Comparative Study of CubeSat Propulsion Systems

Or what to use for which mission…

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CAL POLY SAN LUIS OBISPO

CUBESAT

PolySat

EMu Propulsion

What system should I use?

Many options to choose from, each with benefits and drawbacks.

ACS vs Primary?

High thrust vs high Isp?

Precision impulse bits?

Simplicity?

Satellite size?

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It’s not just about I_{sp}.

Similar to
gas mileage
in a car.

Specific impulse $(I_{sp}) \equiv$ thrust per unit propellant mass:

$$I_{sp} = \frac{T}{\dot{m}_p g}$$

The higher the better, as more thrust per mass of propellant. BUT…

- Often approximated as $I_{sp} \approx \frac{v_{ex}}{g}$ which neglects
  - -> Propellant losses
  - -> Secondary propellant usage (eg. Neutralizers)
- Give no consideration to the thruster system dry mass

What else to consider?

Thrust

- Station keeping vs precision pointing vs primary propulsion.
- Time for mission.

Total Impulse

- Over mission lifetime

Impulse Bits

- Mostly important for precision pointing, attitude control, fine movements, etc

Delta-V

Total usefulness of thruster system. Tells you what missions you can actually do.

This Study - Basics

1) Compiles information on various propulsion systems available or in development
   - Focus on generic types, not specific brands

2) Compare common performance values
   - Specific Impulse (I_{sp})
   - Thrust
   - Power
   - Mass

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3) Calculate and compare delta-V for 3U and 6U CubeSats

$$\Delta v = -I_{sp} g \ln\left(\frac{m_{dry}}{m_{wet}}\right)$$

4) Use results as a guideline for potential propulsion options for CubeSat missions

This Study – Inclusions and Exclusions

Takes into account

- Size/mass of power system required
- Size/mass of thruster
- Size/mass of neutralizer (if any)

Does not directly consider

- Pressure of propellant needed to fit propellant mass in <1U volume
- Required power storage/solar panel area for operation
- Complex propellant feed systems

Uses constant payload and bus sizes for direct comparison

This Study – Propulsion Systems Considered

- Cold Gas Thruster
- Warm Gas Thruster
- Resistojet
- Plasma Electrothermal
- Pulsed Plasma Thruster*
  - * Limited to 40g max propellant
- Electrospray
- Ion Thruster
- Hall Thruster
- Low/High Power RF Thruster
- Monopropellant Thruster

Average values from multiple systems used where possible

(references at end of presentation)

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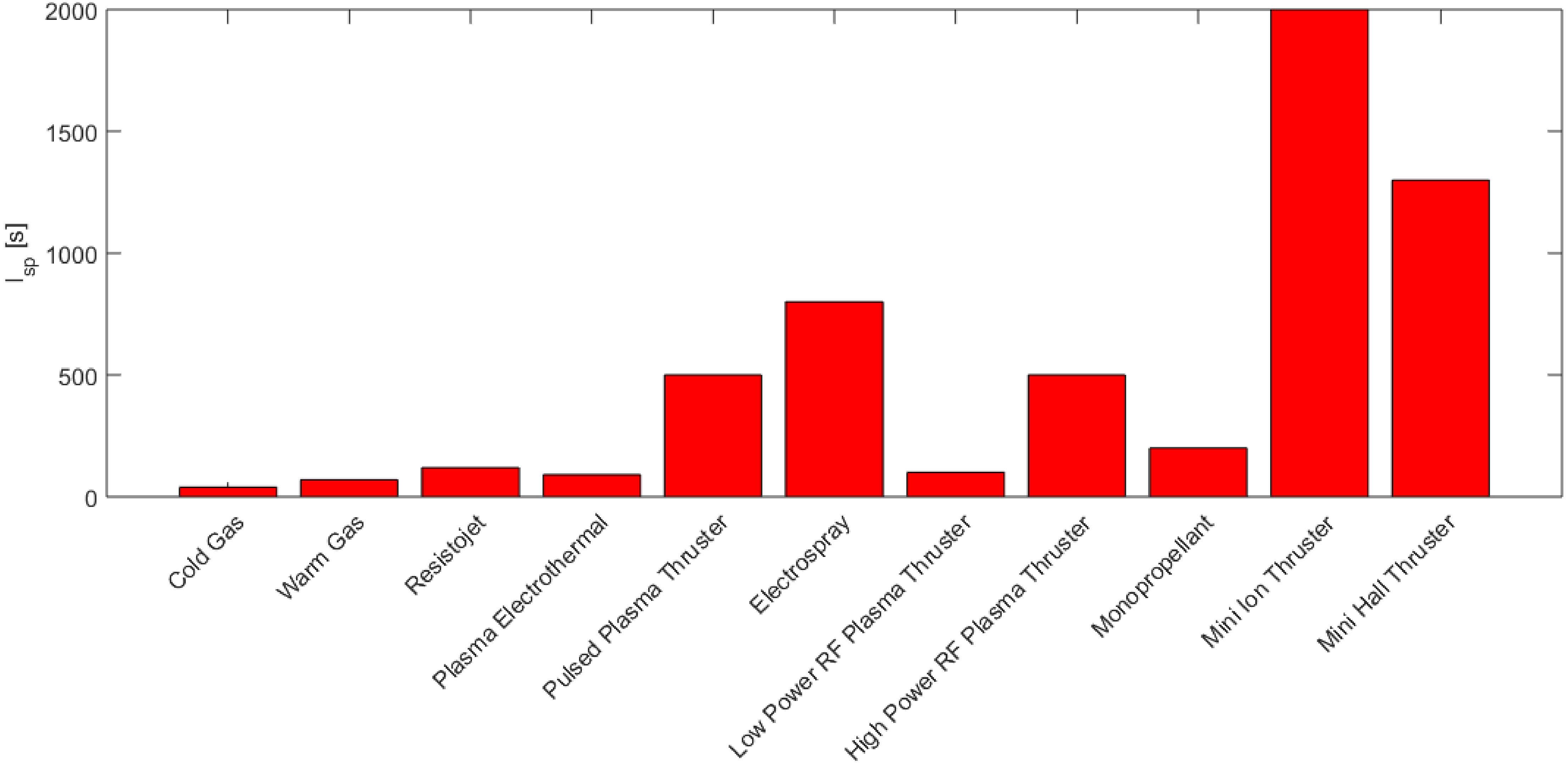
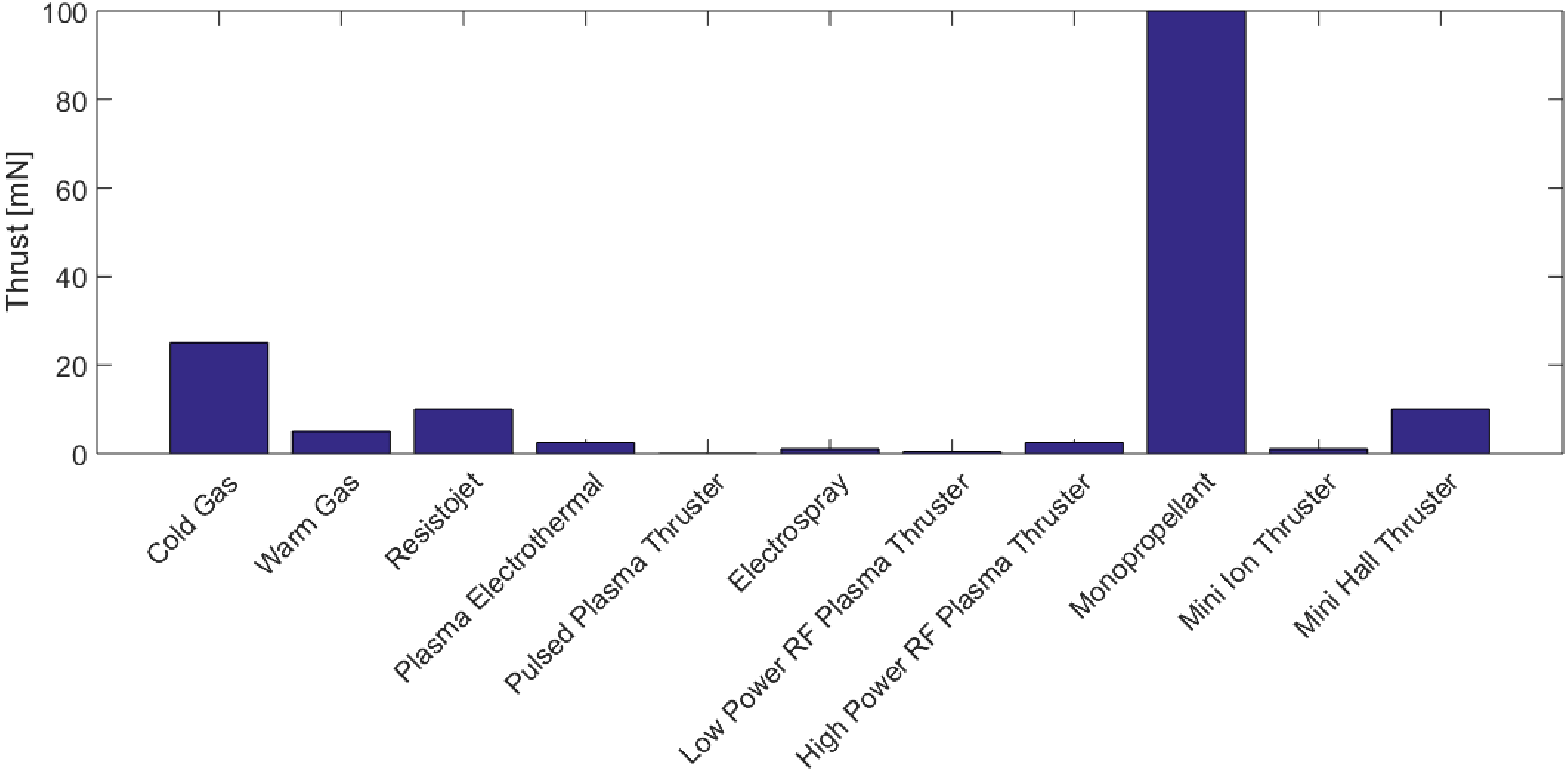
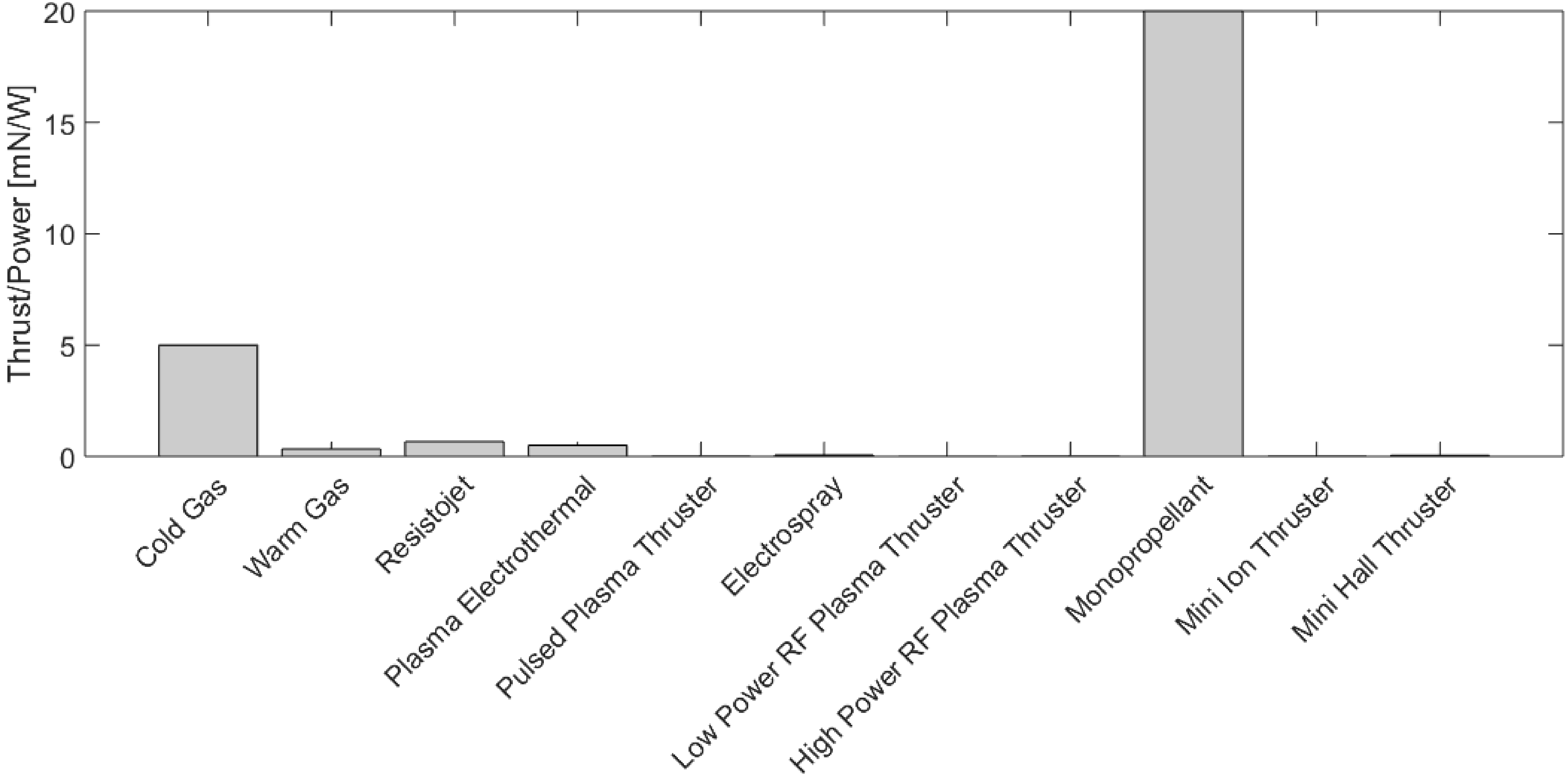
Results - I_{sp}


2000
1500
1000
500
0
I_sp [s]
Cold Gas
Warm Gas
Resistojet
Plasma Electrothermal
Pulsed Plasma Thruster
Electrospray
Low Power RF Plasma Thruster
High Power RF Plasma Thruster
Monopropellant
Mini Ion Thruster
Mini Hall Thruster

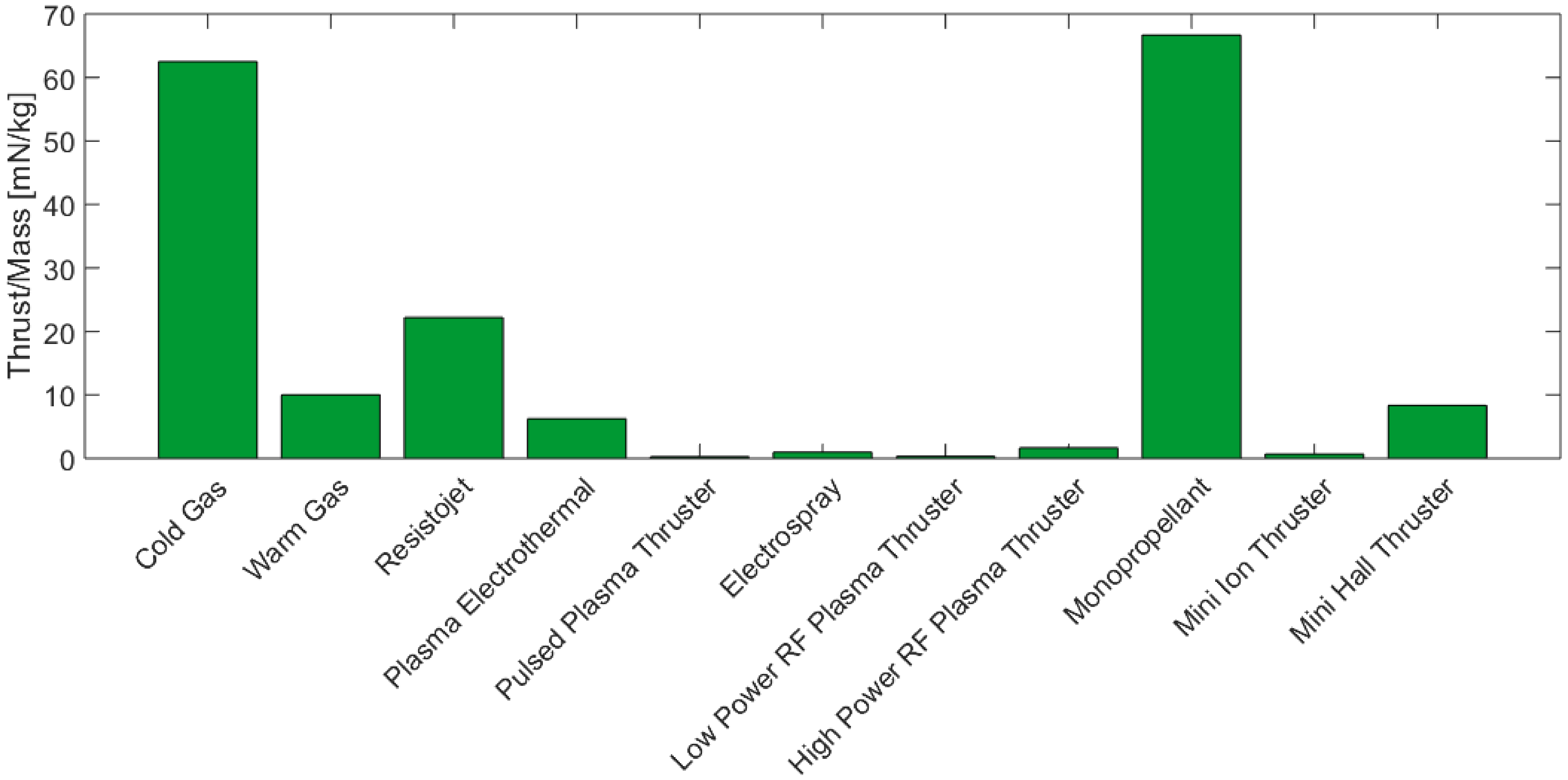
Results – Thrust (raw)



Results – Thrust to Power



Results – Thrust to Mass



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3U delta-V Analysis

$$\Delta v = -I_{sp} g \ln\left(\frac{m_{dry}}{m_{wet}}\right)$$

Assumes 3U CubeSat with

- 1U Payload (1.33kg, 10cm x 10cm x 10cm)
- 1U Bus (1.33kg, 10cm x 10cm x 10cm)
- 1U Propulsion Module (Max 1.33kg, 10cm x 10cm x 10cm)

Maximum propellant mass available

$$m_{prop} = m_{1U} - \mathrm{m_{struct}} - m_{thruster} - m_{power} - \mathrm{m_{neut}}$$

CubeSat mission masses

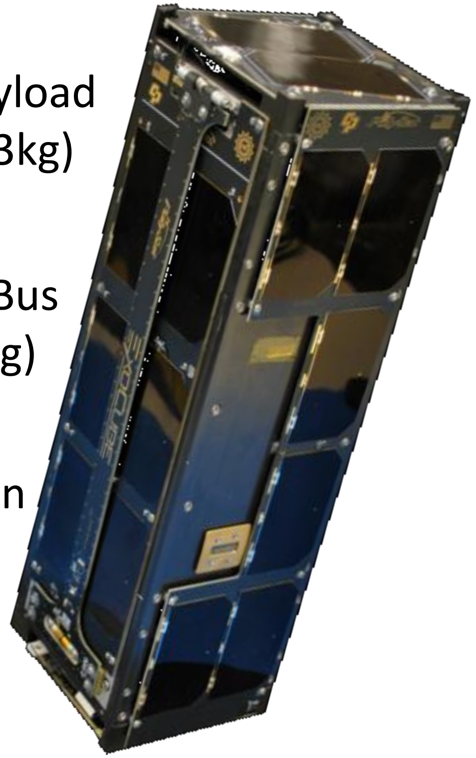
$$m_{dry} = m_{pay} + \mathrm{m_{bus}} + (m_{struct} + m_{thruster} + m_{power} + \mathrm{m_{neut}})$$

$$m_{wet} = m_{dry} + m_{prop}$$

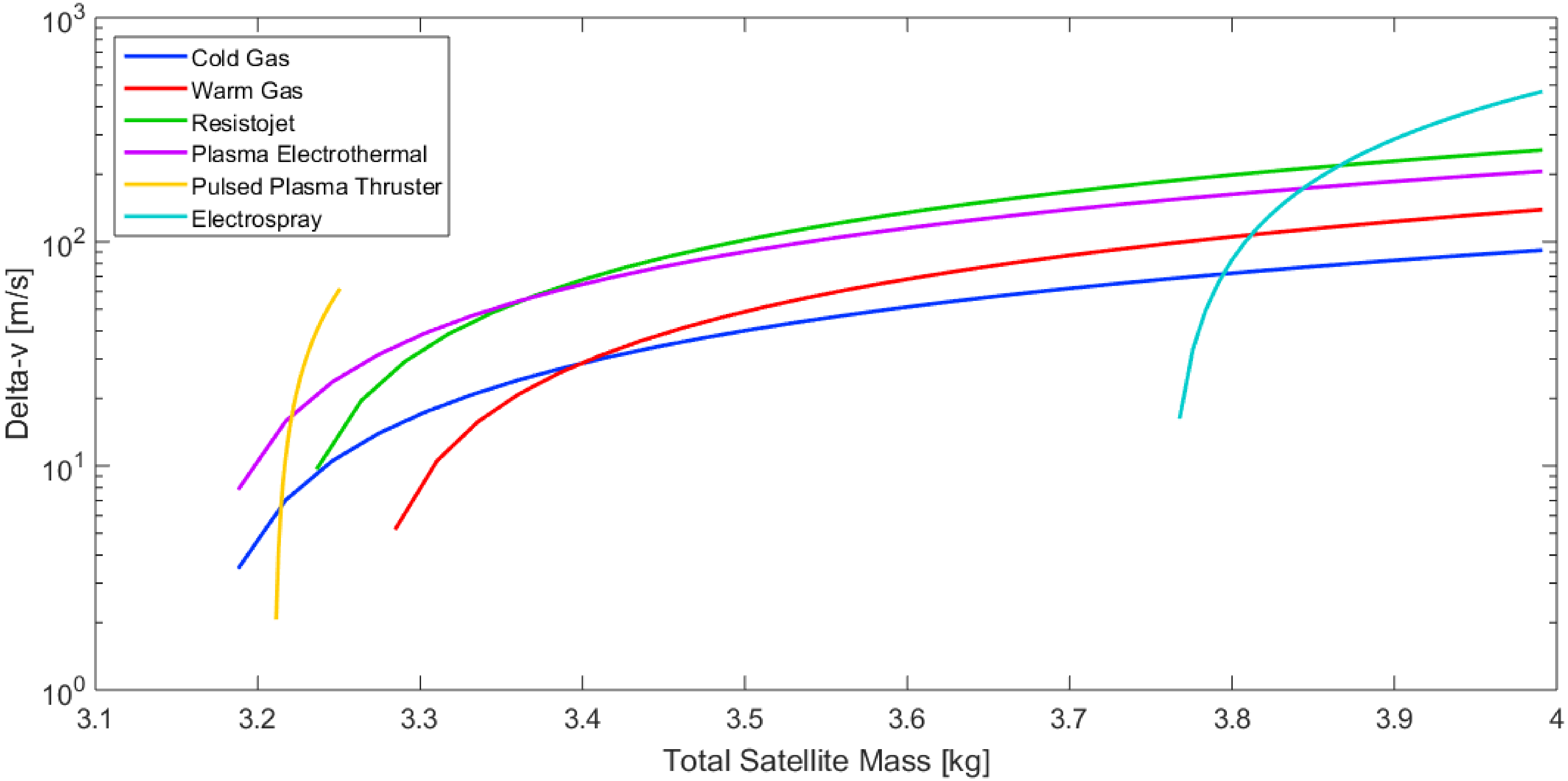
1U Payload (1.33kg)

1U Bus (1.33kg)

1U Propulsion (max 1.33kg)



Results – 3U delta-V

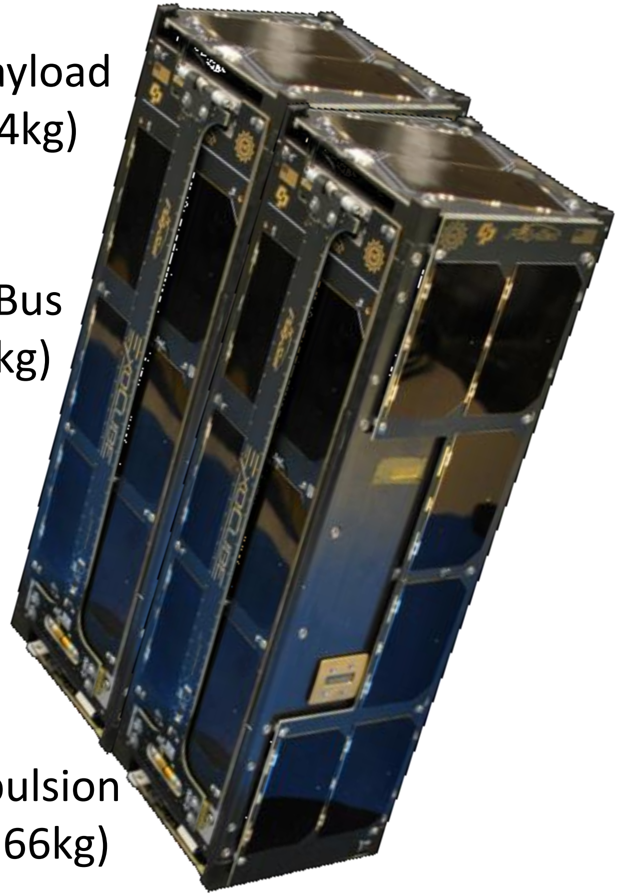


6U delta-V Analysis

$$\Delta v = -I_{sp} g \ln\left(\frac{m_{dry}}{m_{wet}}\right)$$

Assumes 6U CubeSat with

- 3U Payload (4kg, 30cm x 10cm x 10cm)
- 1U Bus (1.33kg, 10cm x 10cm x 10cm)
- 2U Propulsion Module (Max 2.66kg, 20cm x 10cm x 10cm)



Maximum propellant mass available

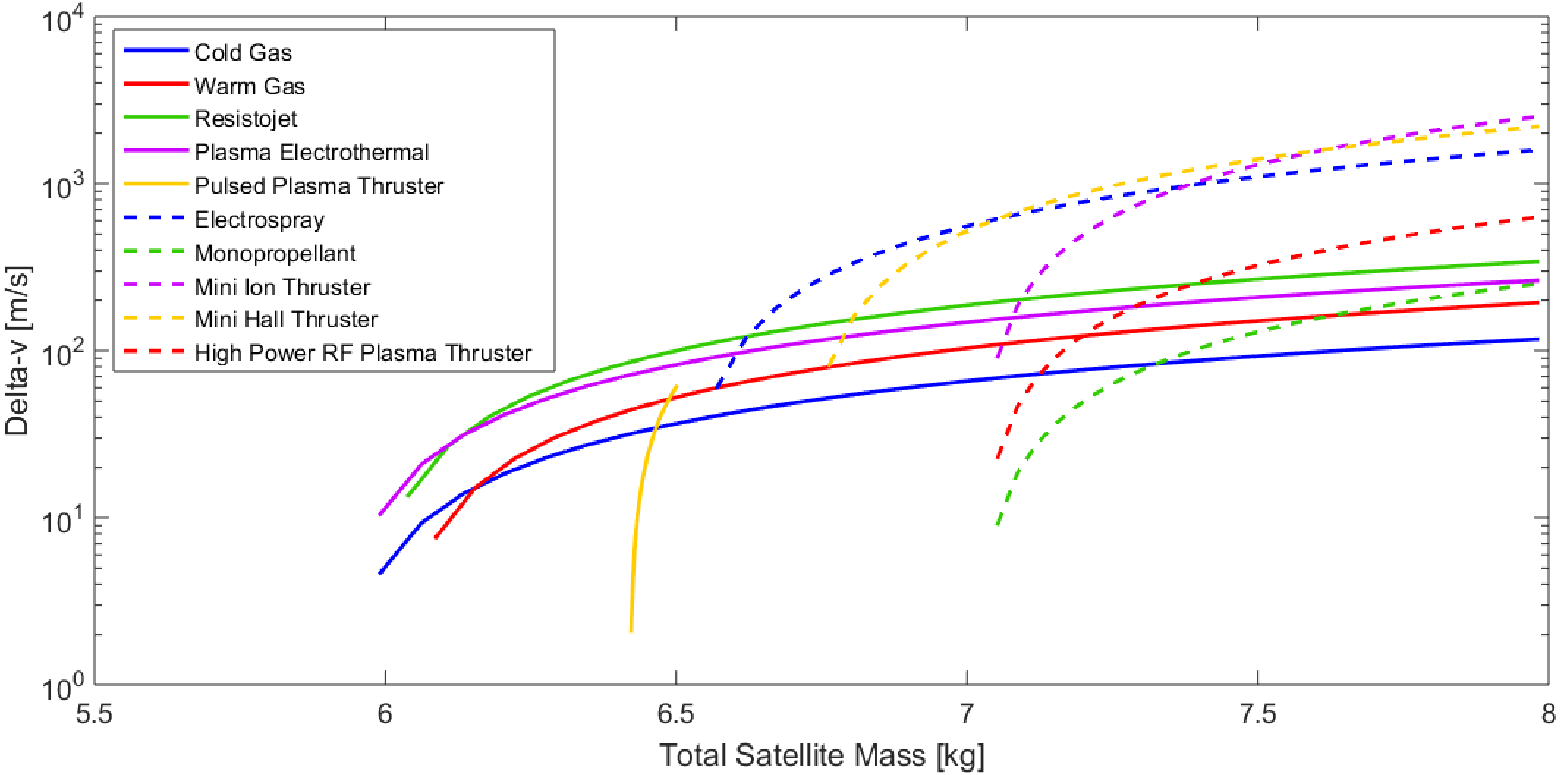
$$m_{prop} = m_{2U} - 2\mathrm{m}_{\mathrm{struct}} - m_{thruster} - m_{power} - \mathrm{m}_{\mathrm{neut}}$$

CubeSat mission masses

$$m_{dry} = m_{pay} + \mathrm{m}_{\mathrm{bus}} + (2m_{struct} + m_{thruster} + m_{power} + \mathrm{m}_{\mathrm{neut}})$$

$$m_{wet} = m_{dry} + m_{prop}$$

Results – 6U delta-V



Summary

Regardless of CubeSat size and mission, there is now a thruster suitable for basically everything…

Each system analyzed here has advantages and disadvantages but fits some need of the CubeSat community

This comparison focused on system masses and delta-V. Also need to consider

- Power
- Propellant storage pressure
- Reliability
- Simplicity
- Cost
- and so on…

Contact me to discuss further or for comparisons for a specific mission/system

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References

Publications from the following companies and institutes were used to find the data for this study. For specific information on values used please contact the author directly (agreig@calpoly.edu)

Aerojet Rocketdyne
Aerospace Corporation
Australian National University
Bradford ECAPS
Busek
Cal Poly SLO
Delft University of Technology
JPL
MIT
Moog
Nano Avionics
NASA
Phase Four
Surrey Space Center
Tethers Unlimited
UCLA
University of South Hampton
VACCO

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