FINAL REVIEW MEETING

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Project ID	De-risking a Novel Electrodeless Propulsion System
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Final Presentation Meeting

STELLAR SPACE INDUSTRIES

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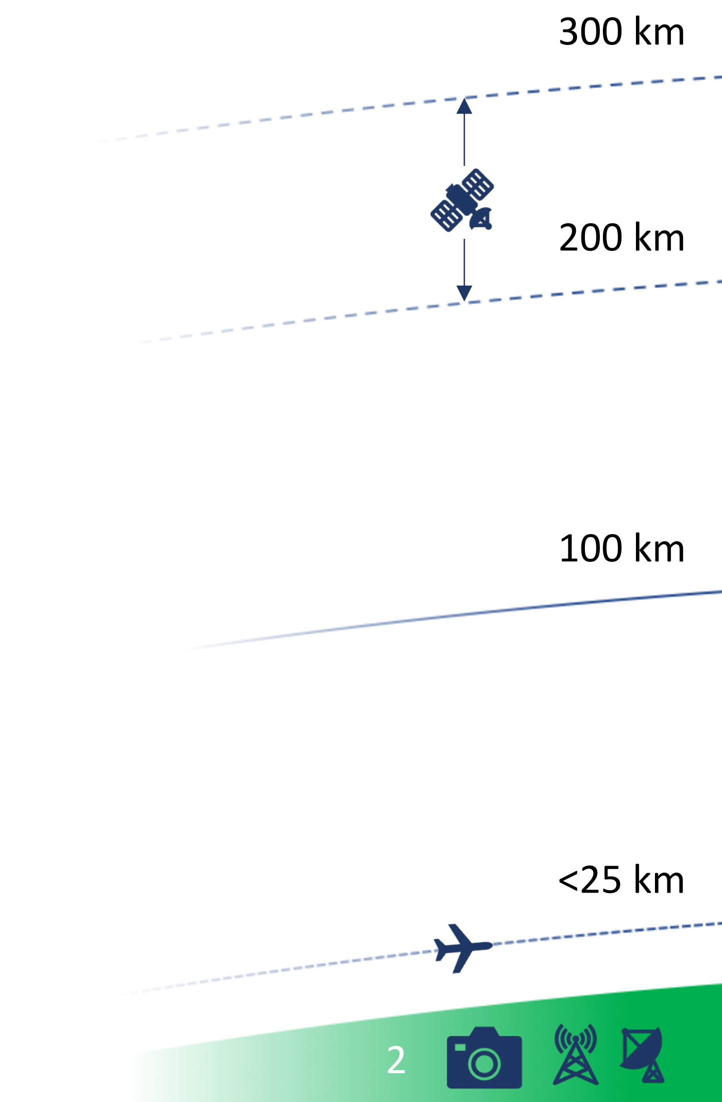
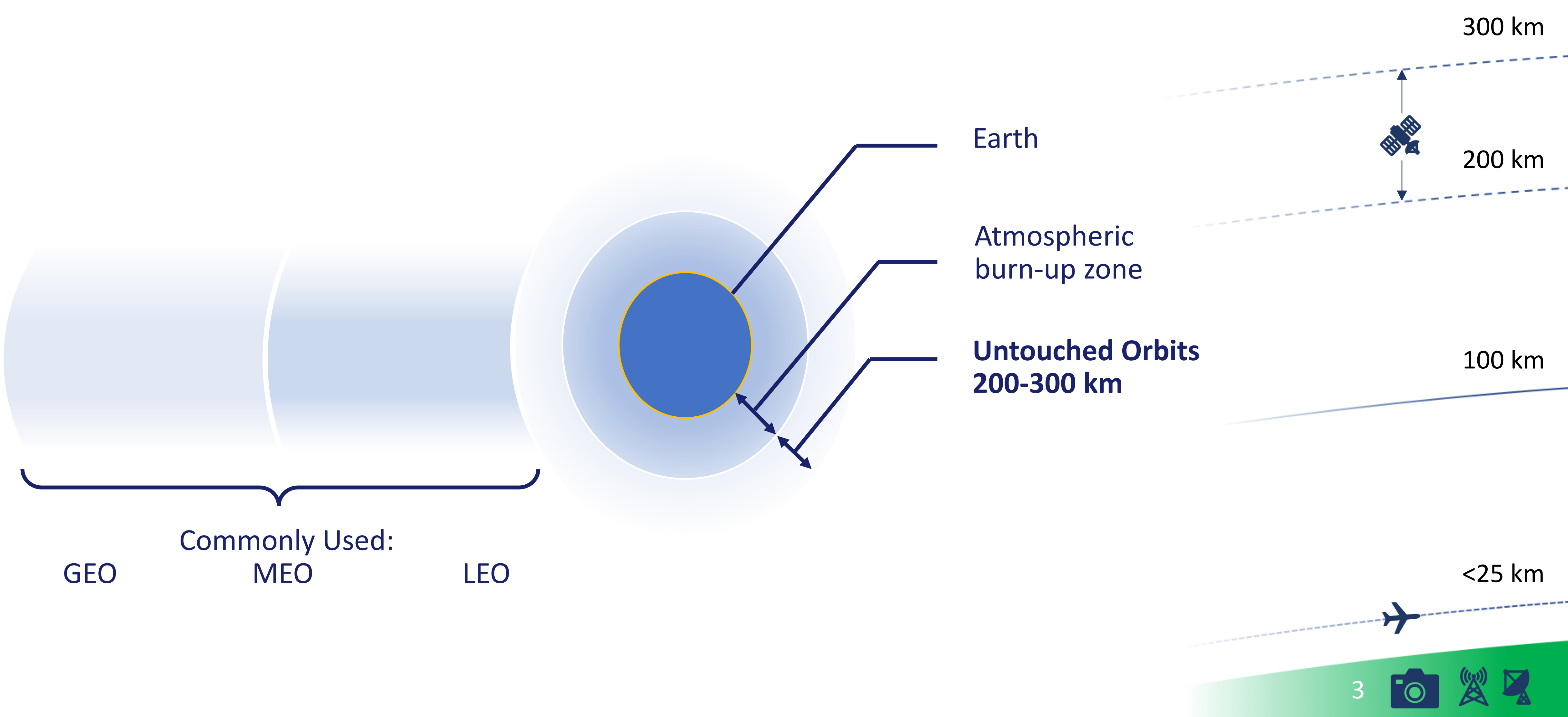


INTRODUCTION

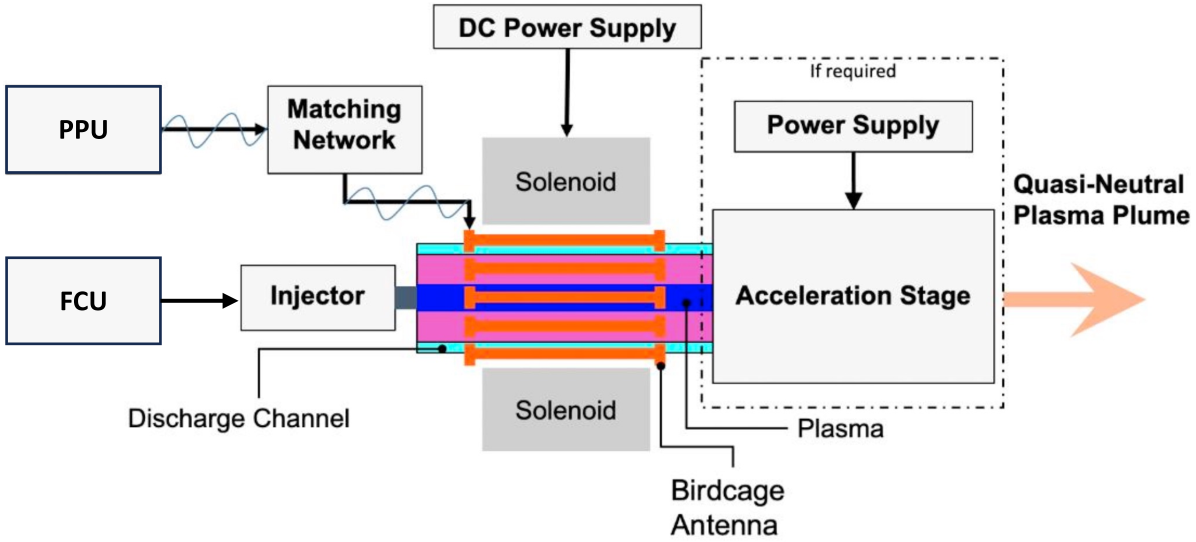
Our Goal: "Making VLEO Accesible"

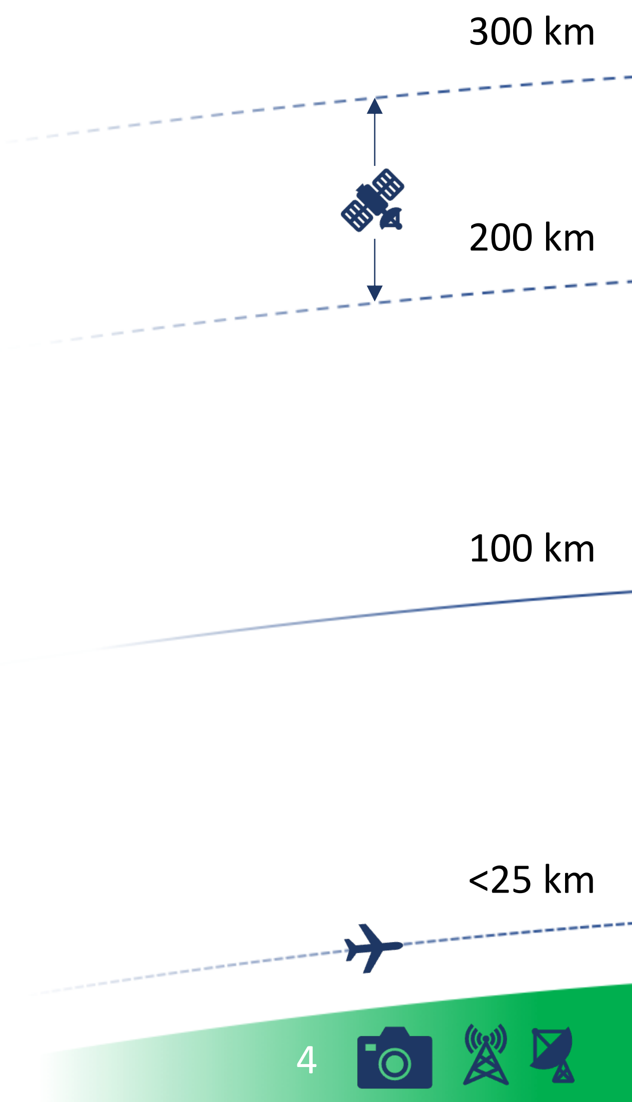


INTRODUCTION

BC-EP Advanced Helicon Thruster

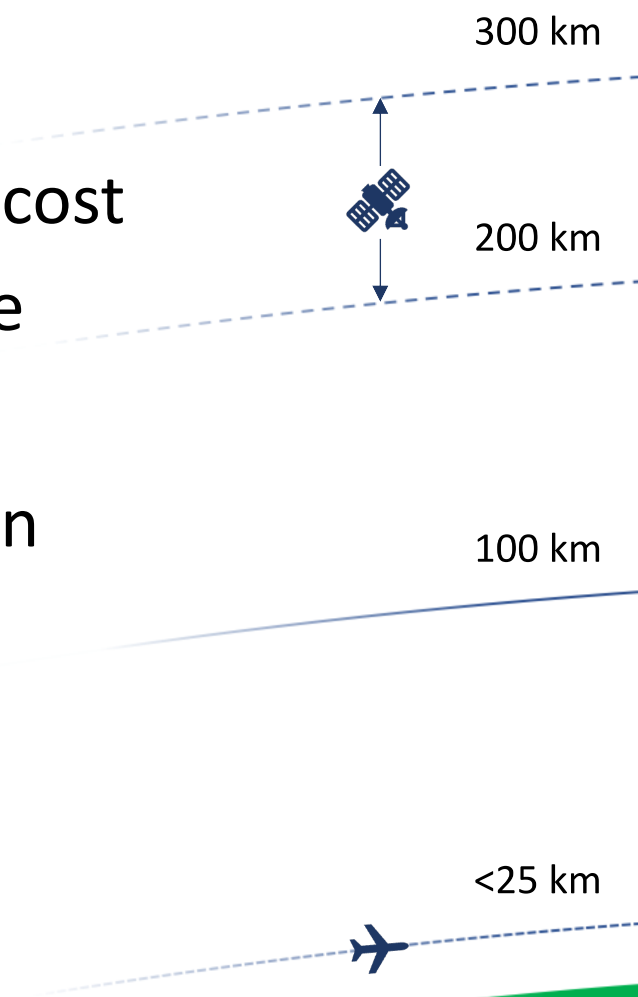
- De-risking phase led by SSI in collaboration with IRS
- Comprises out of **three** key subsystems:
  - **TH** based on MRI antenna technology
  - **FCU** employing novel throttleable piezo actuation
  - **PPU** linear and/or fixed output with high robustness





INTRODUCTION

BC-EP Advanced Helicon Thruster Advantages

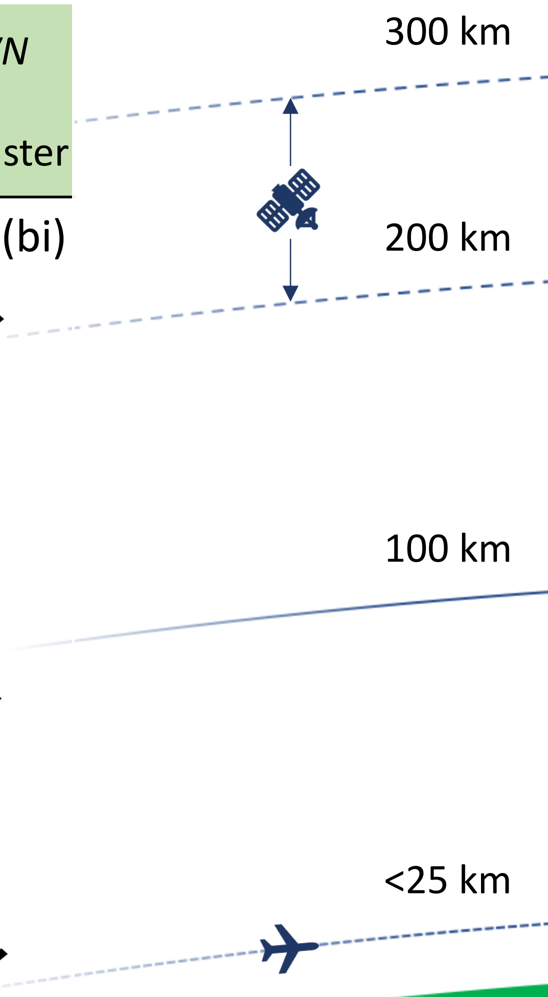


- **Simplicity** – small component count, no plasma contact
- **No neutralizer** – reduced development and production cost
- **Electrodeless operation** – increased operational lifetime
- **Throttleable** – optimizing maneuver profiles
- **Piezo FCU** – low mass and negligible power consumption
- Compatible with **solid/liquid/gaseous propellants**
- Novel ionization methodology using **BC antenna**
- Enables **continuous drag compensation (ABEP)**

INTRODUCTION

Compatitor analyses BC-EP as reference

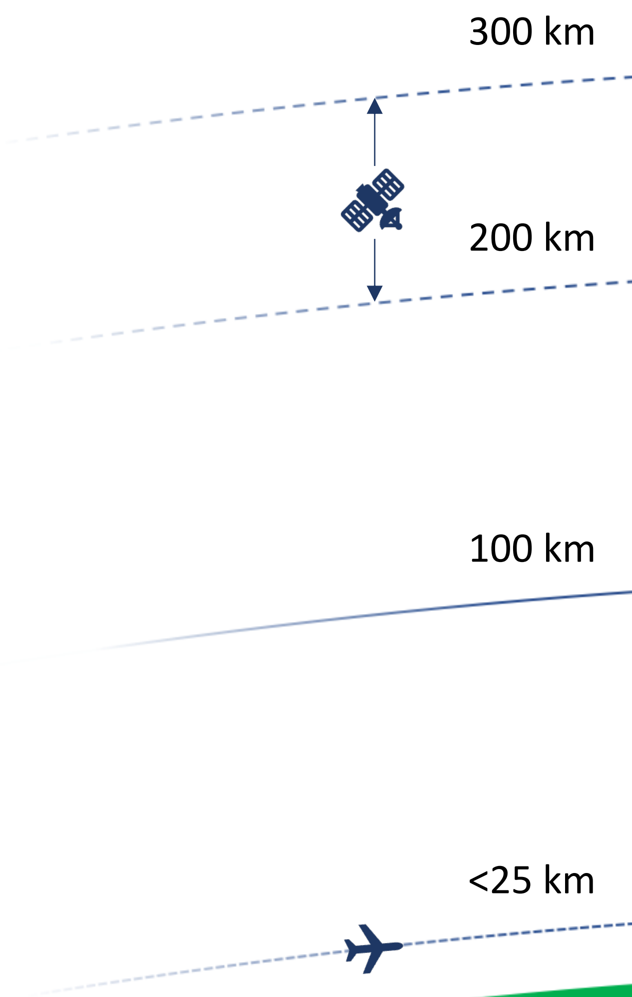
	SSI BC-EP 50-150 W	*Exotrail* ExoMG - micro	*Thrustme* NPT300	*BUSEK* BHT-350	*DAWN* B1 thruster
Thruster type	HPT	HET	Ion	HET	Chem (bi)
Throttleable – (multi-purpose: optimized manoeuvres, de-orbiting, collision avoidance)	✓	✓	✓	✓	✓
Drag compensation – (VLEO station keeping without lifetime penalty)	✓	~	~	~	X
Specific impulse – (indication of propellant mass usage efficiency)	~	~	✓	~	X
Electrodeless – (grids and anodes are prone to erosion due to plasma contact imposing mission lifetime constrains)	✓	X	X	X	✓
Multi-propellant – (corrosive/inert fuel compatible, refuelling and ABEP compatible)	✓	X	X	X	X
No neutralizer – (cathodes increase risk, cost, power consumption and lead time)	✓	X	X	X	✓



DE-RISKING PROJECT OBJECTIVES

TH primary objectives

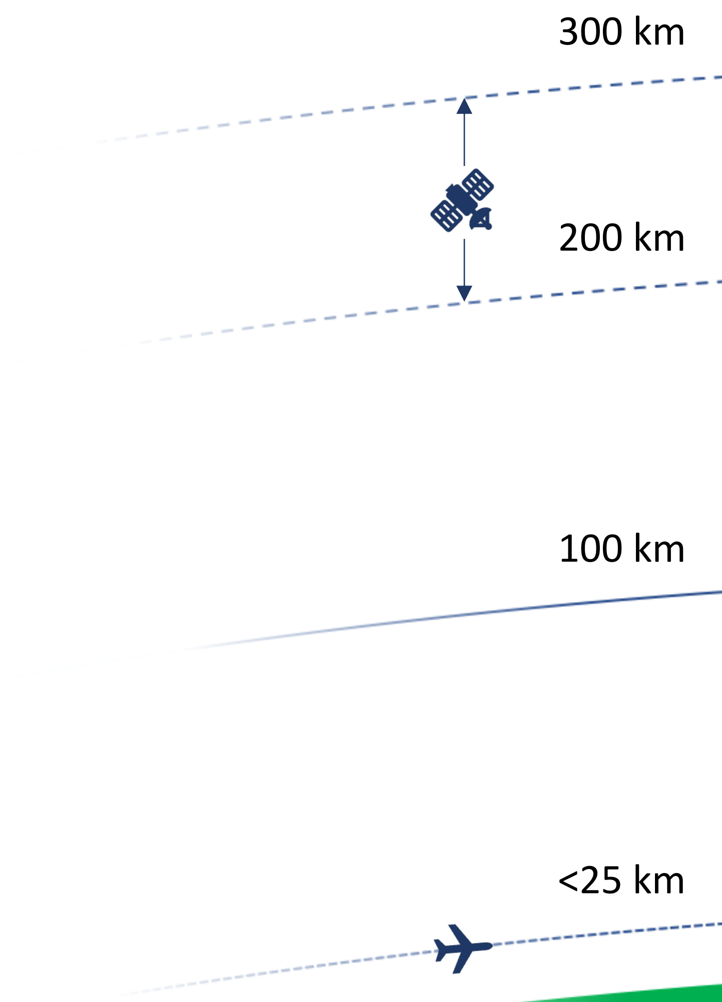
- New design for 50-150 W with lab model as reference
- Dowscaling TH to fit low weight satellites
- Optimise for homogeneous resonance mode
- Reflection coeffcient S_{11} < -20dB @ 40.68 MHz
- Impedance matched to $Z = 50 \pm 0i\ \Omega$



DE-RISKING PROJECT OBJECTIVES

PPU primary objectives

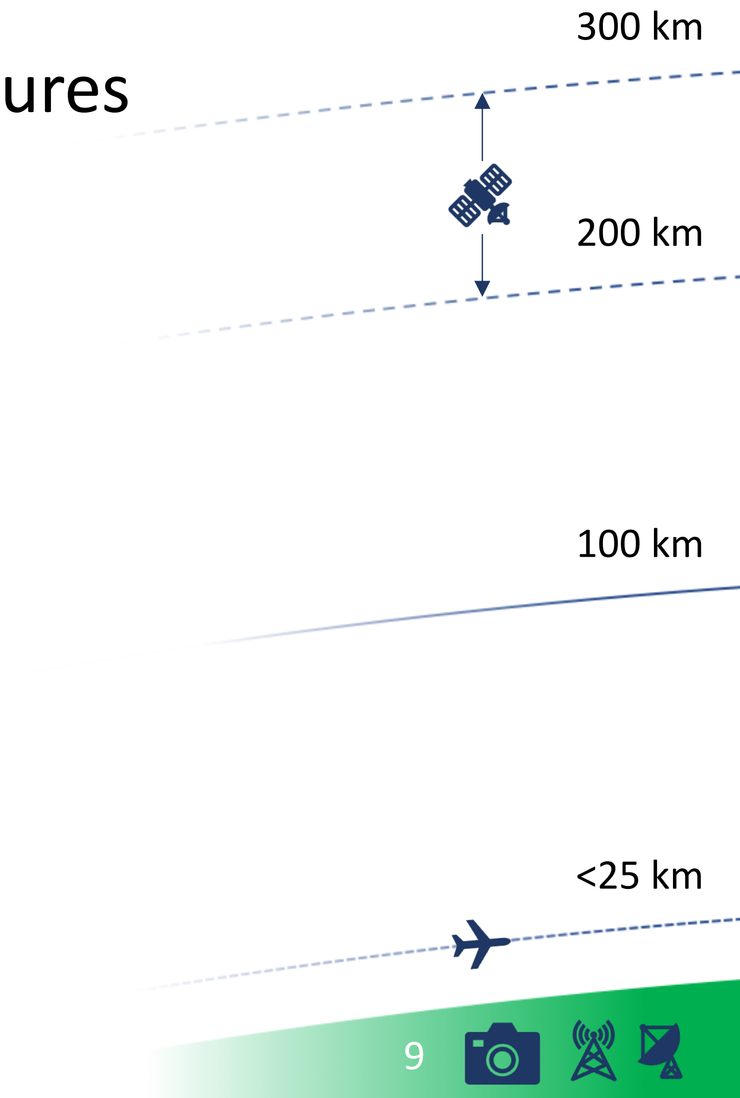
- RF signal output at 40.68 ± 1 MHz
- Variable RF power output 50-100 W ± 5%
- Electrical efficiencies > 50%
- DC/DC converter V_{bus} -> V_{valve} / V_{bias} / V_{gate}
- 10K ON/OFF cycling with degradation < 5%



DE-RISKING PROJECT OBJECTIVES

FCU primary objectives

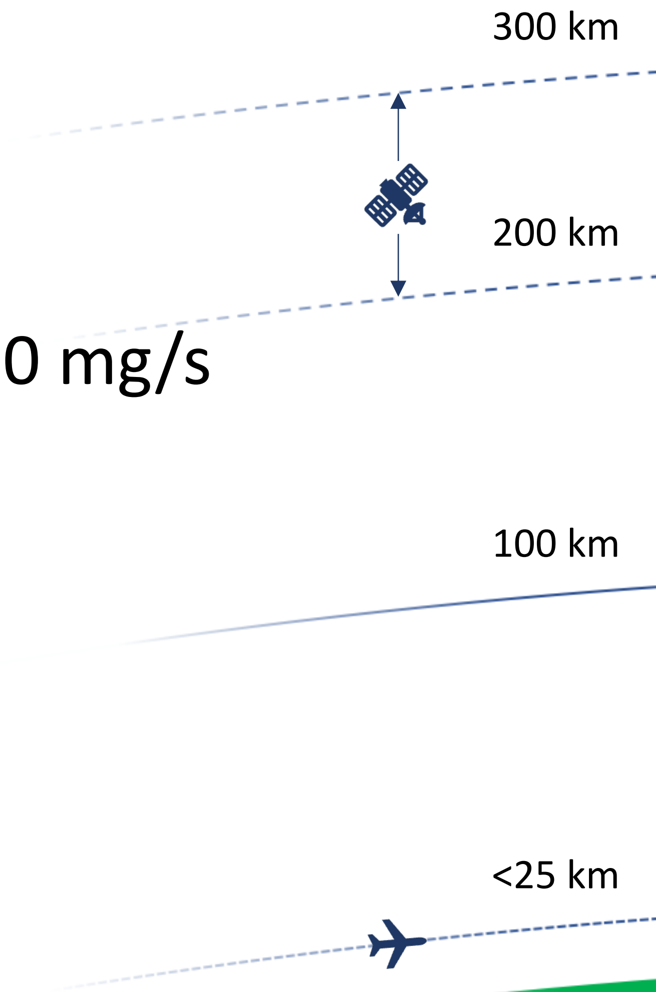
- Develop a minimum of 3 throttleable valve architectures
- Mass flow rate range 0.1 – 1.0 mg/s
- Minimum mass flow accuracy ±5%
- Internal leakage ≤ 10-3 mg/s
- 10K ON/OFF cycling
  - Mass flow degradation < 5%
  - Leakage degradation < 5%



DE-RISKING PROJECT OBJECTIVES

BC-EP primary objectives

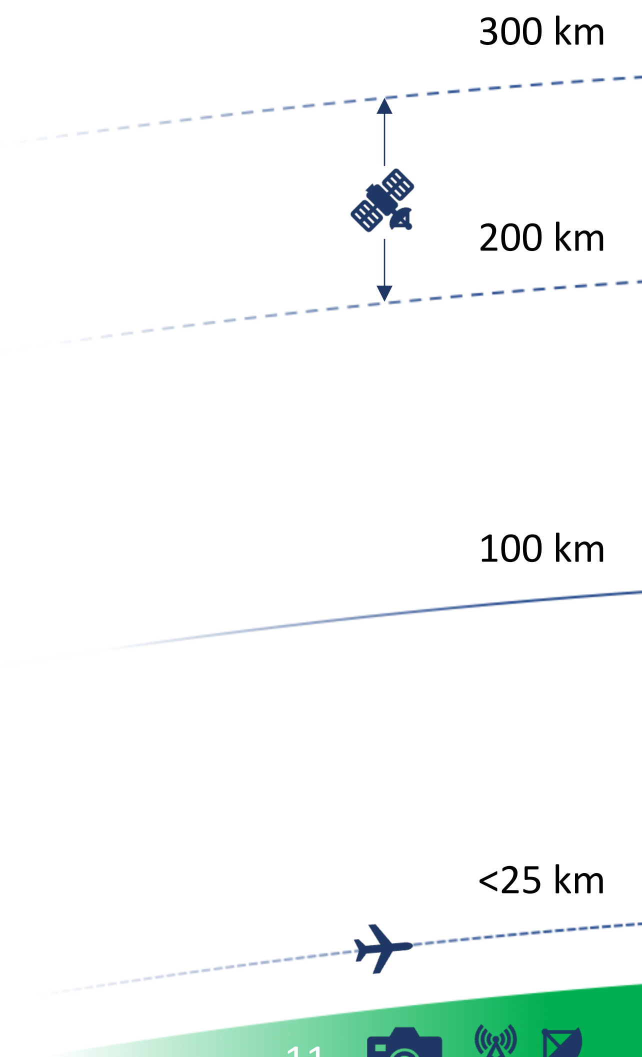
- Subsystems shall ignite plasma using lab model IPT
  - SSI FCU combined with IRS PPU
  - SSI FCU combined with SSI PPU
- Sustained operation within a mass flow range of 0.1- 1.0 mg/s
- Tests shall be conducted using Argon



ACHIEVEMENTS

TH ESA GSTP De-risking

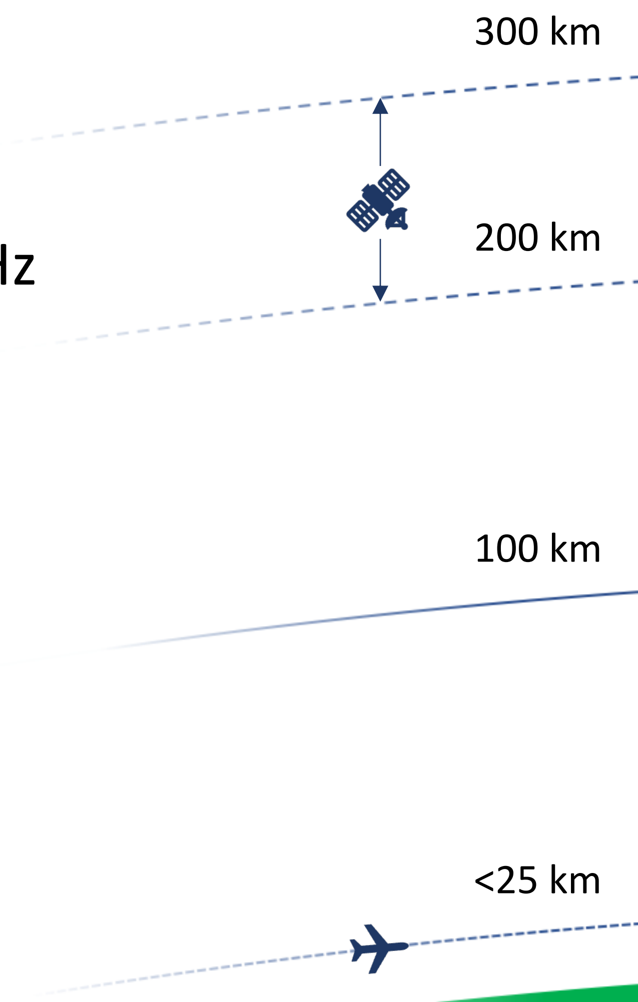
- First version of a CAB BB TH model produced
  - Quartz plasma ignition tube
  - Permanent neodymium magets
  - Dual use injector
  - Brass Faraday cage
  - Insulation achieved using Ceramic holders for PCBs and antenna legs



ACHIEVEMENTS

TH ESA GSTP De-risking

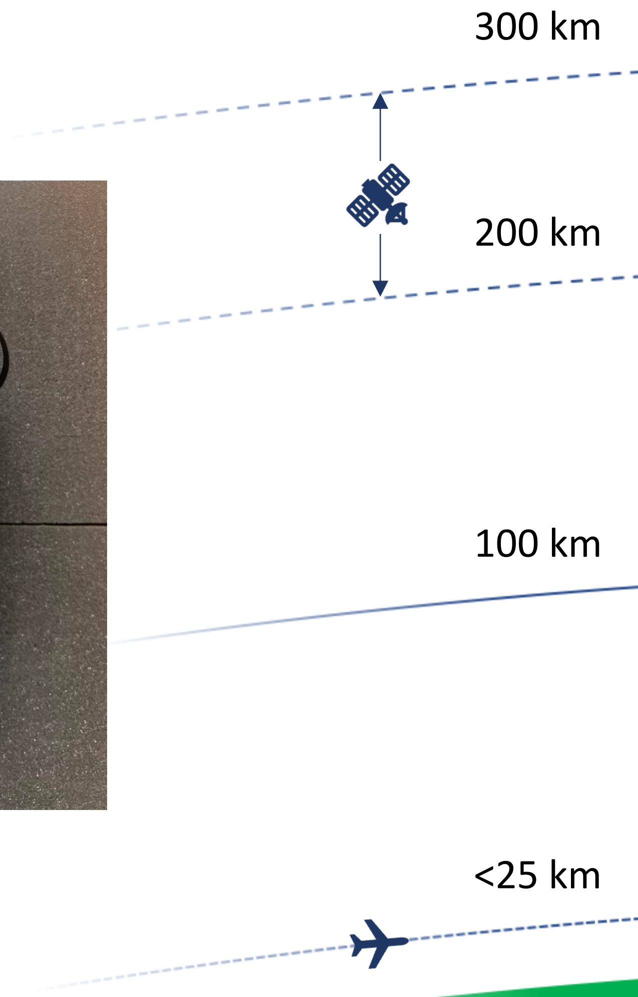
- Reflection coeffcient S_{11} < -33 dB @ 40.68 MHz
  - Resonance frequency at mode 1 @ 40.654 MHz
  - Improved meshing should improve results closer to 40.68 MHz
  - Final tuning performed using the injector



ACHIEVEMENTS

PPU ESA GSTP De-risking

- Two RF amplifiers designed and manufactured
  - Class A – linear type
  - Class E – non linear type
- DC/DC converter manufactered and tested
- Signal generator board for both classes manufactured



ACHIEVEMENTS

FCU ESA GSTP De-risking

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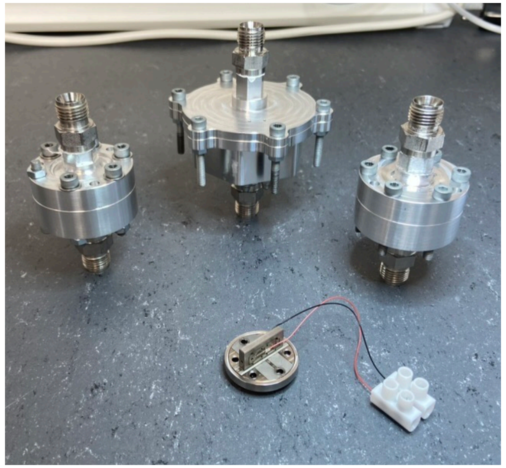
300 km

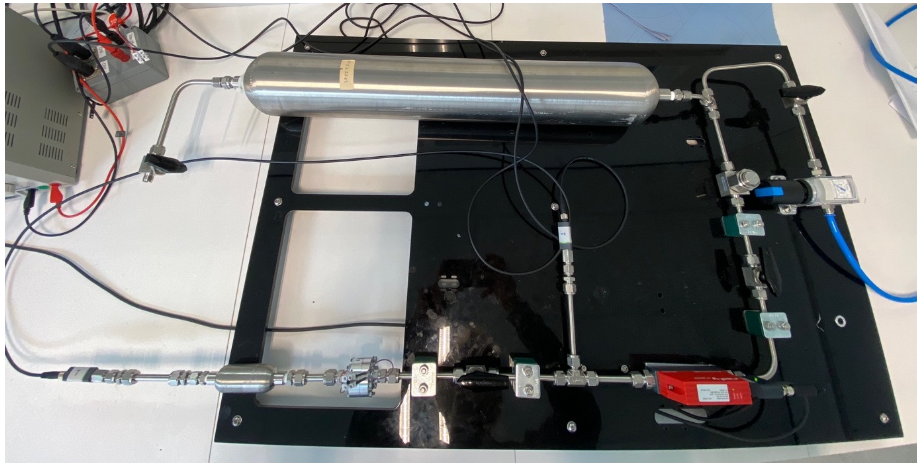
200 km

100 km

<25 km

- 4 Throttleable valve architectures realised
  - Valve specific design criticalities identified
  - ~ 20 Mitigation proposed and where applicable implemented
  - Assembly methodology per valve provided
- Mass flow and leakage test campaign conducted

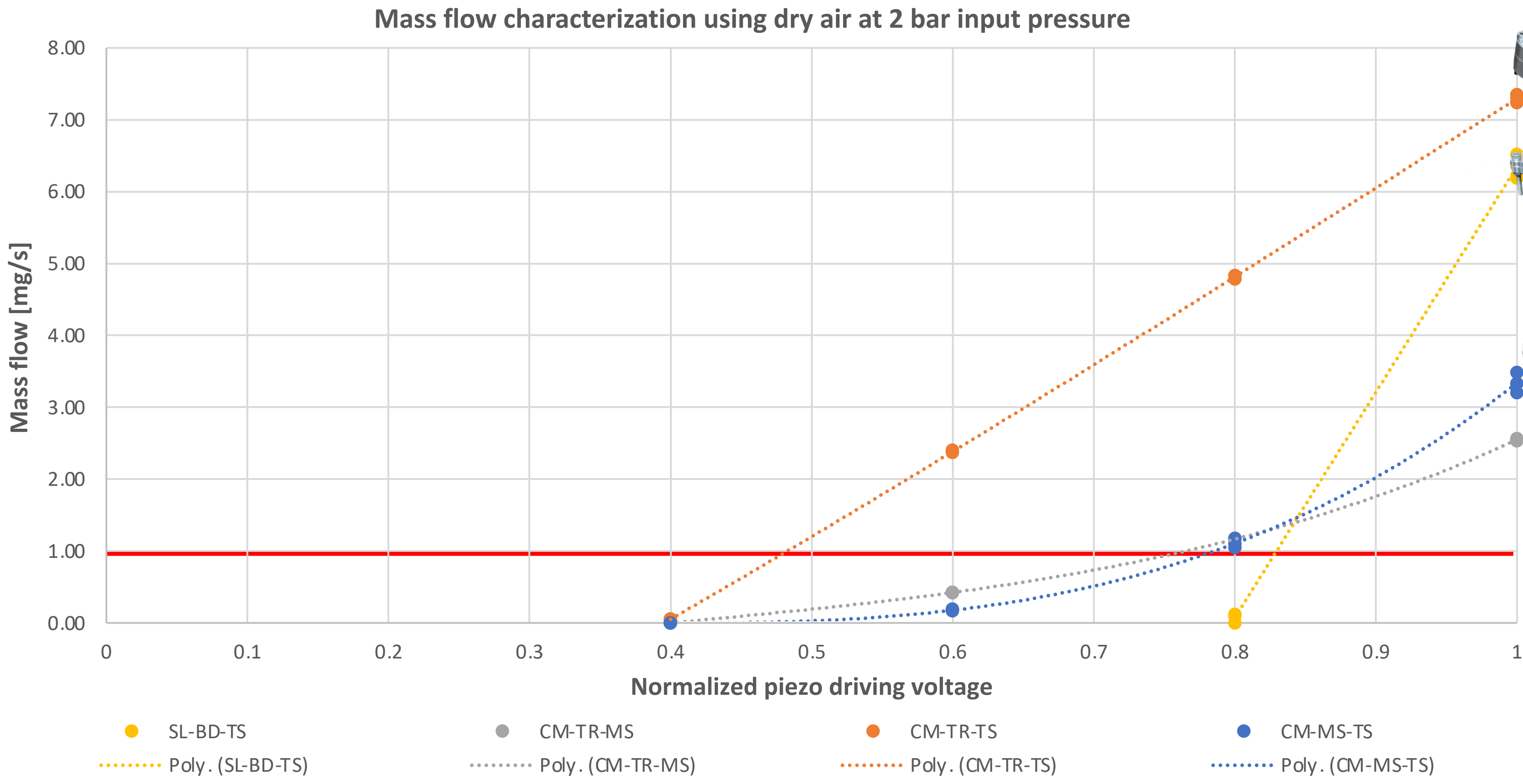


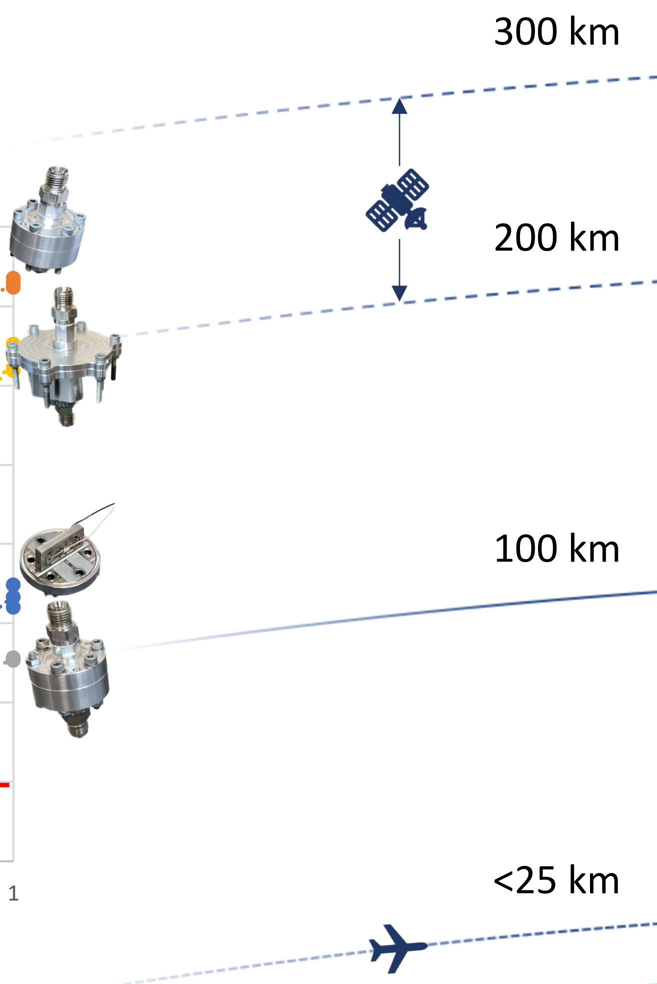


ACHIEVEMENTS

FCU ESA GSTP De-risking

- All valves comply to the mass flow rate requirement

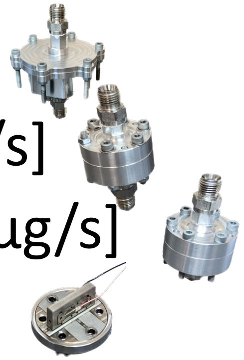




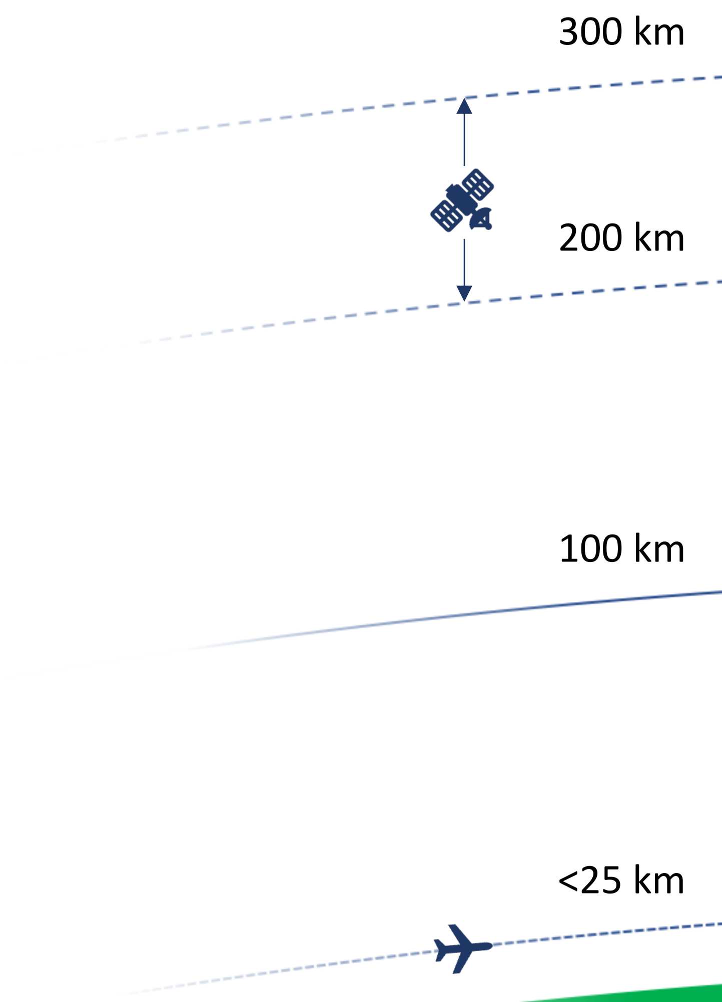
ACHIEVEMENTS

FCU ESA GSTP De-risking

- All valves comply to the Interna leakage requirement
  - SL-BD-TS < 0.1 [µg/s]
  - CM-TR-MS < 0.1 [µg/s]
  - CM-TR-TS < 0.0015 [µg/s]
  - SL-BD-TS < 1.0 [µg/s]



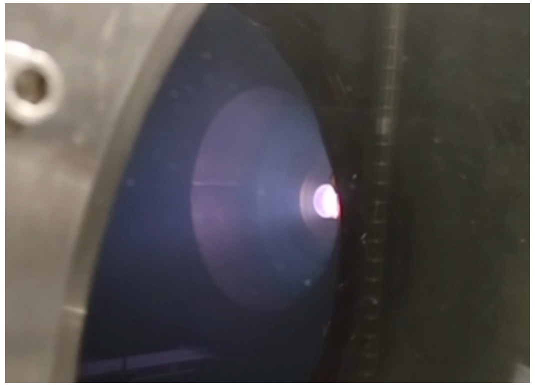
- Life cycle testing only completed with 2 systems
  - Piezo failure and inconsistent measurements to blame
  - Endurance testing impact not negligible
- 2 Systems identified for follow on phase
  - CM-TR-TS and CM-TR-MS

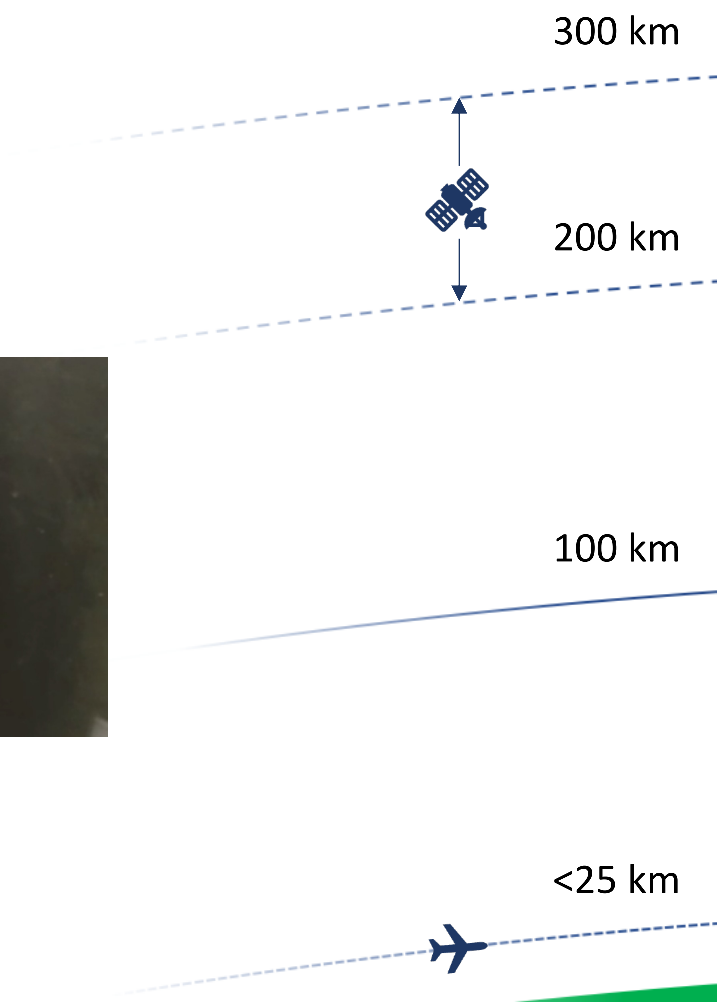


ACHIEVEMENTS

BC-EP Testing, IRS PPU combined with SSI FCU

- Ignition Conditions (13/04/23, 20:02)
  - Backpressure 0.13 Pa
  - RF input power 65 W (on the readout screen)
  - 0.6 mg/s of gaseous argon
  - FCU voltage 65.0 V
  - FCU input pressure 3.017 Bar
- During operation:
  - Nominal operation power 59 W
  - Power reflection $I_{solenoid}$ >9A: 0-15W
  - Power reflection $I_{solenoid}$ 3-6A: 20-35W
  - Fluctuations observed ~ 0.25 Hz

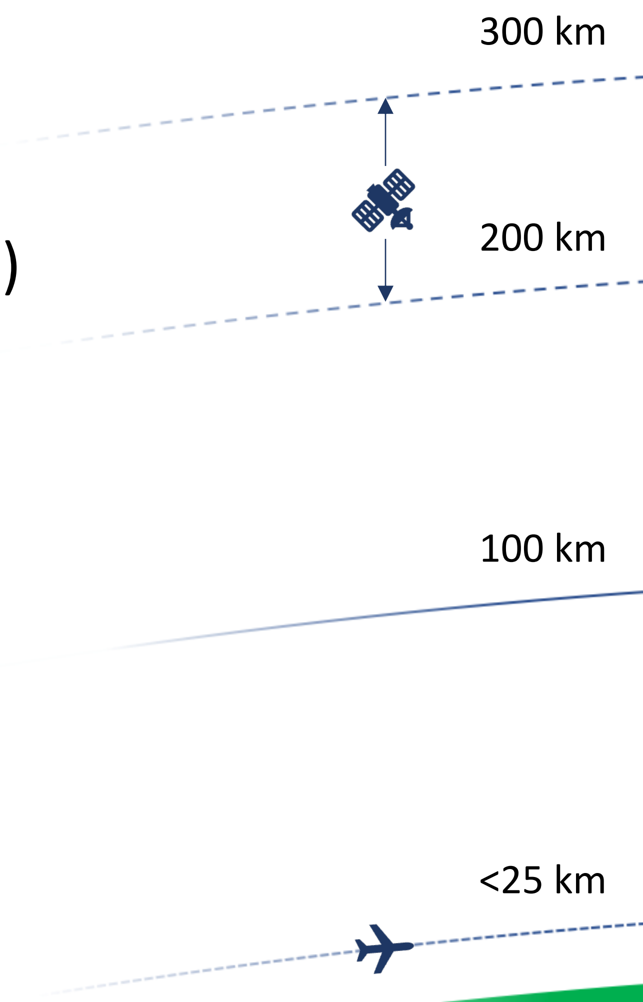




ACHIEVEMENTS

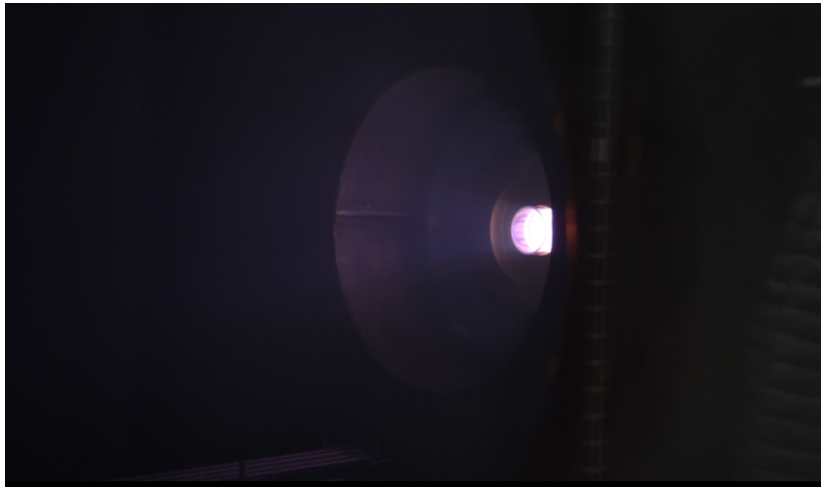
BC-EP Testing, SSI Class E PPU combined with SSI FCU

- Ignition Conditions (14/04/23 17:12)
  - Backpressure 0.13 Pa
  - RF input power 60 W (obtained using indirect measurements)
  - 0.6 mg/s of gaseous argon
  - FCU voltage 89.0 V
  - FCU input pressure 2.0227 Bar
- During Operation:
  - Stable operation at flow rate range of 0.08 – 1.0 mg/s Ar
  - Stable at both high and low solenoid current (3 A & 9 A)
  - RF input power reduced to ~40 W
  - **No plume instabilities observed**

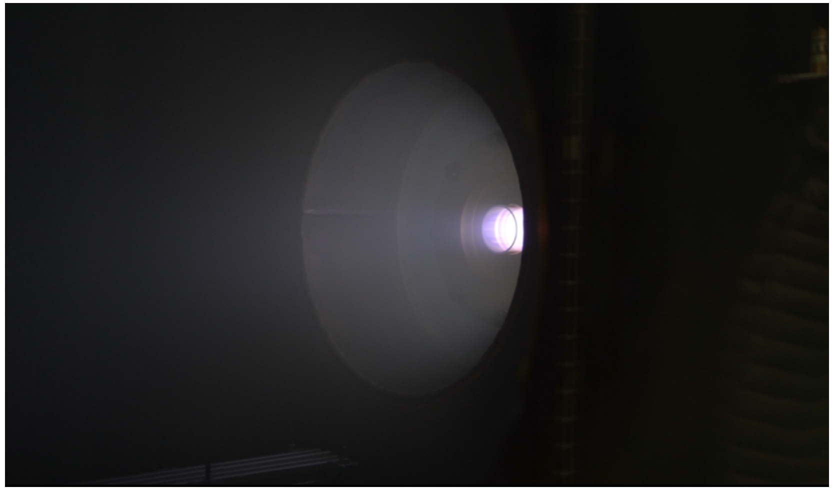


ACHIEVEMENTS

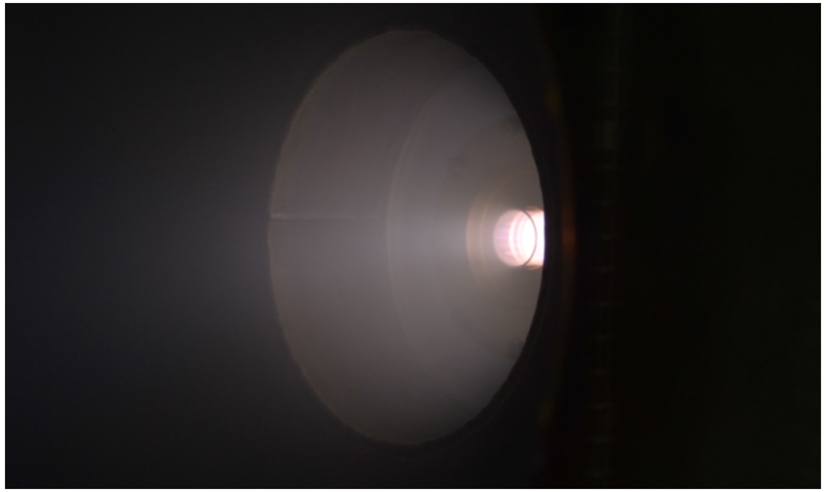
Visual Results



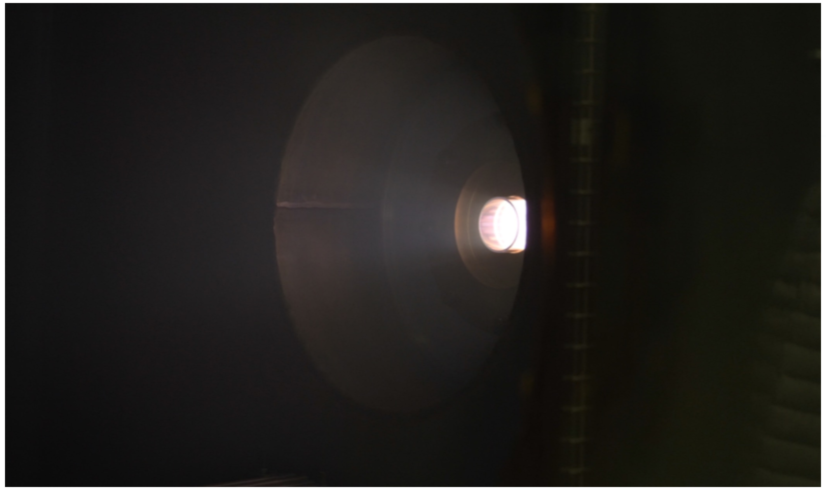
Ignition: 0.60 mg/s Ar @ 60W



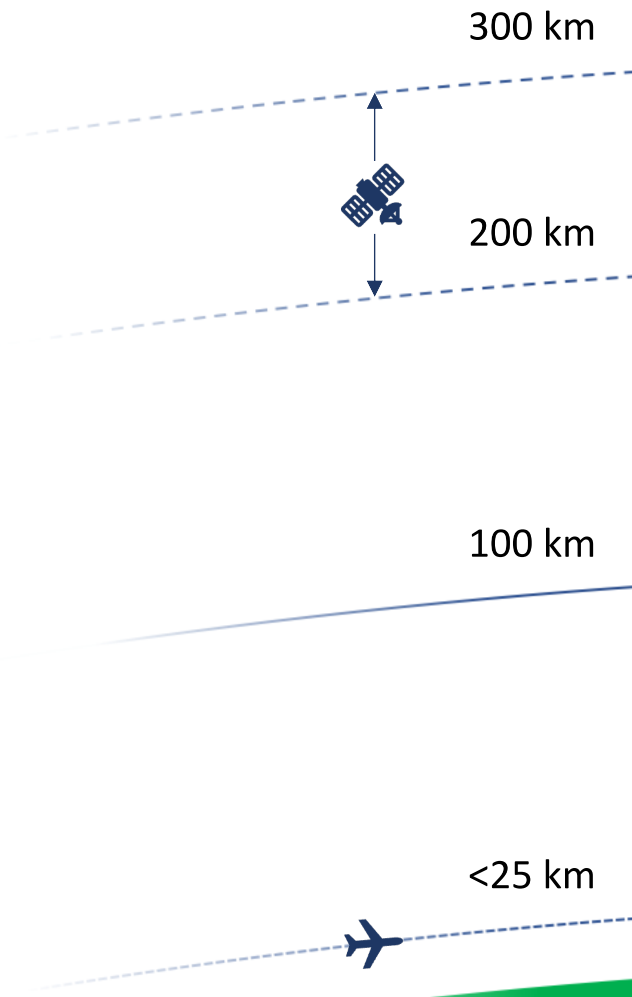
Operation: 0.08 mg/s Ar @ 40W



Operation: 0.50 mg/s Ar @ 40W



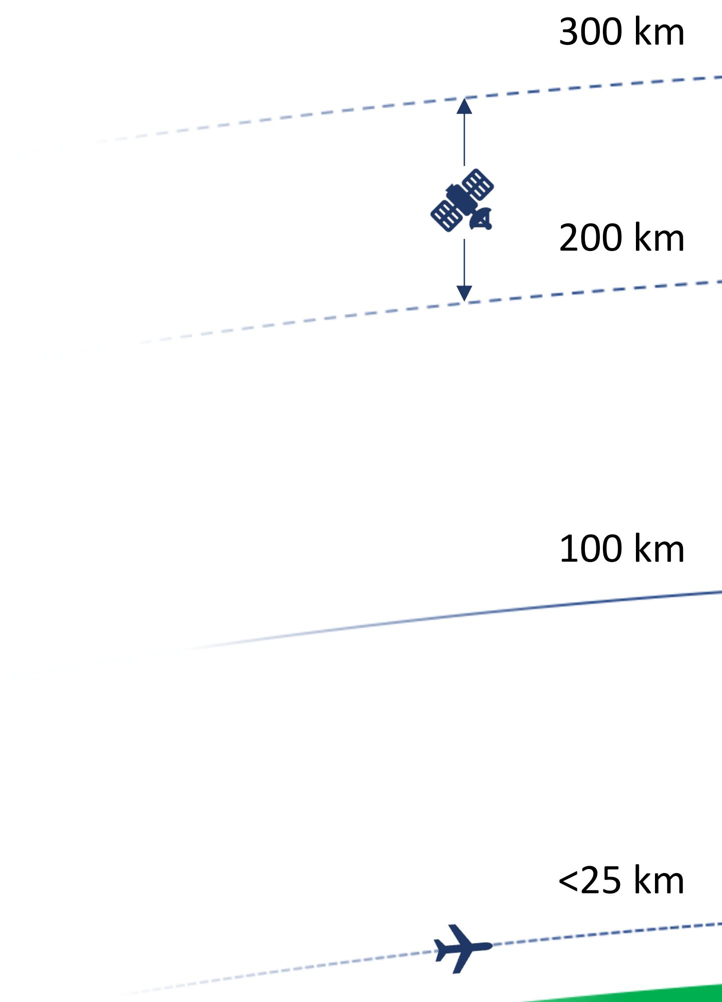
Operation: 1.00 mg/s Ar @ 40W



CONCLUSION

BC-EP De-risking phase

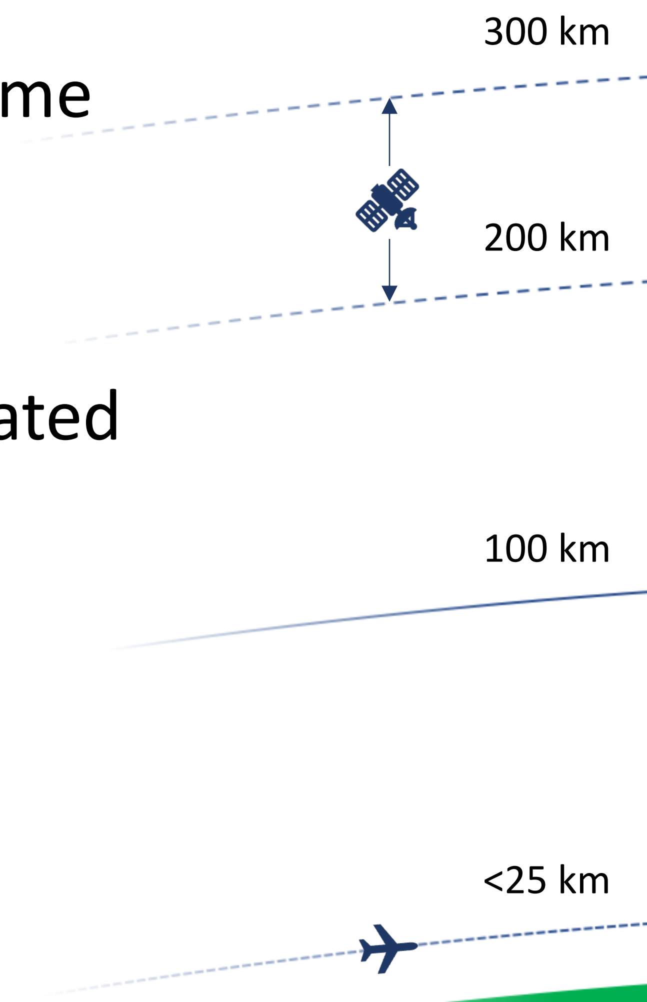
- BB TH dimensional design parameters established
- Preliminary performance BB TH simulated
- Two RF amplifier modules developed and tested
- DC/DC converter developed and tested
- Four throttleable valves developed and tested
- Successful plasma ignition
- Subsystem compatibility demonstrated



OUTLOOK

BC-EP De-risking phase

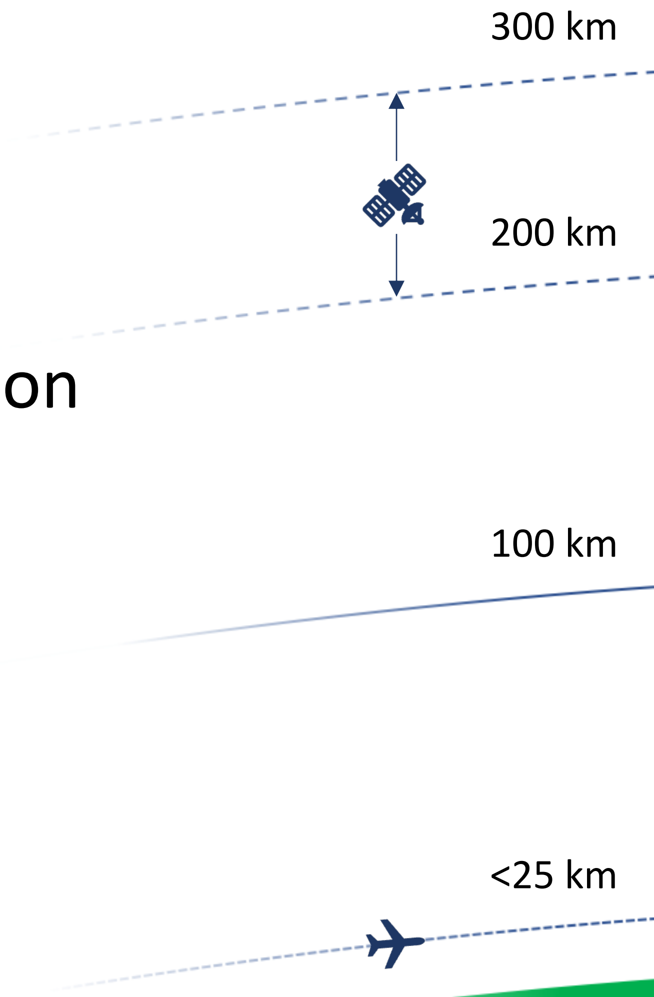
- TH performance measurements within operational regime
- Investigation into alternative propellants
- Thermal effects need to be addressed
- Higher efficiency linear RF amplifier topologies investigated
- Thermal model development of PPU
- Design and develop on-board signal generator for PPU
- Downscale throttleable valves
- Investigate presure regulatory behaviour of the valves



OUTLOOK

BC-EP De-risking phase

- Design of flow circuit board
- Identification of performance charateristic influenced by changing mass flow (closed loop)
- Alternatively, mems thermal mass flow sensor integration



LESSONS LEARNT

BC-EP De-risking phase

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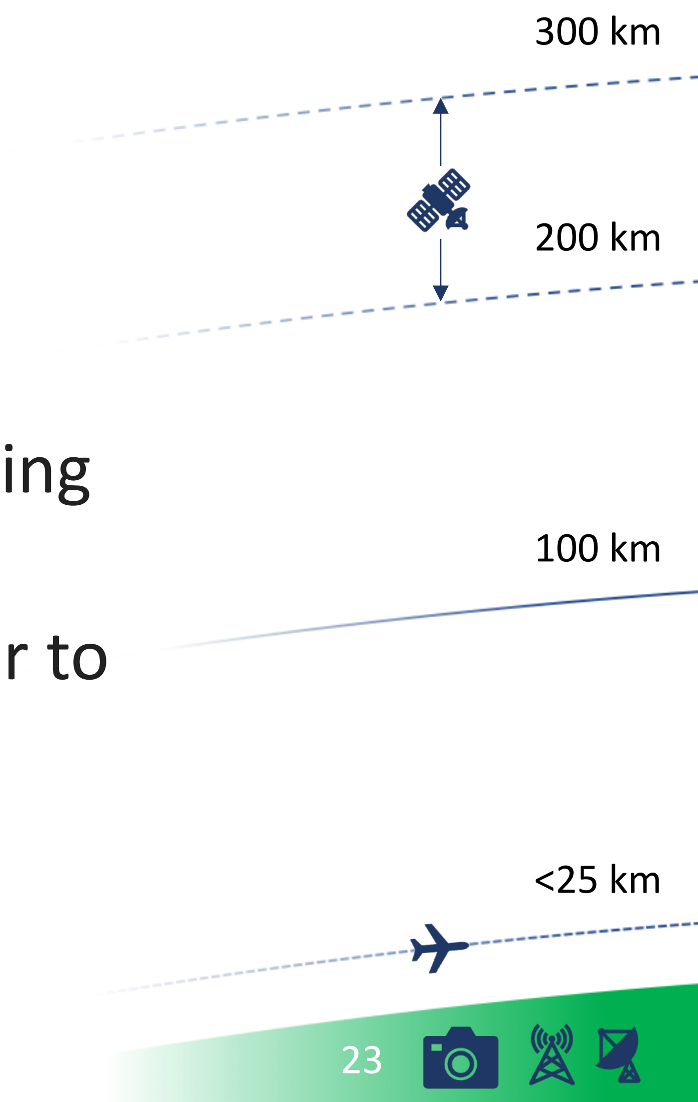
- Introduce a small breadboard test campaign early on within the product development cycle
- Better definition and descriptions of each subsystems in the test loop
- Pre-testing of each subsystem to avoid any delays during major test campaigns
- Bring plenty spare items and tools/equipment in order to avoid delays or incapability to run tests



LET’S BE IN TOUCH

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