Comparison of Green and Conventional Rocket Propellants: System Analysis Tool for in-space Propulsion

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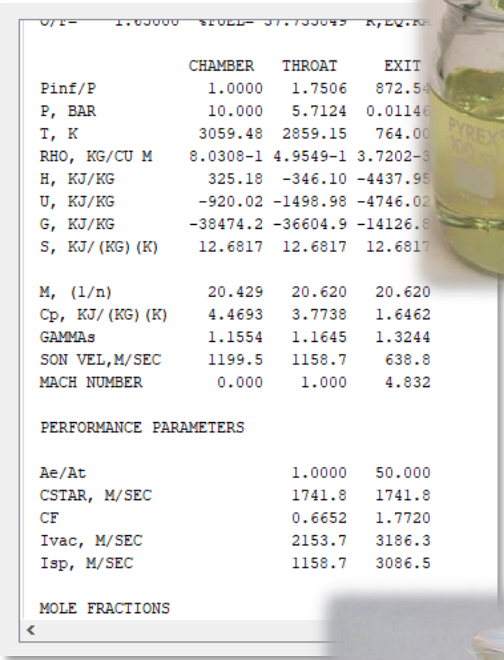
Motivation
Comparison of different propellants

- Global research activities on various green propellants
- Comparison often based solely on I_{sp}
- **But:**
    - Propellant density effects the performance of the overall system
    - Different propulsion system designs can offer additional advantages

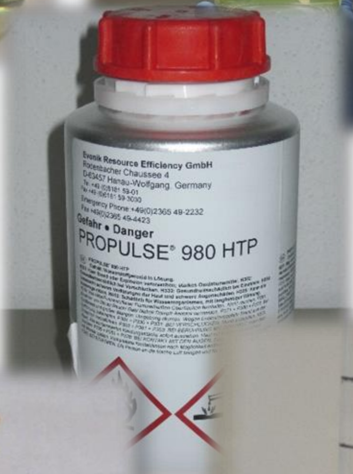


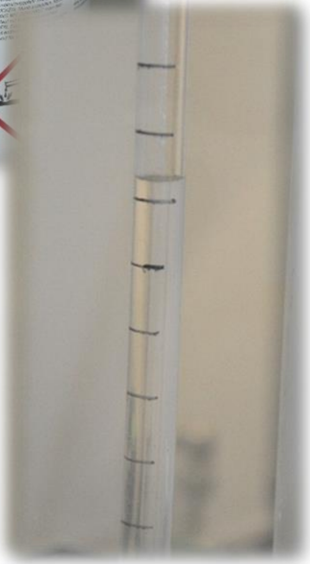
	CHAMBER	THROAT	EXIT
Pinf/P	1.0000	1.7506	872.54
P, BAR	10.000	5.7124	0.01146
T, K	3059.48	2859.15	764.00
RHO, KG/CU M	8.0308-1	4.9549-1	3.7202-3
H, KJ/KG	325.18	-346.10	-4437.95
U, KJ/KG	-920.02	-1498.98	-4746.02
G, KJ/KG	-38474.2	-36604.9	-14126.8
S, KJ/(KG)(K)	12.6817	12.6817	12.6817
M, (1/n)	20.429	20.620	20.620
Cp, KJ/(KG)(K)	4.4693	3.7738	1.6462
GAMMAs	1.1554	1.1645	1.3244
SON VEL,M/SEC	1199.5	1158.7	638.8
MACH NUMBER	0.000	1.000	4.832

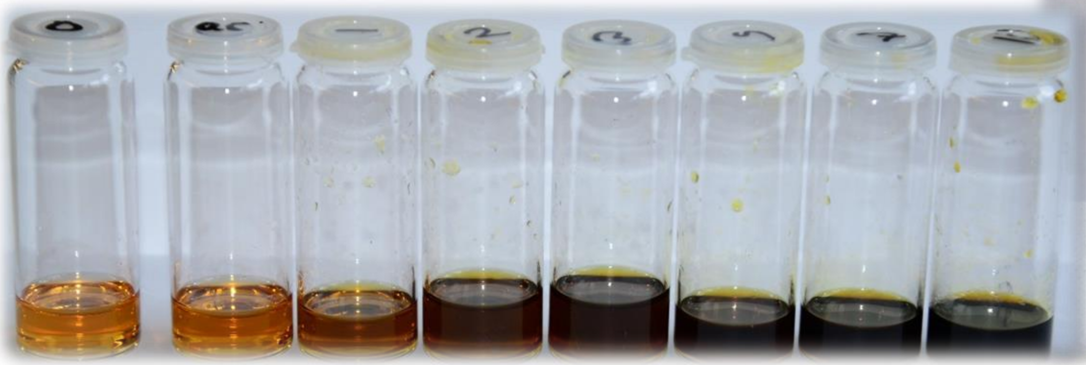
PERFORMANCE PARAMETERS

Ae/At		1.0000	50.000
CSTAR, M/SEC		1741.8	1741.8
CF		0.6652	1.7720
Ivac, M/SEC		2153.7	3186.3
Isp, M/SEC		1158.7	3086.5

MOLE FRACTIONS







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Motivation

Comparison of different propellants

- "Best" propellant choice influenced by spacecraft size/mass and Δv budget
- Performance parameters of existing thrusters are known
- For lower TRL systems often only the theoretical performance is known


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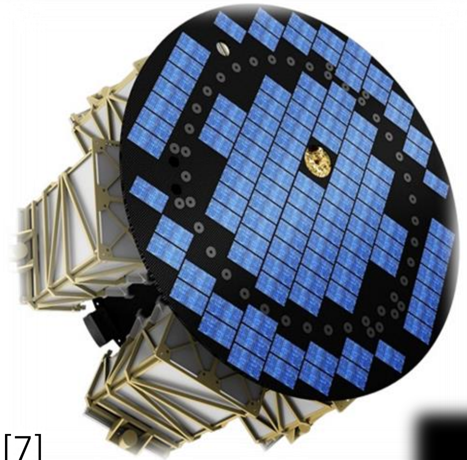
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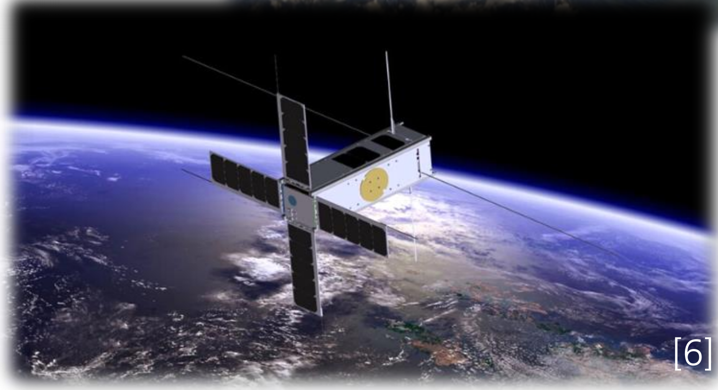
Aim:
- Assess and compare the performance of different green propellants to conventional propellants on a system level
- Comparison of system mass and Δv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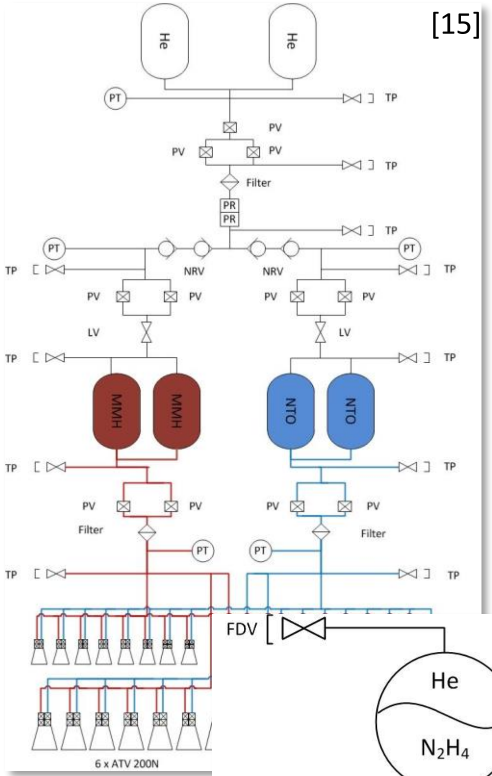
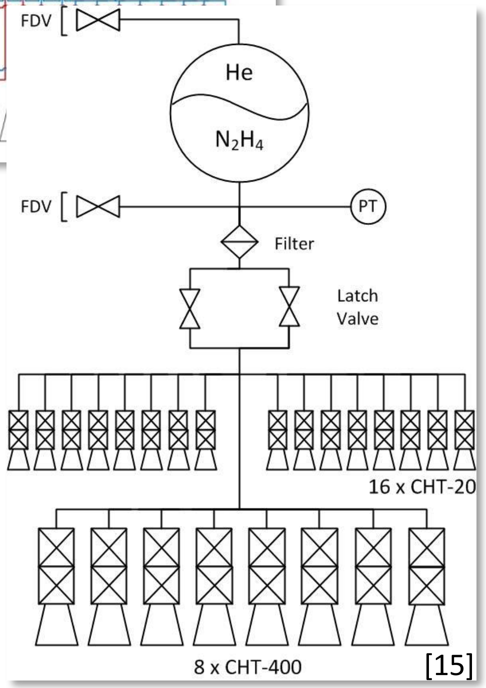
Background and assumptions

- Propellant and propulsion system data from literature [8-41], see reference list
- Performance based on experimental literature data, otherwise CEA calculations with adjustable efficiency losses
- Self-pressurization: No mass for pressurant tank, pressurant piping, pressurant valves and pressurant needed
- All tanks are spherical
- Calculation of tank thickness/mass with Barlow's formula depending on tank/propellant pressure
- Thruster masses based on existing mono- and bipropellant thrusters, system component's masses based on existing systems
- HyNOx thrusters have 50% more mass compared to non-HyNOx thrusters





Calculation steps

Spacecraft Dry Mass

Mass without propulsion system

$$\Delta v = I_{sp} g_0 \ln\left(\frac{m_{sc\ dry} + m_{tanks} + m_{propellant} + m_{pressurant} + m_{prop\ sys}}{m_{sc\ dry} + m_{tanks} + m_{prop\ sys}}\right)$$

Volume of propellant tank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Selection of propellant and efficiency


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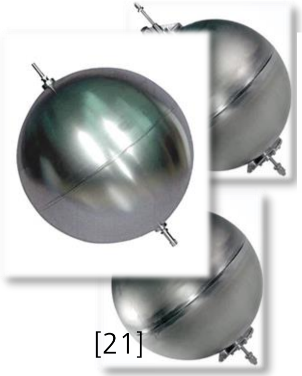
Number of propellant and pressurant tanks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Calculation of Tank, Pressurant mass


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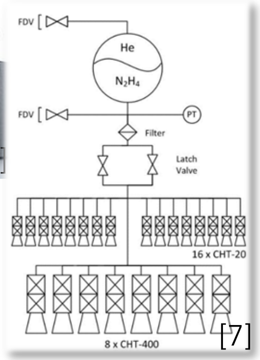
Mass of propulsion system without tanks

Calculation of propulsion system dry mass



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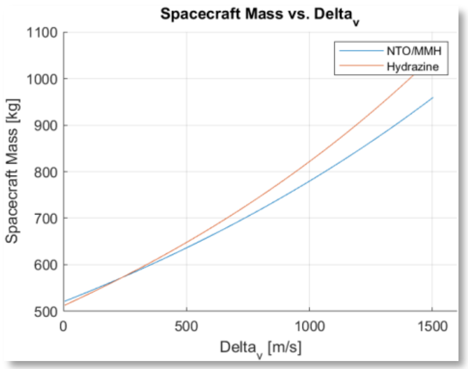
For specific conditions

Calculation of Δv



Calculation of Δv for increase of propellant, pressurant and tank mass

Plotting: Spacecraft Mass vs. Δv

DLR

Calculation steps

Spacecraft Dry Mass

Mass without propulsion system

$$\Delta v = I_{sp} g_0 \ln\left(\frac{m_{sc\ dry} + m_{tanks} + m_{propellant} + m_{pressurant} + m_{prop\ sys}}{m_{sc\ dry} + m_{tanks} + m_{prop\ sys}}\right)$$

Volume of propellant tank

Selection of propellant and efficiency

Number of thrusters, propellant and pressurant tanks

Calculation of Tank and Pressurant masses

$$m_{tank} = \rho_{Ti-6Al-4V} \cdot \frac{4}{3}\pi\left(r_o^3 - r_i^3\right)$$

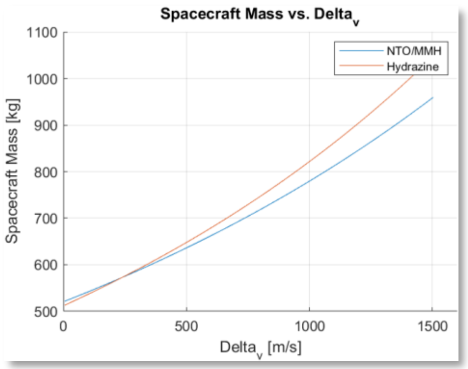
$$t = \frac{p \cdot r_a}{\sigma} \cdot s_f$$

Calculation of propulsion system dry mass

Mass of propulsion system without tanks

Calculation of Δv

For specific conditions



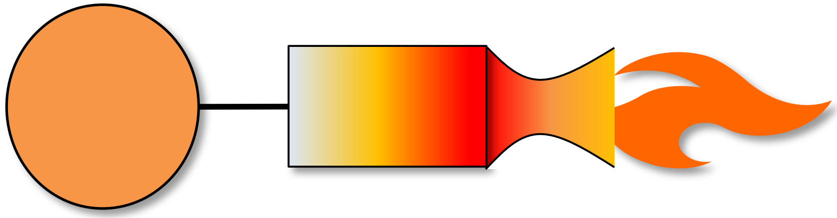
Calculation of Δv for increase of propellant, pressurant and tank mass

Plotting: Spacecraft Mass vs. Δv

Propellants included

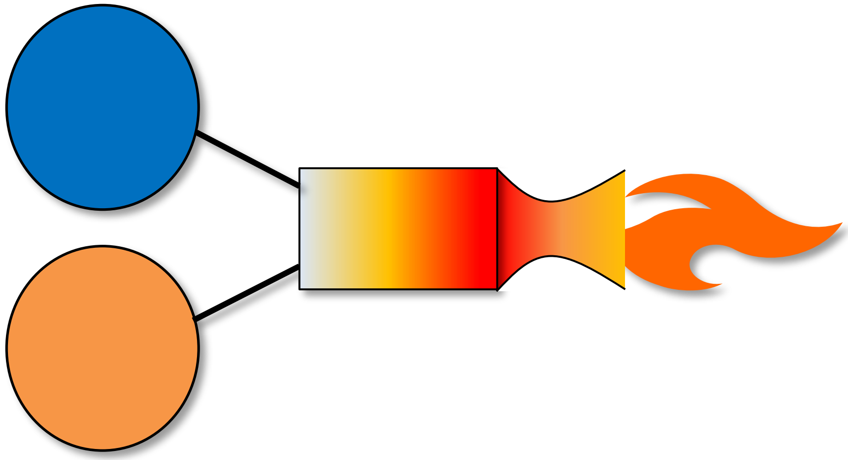
Monopropellants:

- N_2H_4
- LMP-103S
- FLP-106
- H_2O_2
- EUFB (Europen Fuel Blend, premixed N_2O/EtOH)
- HyNOx (DLR premixed N_2O/C_2H_6)
  - Self-pressurized
  - External pressurization
- AF-M315E
- SHP 163



Bipropellants:

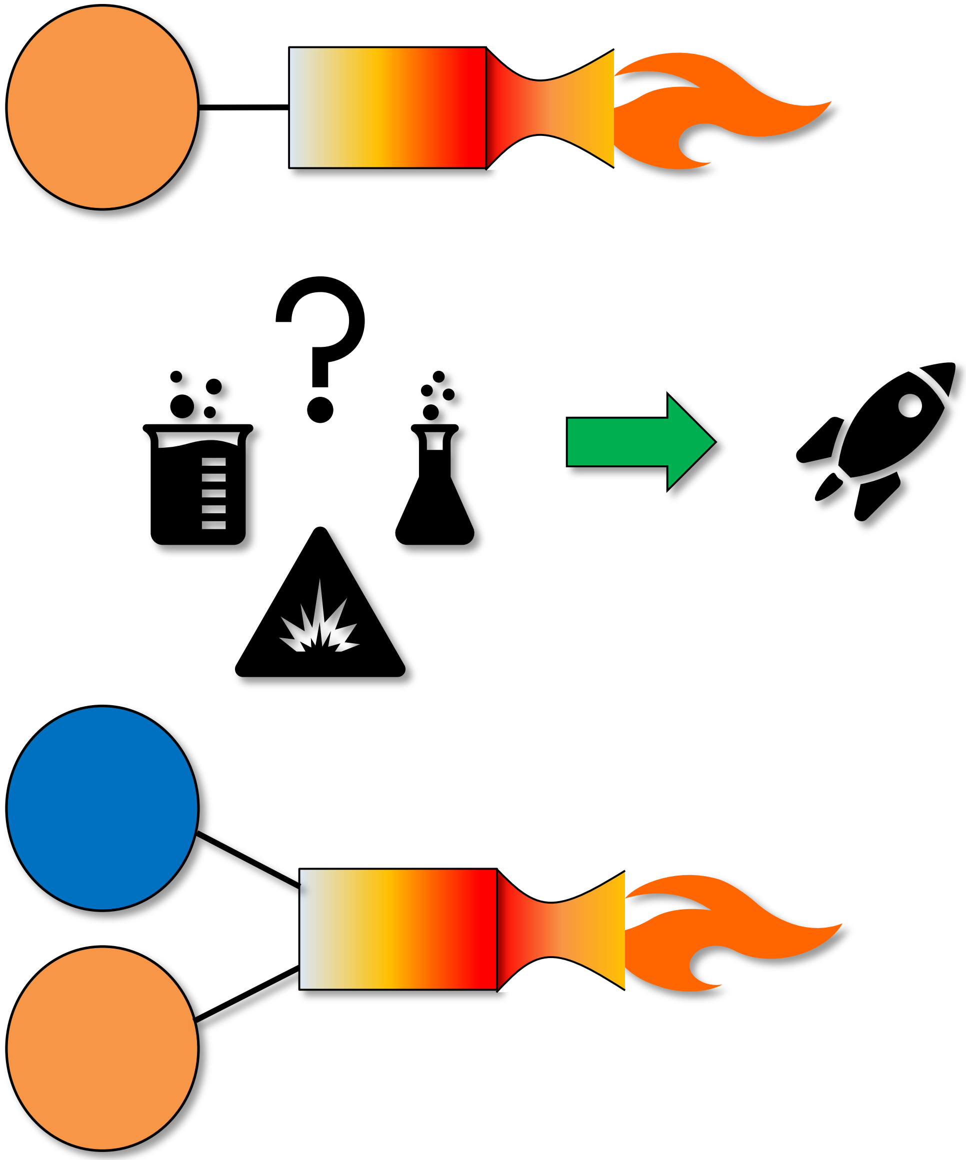
- MMH/NTO
- HIP_11 (DLR Hypergolic Bipropellant)
- HyNOx (DLR non-premixed N_2O/C_2H_6)
  - Self-pressurized
  - External pressurization



Propellants included

Generic propellants:

- Monopropellant, user input:
  - I_{sp}
  - Density
  - Self pressurized: Pressure inside the tank
- Bipropellant, user input:
  - I_{sp}
  - Oxidizer to fuel ratio
  - Density of oxidizer and fuel
  - Self pressurized: Pressure inside the tanks



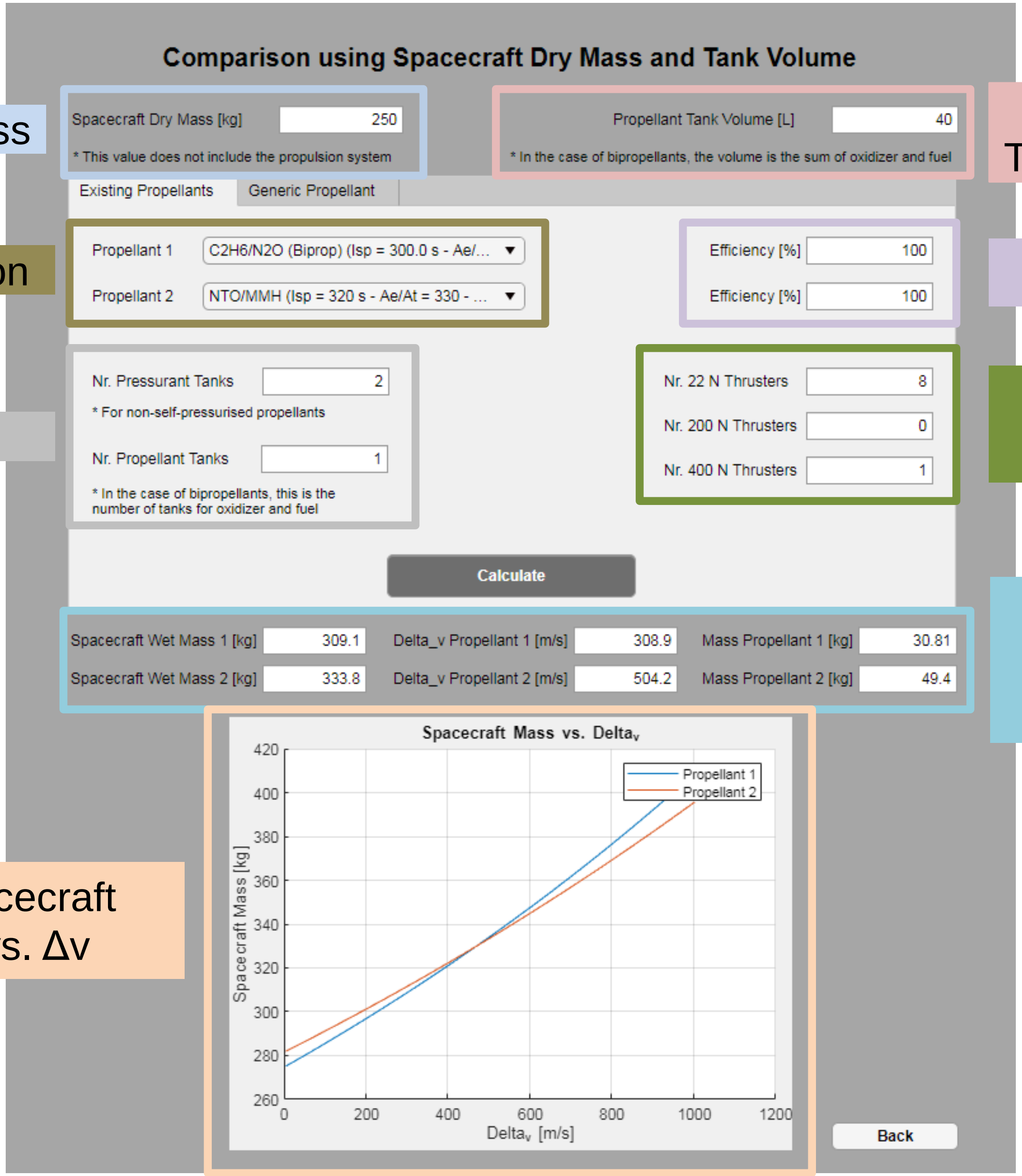
User Interface:

Spacecraft Dry Mass

Propellant selection

Number of tanks

Plot spacecraft mass vs. Δv



Propellant Tank Volume

Efficiency

Number of Thrusters

Results for the given conditions

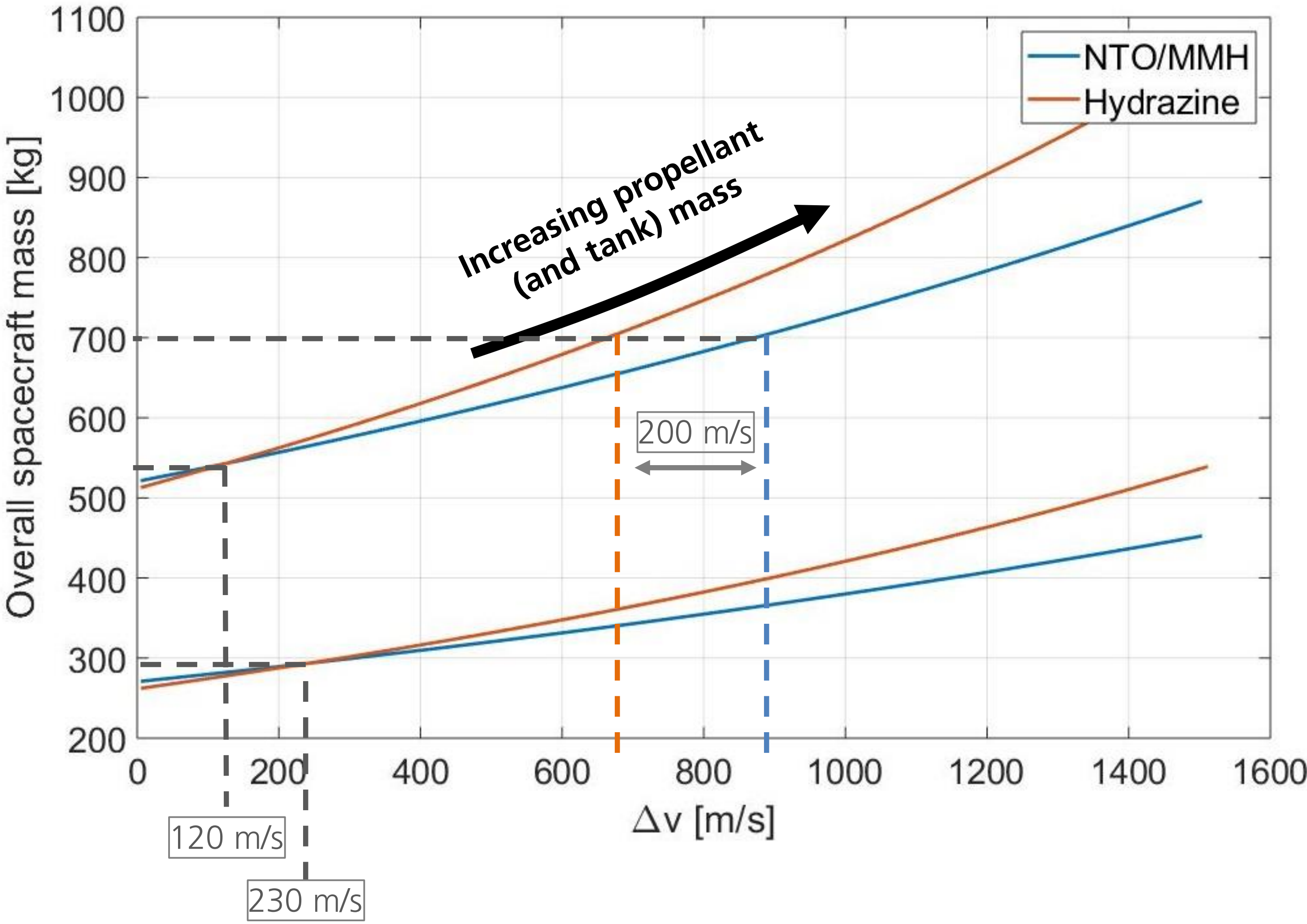
Exemplary results

Hydrazine		
I_{sp}	ε	Eff.%
230	60	100

NTO/MMH		
I_{sp}	ε	Eff.%
320	330	100

Comparison of mono- and bipropellant systems for 250 and 500 kg spacecraft dry mass

- For high Δv requirements the higher I_{sp} of bipropellant systems exceeds the drawbacks of higher system weights
- Pure monopropellant system results in lower spacecraft mass for
  - 250 kg spacecraft when up to 230 m/s Δv are needed
  - 500 kg spacecraft when up to 120 m/s Δv are needed
- For lower spacecraft masses, the lower masses of N_2H_4 systems are more advantageous



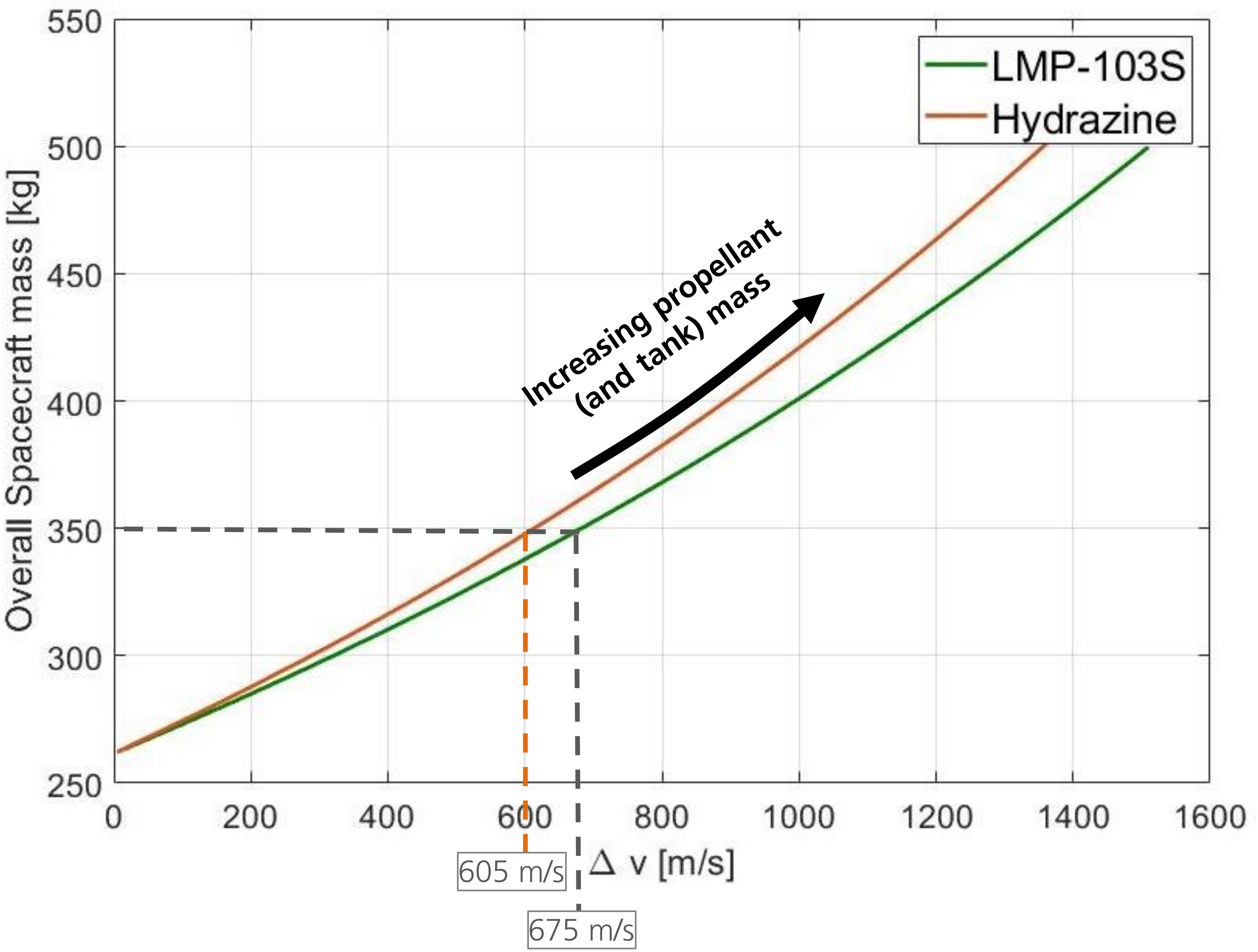
Exemplary results

Hydrazine		Eff.
I_{sp}	ε	%
230	60	100

LMP-103S		Eff.
I_{sp}	ε	%
253	150	100

Comparison of conventional and green mono- propellant systems for 250 kg spacecraft dry mass

- Due to the higher I_{sp} and density of LMP-103S additional Δv can be gained for the same spacecraft mass
  - For e.g. 350 kg overall mass the Δv gain is 70 m/s (605 vs. 675 m/s)



Exemplary results

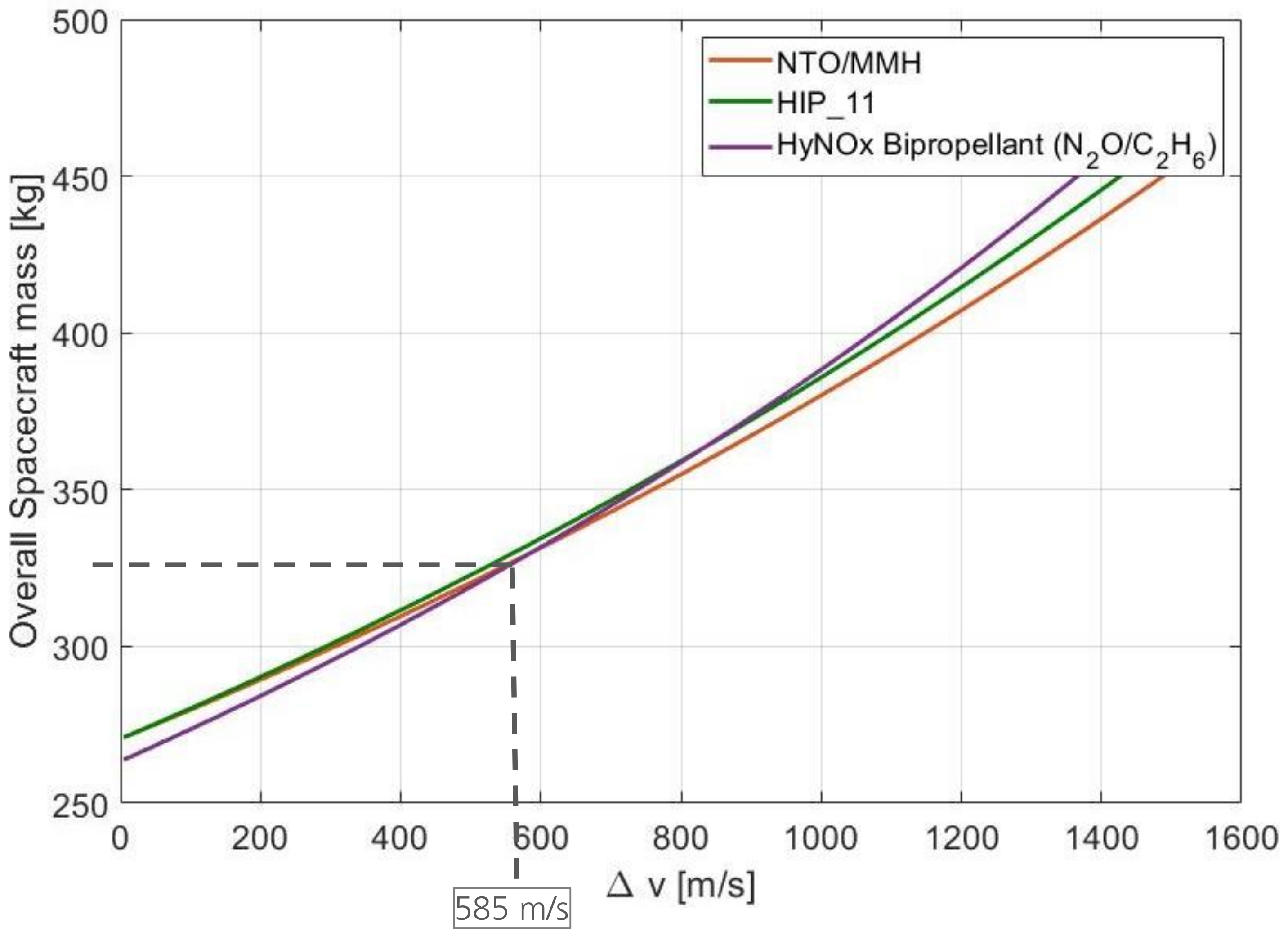
NTO/MMH		
I_{sp}	ε	Eff.%
320	330	100

HIP_11		
I_{sp}	ε	Eff.%
316	330	96

HyNOx		
I_{sp}	ε	Eff.%
314	330	96

Comparison of conventional and green mono-propellant systems for 250 kg spacecraft dry mass

- Up to a Δv of 585 m/s HyNOx beneficial due to lower system mass – no external pressurization needed
- Above Δv of 585 m/s higher Δv available with conventional NTO/MMH
- HIP_11 as hypergolic green propellant is suitable for higher Δv requirements, despite slightly lower performance than conventional NTO/MMH

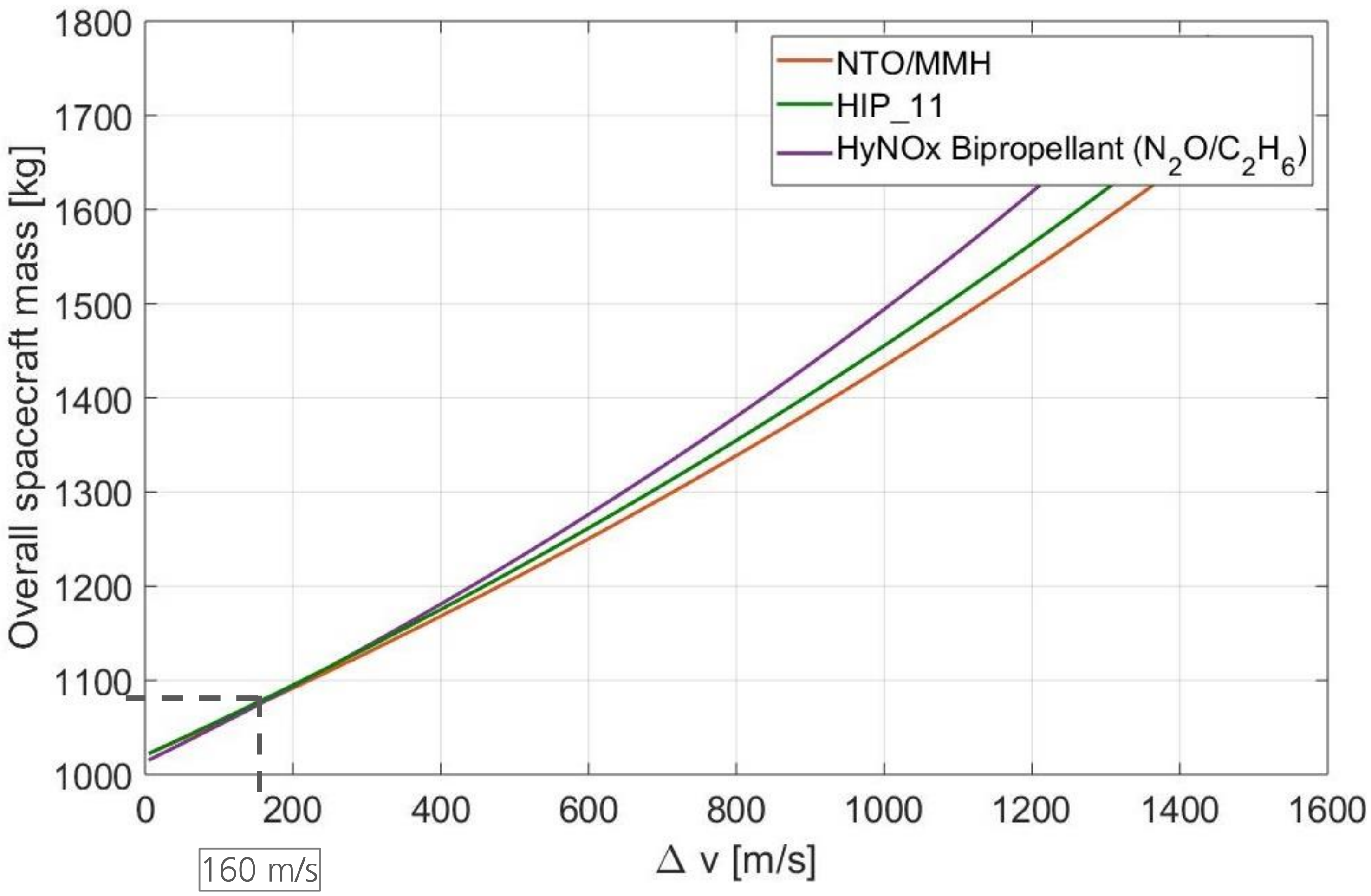


Exemplary results

NTO/MMH		
I_{sp}	ε	Eff.%
320	330	100

HIP_11		
I_{sp}	ε	Eff.%
316	330	96

HyNOx		
I_{sp}	ε	Eff.%
314	330	96

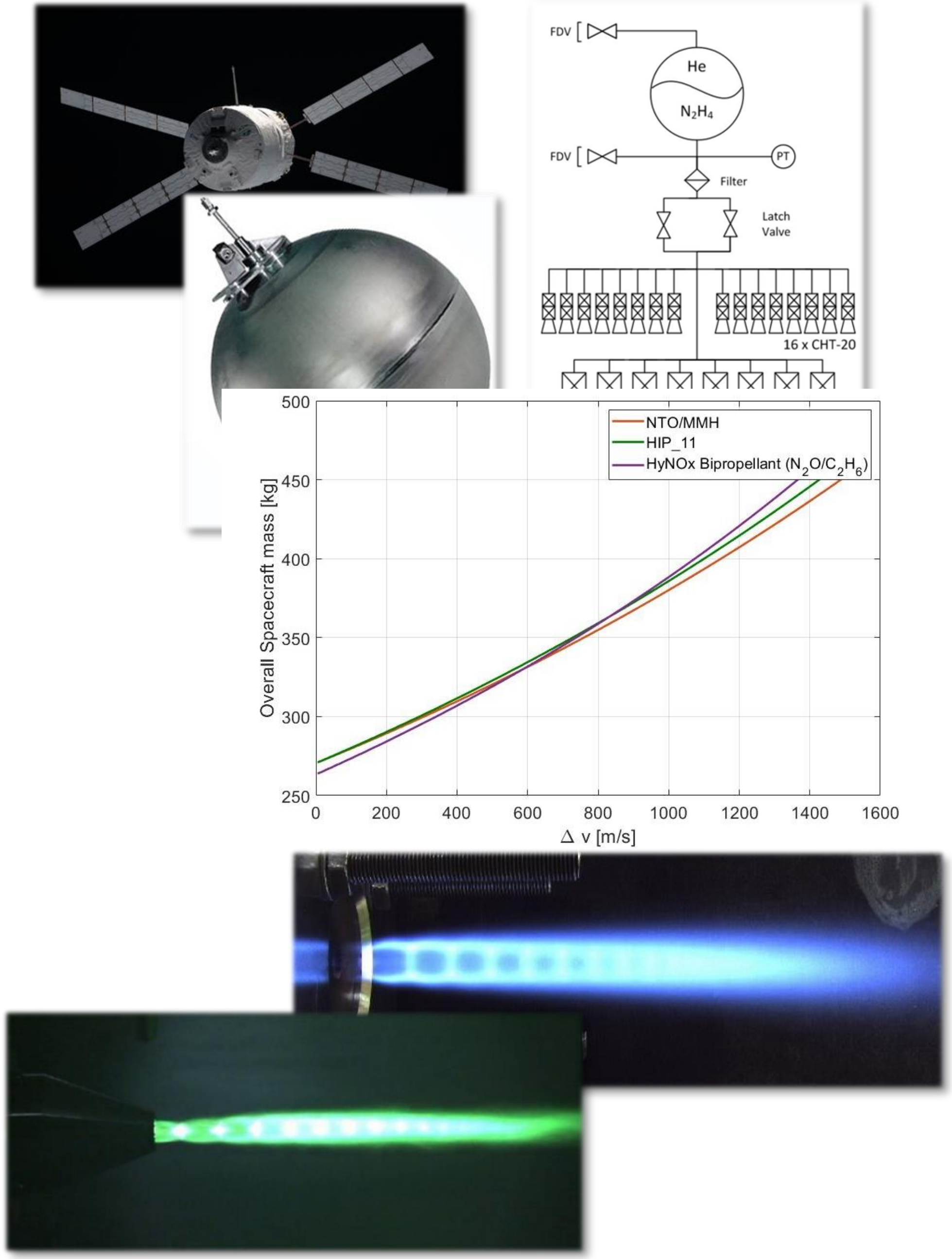


Comparison of conventional and green mono-propellant systems for 1000 kg spacecraft dry mass

- Up to a Δv of 160 m/s HyNOx beneficial due to lower system mass – no external pressurization needed
- Due to lower I_{sp} of HyNOx, lower density and higher tank pressures above 160 m/s HIP 11 or NTO/MMH is advantageous
- HIP_11 as hypergolic green propellant is suitable for higher Δv requirements, despite slightly lower performance than conventional NTO/MMH

Summary

- Basic comparison tool for different conventional and green propellants developed
- Tool takes spacecraft mass, propulsion system mass, tank masses, propellant, pressurant and thruster masses into account
- A specific propellant can be selected or a generic propellant can be defined
- I_{sp} efficiency, number of tanks (propellant, pressurant), number and size of thrusters can be adjusted
- Green propellants can offer Δv or spacecraft mass advantages compared to conventional propellants, even for lower I_{sp} and/or density
- Tool will be optimized and extended based on available literature data



Thank you for your attention!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