

# Keynote speech #3

Chair: Prof. V. Wheatley - University of Queensland, Australia

## A Summary of Hypersonic Flight Missions and recent Developments by Mobile Rocket Base

*Frank Scheuerpflug - MORABA/DLR*

# A Summary of Hypersonic Flight Missions and recent Developments by Mobile Rocket Base

Frank Scheuerpflug



22–26 September  
Tours, France

- We build and fly Sounding Rockets
- Up to 10 launches per year
- 60 people

# Mobile Rocket Base (MORABA) of DLR



Mobile TM/TC Station



RIR-774-C RADAR



Mobile Launcher MAN-2





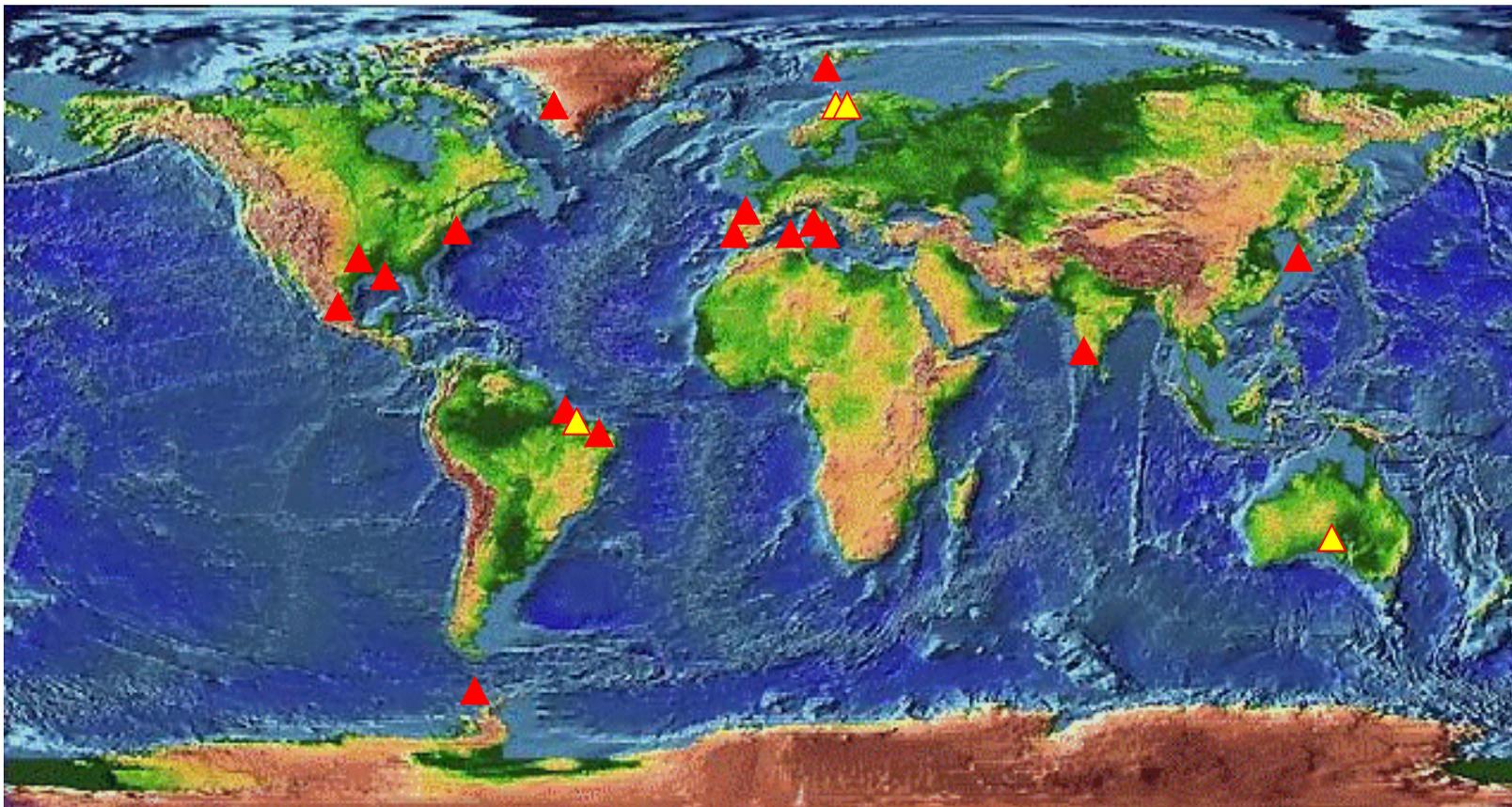
22–26 September  
Tours, France

# Operational Sites Utilized by MORABA

Huelva, Spain  
Biscarosse, France  
Perdas de Fogu, Sardinia  
Greenland  
Spitzbergen, Norway  
**Andenes, Norway**  
**Kiruna, Sweden**  
Karystos, Greece  
Kreta, Greece

Wallops Island, USA  
Matagorda, USA  
White Sands, USA  
Palestine, USA

Kourou, French Guyana  
**Alcântara, Brazil**  
Natal, Brazil



Kagoshima, Japan

**Woomera, Australia**  
Coober Pedy, Australia  
**Koonibba, Australia**

Adelaide Island, Antarctica      Thumba, India



## Research Domains

- Atmospheric Physics
- Research under Microgravity
- Astronomy
- Student Education

## Mission CONOPS

- Unguided Solid Rocket Vehicle
- Steep, parabolic trajectory
- Parachute Recovery



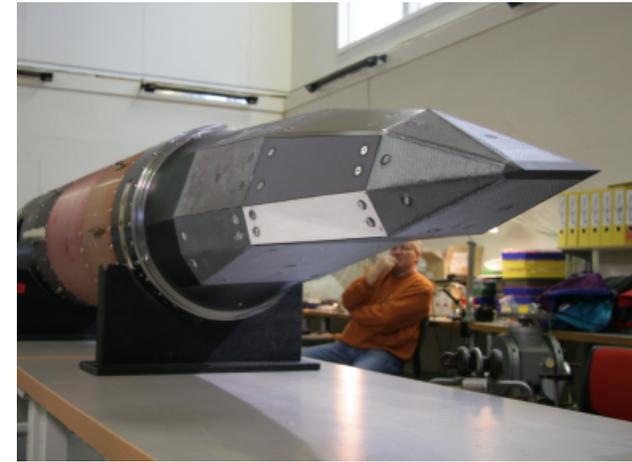
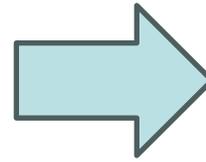
TEXUS 1, 1977



TEXUS 60, 2024



Traditional microgravity payload



First hypersonic payload SHEFEX I

- I. Mission Designs in Hypersonics Research
- II. Some Adjustments of Launch Vehicles
- III. Overview of hypersonic research missions done 2005 - Now

A large hypersonic missile is mounted on a blue and yellow transport cradle. The missile has a grey nose cone with black and white stripes, and a black body with orange and white markings. A worker in a blue uniform is standing next to the cradle, looking at the missile. The scene is outdoors, with a white building and a rocky hillside in the background.

# Adjusted Mission Designs for Hypersonic Research

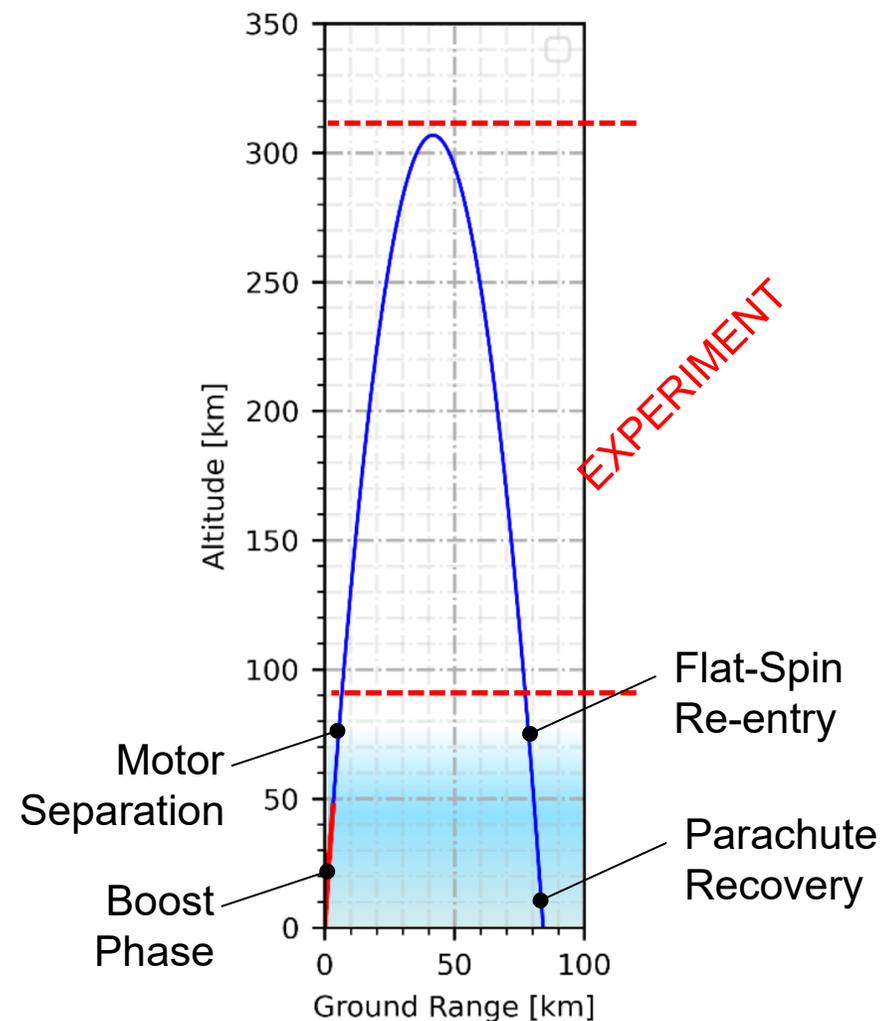
## Up-and-Over Mission Design

- Quick Atmospheric Passage
- Two Experiment Windows during atmospheric crossing
- Optional exo-atmospheric cold gas maneuver to re-align vehicle with reentry vector

➔ Low Load Level

➔ Measurement time typically 30 s

➔ Rapid change in atmospheric flight conditions





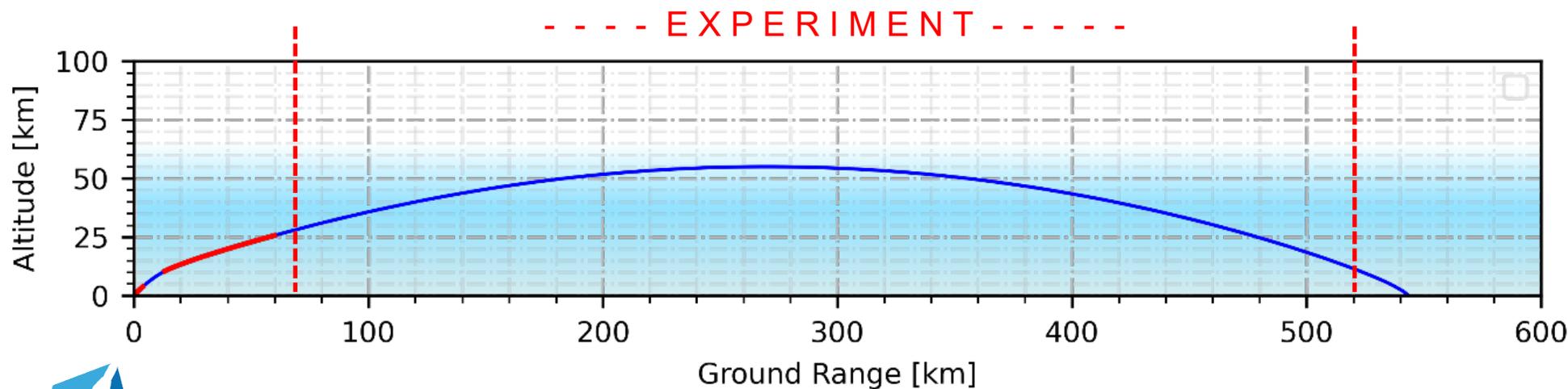
SHEFEX-I	HiFiRE-5	HiFiRE-3	SCRAMSPACE	HiFiRE-7	HiFiRE-5B	ROTEX-T	BOLT-1	HiFLIER	SOAR	BOLT-1B
10/2005	04/2012	03/2013	09/2013	03/2015	05/2016	07/2016	06/2021	10/2023	11/2023	09/2024
Andøya	Andøya	Andøya	Andøya	Andøya	Woomera	Esrange	Esrange	Esrange	Andøya	Andøya
Partial Success	2 <sup>nd</sup> stage ignition failure	Success	Booster Failure	Success	Success	Success	2 <sup>nd</sup> stage Instability	Success	Success	Success

## Supressed Mission Design

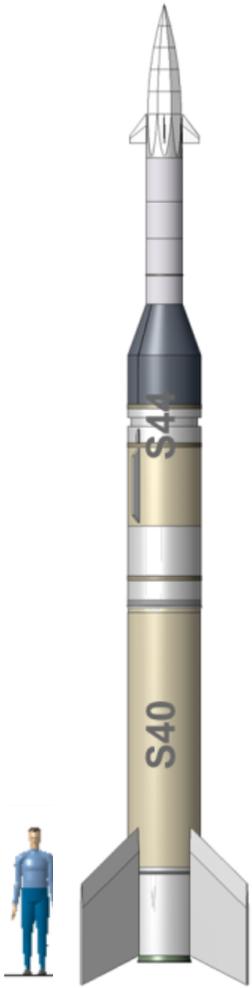
- Shallow launch angle (65-75°)
- Gravity Turn before second stage ignition

- ➔ Long & steady hypersonic conditions (typically 3 min)
- ➔ No Cold Gas Re-alignment required

- ➔ Payload recovery expensive (often prohibitively)
- ➔ High telemetry bandwidth and transmission power required to obtain data
- ➔ High Thermal Loads (!!!)
- ➔ Trajectory dispersion can become challenging

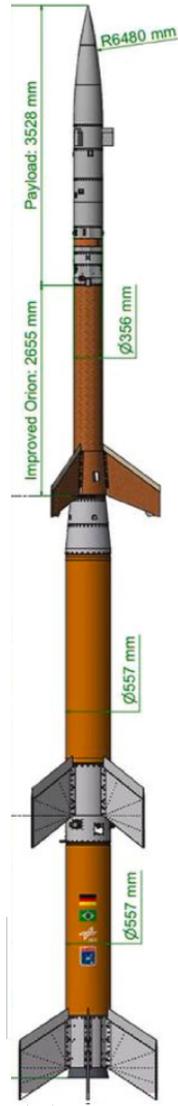


# Hypersonic Missions using Suppressed Designs



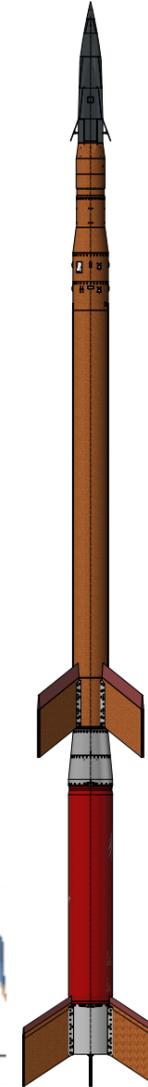
**SHEFEX-2**  
06/2012  
Andøya  
Success

Payload	710 kg
Ground Range	800 km
Apogee	177 km



**STORT**  
06/2022  
Andøya  
Success

Payload	200 kg
Ground Range	370 km
Apogee	38 km



**ATHEAT**  
Happening Now  
Andøya



Payload	250 kg
Ground Range	530 km
Apogee	54 km



# Thermal Hardening



Leading Edge buckling due to kinetic heating during the descent of SHEFEX I, October 2005



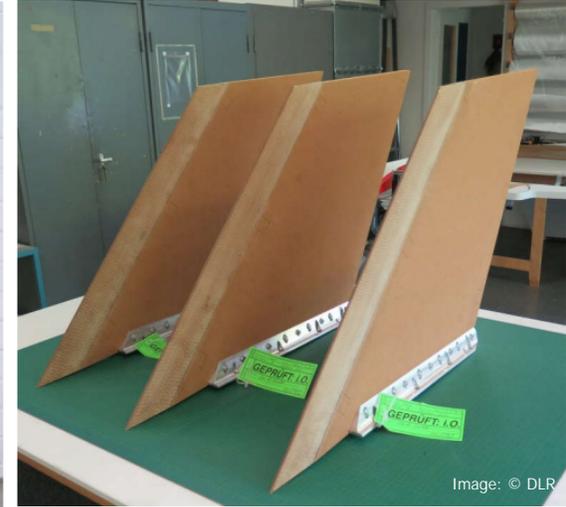
Heritage fin recovered from standard Micro-g Mission (TEXUS 48, 2011)



Cork Tree - Quercus  
Suber  
([Wikipedia])



Cork Coating on Schiaparelli Mars Sonde  
(ESA)



Various primary structures coated with cork

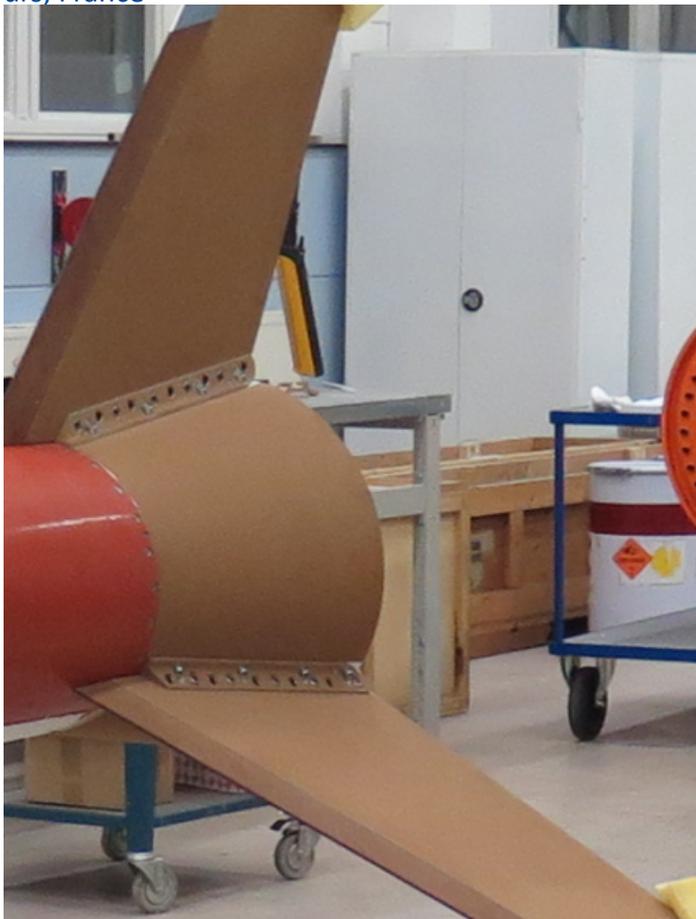
First Stage (Ma < 1.5)  
No thermal coating

Second Stage (Ma < 5)  
Fins Coated & Conical  
Interstage Coated

Third Stage (Ma ≈ 8)  
All items incl. Steel motor case  
coated, screw holes siliconized

START Launch Vehicle at U3 Launcher, Andøya 2022

Image: © DLR

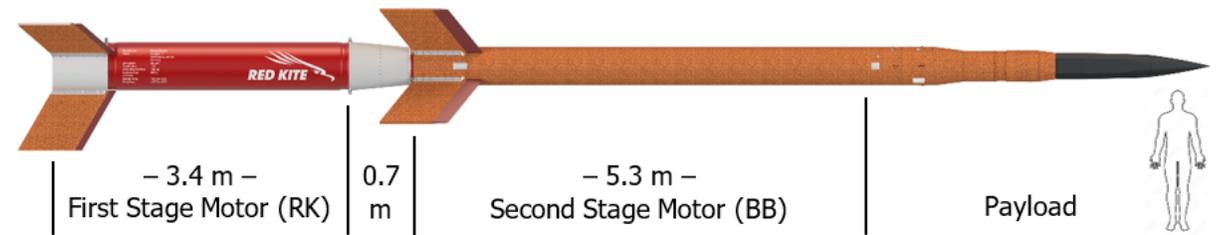
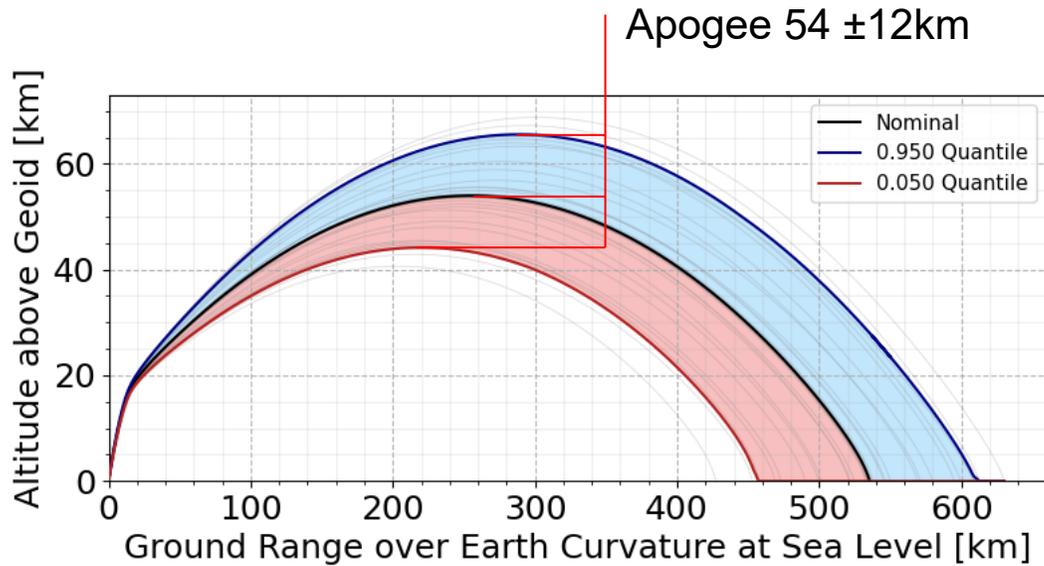


Footage fin and tailcan assembly structures from MAPHEUS missions



# Dispersion Mitigation

- Trajectory dispersion can become problematic, especially in suppressed mission designs



ATHEAt vehicle (slated for launch in Oct 2025)

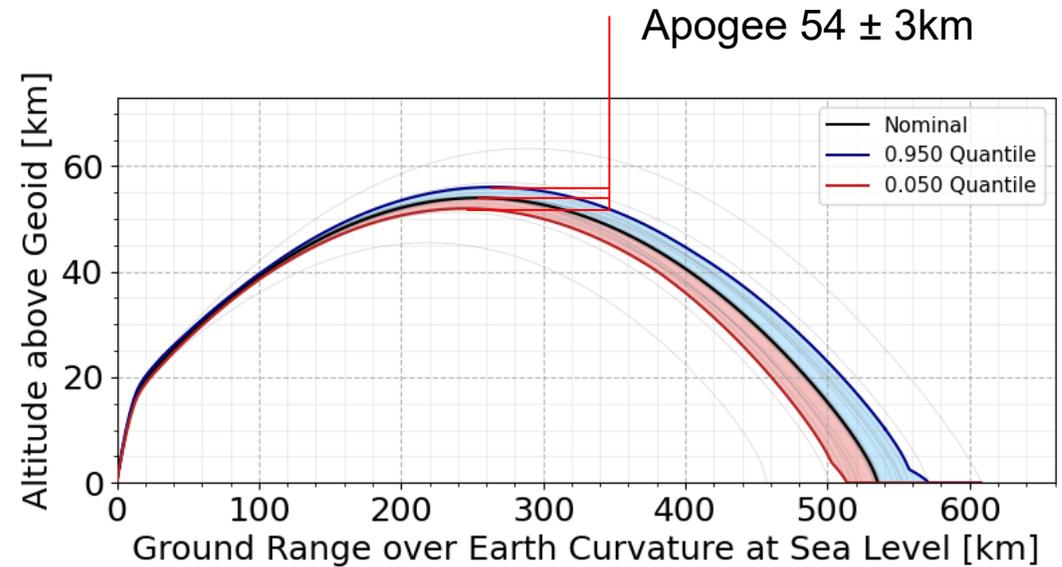
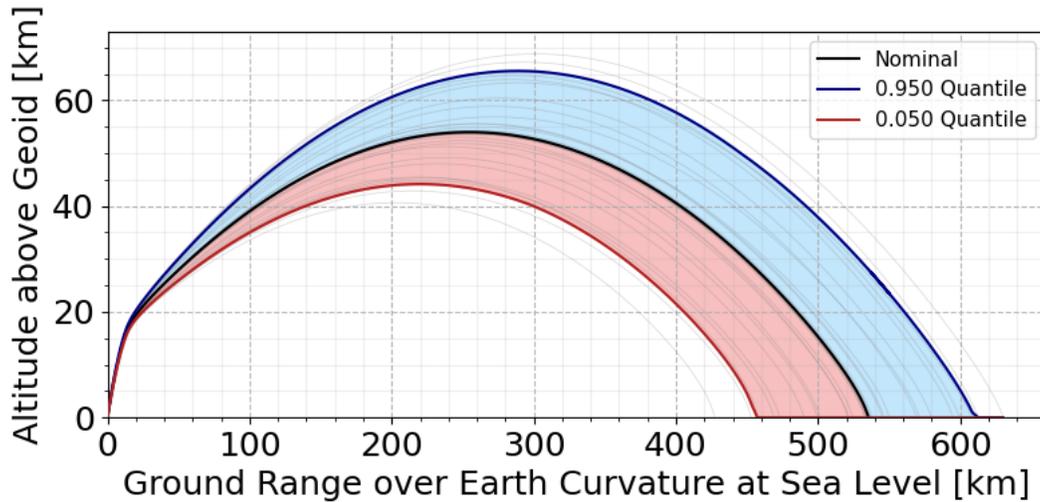
# Dispersion Mitigation: Autonomous Upper Stage Ignition

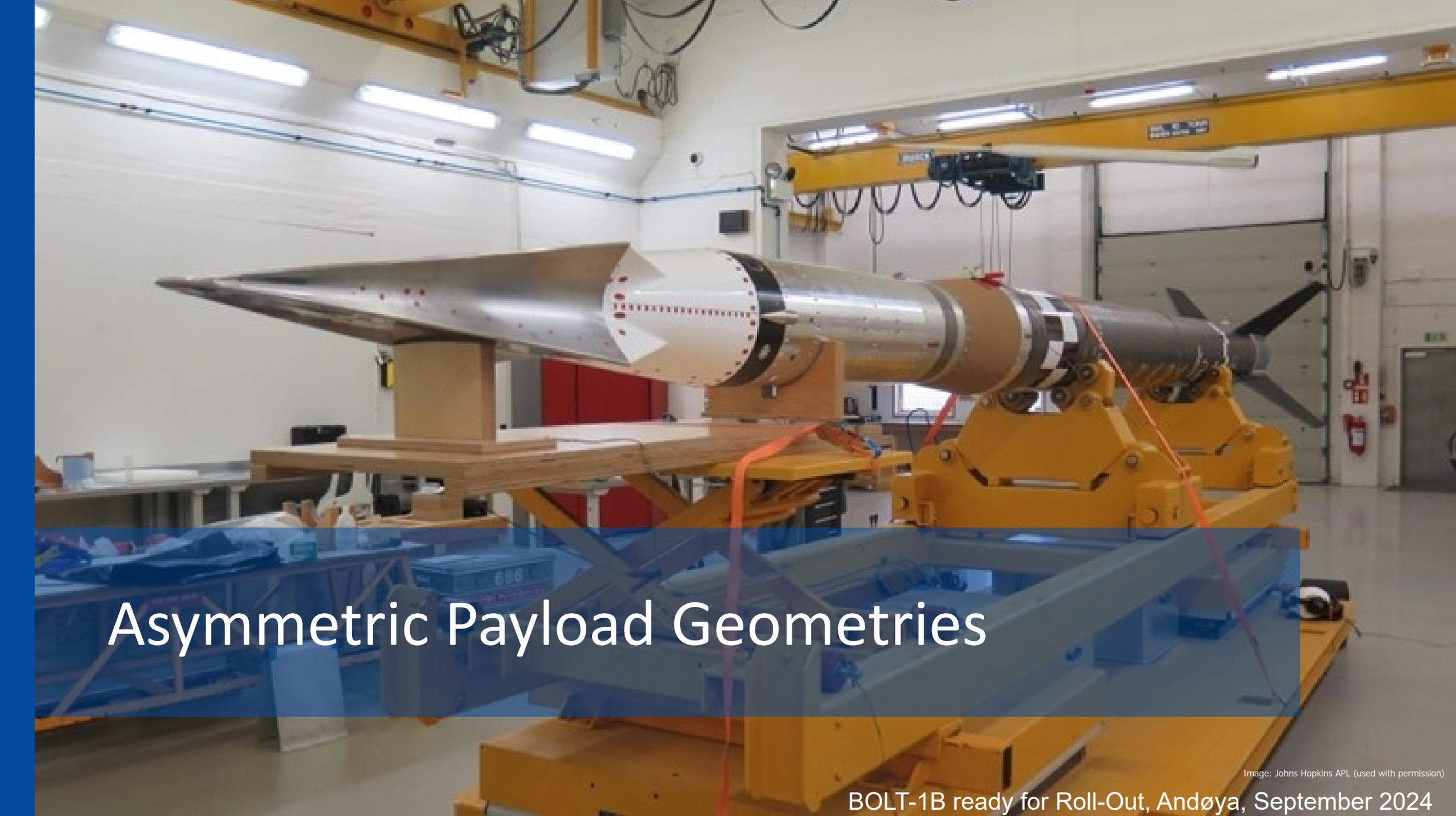
- Mitigate by making the ignition time of the last stage a function of the flight state after first stage burnout:

$$\text{Ignition Time (Upper Stage)} = f \left[ \begin{array}{l} \overrightarrow{pos} \\ \overrightarrow{vel} \\ \overrightarrow{att} \end{array} \right]_{\text{first stage}}^{\text{after burnout}}$$

- Implemented on-board
- No flight termination equipment required

## ➔ Precise achievement of target flight conditions

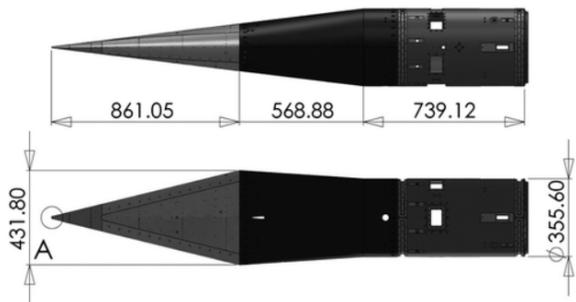




# Asymmetric Payload Geometries

Image: Johns Hopkins APL (used with permission)

BOLT-1B ready for Roll-Out, Andøya, September 2024



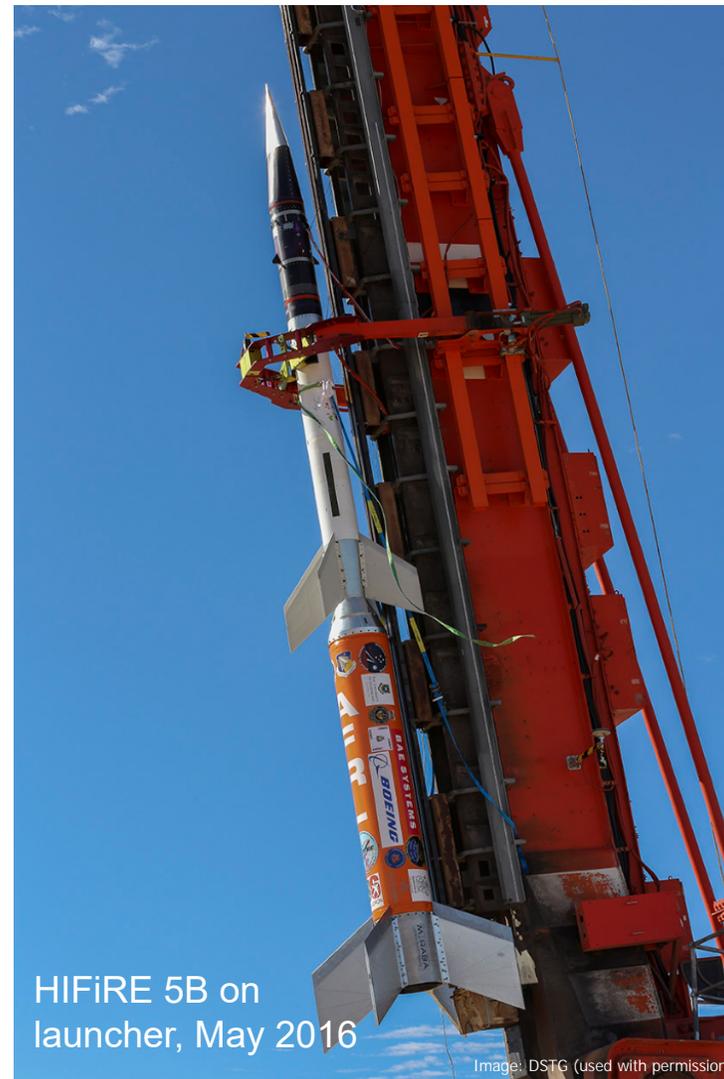
HIFiRE 5  
elliptical  
forebody [15]



HIFiRE 5b payload  
mated with Improved  
Orion second stage

Image: DSTG (used with permission)

# Asymmetric Payload Geometries



HIFiRE 5B on  
launcher, May 2016

Image: DSTG (used with permission)



Image: Johns Hopkins APL (used with permission)

BOLT I forebody during  
environmental testing

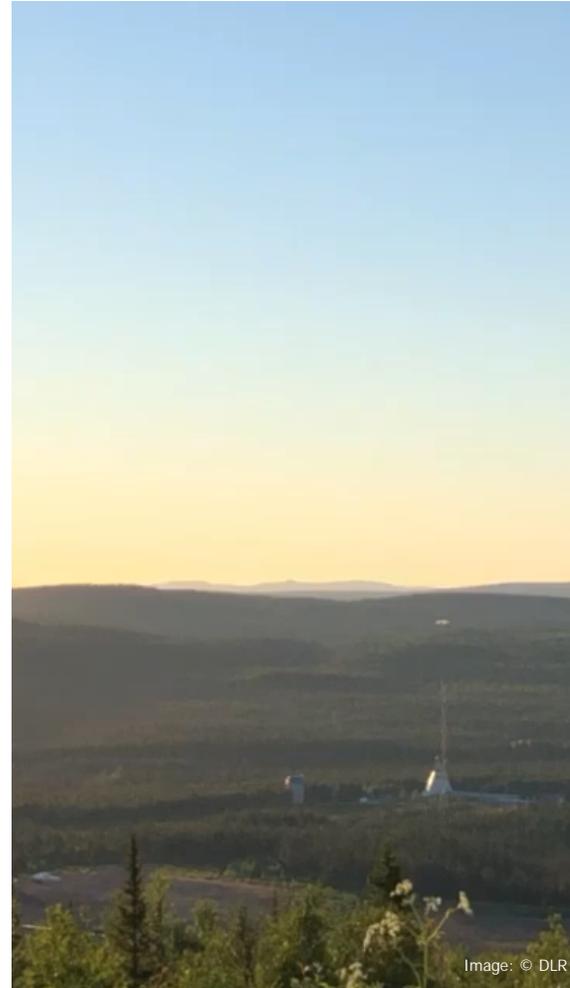


Image: © DLR

BOLT I leaving the launcher  
(1000 fps), Esrange 2021

## Asymmetric Payload Geometries

- Nominal first stage burn
- Cork screw motion upon first stage sep
- Apogee 78 km (vs. 264 planned)
- Mach 3 (vs. 7 planned)



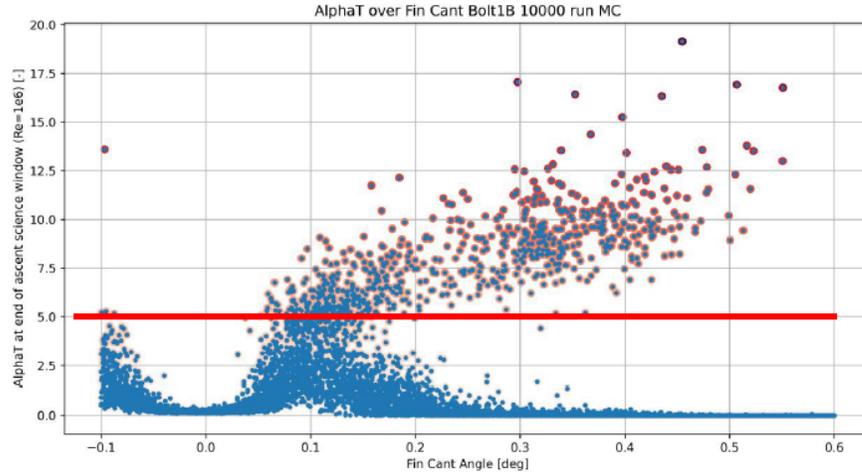
BOLT I launch captured from  
Radar Hill



BOLT I impact site



- BOLT 1 Failure triggered the (tedious!) expansion of flight dynamics modelling to asymmetric configurations
- We changed launch vehicle configuration and flew successfully.



Monte Carlo Analysis of a BOLT 1B-like configuration showing clear non-linear behaviour in some runs.



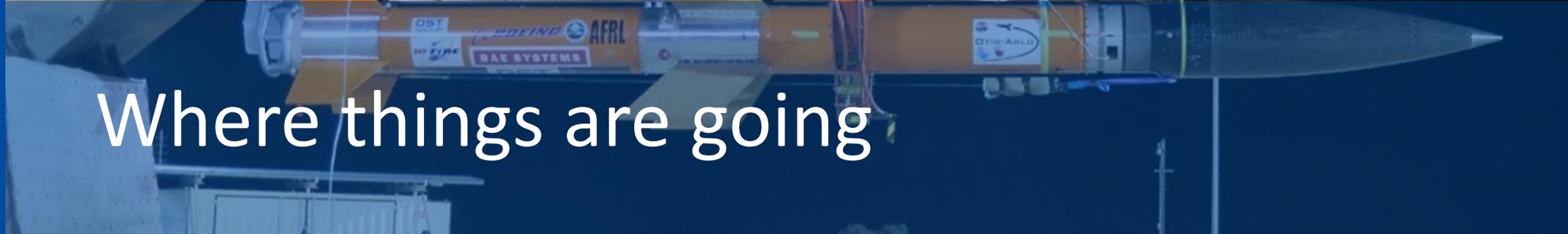
BOLT 1B launched from U3, Andoya, Sep 2024

# HIFiRE 4 launch vehicle, July 2017

Image: DSTG (used with permission)



HIFiRE 4 waverider [3]



Where things are going

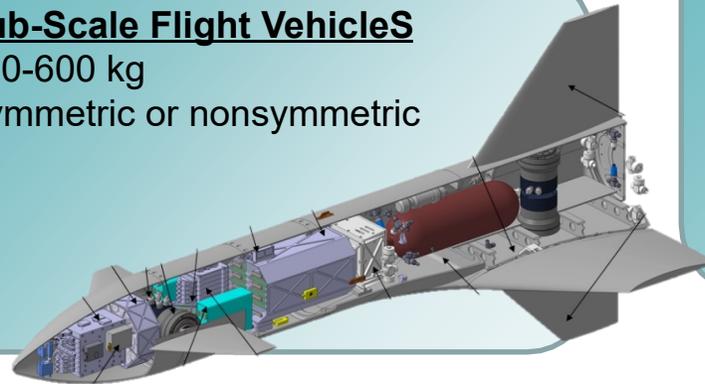
## Single Components and Technologies

150-300 kg  
Symmetric in at least 2 axes



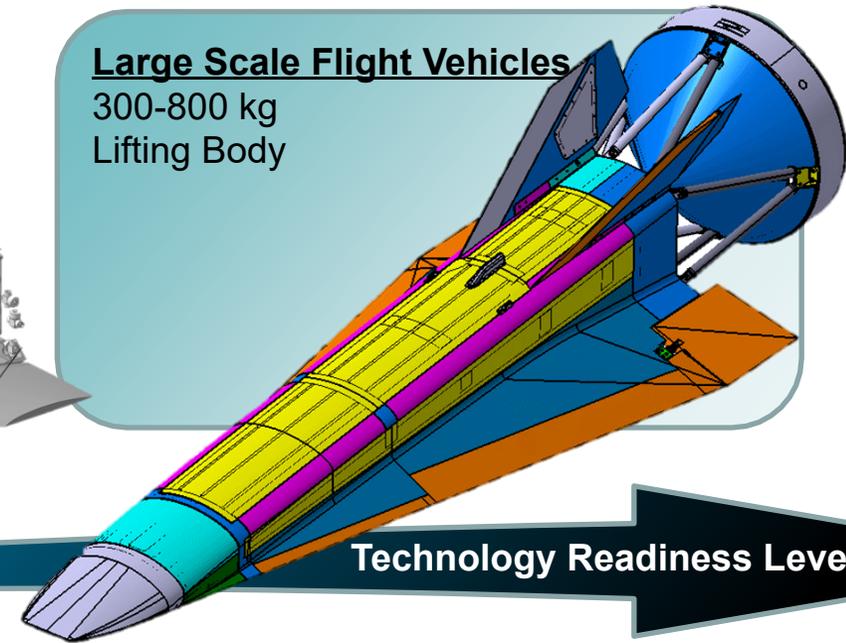
## Sub-Scale Flight VehicleS

300-600 kg  
Symmetric or nonsymmetric



## Large Scale Flight Vehicles

300-800 kg  
Lifting Body



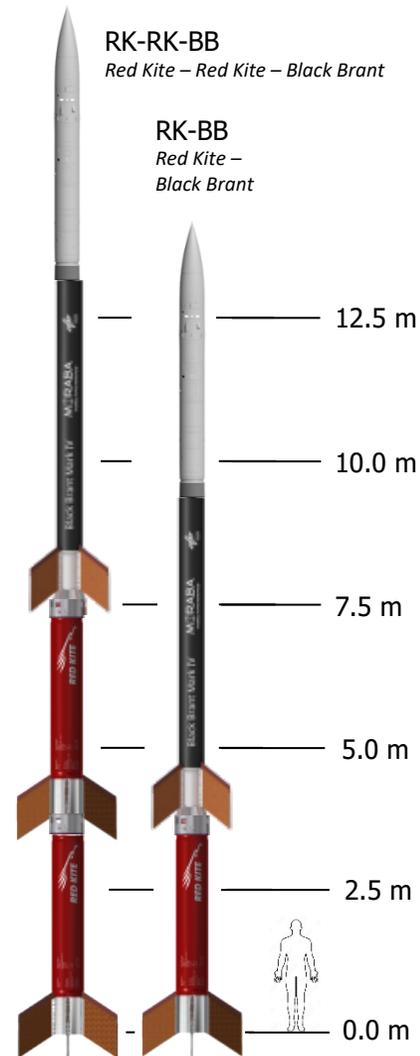
Technology Readiness Level

**Single Components and Technologies**  
150-300 kg  
Symmetric in at least 2 axes



## 1. FASTER (> Ma 10)

➔ Incremental further improvement using motors and subsystems we already have



## Where are we going?



### BLACK BRANT Mk4

- 30 s burn duration
- 1000 kg of composite propellant

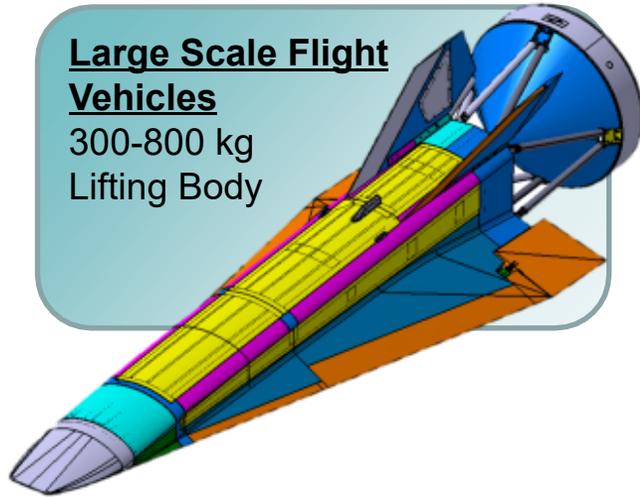


### RED KITE

- 12 s burn duration
- 900 kg of composite propellant

**Large Scale Flight Vehicles**

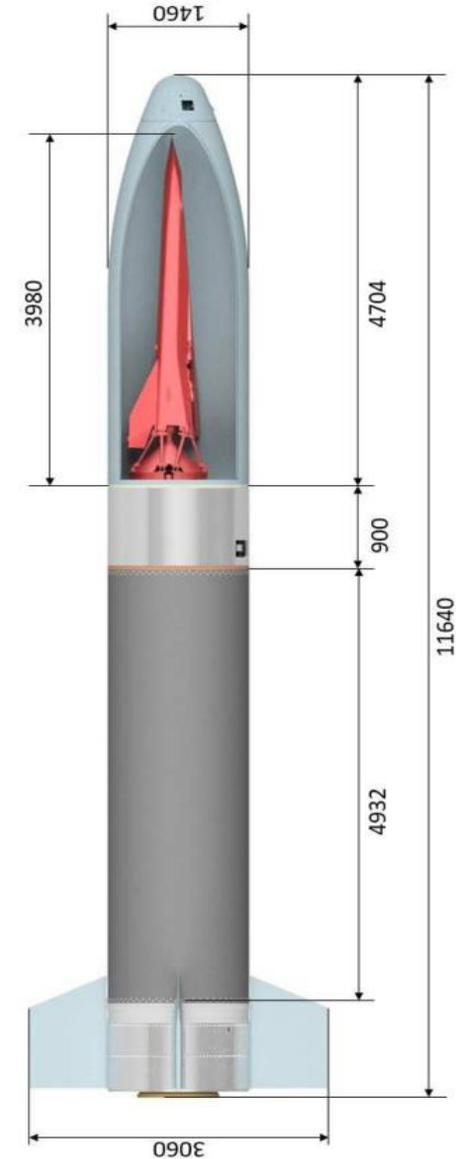
300-800 kg  
Lifting Body



# Where are we going?



S50 Motor  
(12 ton composite propellant, 86s Burn Time)



VS-50 launch vehicle

## 2. Integrated Flight Vehicles

- ➔ Larger motors and Thrust vector guidance



Thrust Vector System Test



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## Conclusion

- 14 hypersonic testing missions since 2005 (**11 successful**)
- **Increasing demand** both in quantity and quality of launches
- Determined to pursue and **expand our activities** in the field



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Thank you!



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