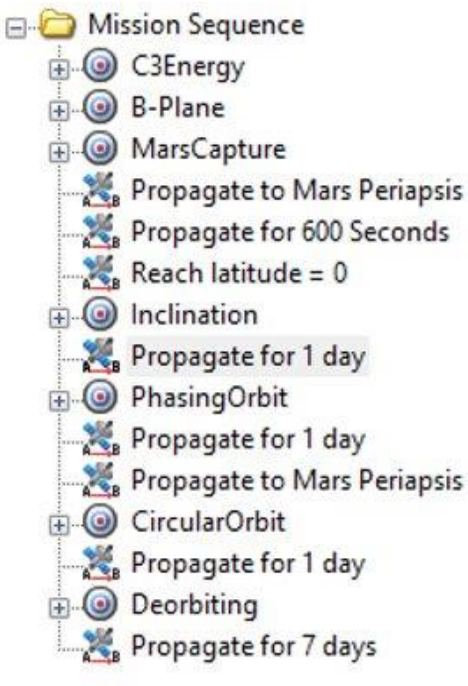
TRAJECTORY & MISSION SEQUENCE





Launch Date	C3 Energy Burn [km/s]	Mars B-plane Burn [km/s]	Mars Capture Burn [km/s]	Inclination Burn [km/s]	Phasing Orbit Burn [km/s]	Phobos Circular Orbit Burn [km/s]	De-orbitting Maneuver [km/s]	Total DV [km/s]
31/10/2026	0.23119	0.56794899	0.8781101	0.484194109	0.021446442	0.3557810211	0.54841318	3.08708385

TRAJECTORY & MISSION SEQUENCE

Start

October 31st 2026

1 C3 Energy Burn

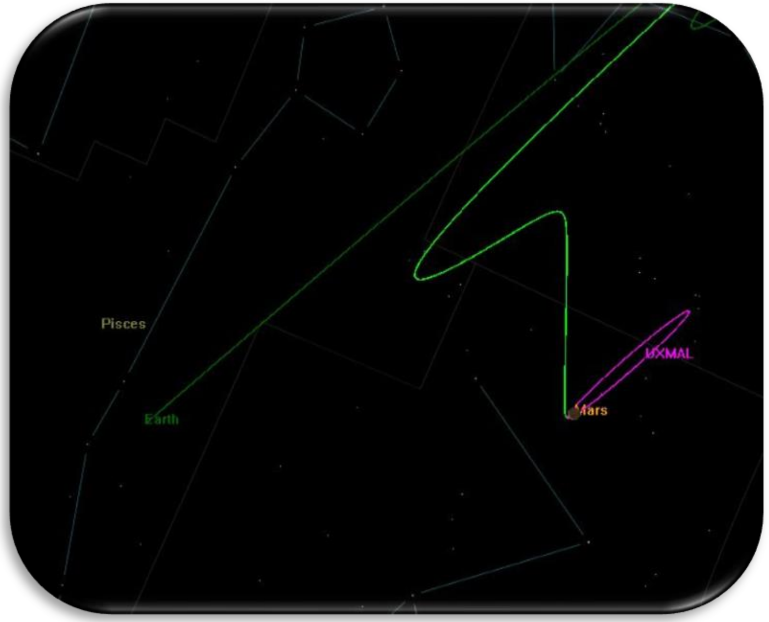
2 Mars B-plane Burn

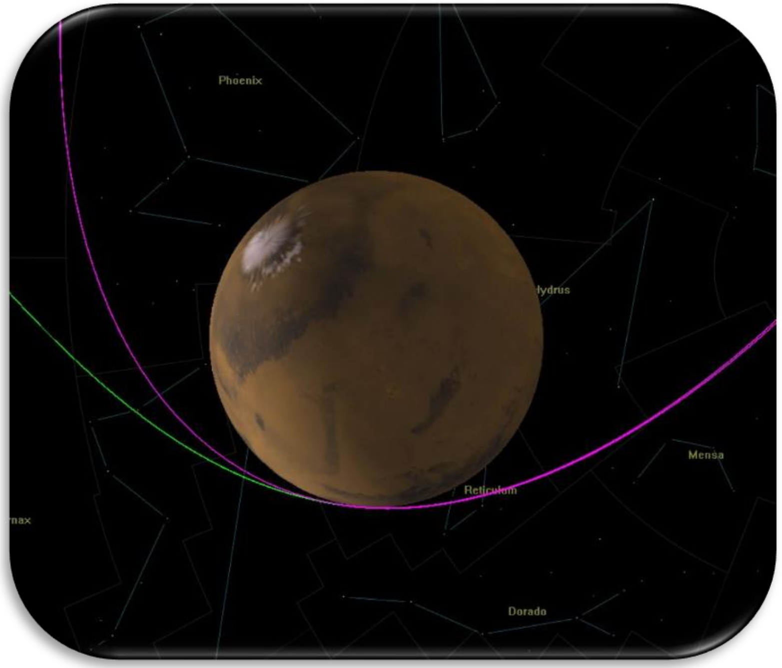
TRAJECTORY & MISSION SEQUENCE

Start

October 31st 2026

3 Mars capture Burn



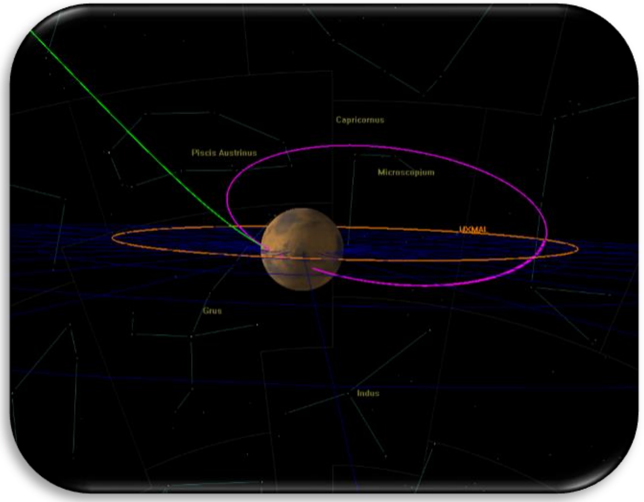


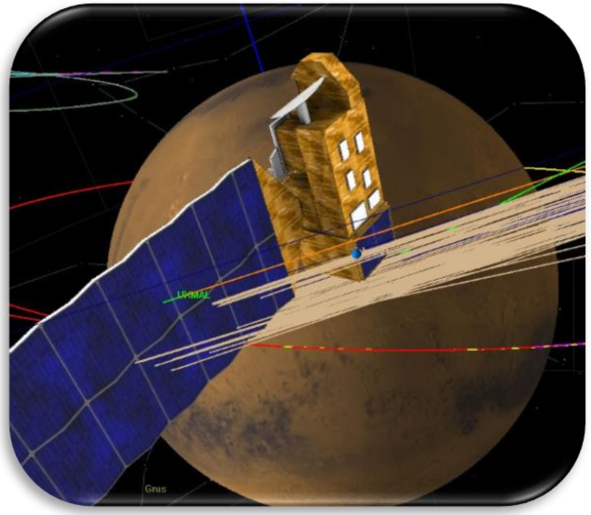
TRAJECTORY & MISSION SEQUENCE

Start

October 31st 2026

4 Inclination Burn



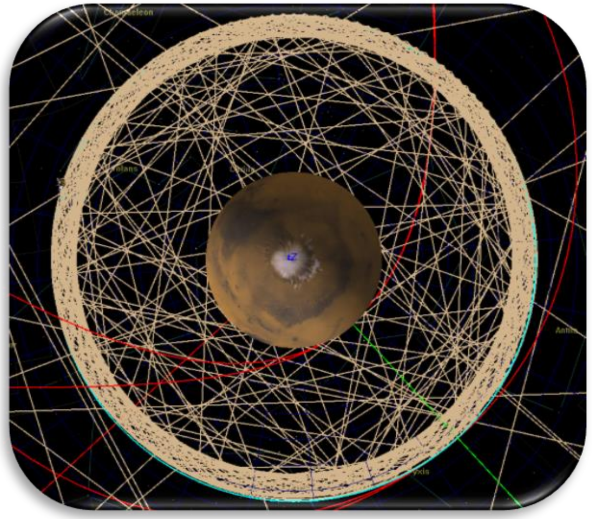


Phasing Orbit Burn 5

TRAJECTORY & MISSION SEQUENCE

Start

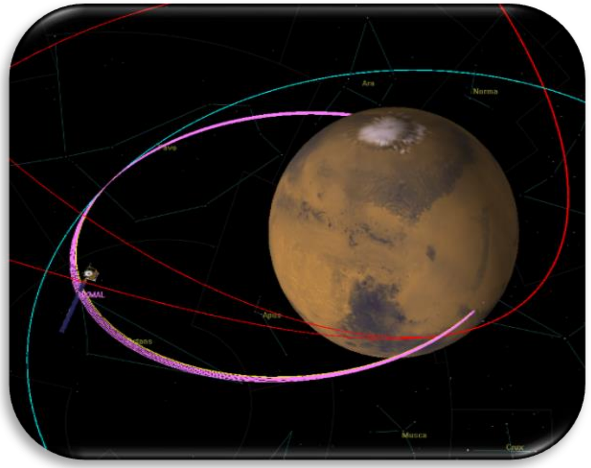
October 31st 2026



Phobos circular orbit Burn

6

Corrective Orbit Burn



De-orbiting Burn

7

End

LAUNCH OPPORTUNITIES

	Earth Departure Date	Mars Arrival Date	C3 Energy	Right Ascension	Declination	Mars Arrival Excess Speed [km/s]
Opportunity 2026	11/14/26	08/09/27	11,11	120	28,28	2,915
	10/31/26	08/19/27	9,144	130,7	23,16	2,729
	11/14/26	08/09/27	11,11	120	28,28	2,915
	11/06/26	09/08/27	9,646	130	32,8	2,565
Opportunity 2028	Earth Departure Date	Mars Arrival Date	C3 Energy	Right Ascension	Declination	Mars Arrival Excess Speed [km/s]
	12/10/28	07/20/29	9,048	158,9	1,581	4,892
	12/02/28	10/16/29	8,928	185,1	29,34	3,261
	01/17/29	09/02/29	24,12	140,9	1,581	3,593
	11/20/28	09/18/29	9,315	182,8	25,51	2,966

Source: [1] Interplanetary Mission Design Handbook: Earth-to-Mars Mission Opportunities 2026 to 2045, Laura M. Burke et. al.

ΔV BUDGET

Based on **mission requirements**:

- The propulsion system must provide the 7 impulses being capable of restart and pause the engine within the required time.
- The Thrust must be sufficient for approximate ideal orbit transfer.
- The propulsion system must have the capability to control the attitude of the satellite.
- A correction maneuver is also obtained with ACS Thrusters.

Launch Date	C3 Energy Burn [km/s]	Mars B-plane Burn [km/s]	Mars Capture Burn [km/s]	Inclination Burn [km/s]	Phasing Orbit Burn [km/s]	Phobos Circular Orbit Burn [km/s]	De-orbitting Maneuver [km/s]	Total DV [km/s]
31/10/2026	0.23119	0.56794899	0.8781101	0.484194109	0.021446442	0.3557810211	0.54841318	3.08708385
14/11/2026	0.631941	0.54594906	2.562749	0.33828268	0.729701	0.083892	0.8278835	4.892514
12/10/2028	0.376557	6.59930551	6.316753	0.660495664	0.425761	0.080628	0.8053112	14.4595

ASSUMPTIONS, TRADE-OFFS

Based on selection criteria of:

- ECSS-E-ST-35C Rev. 1 Space engineering: Propulsion general requirements
- ECSS-E-ST-35-01C Space engineering: Liquid and electric propulsion for spacecraft

ECSS Criteria	Performance		Mision req.		Resulting Layout			Compatibility and contamination		Experience	Availability of components	
Sub criteria	Isp [s]	Thrust [N]	T mission	Re-ignitability	System complexity	Total Mass & Volume	Required Power	Sys. Compatibility	Contamination	Technology Status	Availability	Total Cost
Hybrid	250	800	Short	Low	Med	High	Low-Med	Med	Med	Not flight proved	Low-Med	Med
Liquid Monopropellant	225	600	Short	Med-High	Med-Low	High	Low-Med	Med	High	Fully developed	High	High
Liquid Bipropellant	340	1000	Short	Med-High	High	High	Low-Med	Med	High	Fully developed	High	High-med
Electrostatic	10000	0.5	High	High	Med-high	Low	High	Low	Low-Med	Fully developed	High	Low
Electromagnetic	5000	200	Med	Med	High	Low	High	Low	Low	In Development	Low	Low
Nuclear (Solid Core)	1000	+1000	Short	Low	Med-high	Med	Med	Low	High	Not flight proved	Low	Low-med
Other (Solar Sail)	-	~1	High	Low-Med	Low	Low-Med	None	High-Med	Low(none)	Flight proved	Low	Low

*Data obtained from diverse sources, for full description of the references please refer to the report.

ASSUMPTIONS, TRADE-OFFS

Based on selection criteria of:

- ECSS-E-ST-35C Rev. 1 Space engineering: Propulsion general requirements
- ECSS-E-ST-35-01C Space engineering: Liquid and electric propulsion for spacecraft

	Isp [s]	Thrust [N]	T mission	Re-ignitability	System complexity	Total Mass & Volume	Required Power	Sys. Compatibility	Contamination	Technology Status	Availability	Total Cost	SCORE
Hybrid	2	4	5	2	3	2	4	3	3	3	2	3	3.08
Liquid Monopropellant	2	4	5	4	4	1	4	3	1	5	5	1	3.17
Liquid Bipropellant	2	5	5	4	1	2	4	3	1	5	5	2	3.29
Electrostatic	5	1	1	5	2	5	1	1	4	4	5	5	3.25
Electromagnetic	4	3	3	5	1	5	1	1	5	2	1	5	3.13
Nuclear	3	3	4	1	2	3	2	1	1	3	1	4	2.55
Other(Solar Sail)	-	1	1	2	5	4	5	1	5	3	1	5	3.01
Weight	0.080	0.080	0.110	0.064	0.061	0.106	0.083	0.076	0.068	0.102	0.057	0.114	

SYSTEM ARCHITECTURE OVERVIEW

Pressurized Feed System
- Propellant: Hydrazine
- Oxidizer: NTO(MON-3)
- Pressurant: Helium

Cilindrical Design (2 tanks)
- Less complexity, Less components, higher reliability
- Gravity center only shift along z-axis
- Easier spacecraft operations

Attitude Control System
- 4 Reactions wheels
- 2 Thrusters for desaturation & redundancy

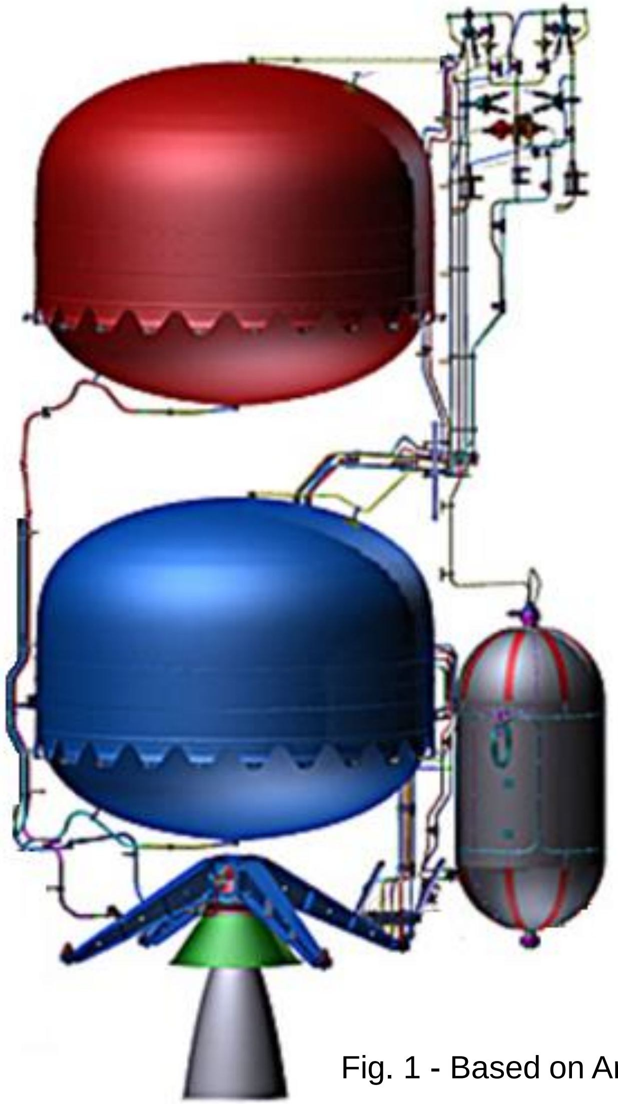


Fig. 1 - Based on Ariane-space scheme [2]

SYSTEM ARCHITECTURE – ENGINE SELECTION I

Engine selection trade-off analysis:

	Thrust [N]	Isp [s]	Flow Rate [g/s]	Inlet pressure (bar)	Weight [Kg]	Total Impulse [kN * s]	TRL	Fuel	Oxidizer	Contamination	European supplier	Supplier
400N BI-PROPPELLANT APOGEE MOTOR	425	321	135	15,0	4,3	-	9	MMH	MON-3	Moderate	Yes	Ariane
LEROS 1c Apogee Engine	458	324	144,10	17,0	4,76	13200	9	Hydrazine	MON	High	EES	Nammo
LEROS 1b Apogee Engine	635	317	204,20	17,0	4,5		9	Hydrazine	MON	High	EES	Nammo
LEROS 4 Interplanetary Engine	1000	321	317,56	15,4	8,41	13600	9	MMH	NTO (MON-3)	Moderate	EES	Nammo
R-4D-11 490 N (110 lbf) Bipropellant Rocket Engine	490	317,5	157,32	15,0	3,76	20016	9	MMH	NTO (MON-3)	Moderate	No	Aerojet Rocketdyne
R-4D-15 HiPAT™ 445 N (100 lbf) High Performance	445	322,2	141,31	15,0	5,2	13019	9	MMH	NTO (MON-3)	Moderate	No	Aerojet Rocketdyne
R-4D-15 HiPAT™ 445 N (100 lbf) Dual Mode High Performance	445	329	138,30	16,2	5,2	9550	7	Hydrazine	NTO (MON-3)	High	No	Aerojet Rocketdyne
R-42DM 890N (200 lbf) Dual Mode High Performance Rocket Engine	890	327,00	277	18,3	7,3	20000	7	Hydrazine	NTO (MON-3)	High	No	Aerojet Rocketdyne
AMBR 556 N (125 lbf) Dual Mode High Performance Rocket Engine	556	329	172,27	15,0	4,9	5792,9	6	Hydrazine	NTO (MON-3)	High	No	Aerojet Rocketdyne
MMH Bipropellant Thrusters	478	316	154,20	17,2	4,53	-	9	MMH	MON-3	Moderate	No	IHI
Hydrazine Bipropellant Thruster	450	329	139,43	16,3	4,5	-	9	Hydrazine	NTO	High	No	IHI

*Data obtained from the suppliers' webs/datasheets available online (Nominal values)

SYSTEM ARCHITECTURE – ENGINE SELECTION II

Engine	Thrust [N]	Isp [s]	Weight [Kg]	TRL	Fuel cost (P+Ox) [3]	Pressure inlet	Contamination	Euro. Supplier	SCORE
400N BI-PROPPELLANT APOGEE MOTOR	1,0	4,5	9,0	9	1,0	10,0	10	10	5,72
LEROS 1c Apogee Engine	1,5	6,5	8,1	9	10,0	4,5	1	5	5,82
LEROS 1b Apogee Engine	4,3	1,7	8,6	9	10,0	4,5	1	5	5,39
LEROS 4 Interplanetary Engine	10,0	4,5	1,0	9	1,0	8,9	10	5	5,70
R-4D-11 490 N (110 lbf) Bipropellant Rocket Engine	2,0	2,0	10,0	9	1,0	10,0	10	1	4,68
R-4D-15 HiPAT™ 445 N (100 lbf) High Performance	1,3	5,3	7,2	9	1,0	10,0	10	1	4,94
R-4D-15 HiPAT™ 445 N (100 lbf) Dual Mode High Performance	1,3	10,0	7,2	7	10,0	6,7	1	1	5,83
R-42DM 890N (200 lbf) Dual Mode High Performance	8,3	8,6	3,1	7	10,0	1,0	1	1	5,82
AMBR 556 N (125 lbf) Dual Mode High Performance	3,1	10,0	7,8	6	10,0	10,0	1	1	6,26
MMH Bipropellant Thrusters	1,8	1,0	8,5	9	1,0	3,9	10	1	3,68
Hydrazine Bipropellant Thruster	1,4	10,0	9,3	9	10,0	6,4	1	1	6,14
Weight	0,143	0,179	0,080	0,107	0,179	0,098	0,098	0,116	

PRELIMINARY RESULTS

Type	Engine	Press. Gas	Wet Mass [kg]	Fuel Mass [kg]	Dry Mass [kg]	Tank Mass [kg]	Valid?
Mono-propellant	MR-106L 22N	Nitrogen	6121.5	4961.1	1160.4	387.1	Yes
	MR-106L 22N	Helium	4820.0	3906.4	913.7	226.3	Yes
Bi-propellant	AMBR 556N	Nitrogen	2490.6	1729.6	761.5	148.3	Yes
	AMBR 556N	Helium	2312.9	1605.7	707.2	110.8	Yes
	R-4D-15 HiPAT	Nitrogen	2583.5	1810.9	772.6	158.6	Yes
	R-4D-15 HiPAT	Helium	2385.4	1672.0	713.4	117.9	Yes

SYSTEM BEHAVIOUR - OVERVIEW

Input Variable	Value
Total Δv [m/s]	~ 3100
Pressure, Propellant Tanks [bar]	15 + 5
Initial Pressure, Helium Tank [bar]	300 *[4]*
Engine ISP [s]	329
Margins	Various *[5]*

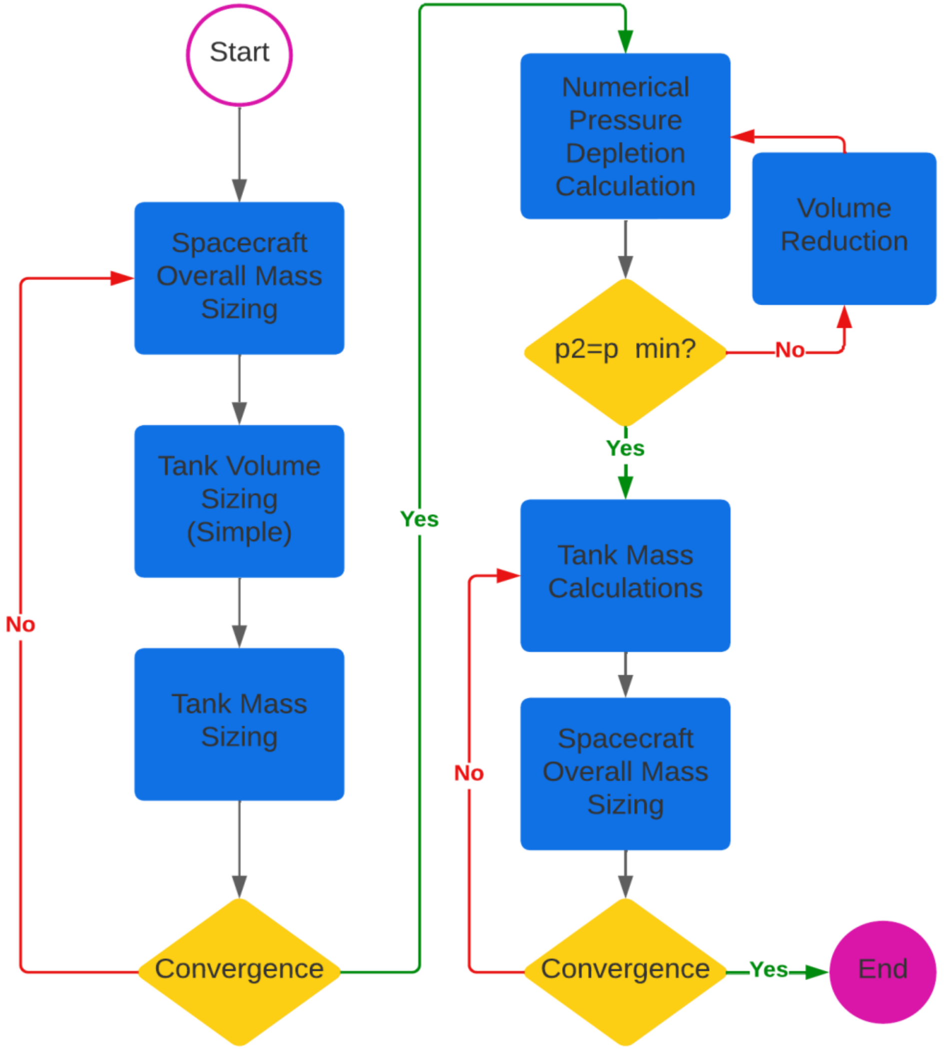


Fig. 2 – Overview of MATLAB code designed.

SYSTEM BEHAVIOUR - HELIUM TANK

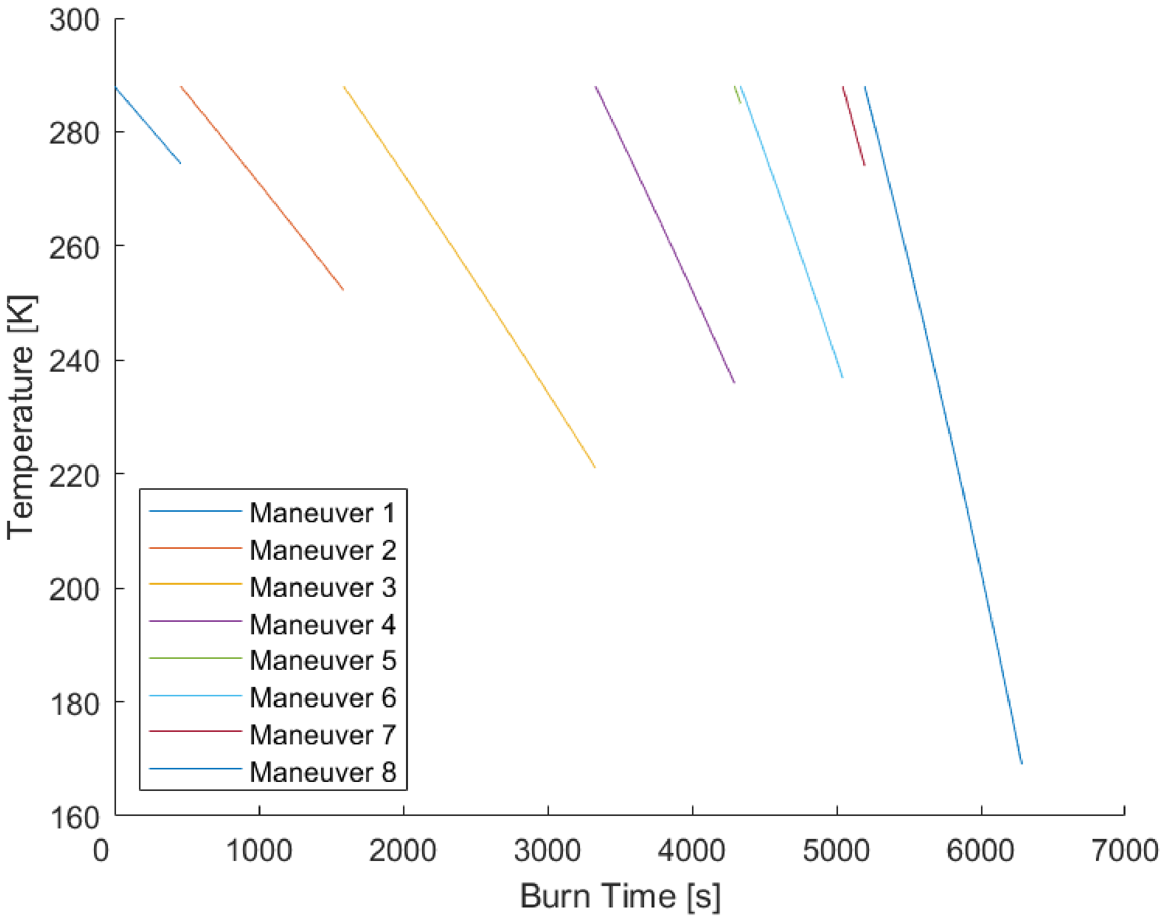


Fig. 3 – Temperature evolution through cumulative burn times.

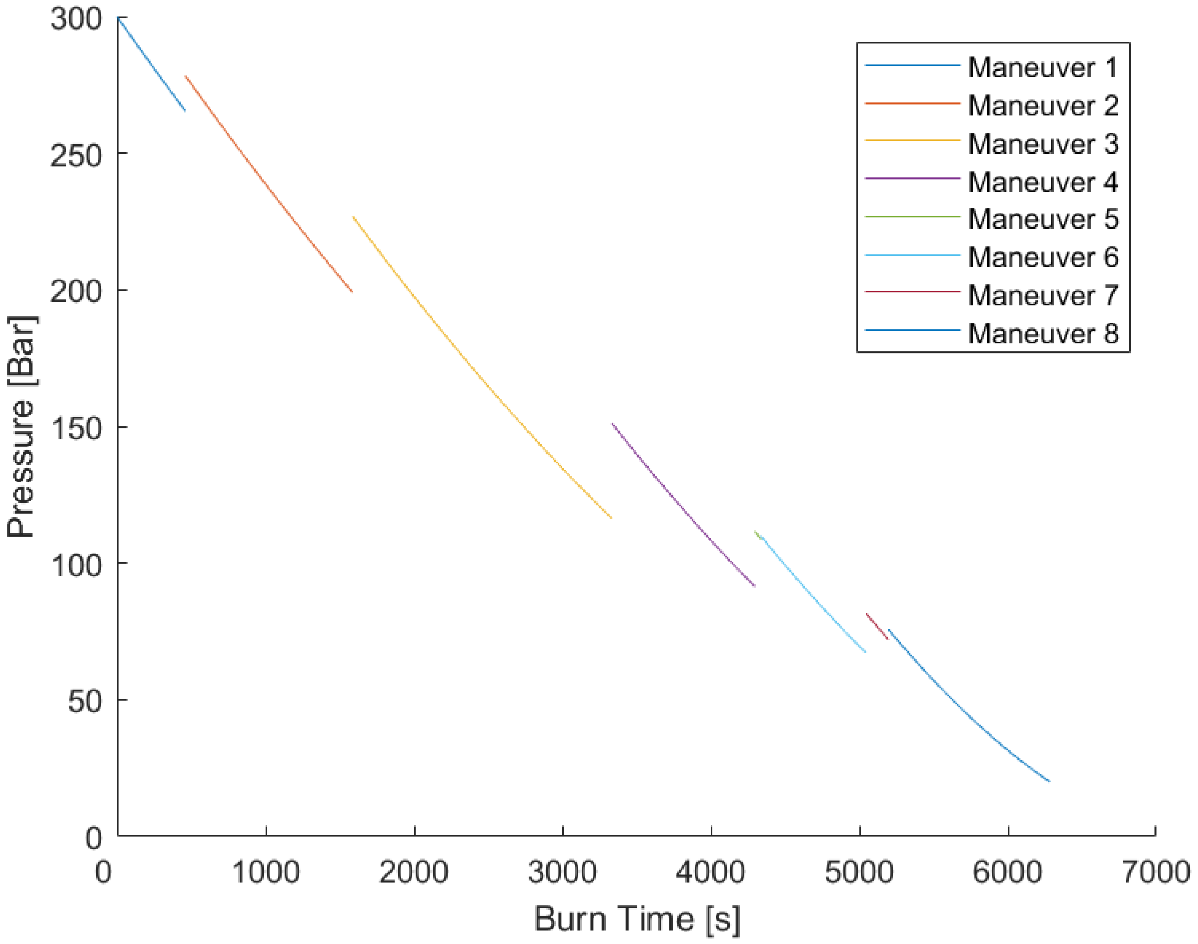


Fig. 4 – Pressure evolution through cumulative burn times.

MASS, VOLUME & POWER BUDGET

Masses	Final Mass [kg]
Wet	2106.8
Dry	790.54
Propellant	1316.3
Hydrazine	572.30
NTO	743.10
Tank System	97.308
Helium	3.8672

Tank	Volume [L]	Diameter [m]
Hydrazine	502.54	0.9864
NTO	455.06.	0.9543
Helium	88.229	0.5523

Component	Power [W]
Valve, Main Engine	45
ACS	20
All other Subsystems	550
Total	615

P&ID SCHEMATIC

Five Sections:

1. Pressurant Gas Tanks
2. PCA – Pressure Control Assembly
3. Propellant Tanks
4. PIA – Propellant Isolation Assembly
5. Thrusters

Quantity	Subcomponent	Acronym	Unit Mass [kg]	Total Mass [kg]
12	Fill and Drain Valve	FDV	0.10	1.20
8	Pressure Sensor	PS	0.23	1.84
9	Pyrotechnical Valve – normally open	PVO	0.20	1.80
14	Pyrotechnical Valve – normally closed	PVC	0.20	2.80
7	Filter	F	0.10	0.70
2	Pressure Regulator	PR	2.31	4.62
4	Check Valve	CV	1.36	5.44
8	Latch Valve	LV	0.34	2.72
1	Main Thruster	MT	4.90	4.90
2	Attitude Control Thruster	ACT	0.97	1.94

Source: *[6]*

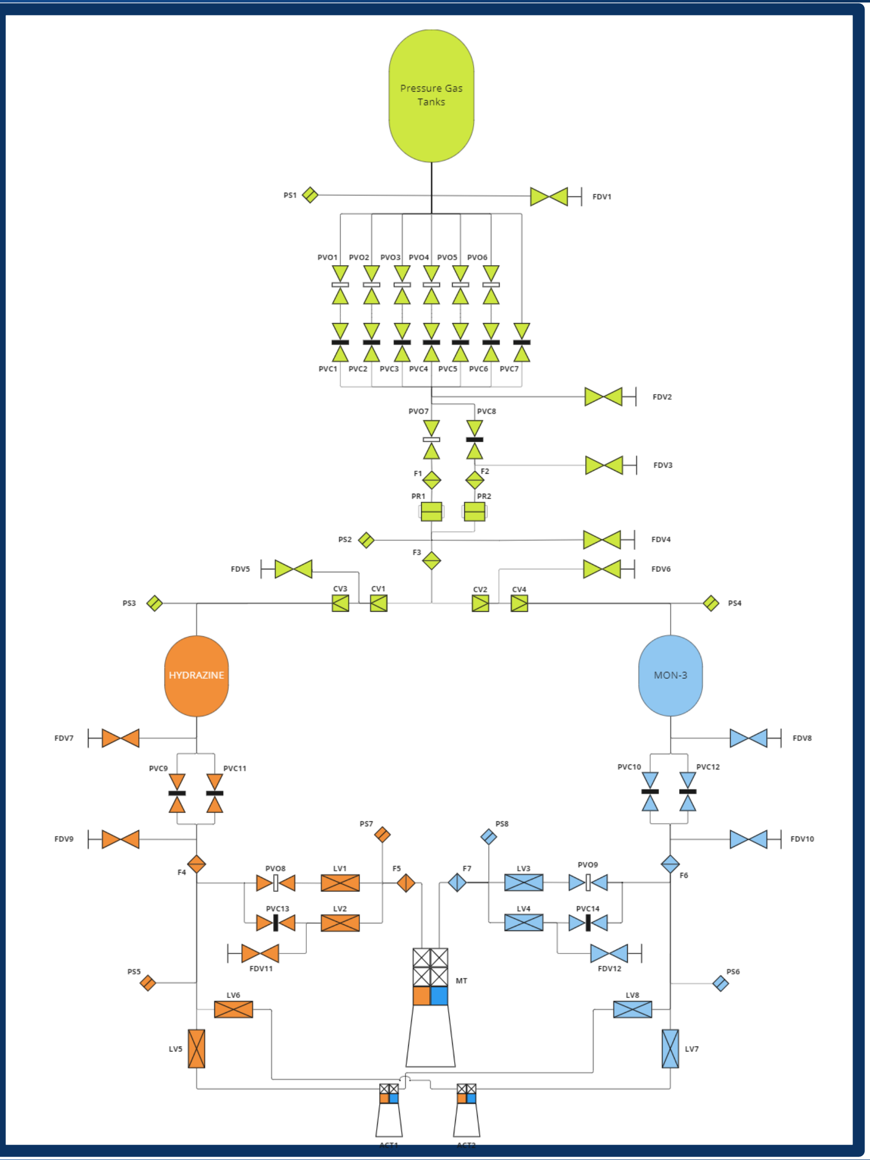
Helium Tanks

PCA

Propellant Tanks

PIA

Thrusters



P&ID SCHEMATIC

Propellant Storage & Initial Pressure Measurement

- Helium stored in tanks
- PS1 - Initial pressure check

Pyrotechnic Valves for Mission Sequence

- 7 Impulses
- PVO1-6,PVC1-7 - Working together
- PVC7 - Tank depletion for last burn

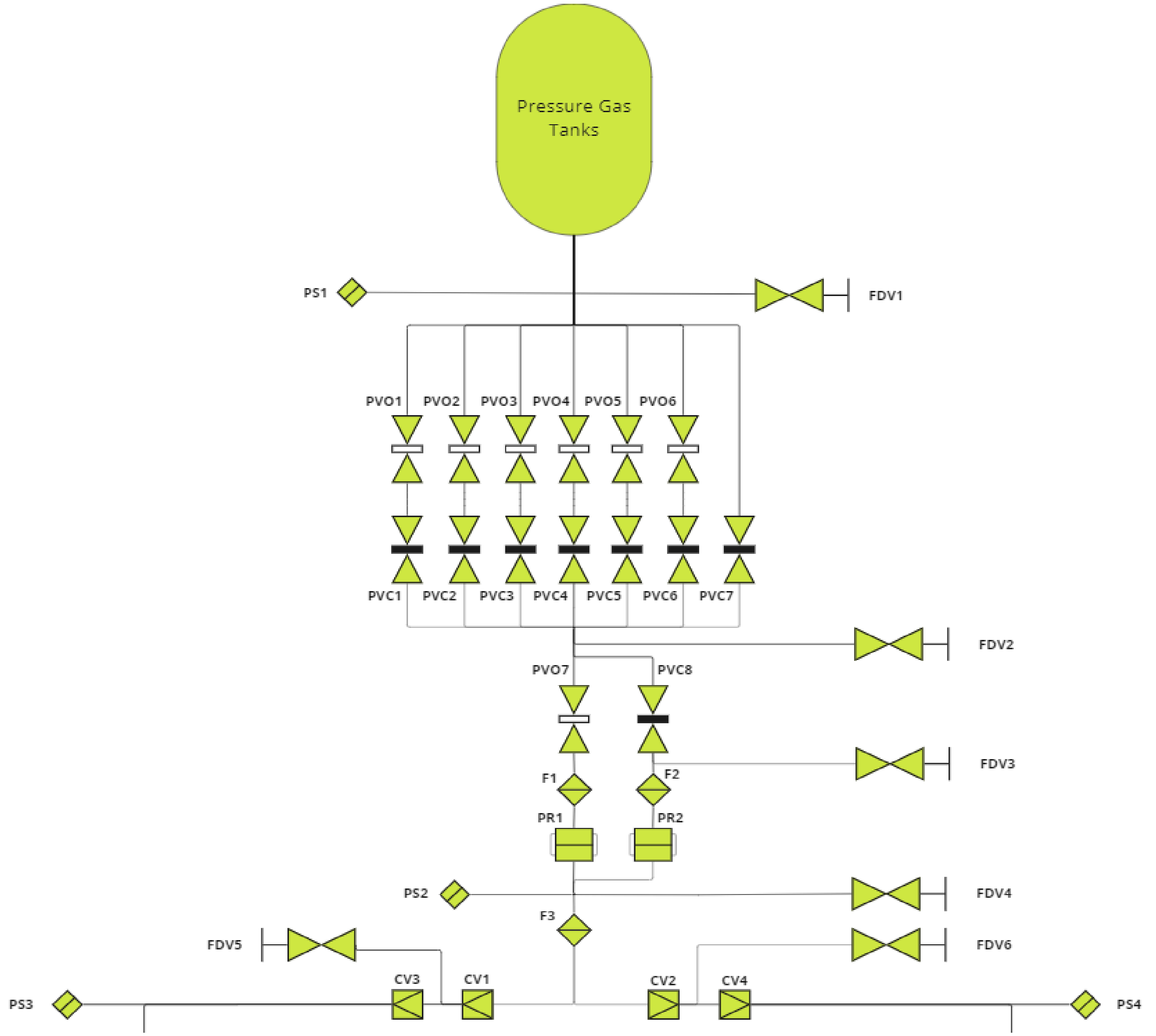
Filter & Double Pressure Regulator

- F1 - Cleans gas before regulator
- PR1 - Regulates gas pressure
- PR2 - In case of PR1 failure
- PS2 - Verifies correct output pressure

Check Valves

- F3 - Cleans gas before check valves
- C3,4 - Prevent backflow

[PROP-040,050,060]



P&ID SCHEMATIC

1st Redundancy & Branch Separation

- PVC9,11 - Redundancy
- F4 - Eliminates contaminants before mass flow reaches ACT1,2
- Mass flow separated to MT & ACT

2nd Redundancy & Main Thruster

- LV1,2 - Redundancy
- PS7 - Verifies correct output pressure
- F5 - Cleans debris for maximum combustion efficiency

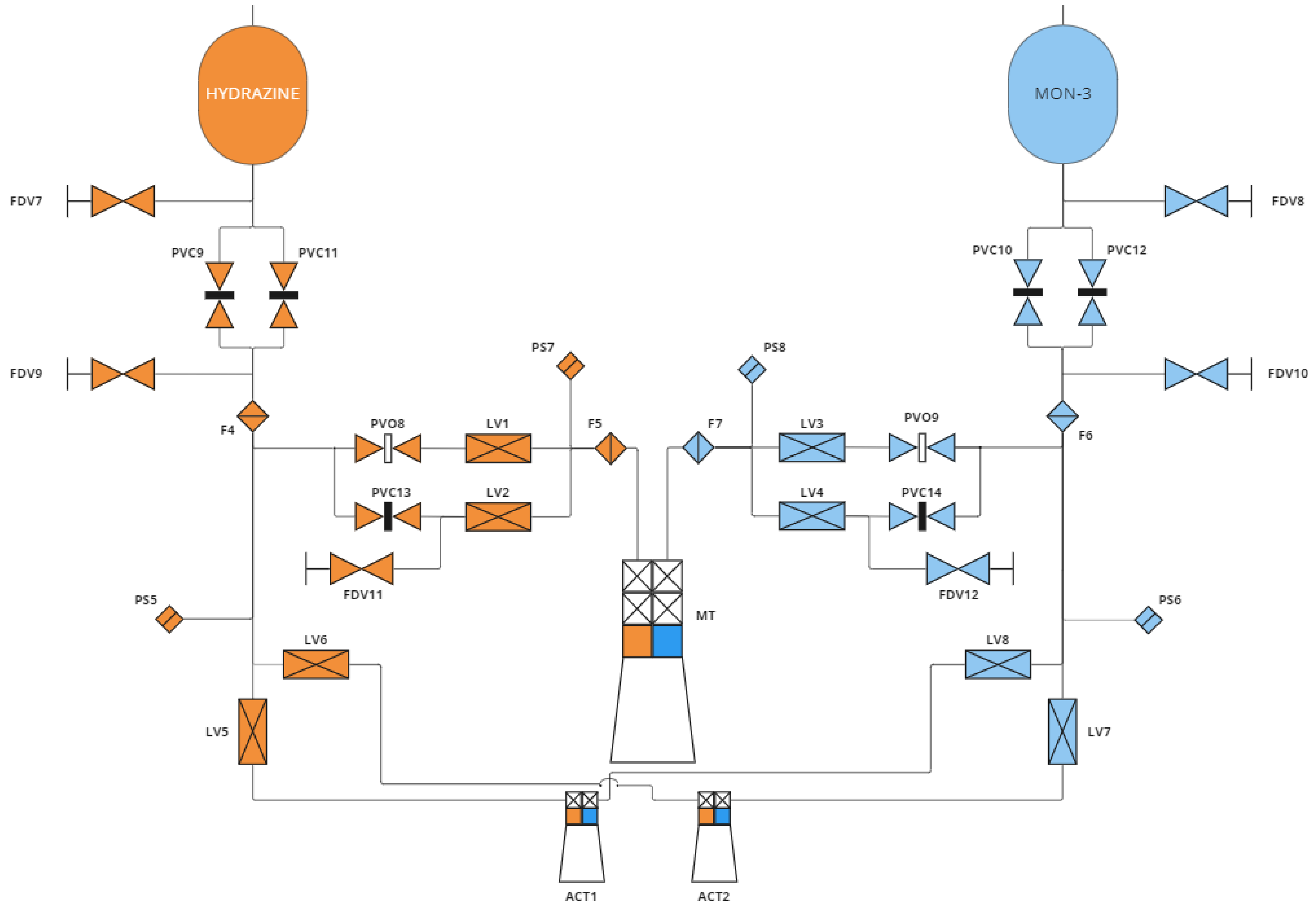
3rd Redundancy

- Latch valves in commercial thruster

Attitude Control System

- ACT1,2 - Desaturate 4 Reaction Wheels
- PS5 - Check pressure for ACT1,2
- LV5,6 - Correspond to ACT1,2

[PROP-030]



TECHNOLOGY NEEDS - ACS REACTION WHEELS

Quantified perturbations define ACS characteristics:

- Solar Radiation Pressure
- Sun Third-Body Problem
- Magnetic Field Disturbance

Thrust Misalignments and **Nozzle Direction Deviation** corrections. **[PROP-020]**
Moments of inertia and dimensions of reaction wheels calculated from spacecraft characteristics.

Minimum Angular Momentum @ Nominal Speed of 27 Nms.
Commercially Available Reaction Wheel: **Rockwell Collins RSI 30-280-30**

Main Technical Data – RSI 30-280-30	Values
Angular Momentum @ Nominal Speed	30 Nms
Operational Speed Range	3000 rpm
Motor Torque @ Nominal Speed	280 mNm
Diameter	347 mm
Height	124 mm
Mass	8.5 kg
Power Consumption @ Steady State	20 W
Power Consumption @ Maximum Torque	150 W

RSI 30-280-30

Fig. 5 - Rockwell Collins RSI 30-280-30 Reaction Wheel used. [8]

Reaction Wheel Implementation:

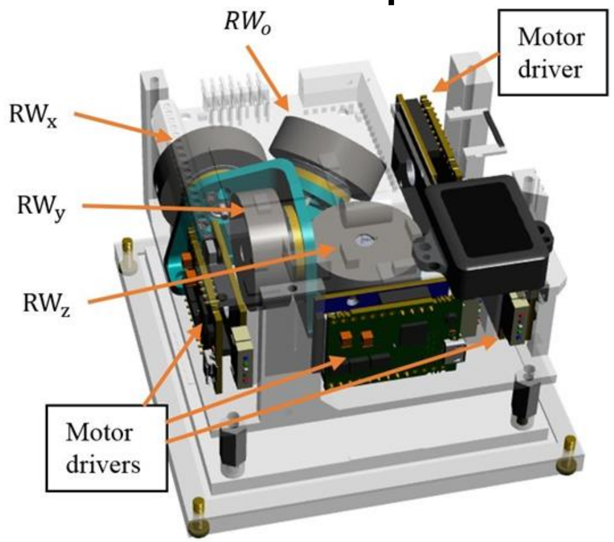


Fig. 6 – Example of Implementation of 4 Reaction Wheels. [8]

TECHNOLOGY NEEDS - ACS THRUSTERS

Status: Ready for flight qualification
Not in Production

Expected to be available by 2026.

Main Technical Data – Aerojet Rocketdyne R-6F 22N	Values
Propellant	Hydrazine/NTO
Nominal Thrust	22 N
Nominal Specific Impulse	295 s
Inlet Nominal Pressure	6.9-20.79 bar
Valve Power	11 W
Mass	0.965 kg
Propellant Mass	54.5 kg

Aerojet Rocketdyne R-6F 22N

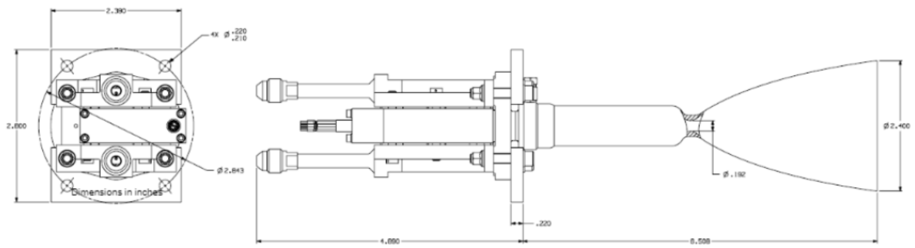


Fig. 7 – Schematic of R-6F 22N. [7]

Fig. 8 – Aerojet Rocketdyne R-6F 22N. [7]

TECHNOLOGY NEEDS – MAIN THRUSTER

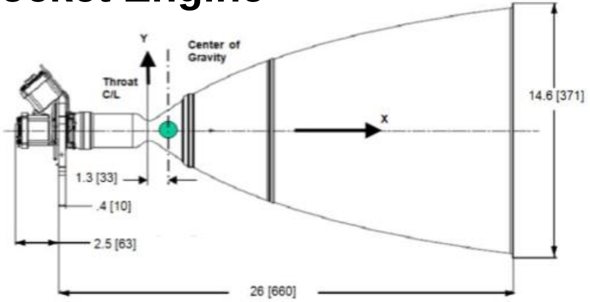
Status: Ready for final flight design/analysis, and qualification
Not in Production

Expected to be available by 2026.

[PROP-010]

Main Technical Data – Aerojet Rocketdyne AMBR 556N	Values
Propellant	Hydrazine/NTO
Nominal Thrust	556 N
Nominal Specific Impulse	329 s
Inlet Nominal Pressure	>14 bar
Chamber Pressure	10.3-11.7 bar
Nominal Mixture Ratio (O/F)	1.0-1.3
Demonstrated Steady State Firing Duration	2700 s
Valve Power	45 W
Mass	4.9 kg
Propellant Mass	1338.6 kg

AMBR 556N Dual Mode High Performance Rocket Engine



Dimensions in inches [millimeters].

Fig. 9 – Schematic of AMBR 556N Dual Mode High Performance Rocket Engine [7].

Fig. 10 – AMBR 556N Dual Mode High Performance Rocket Engine. [7]

TECHNOLOGY NEEDS – TANKS

Main Technical Data – IHI AeroSpace Tank	Values
Material	Ti (forging)
	Al
	CFRP/Al
Total Volume (unpressurized)	552 L
Internal Device	Diaphragm
Size	1087 ID Sphere

Main Technical Data – PVG Family 80-120 HPV Tank		Values
Fluids		He, N
Material	Shell	Ti-6Al-4V
	Tube	Ti-3Al-2.5V
	Overwrap	Epoxy-based CFRP
Total Volume (unpressurized)		80-120 L
Tank Dry Mass		23.5 kg
Diameter (max pressurized)		432.0 mm

IHI AeroSpace Propellant Tank

Fig. X – 430L Propellant Tank by IHI AeroSpace, analogous to required tank.[9]

PVG Family 80-120 High Pressurant Tank (HPV) - Helium

Fig. X – Helium Gas Tank PVG Family 80-120 by MT Aerospace.[10]

CONCLUSIONS

CONCLUSION

Spacecraft meets Ariane 62 requirement – Dimensions.
Performance-optimized architecture – Bipropellant Hydrazine/NTO.
Minimize DV through mission sequence under time constraints.
Mitigation of critical failure by 3 inhibits.
All the Design Challenge requirements and additional ECSS Standards have been met.
Importance of project management and weekly meetings.

FUTURE DIRECTIONS

Calculation of Overall Costs – unaccessible online
Validity Check with further ECSS standards
Optimized Deorbiting – Possible Aeroassistance
Physical Testing expands limited knowledge on instruments

THANKS FOR YOUR ATTENTION!

QUESTIONS:

REFERENCES

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[2] System Architecture

[3] Propellant Prices

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[7] Main and Attitude Control System Thrusters

[8] Example of Implementation of 4 Reaction Wheels

[9] Propellant Tanks

[10] Helium Gas Tanks