# Thermal Testing Strategy of Development Thermal Module for Dragonfly Lander

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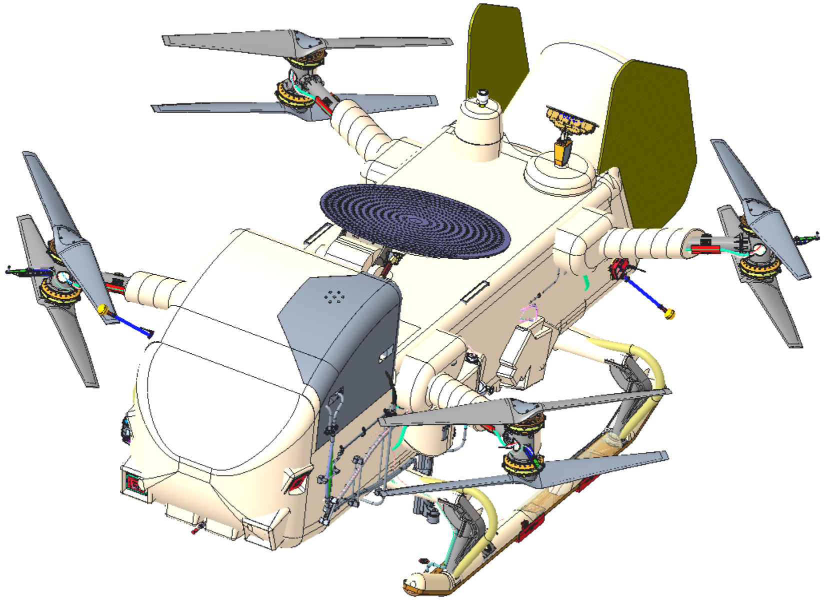
# Overview

- This presentation will discuss the Development Thermal Module (DTM) test program for the Dragonfly lander:
- **Dragonfly Mission**
  - Overview of Dragonfly's operational environment, along with introduction to thermal control system
  - Previous testing and lessons learned
  - APL Test Facilities – TITAN chamber
- **Development Thermal Module**
  - Overview of DTM construction and purpose
  - Test instrumentation and methodology
  - Future work and upcoming testing

# Dragonfly – Background

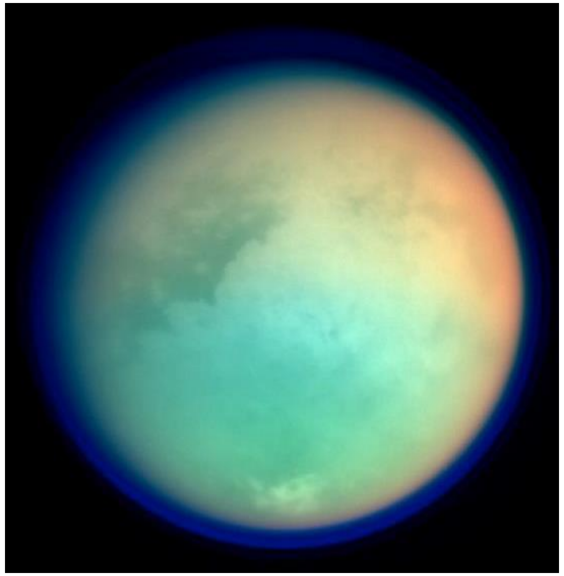
- Dragonfly is a New Frontiers mission to study Saturn's moon, Titan
  - Octocopter lander will fly on the Titan surface, taking advantage of its thick atmosphere and low gravity…
  - Conversely, the thick atmosphere and cryogenic surface temperatures make thermal design challenging
- Electrical power is supplied through an MMRTG, which also provides ~1800W of "waste" heat
  - Thermal control system (TCS) will utilize foam insulation in order to maintain operational temperature of lander systems
  - Along with keeping heat in, the TCS will also feature a cold duct thermal trim for heat rejection to regulate lander internal temperature
  - Design of TCS will need to be verified through test and analysis cycle



**Dragonfly Lander**

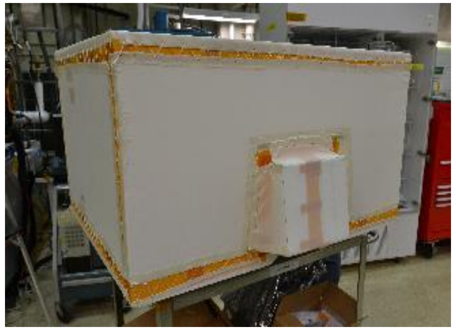
# Titan Environment

- Surface Temperature: 94K (-179° C)
  - This temperature is fairly stable with little diurnal/seasonal variation, an important trait for testing purposes
  - Small possibility of methane rain, wind conditions are typically < 1 m/s
- Surface Gravity: 0.14g (1.352 $m/s^2$)
  - 1/7th Earth gravity
- Surface Pressure of 146 kPa, density of 5.44 $kg/m^3$
  - Titan atmosphere is largely Nitrogen
  - ~1.5 times Earth atmospheric pressure (101 kPa)
  - ~4.5 times Earth atmospheric density (1.2 $kg/m^3$)



# Thermal Balance Test Methodology

- Lander heat leaks are managed through the Thermal Exterior Losses (TEL) document
  - TEL accounts for all heat leaks associated with lander foam and its penetrating through components: arms, instruments, harness, etc.
  - This is where testing comes in: pre-test analytical predictions are sent to TEL, then refined with thermal test/model correlation cycle
- Heat leaks are determined with thermal analysis and experimental “thermal balance” testing:
  - Measure amount of heater power required to keep test article at a steady-state set point temperature, often 0° C
  - Can be used to determine heat leak associated with items that penetrate through insulation with some configuration changes



*Complete test article heat leak*

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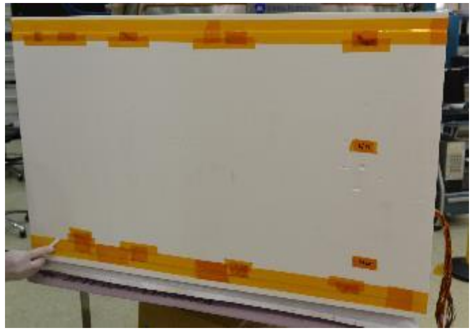

*Control test article heat leak*

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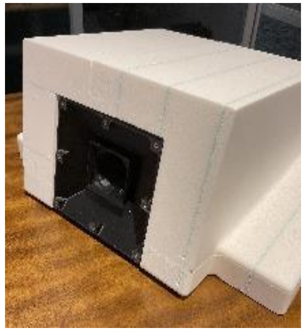
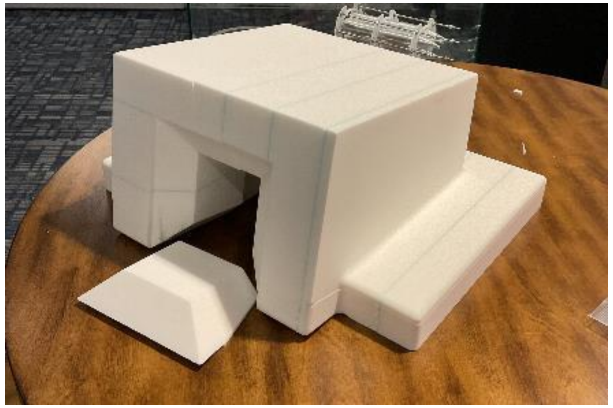
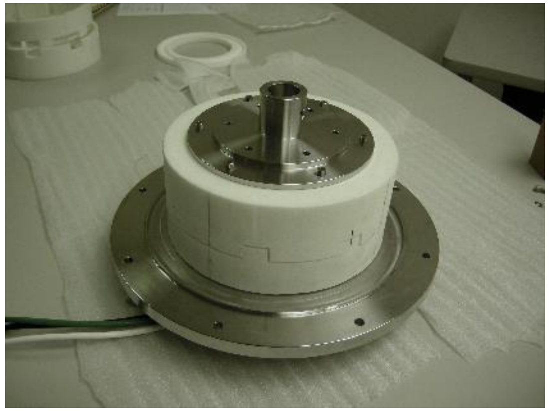


*Component heat leak*

# Lander Insulation – Rohacell

- Primary lander insulation is Evonik Industries Rohacell™ foam insulation, chosen for low thermal conductivity, low density, RF transparency and machinability
  - APL testing shows ≤0.035 W/mK effective thermal conductivity for a 3 in. thick panel in a -180° C environment with a 80-20 Modular Box
  - Easily machinable into complex shapes, multiple panels can be bonded together to create thicker components



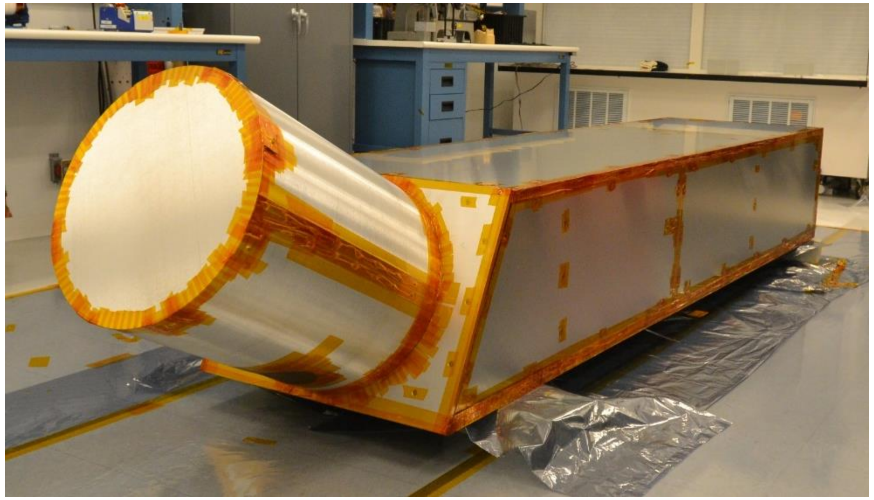


# Foam Design – Lessons Learned

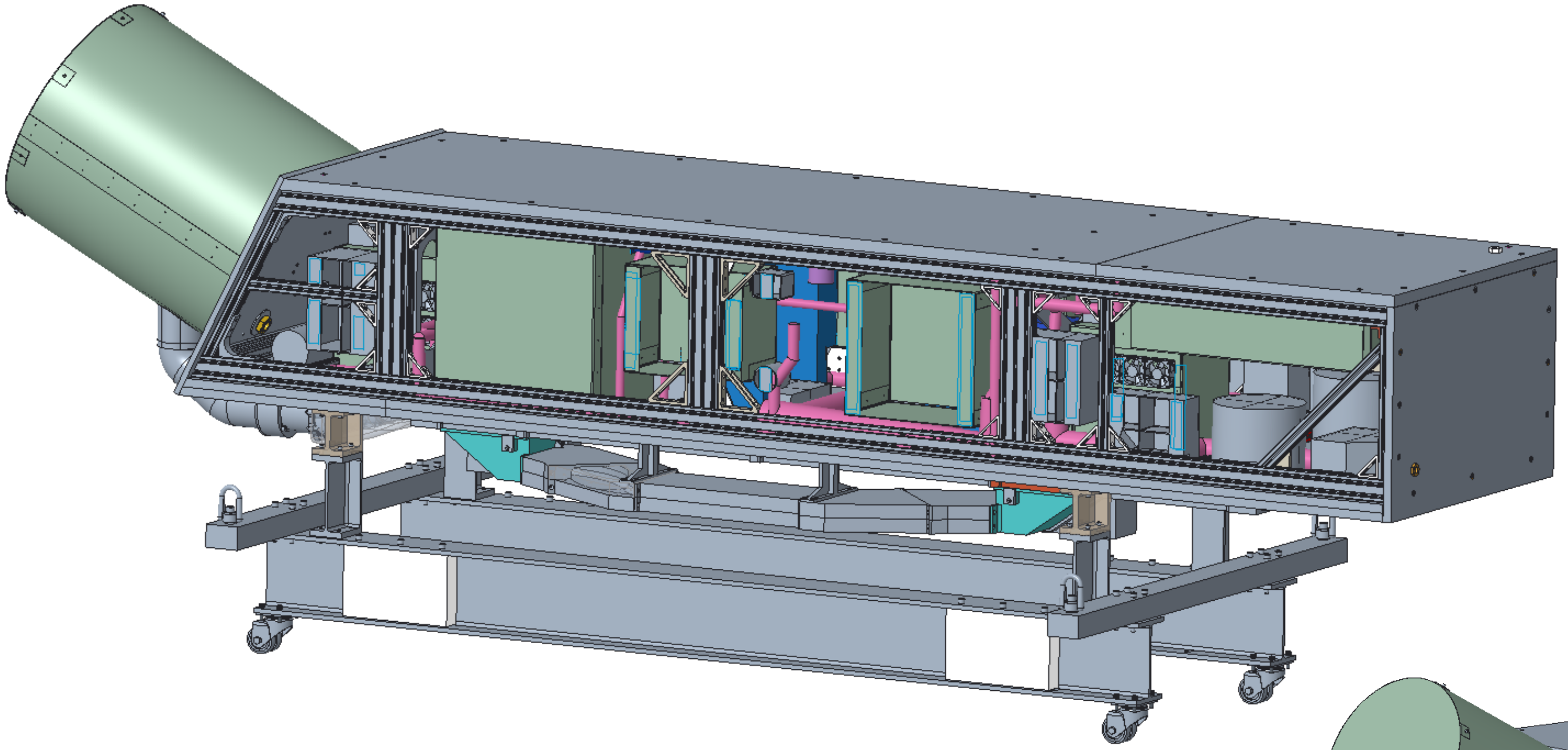
- “Chimney effect” creates opportunities for large heat leaks; any gaps between foam and lander honeycomb panel create a potential for heat leak
  - “Compartmentalizing” gaps into smaller spaces reduces heat leaks in the event of a crack
  - Wrapping test articles with packing wrap has made it insensitive to insulation seam gaps/cracks
- CTE effects – single vs. multiple layer insulation designs
  - Thermal distortion can open gaps between insulation panels
  - Nested pieces of foam help guard against air intrusion by creating a “torturous air path”
  - Multiple layers of insulation reduce thermal distortion by reducing temperature gradient across each layer

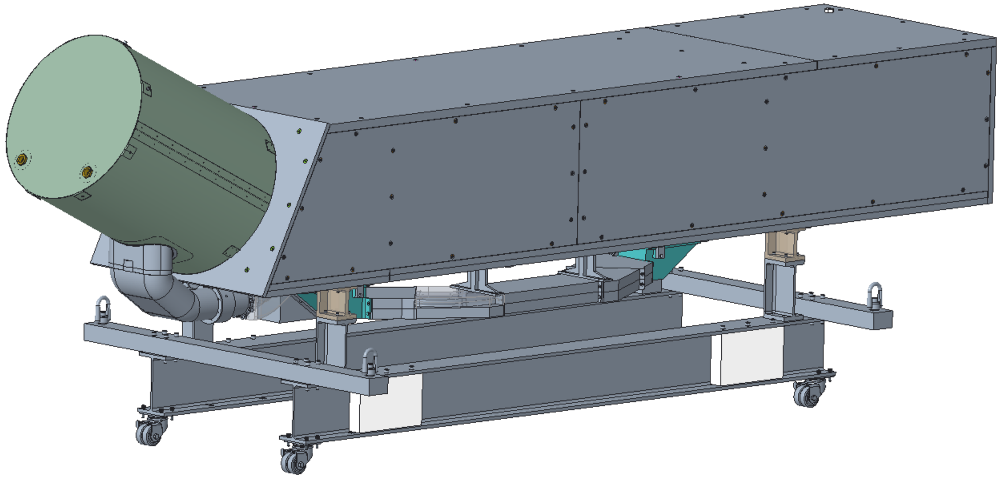
# Development Thermal Module (DTM)

- Full-scale thermal test article for Dragonfly lander
  - 80/20 frame with honeycomb panels of representative thickness, allows for modular installation of test articles (arms/legs, camera modules, DraMS attic)
  - Initial testing will use polystyrene foam insulation while Rohacell insulation design is being finalized
  - DTM features ~180 thermocouples, as well as air velocity and pressure sensors for CFD correlation purposes
  - Geometrically representative boxes are installed inside DTM to mimic flow restrictions from lander electronics boxes
- Heater unit and ducting fan system circulates warm air throughout DTM
  - Cold duct trim device branches off main duct, with butterfly valve controlling bypass flow/heat rejection



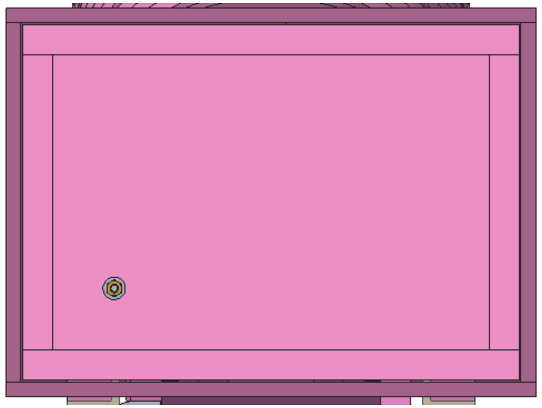
# DTM Cutaway

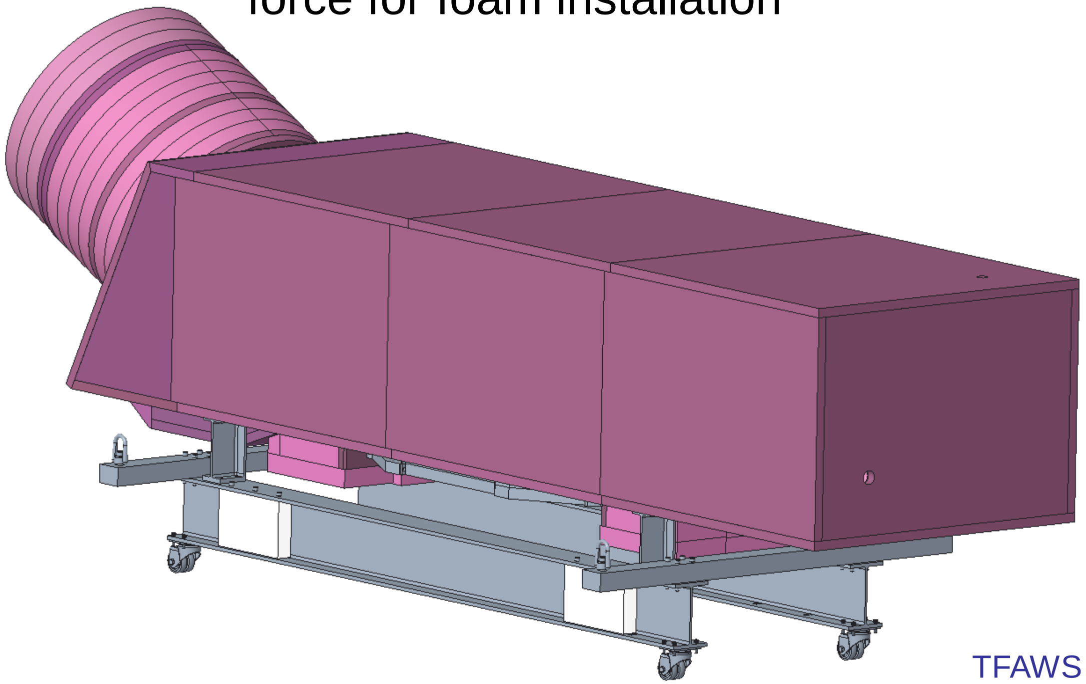


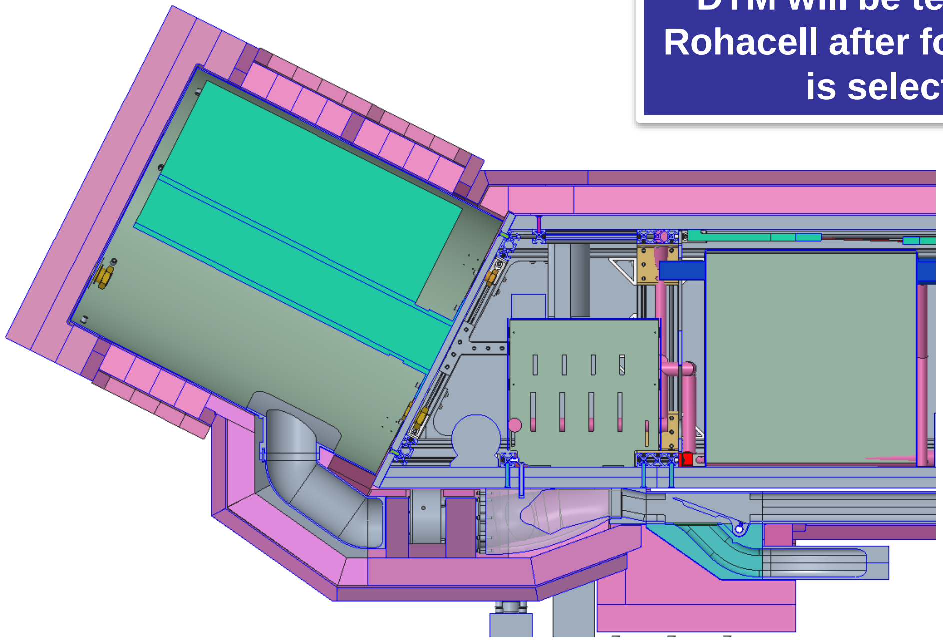


# Preliminary DTM Foam Insulation

- DTM initial test insulation consists of two layers of polystyrene foam, with a total thickness of 3”
  - Multilayered design reduces CTE effects by reducing temperature gradient across each panel
  - Panel seams are staggered and will be taped closed with Kapton to prevent direct mass transfer
  - Sailcloth blanket on the foam exterior will provide additional compressive force for foam installation







**DTM will be tested with Rohacell after foam design is selected**

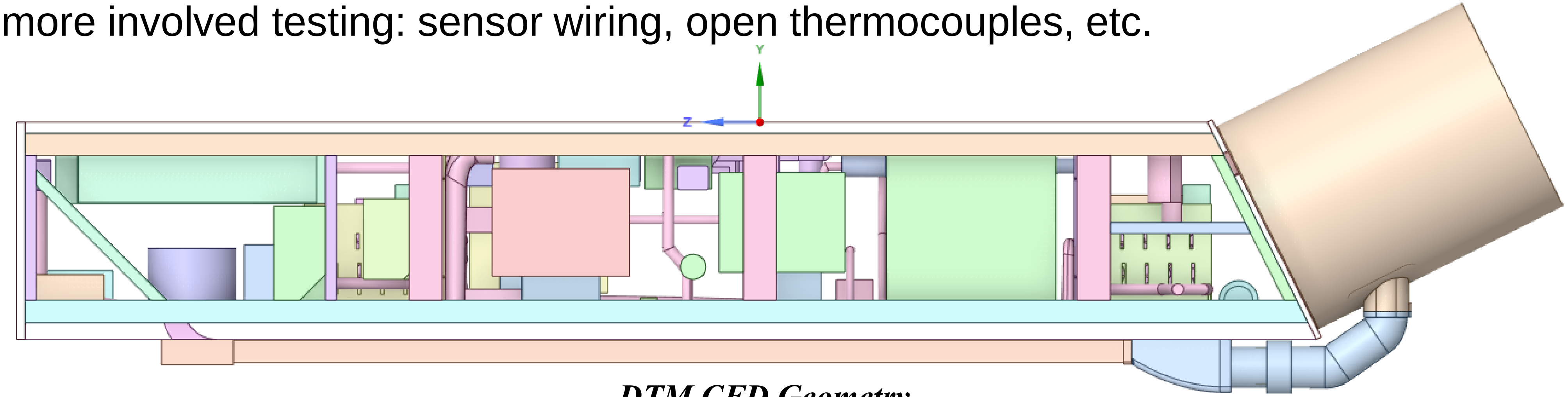
# TITAN Chamber

- Future flagship thermal chamber for Dragonfly will allow for entire flight lander to be tested in nitrogen cryogenic environment at 0.5 atm pressure
  - 0.5 atm on Earth provides equivalent natural convection as on Titan
  - Internal working dimensions of 15 ft. x 15 ft. x 15 ft.

- Operating temperatures from -180C to +150C
- Operating pressures from 0.3 – 1.0 atm

# DTM – Airflow Testing

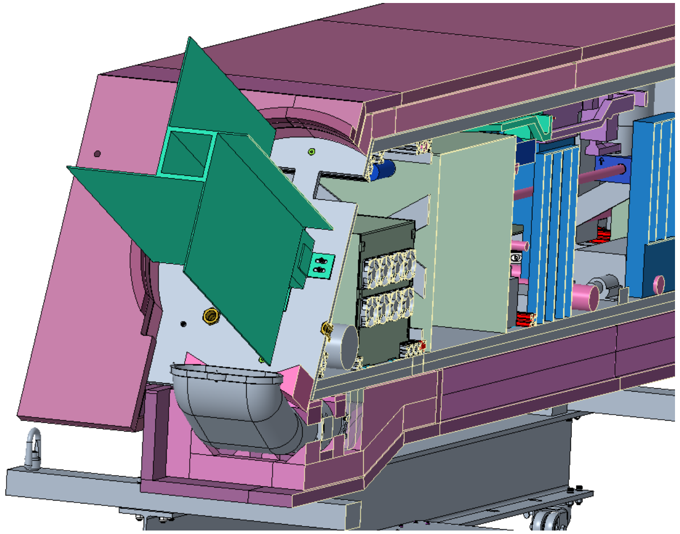
- Titan chamber installation is slated for completion in Q4 2023, initial testing can be conducted in room ambient conditions
- Initial room testing consists of running the DTM duct fans
  - Room temperature airflow test will provide initial data for CFD correlation, particularly focusing on system pressure drop
  - Boxes representing high dissipation electronics (battery, rotor drive electronics) will receive their own fans to represent impact in flight design
  - Additionally, room test gives an opportunity to diagnose GSE installation problems before more involved testing: sensor wiring, open thermocouples, etc.

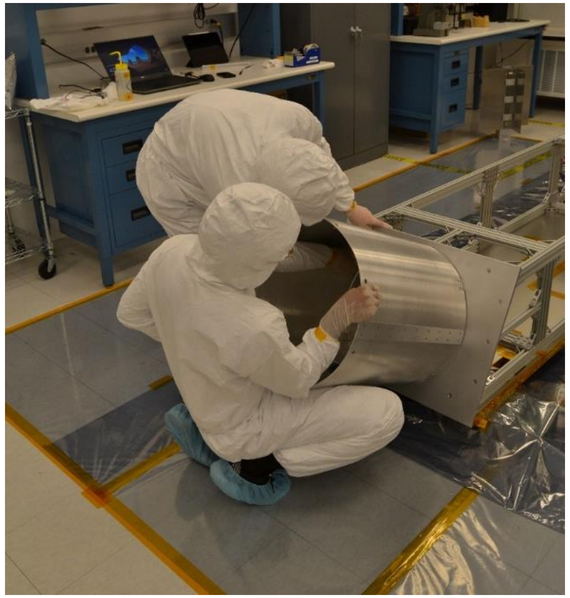



*DTM CFD Geometry*

# DTM – Room Temperature Testing

- Additional room ambient testing will heat the DTM to induce a temperature gradient
  - Provides additional correlation data for DTM CFD model, as well as further diagnostic testing for heater unit wiring
  - Thermal analysis and correlation may provide insights on potential CTE concerns or improper insulation installation prior to cryogenic testing



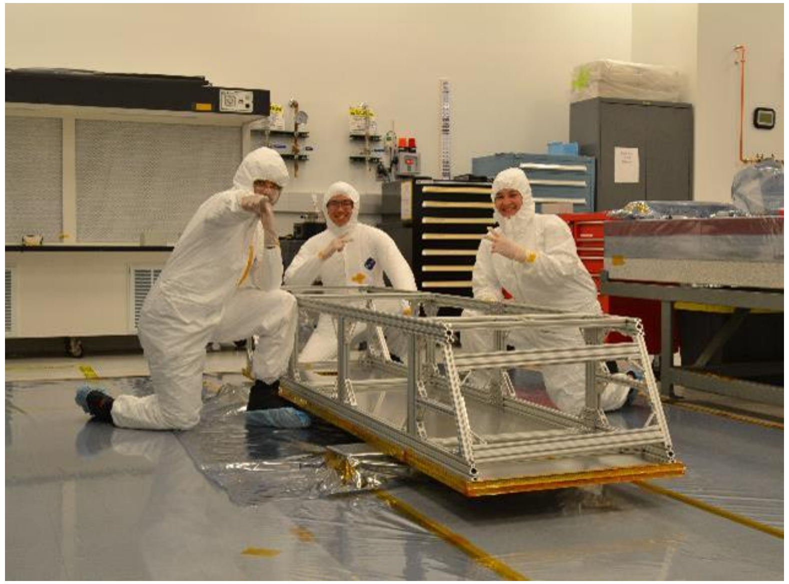


# DTM – Cryogenic Testing

- Cryogenic testing in Titan chamber will provide first look at a full-scale test article's performance in Titan conditions
  - Components first undergo individual thermal balance testing to determine heat – DTM will then be a holistic thermal balance test for the entire lander
  - Cryogenic testing will validate heat rejection capacity for cold air duct trim device
  - DTM insulation will be subjected to harsh temperature gradient, will reveal CTE-related problems with insulation design
  - Post-test correlation will provide the best estimate for TCS performance on Titan
- While previous thermal balance tests controlled to a set-point internal temperature, DTM testing will control heater unit to 1800W output to mimic MMRTG output

# Future Work

- DTM is currently undergoing final assembly:
  - DTM structure has completed assembly and has undergone body sealing testing with excellent results
  - Support cart will be used to transport and lift DTM, needs to be proof tested prior to installation
  - Foam insulation is currently being fabricated and assembled onto DTM structure
  - DTM GSE and internal boxes are currently being installed
- Room temperature test program is scheduled to begin late Q3 2023, with cryogenic testing occurring in Q4 2023
  - Additional test articles representing lander arms/legs, DRaMS attic, cameras, are currently being designed and will be installed on DTM later in the test program



DRAGONFLY