Development Test Module (DTM): Building a Thermal Desktop Model for Full-Scale, Convective Test Correlation

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CONTENT

Initial Testing Phase 1.1 Module Preparation

Image credit: NASA/Johns Hopkins APL/Ed Whitman

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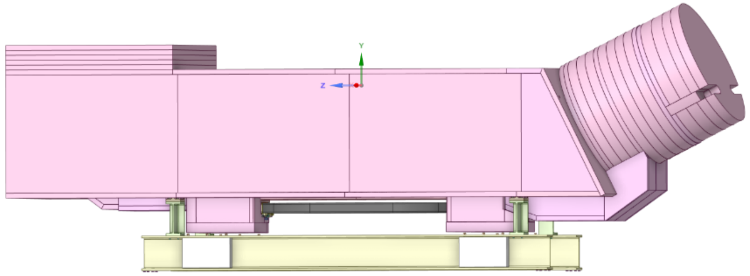


Development Test Module CAD Model

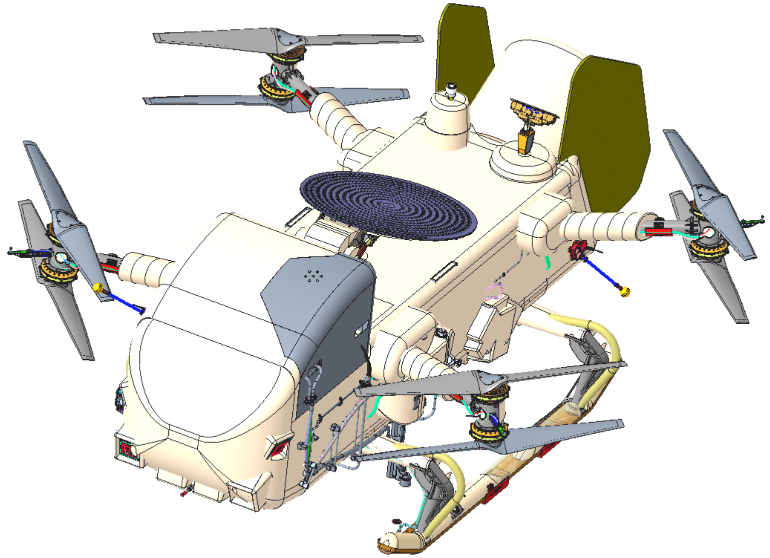
Development Test Module in Titan Chamber

Image credit: NASA/Johns Hopkins APL/Collette Gillaspie

MISSION OVERVIEW

- Dragonfly, NASA New Frontiers medium-class mission
  - Nuclear-powered octocopter to investigate prebiotic chemistry on Titan and assess potential for past or extant water and hydrocarbon-based life
  - Mission to operate in dense, convective atmosphere with no prior precedent

Titan Metrics	Earth Multipliers
-180ºC	13 × Colder than Earth's average temperature at sea level
0.3 m/s	0.10 × Slower than Earth's average wind speed
1.45 atm	1.5 × Earth's atmospheric pressure at sea level
1.35 m/s^2	0.14 × Earth's gravity at sea level
5.4 kg/m^3	4.5 × Earth's atmospheric density at sea level



Dragonfly Lander CAD Model

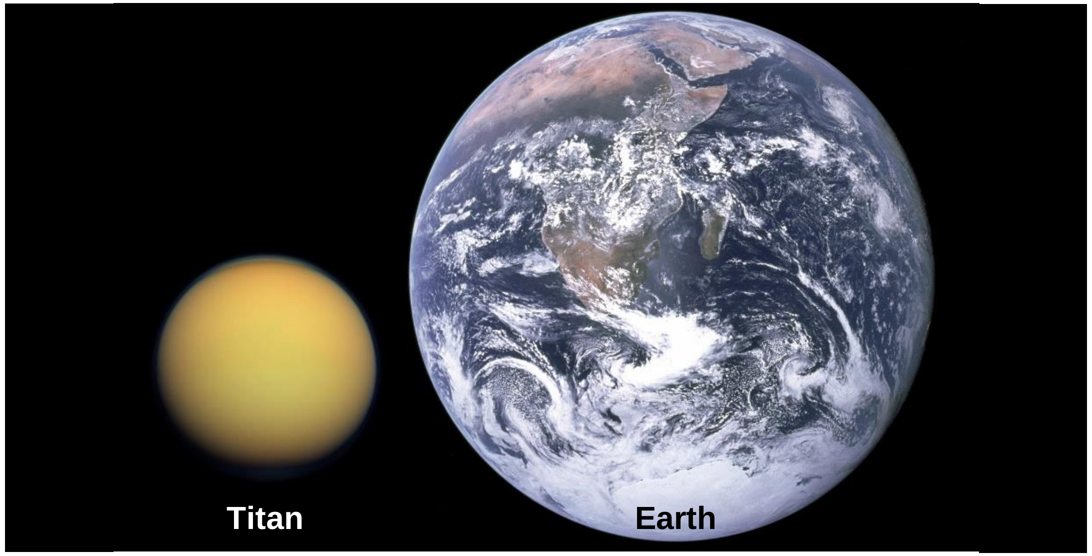


Image credit: https://commons.wikimedia.org/wiki/File:Titan,_Earth_%26_Moon_size_comparison.jpg#/media/File:Titan,_Earth_&_Moon_size_comparison.jpg

MOTIVATION

- Current thermal analysis for Titan hibernation relies solely on uncorrelated Dragonfly lander Thermal Desktop model
  - → Development Test Module (DTM) model correlation in Thermal Desktop expected to enhance confidence in lander model, critical for mission success
- Prediction accuracy uncertain due to Thermal Desktop limitations in modeling convective heat transfer
  - → DTM correlation enables alignment between computational fluid dynamics (CFD) lander model and Thermal Desktop lander model in Titan hibernation, ensuring temperature predictions match test data in convective environments
- Presence of multiple thermal models complicates thermal information retrieval
  - → DTM correlation can inform modeling that consolidates data across all thermal cases (e.g., cruise, entry, descent, landing, Titan convection), commissioning a comprehensive source of information

HISTORY OF DEVELOPMENT TEST MODULE (DTM)

October 2023
Phase 1.1: Polystyrene
- Thermal balance
- CFD correlation

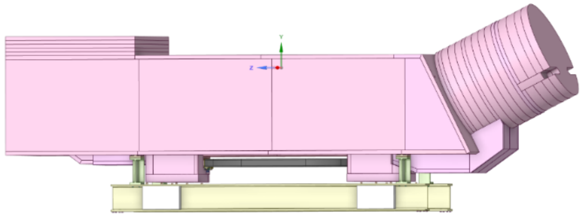
April 2024
Phase 1.2: Polystyrene
- Cold duct concept
- CFD correlation

October 2024
Phase 1.3: Polystyrene
- Flight-like cold duct
- MMRTG TSIM testing
- CFD & TD correlation

Mid-2025
Phase 2: Flight-like foam
- Flight-like foam validation
- Heat leak validation
- Thermal control of cold duct
- EM tests
- CFD & TD correlation

DTM Lift out of Titan Chamber Following Phase 1.1 Testing
Image credit: Johns Hopkins APL/Collette Gillaspie

DTM Inspection Following Phase 1.2 Testing
Image credit: Johns Hopkins APL/Dahway Lin



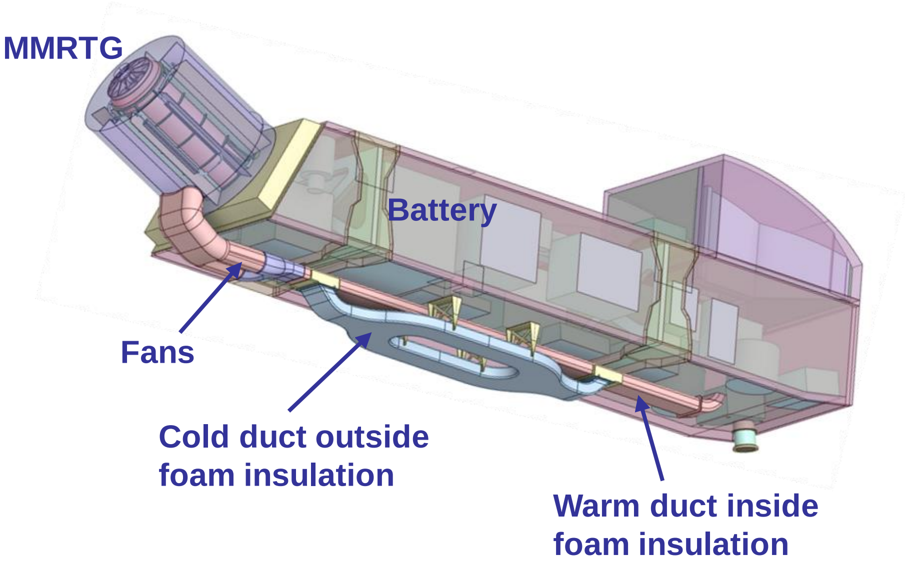
DTM CAD Model, Phase 1.3

Flight foam material candidates: ROHACELL® (left) and SOLIMIDE® (right)
Image credit: Johns Hopkins APL/Marisa Teti

CAD ≡ Computer-aided design
CFD ≡ Computational fluid dynamics
EM ≡ Engineering model
MMRTG ≡ Multi-mission radioisotope thermoelectric generator
TD ≡ Thermal Desktop
TSIM ≡ Thermal simulator

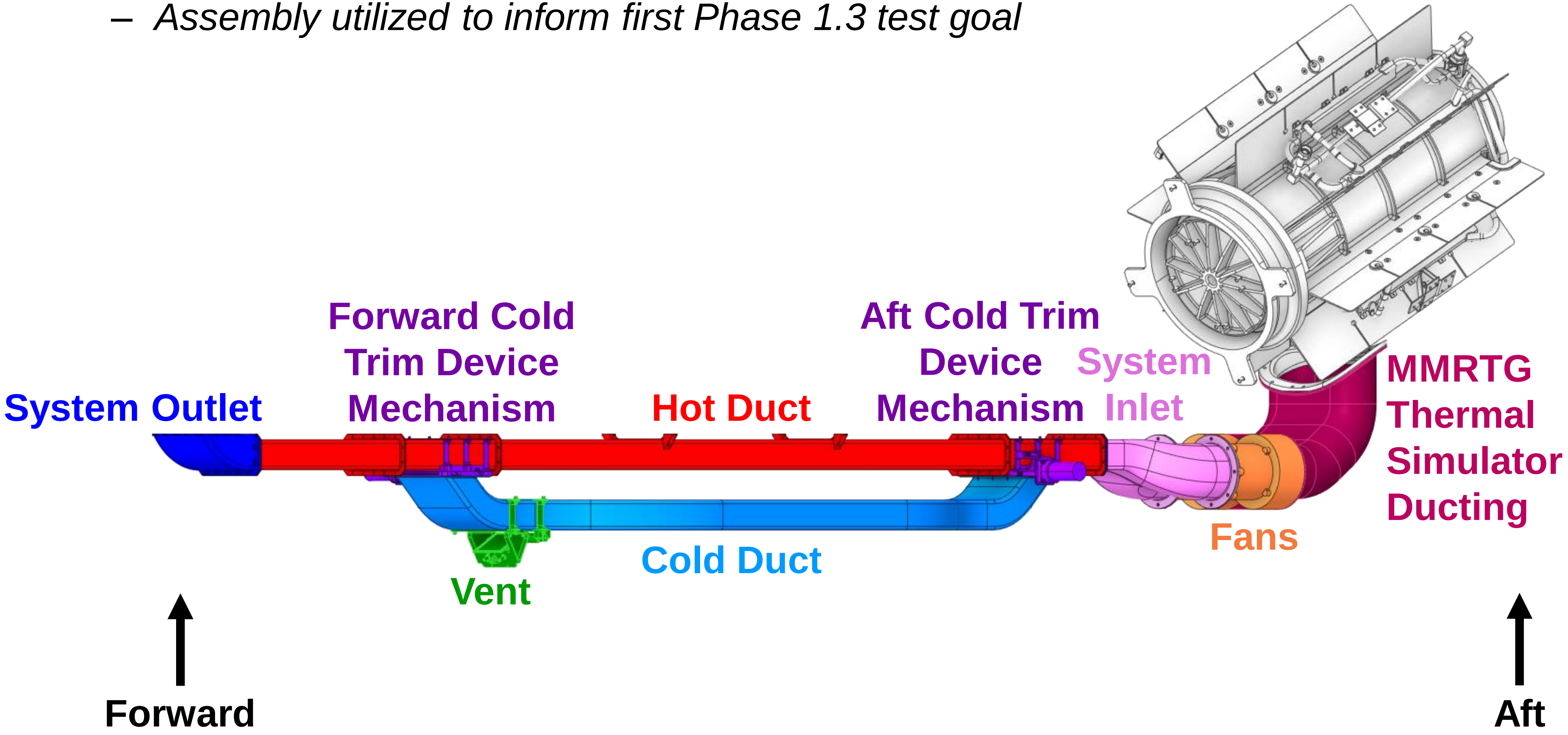
DTM THERMAL CONTROL KEY COMPONENTS

- MMRTG thermal simulator (TSIM) to provide power and heat to lander
- Foam insulation to conserve MMRTG TSIM heat
- Fans to facilitate convective cooling
- Cold duct with trim device to regulate lander internal temperatures



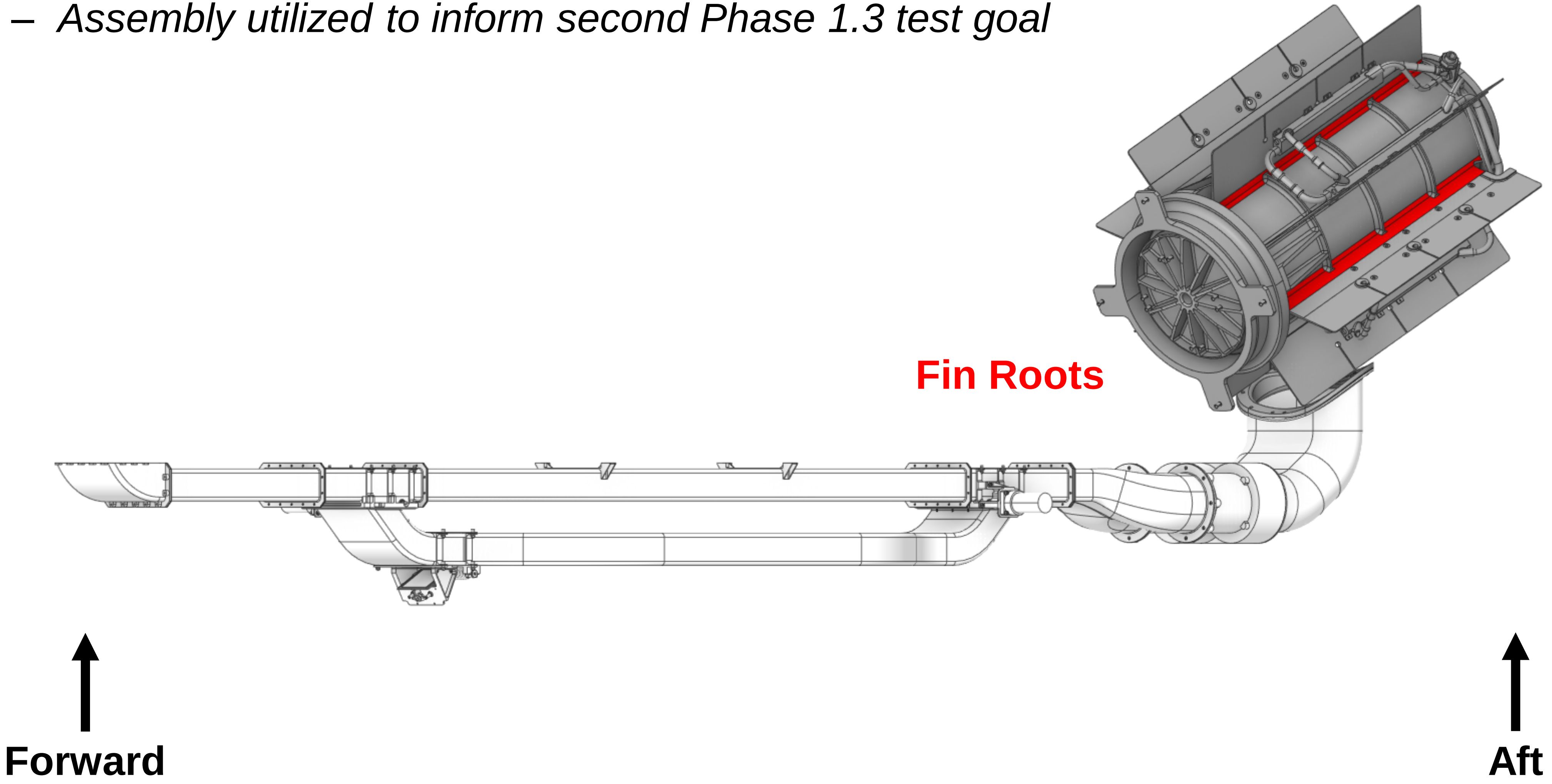
DTM THERMAL CONTROL KEY COMPONENTS

- Lander air management assembly
  - *Assembly utilized to inform first Phase 1.3 test goal*



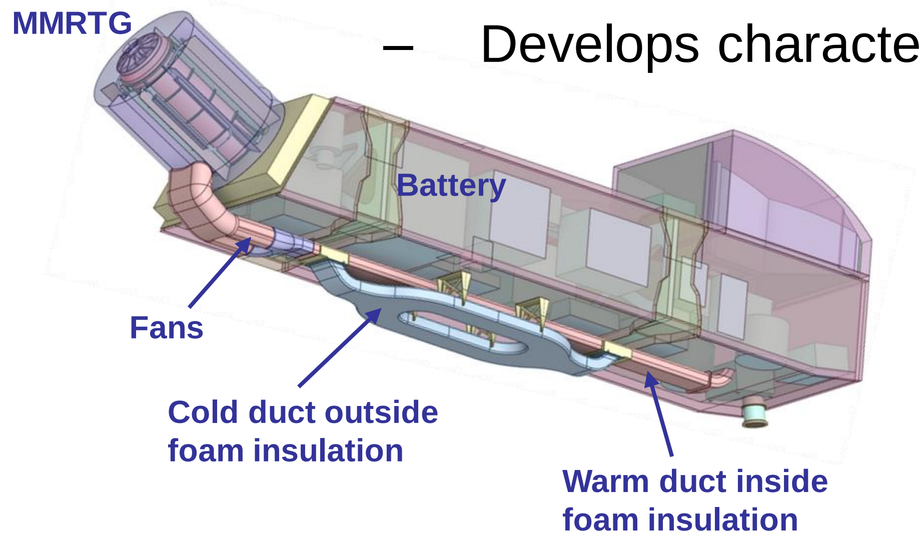
DTM THERMAL CONTROL KEY COMPONENTS

- MMRTG TSIM
  - *Assembly utilized to inform second Phase 1.3 test goal*



PHASE 1.3 TEST GOALS

1. Determine Flight-Like Cold Duct Heat Rejection Capacity
   – Nullifies local flow velocity around cold duct
   – Reassesses heat rejection capacity of flight-like cold duct in ~0 m/s wind conditions
   – Validates heat rejection rate as a function of cold duct trim device angle
2. Understand MMRTG Thermal Management
   – Configures TSIM to maximum thermal output
   – Optimizes MMRTG fin root temperatures for maximum electrical power output
   – Modulates battery temperature via cold duct trim device aperture adjustments
   – Develops characteristic curve for fin root temperature as a function of fan speed



DTM Thermal Control Key Components
- **MMRTG TSIM to provide power and heat to lander**
- **Foam insulation to conserve MMRTG TSIM heat**
- **Fans to facilitate convective cooling**
- **Cold duct with trim device to regulate lander internal temperatures**

PHASE 1.3 TEST GOALS

1. Determine Flight-Like Cold Duct Heat Rejection Capacity

Titan Chamber:
0.5 atm, ambient natural convection, -180ºC (i.e., "dead" calm, worst case for cold duct)

- Nullifies local flow velocity around cold duct
- Reassesses heat rejection capacity of flight-like cold duct in ~0 m/s wind conditions
- Validates heat rejection rate as a function of cold duct trim device angle

2. Understand MMRTG Thermal Management

Titan Chamber:
0.5 atm & 0.92 atm, ambient forced convection, -180ºC

- Configures TSIM to maximum thermal output
- Optimizes MMRTG fin root temperatures for maximum electrical power output
- Modulates battery temperature via cold duct trim device aperture adjustments
- Develops characteristic curve for fin root temperature as a function of fan speed

PHASE 1.3 TEST CASES

Case	Configuration	Measurement
Reference Cases: Cold Duct Heat Rejection under Ambient Forced Convection, 0.5 & 0.92 atm	• Ambient forced convection in effect due to absence of baffle box surrounding flight-like cold duct • -180ºC ambient temperature • Equivalent MMRTG heat source: MMRTG TSIM • Replicates previous testing (i.e., Phase 1.2) to assess variations introduced by flight-representative split cold duct, cold duct trim device prototype with test motors, and MMRTG TSIM	Cold duct heat rejection rate
Cold Duct Heat Rejection under Ambient Natural Convection, 0.5 atm	• Ambient natural convection effects produced via baffle box surrounding flight-like cold duct • -180ºC ambient temperature • Equivalent MMRTG heat source: MMRTG TSIM	Cold duct heat rejection rate
MMRTG Thermal Management under Ambient Forced Convection, 0.5 & 0.92 atm	• Ambient forced convection in effect due to absence of baffle box surrounding flight-like cold duct • -180ºC ambient temperature • Equivalent MMRTG heat source: MMRTG TSIM	Fin root average temperature

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PHASE 1.3 TEST CASES

Case	Chamber Pressure [atm]	Battery Temperature, T_b [^oC]	Fin Root Temperature, T_{fr} [^oC]	Cold Duct Trim Device Configuration	Heat Input(s) [W]
Reference Cases: Cold Duct Heat Rejection under Ambient Forced Convection, 0.5 & 0.92 atm	0.5	$T_{b0} = 0$	N/A	Closed	TBD (Trimmed to meet T_{b0})
	0.5	$T_{b0} = 0$	N/A	Angle sweep from closed to near max aperture	TBD (Trimmed to meet T_{b0})
	0.5	$T_{b0} = 0$	N/A	Fully open	TBD (Trimmed to meet T_{b0})
	0.92	$T_{b0} = 0$	N/A	Closed	TBD (Trimmed to meet T_{b0})
	0.92	$T_{b0} = 0$	N/A	Angle sweep from closed to near max aperture	TBD (Trimmed to meet T_{b0})
	0.92	$T_{b0} = 0$	N/A	Fully open	TBD (Trimmed to meet T_{b0})
Cold Duct Heat Rejection under Ambient Natural Convection, 0.5 atm	0.5	T_{b1}	N/A	Fully open	1850
	0.5	T_{b1}	N/A	Closed	TBD (Trimmed to meet T_{b1})
	0.5	T_{b1}	N/A	Angle sweep from closed to near max aperture	TBD (Trimmed to meet T_{b1})
	0.5	T_{b2}	N/A	Fully open	TBD* (Trimmed to meet T_{b2})
	0.5	T_{b2}	N/A	Closed	TBD* (Trimmed to meet T_{b2})
MMRTG Thermal Management under Ambient Forced Convection, 0.5 & 0.92 atm	0.5	$T_{b3} = 20$	$120 \leq T_{fr} \leq 140$	Adjusted to meet T_{b3}	1400 (TBR)
	0.92	$T_{b3} = 20$	$120 \leq T_{fr} \leq 140$	Adjusted to meet T_{b3}	1850 (TBR)
	0.92	$T_{b3} = 20$	$120 \leq T_{fr} \leq 140$	Maintain angle from previous case; vary fan speed and assess changes to T_{fr}**	1850 (TBR)

*Additional heater input needed to maintain battery above 0^oC.

**Generates T_{fr} versus fan speed curve.

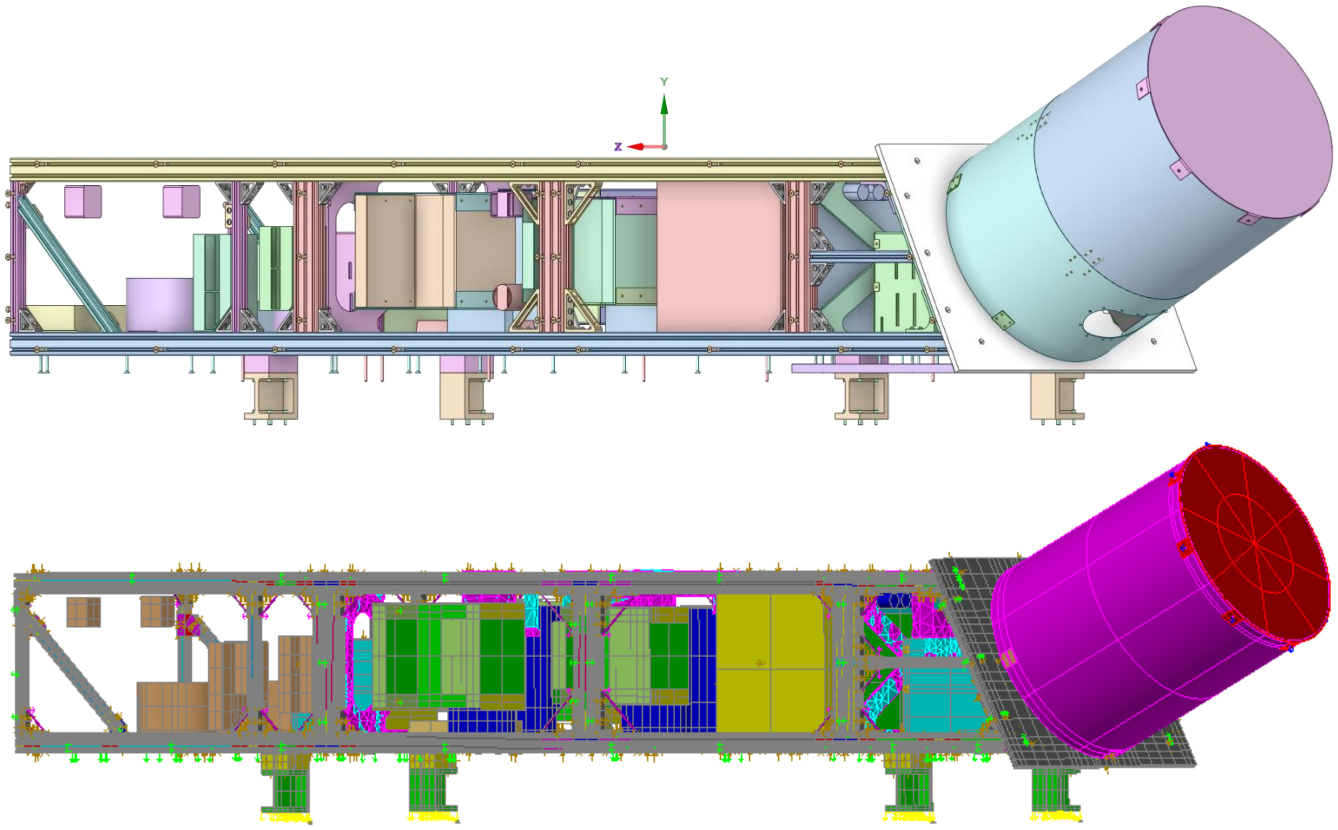
MODEL-DRIVEN SOLUTIONS ALIGNED WITH MOTIVATION

- DTM model correlation in Thermal Desktop expected to enhance confidence in lander model, critical for mission success
- DTM correlation enables alignment between CFD lander model and Thermal Desktop lander model in Titan hibernation, ensuring temperature predictions match test data in convective environments
- DTM correlation can inform modeling that consolidates data across all thermal cases (e.g., cruise, entry, descent, landing, Titan convection), commissioning a comprehensive source of information

One of the key objectives is to consolidate a comprehensive, trustworthy resource for thermal data across all cases in Thermal Desktop. Another objective is to resolve the key uncertainty in Thermal Desktop modeling: accurately representing convection and ensuring alignment with CFD results.

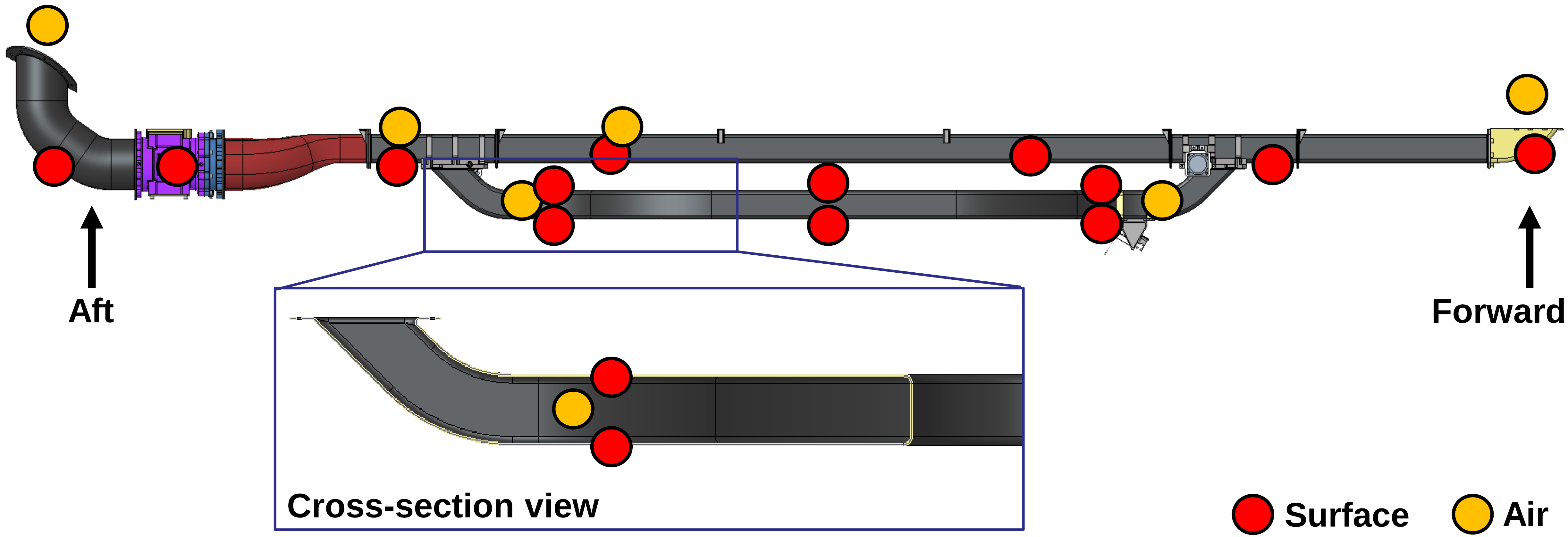
MODELING OVERVIEW

- Image on bottom right illustrates current state of DTM Thermal Desktop model
- Phase 1.3 model includes
  - 80/20 frame
  - All internal components
  - TSIM can and mounting configuration
  - Standoffs
  - Conductive interfaces between components
  - Convection and ambient temperature conditions
  - Representative optical and thermophysical properties



LANDER AIR MANAGEMENT ASSEMBLY THERMOCOUPLES

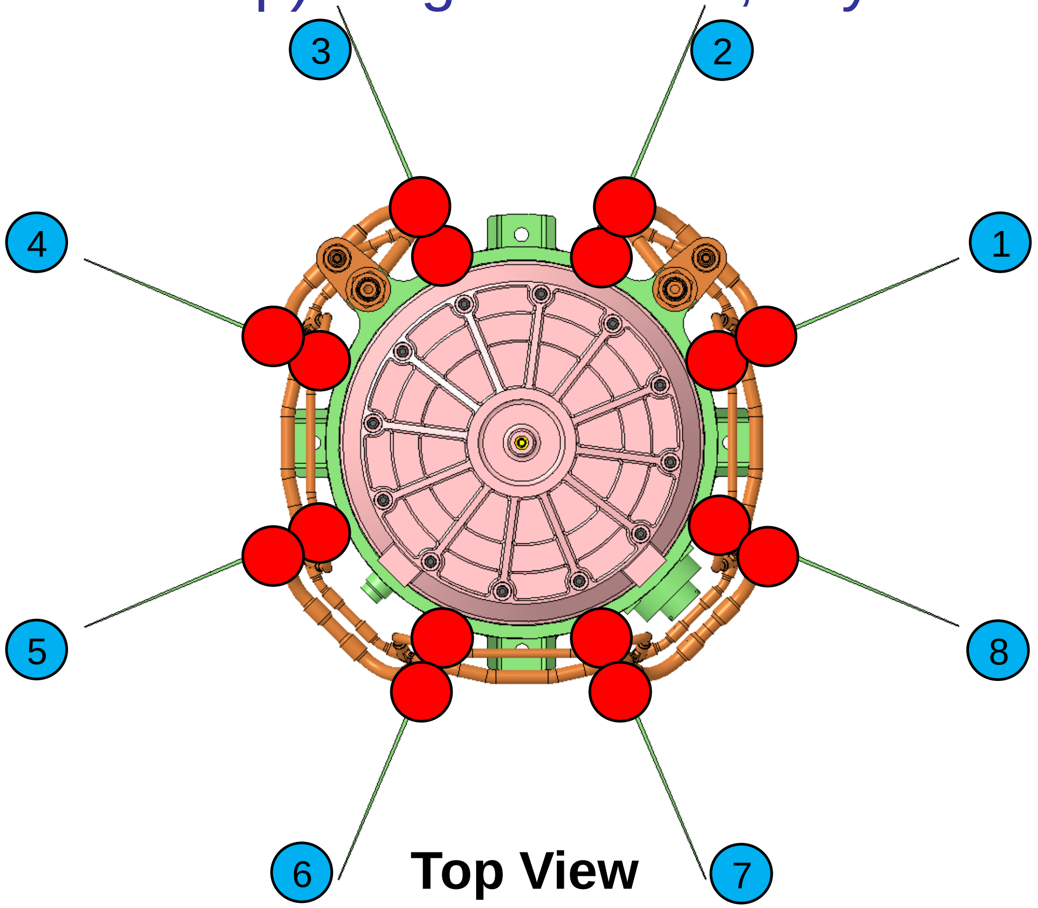
- Ansys SpaceClaim facilitates capture of intricate geometry and accurate definition of thermocouple locations (i.e., “Temperature Measures” in Thermal Desktop) for goal-driven, key model thermal control components

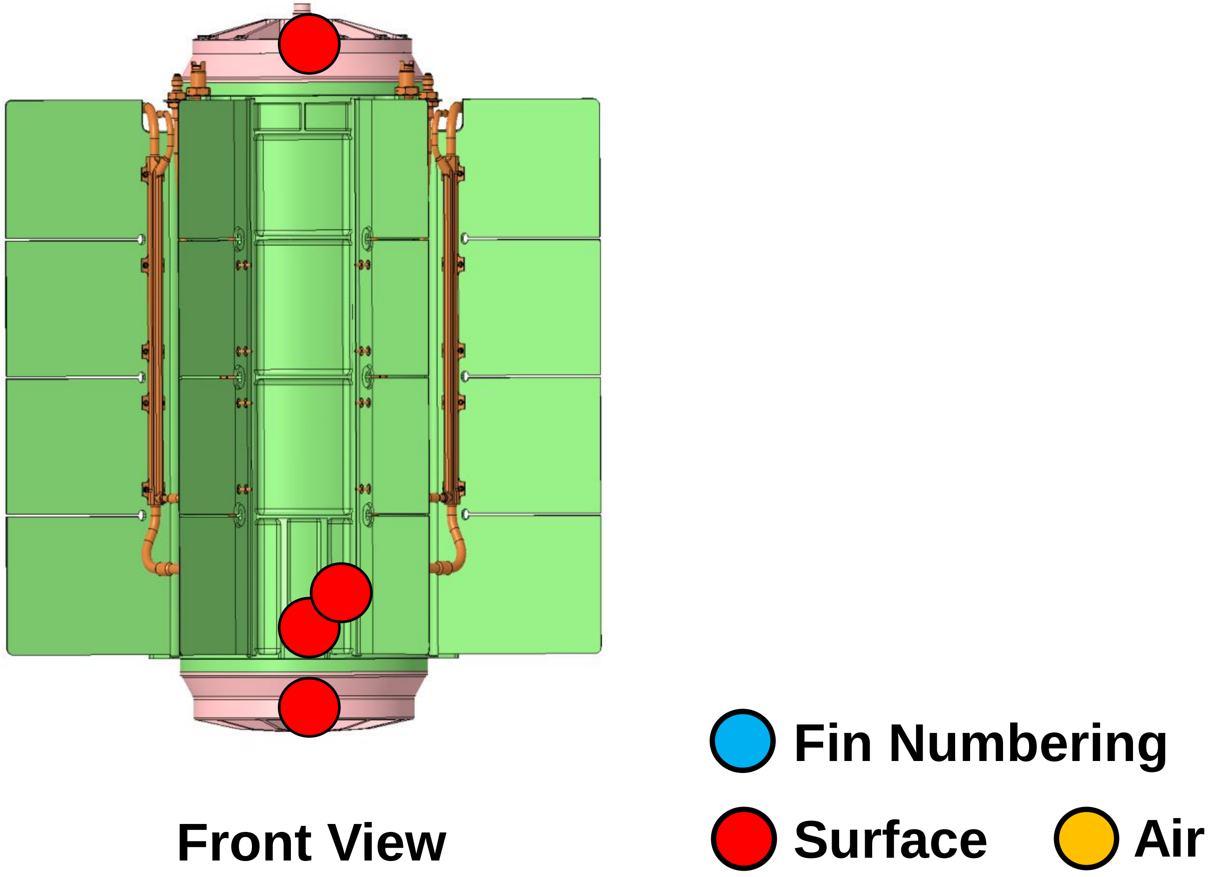


Slide figure credit: Dahway Lin

MMRTG THERMAL SIMULATOR THERMOCOUPLES

- Ansys SpaceClaim facilitates capture of intricate geometry and accurate definition of thermocouple locations (i.e., “Temperature Measures” in Thermal Desktop) for goal-driven, key model thermal control components





Slide figure credit: Dahway Lin

FUTURE WORK

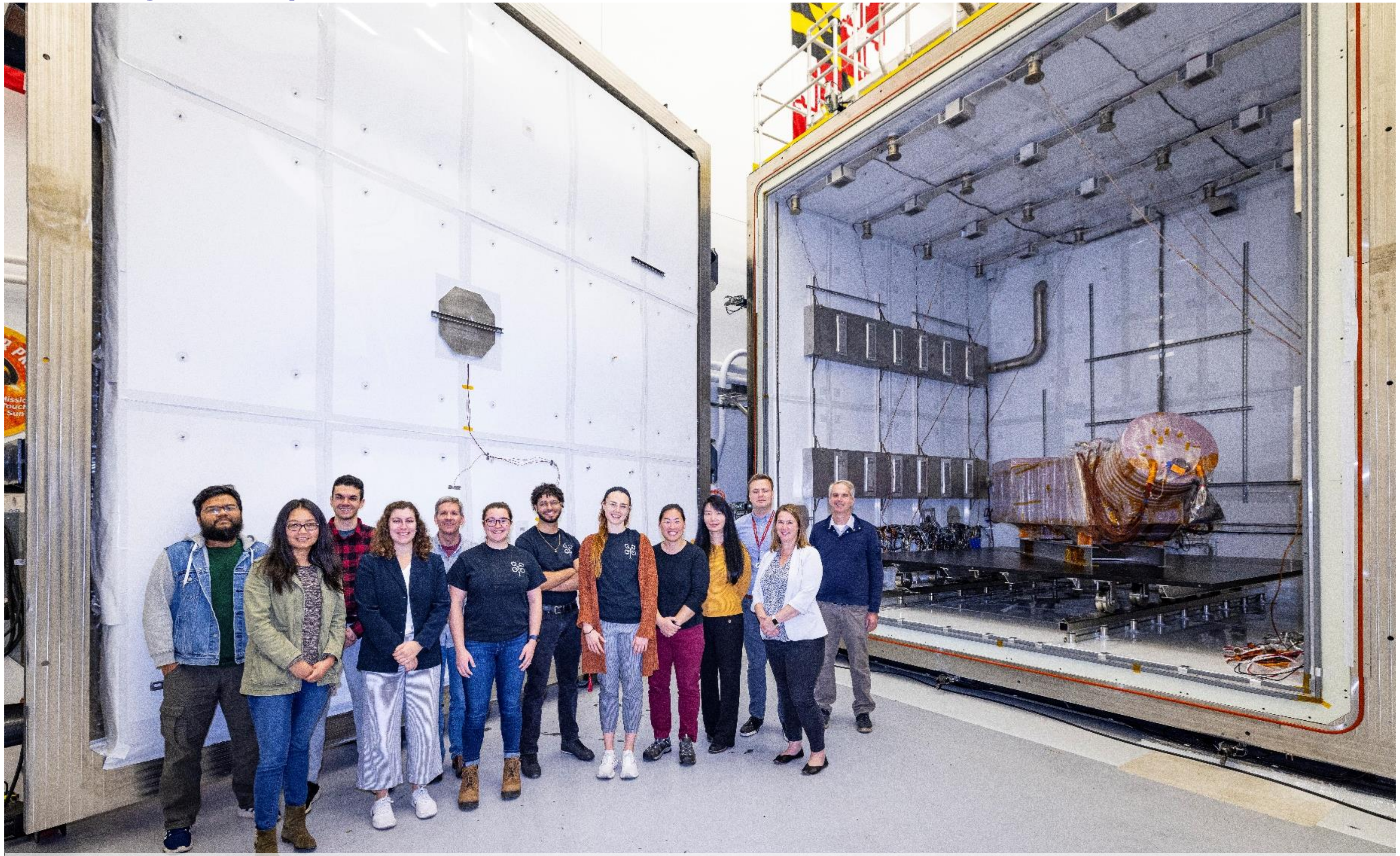
- Defeature, mesh, and integrate Lander Air Management Assembly into model
- Extract MMRTG model and fluid flow topology from the full lander model, modify it to align with TSIM configuration used in Phase 1.3, and integrate into Thermal Desktop
- Defeature, mesh, and integrate foam design utilized in DTM Phase 1.3 testing
- Configure DTM internal airflow network
- Produce preliminary temperature estimates that correspond to thermocouple locations on DTM
- Tune following parameters:
  - Material (e.g., insulative polystyrene) thermal conductivity, *k*
  - Convective heat transfer coefficient, *h*
  - Contact conductances

DTM PATH FORWARD

- Upon correlating model associated with current phase of testing (i.e., Phase 1.3), DTM Thermal Desktop model will be updated to Phase 2.0
- Phase 2.0 will incorporate:
  - Flight-like foam integration
  - Attachment methods representative of Dragonfly lander
  - Foam encapsulation for particulate mitigation
  - Seam sealing for heat leak prevention
  - MMRTG thermal simulator and mounting configuration
  - Cold duct trim device mechanism control verification
- Phase 2.0 model correlation data will be utilized to validate heat leak margins against current estimates in Lander Thermal Exterior Losses calculations
- In interim, objective is to correlate Thermal Desktop DTM model with Phase 1.3 testing prior to Therm-Mech CDR slide submission in December

THANK YOU!

- I will now take your questions at this time.



Several Members of DTM Team Posing Next to Module in Titan Chamber

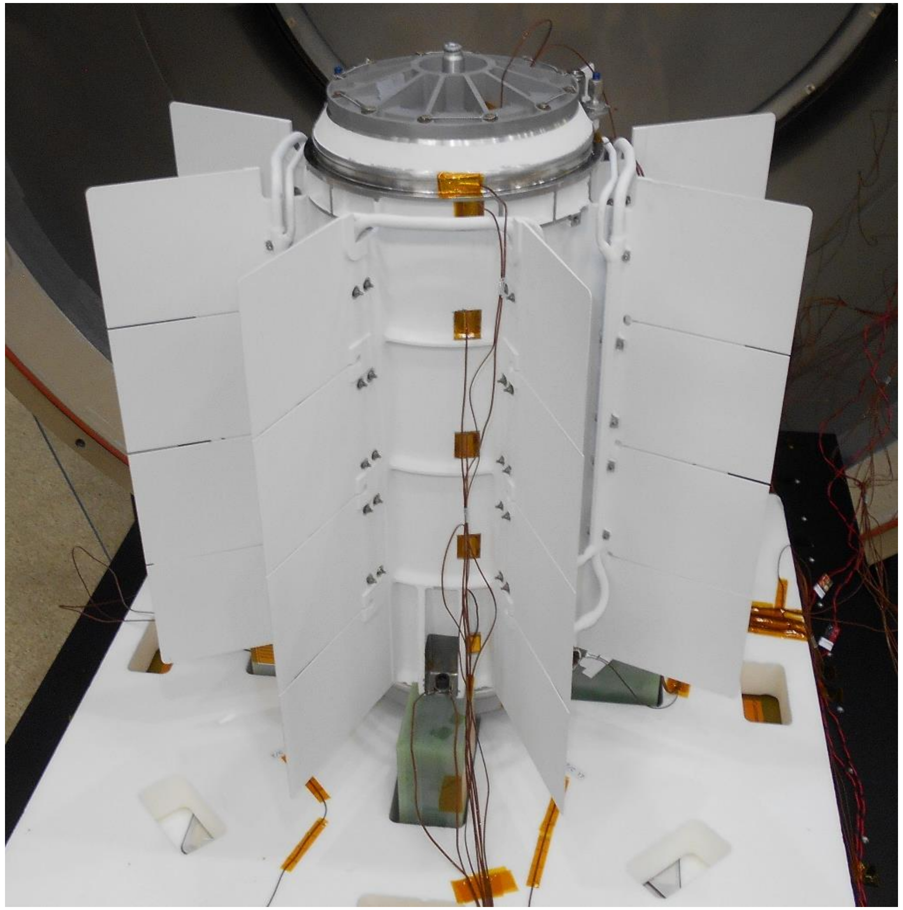
Image credit: NASA/Johns Hopkins APL/Ed Whitman

BACKUP SLIDES

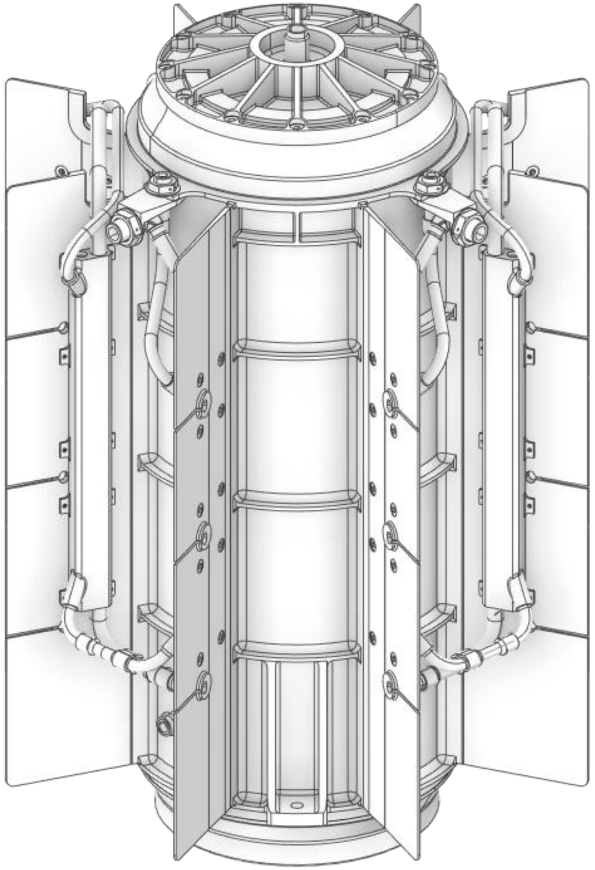
DTM SENSORS

- 231 thermocouples (TCs) measure temperatures across DTM
  - 130 TCs pass through can bulkhead
  - 101 TCs pass through alternative locations
- 15 IST FS7 air flow sensors measure air velocity across DTM
- 4 Omega PX275 differential pressure sensors measure the pressure drop across the flow loop
  - Sensors compare pressures across two ports
  - Ports are connected to measurement points within DTM via tube
- Chamber convection measured with convection puck sensors
  - Aluminum disk with heater and thermocouple attached

MMRTG THERMAL SIMULATOR



Mars Science Laboratory Thermal Simulator
Image credit: Johns Hopkins APL/James Parkus



MMRTG Thermal Simulator for Use on DTM