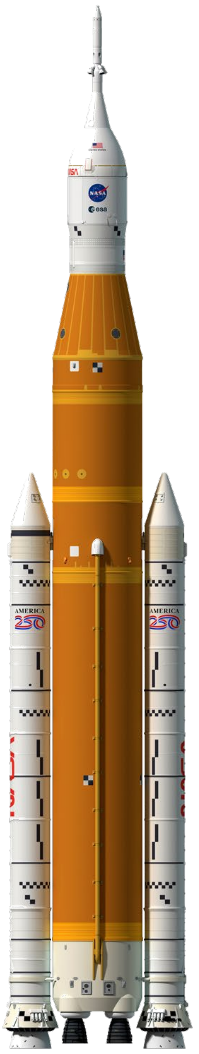
Artemis II Mission Performance of the Orion Active Thermal Control System



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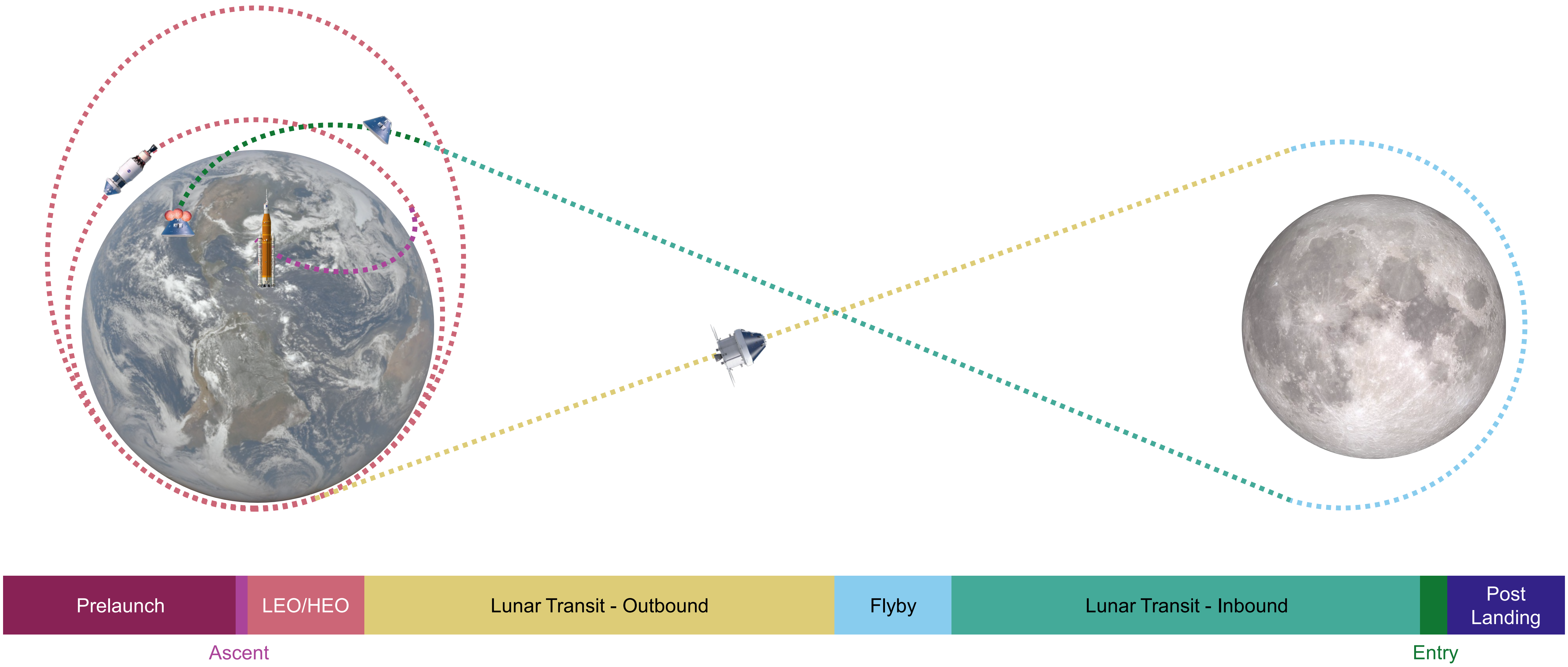
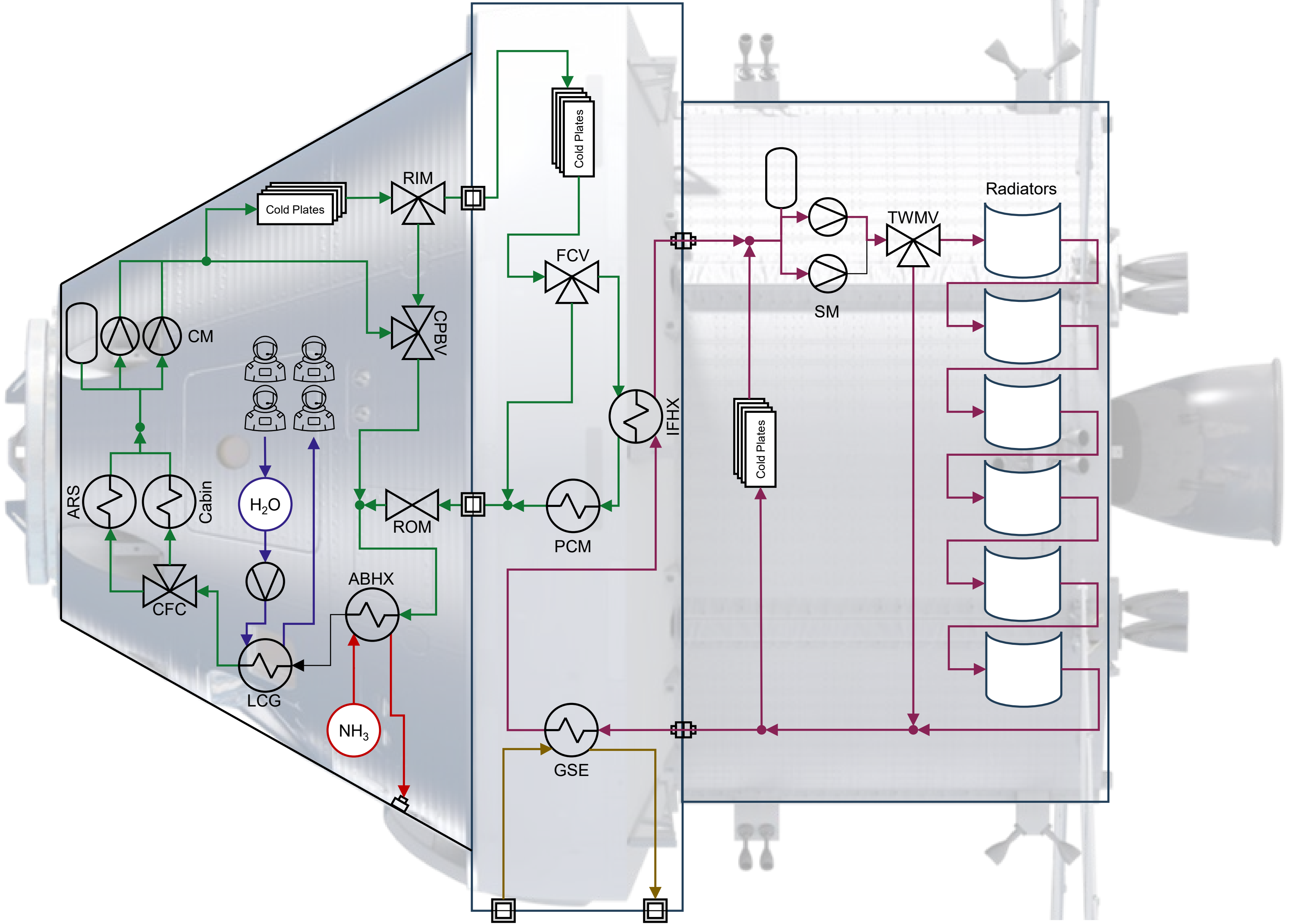
Introduction

- Artemis II launched on April 1, 2026 – first crewed mission to the moon in 54 years
- Orion is the exploration spacecraft that carries and sustains the crew
  - Launch Abort System
  - Crew Module
  - Crew Module Adapter
  - European Service Module
  - Spacecraft Adapter/Jettisonable Panel
- Active Thermal Control System (ATCS) is responsible for managing crew and vehicle heat loads
- Orion Integrated Thermal Model (ITM) used to bound hot and cold mission cases for nominal and contingency scenarios

Artemis II Mission Profile



ATCS Overview



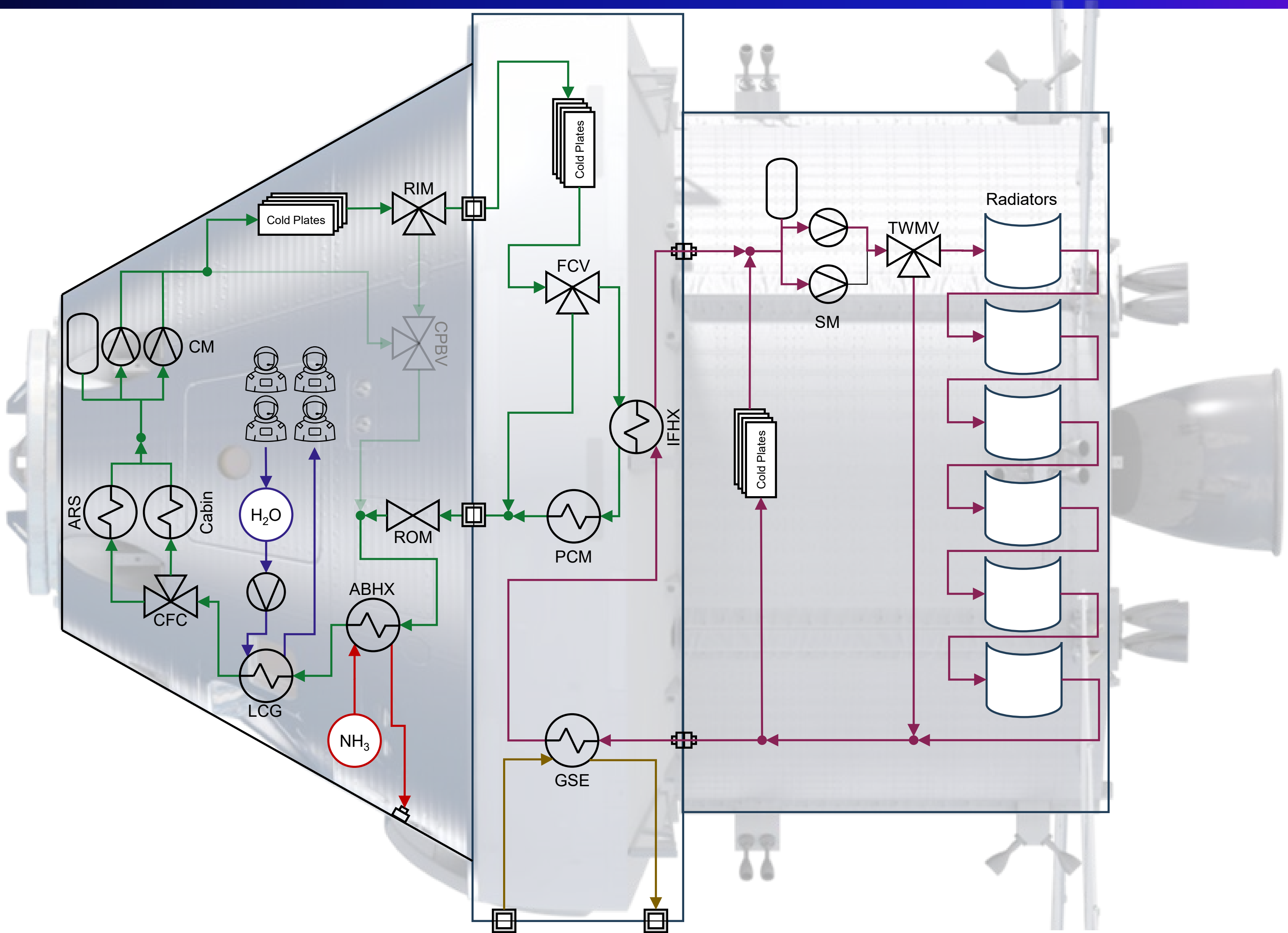
Heat Exchangers
- IFHX – Interface Heat Exchanger
- PCM – Phase Change Module Heat Exchanger
- GSE – Ground Support Equipment Heat Exchanger
- ARS – Air Revitalization System Heat Exchanger
- Cabin – Cabin Heat Exchanger
- LCG – Liquid Cooling Garment Heat Exchanger
- ABHX – Ammonia Boiler Heat Exchanger

Pumps
- CM - Crew Module Pumps
- SM - Service Module Pumps

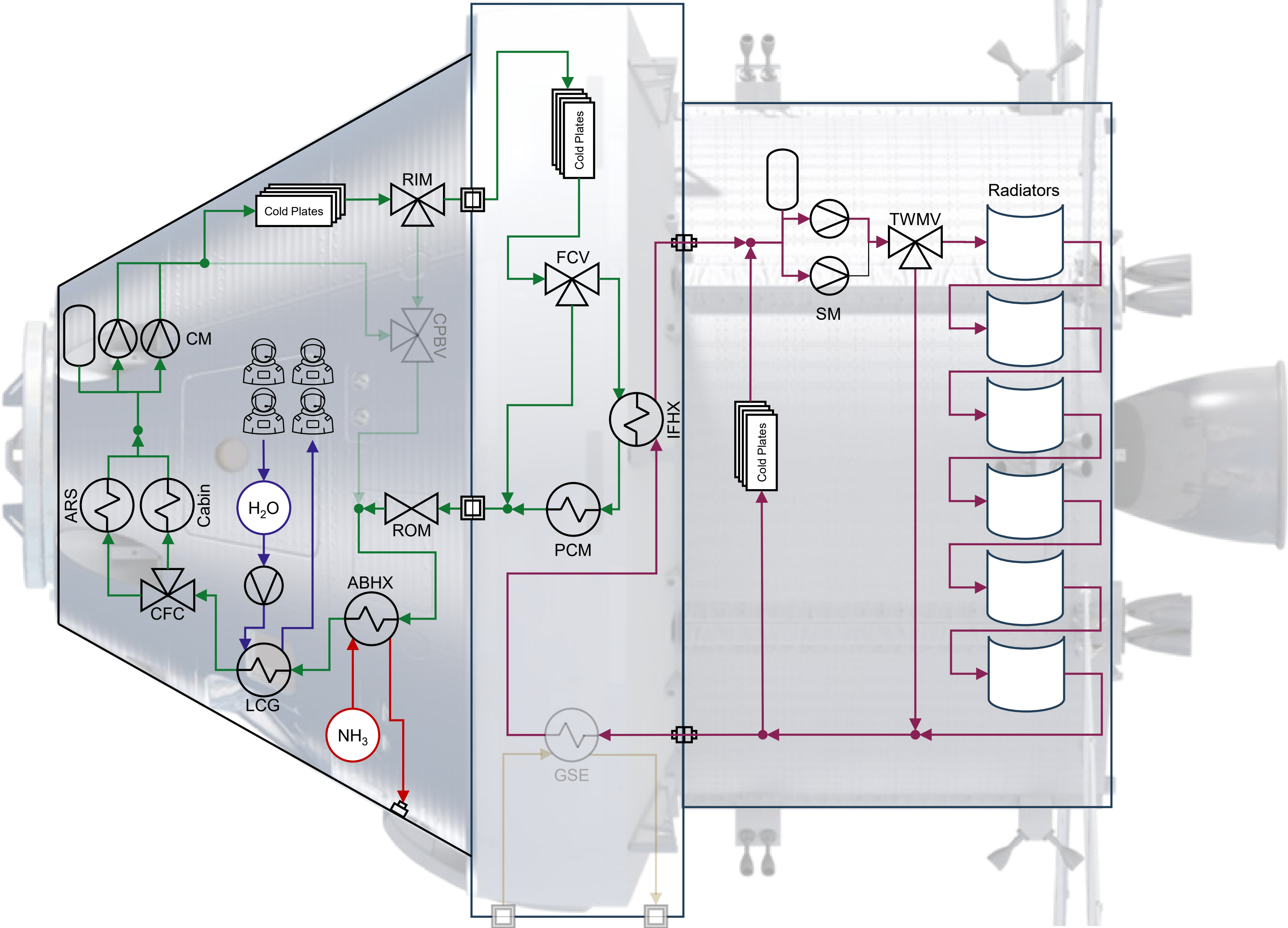
Valves
- CFC – Coolant Flow Control Valve
- FCV – Flow Control Valve
- TWMV – Three-Way Mixing Valve
- RIM – Radiator Inlet Manifold Valve
- ROM – Radiator Outlet Manifold Valve
- CPBV – Cold Plate Bypass Valve

Working Fluids
- HFE – Hydrofluoroether
- PGW – Propylene Glycol/Water
- NH_3 – Ammonia
- H_2O – Water
- GR – Ground Refrigerant

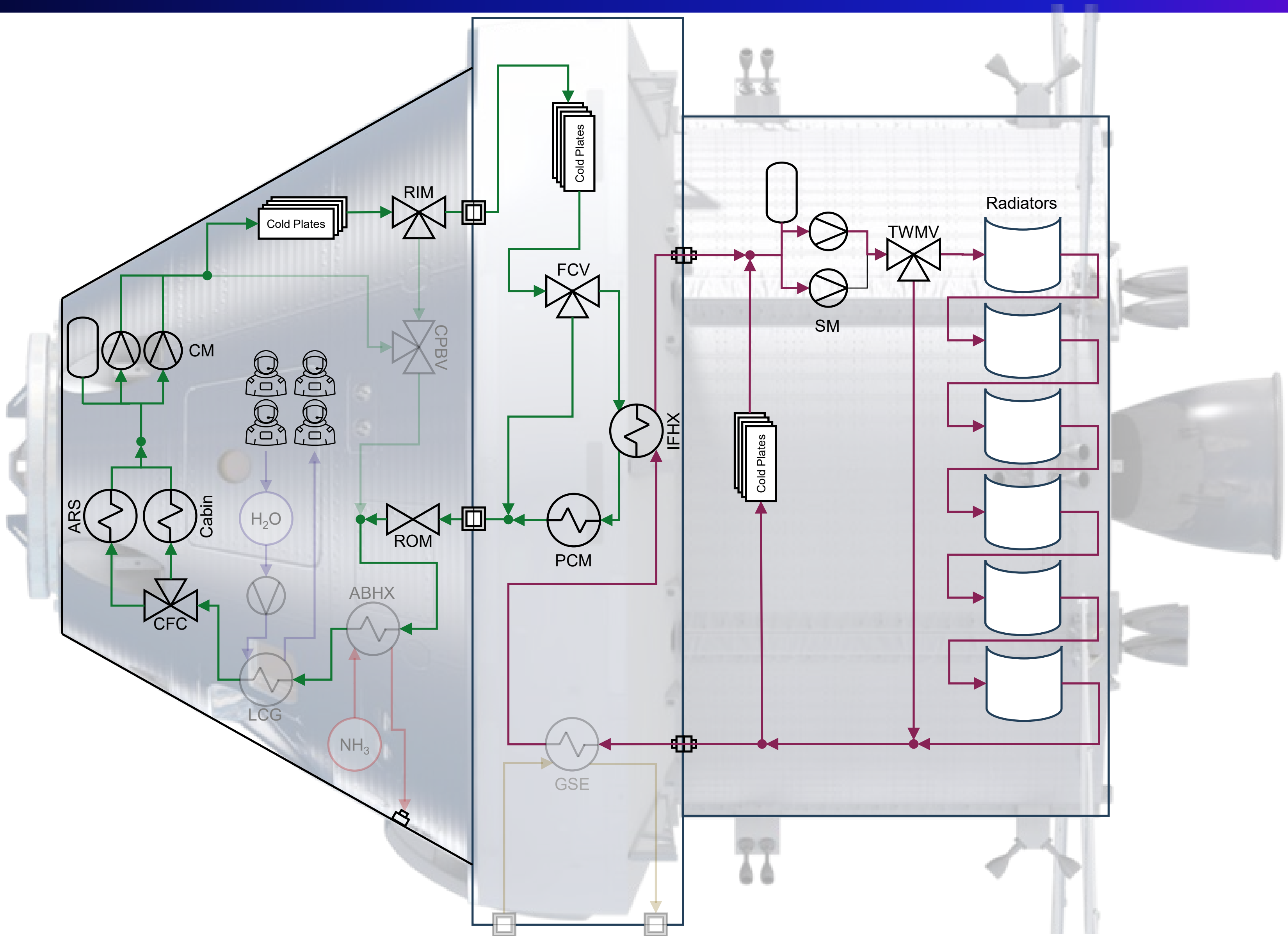
ATCS Overview - Prelaunch



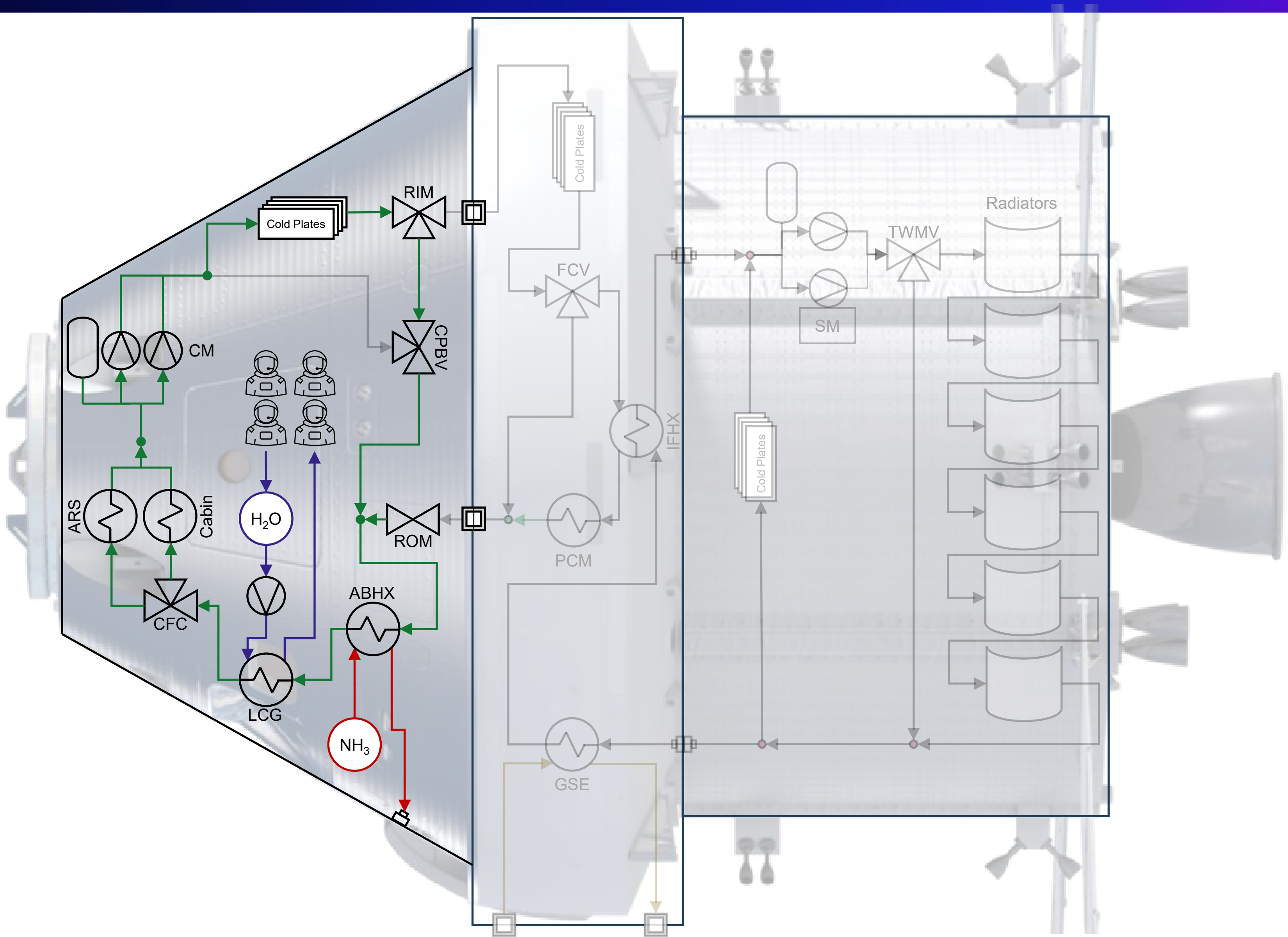
ATCS Overview – Ascent



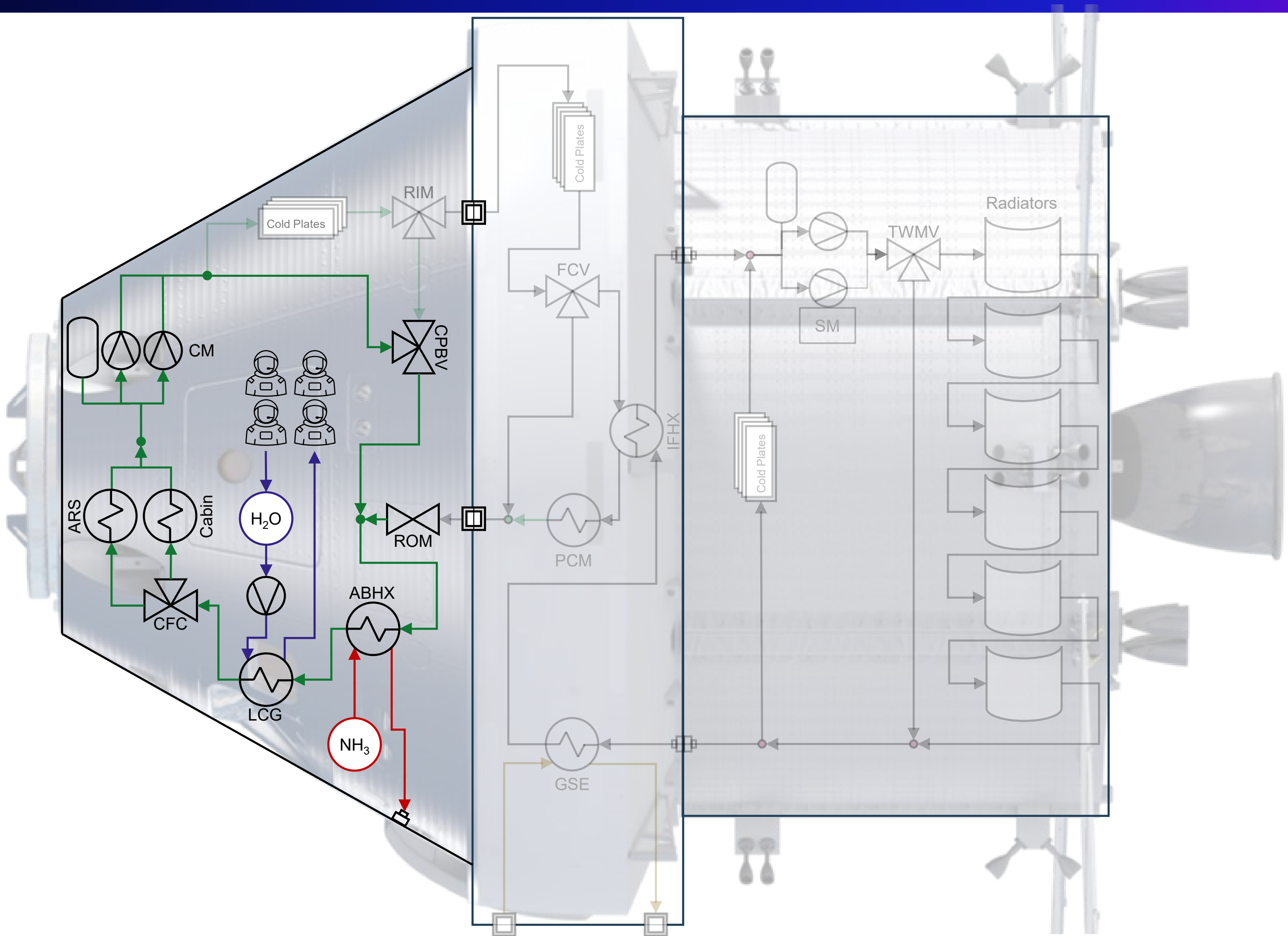
ATCS Overview – Earth Orbit, Lunar Transit, &Flyby



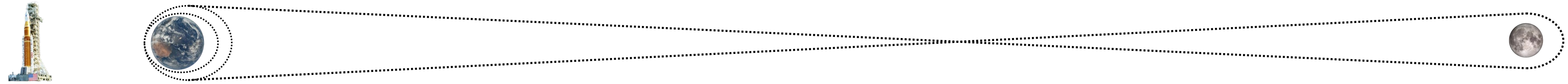
ATCS Overview – Entry



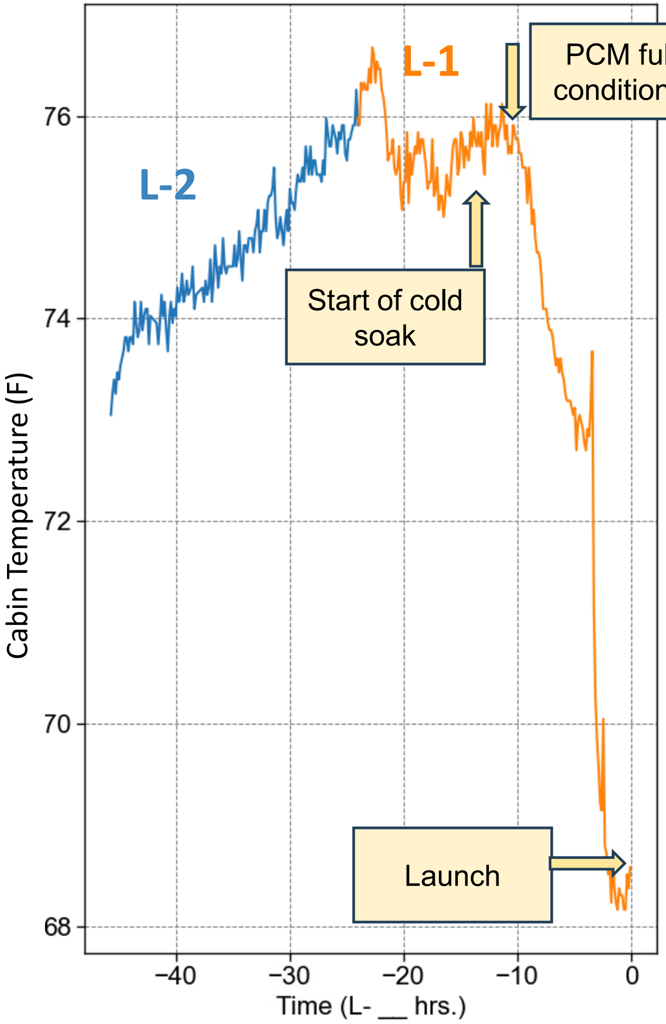
ATCS Overview – Post Landing

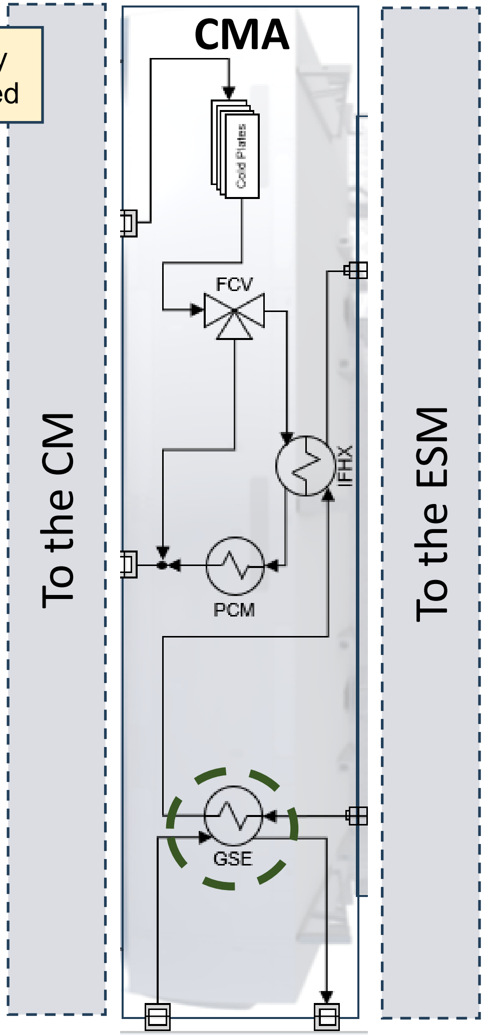


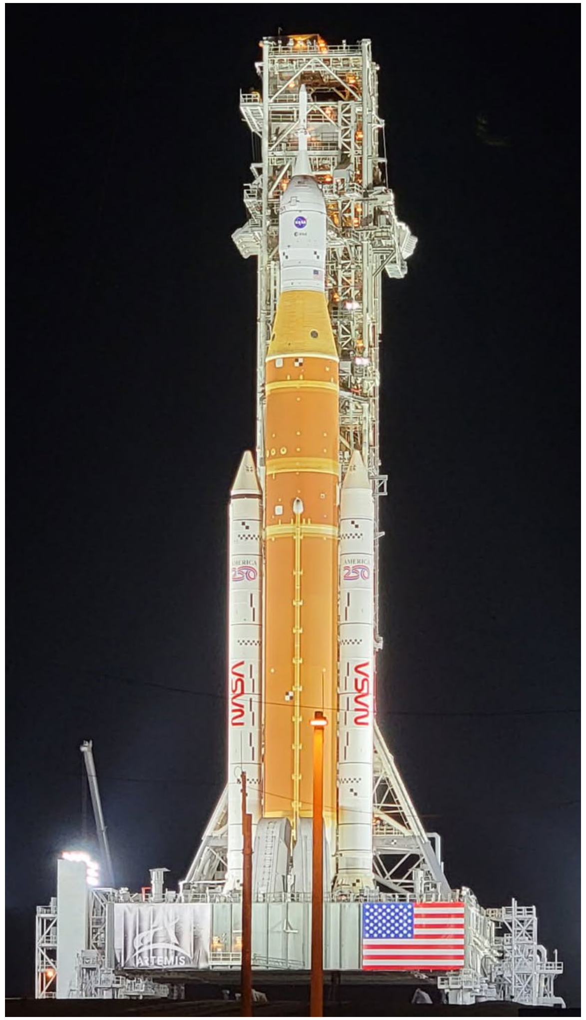
Prelaunch



- Cold Soak Orion on pad to prepare for heat loads of launch
  - Cold freon provided to radiator loops by ground systems
  - Cool/Dry purge air on Service Module, under Launch Abort System, and Crew Module backshell.
  - Cool off ATCS systems, cabin air, etc.
  - Freeze Phase Change Material Heat Exchanger – first freeze < 50 degF

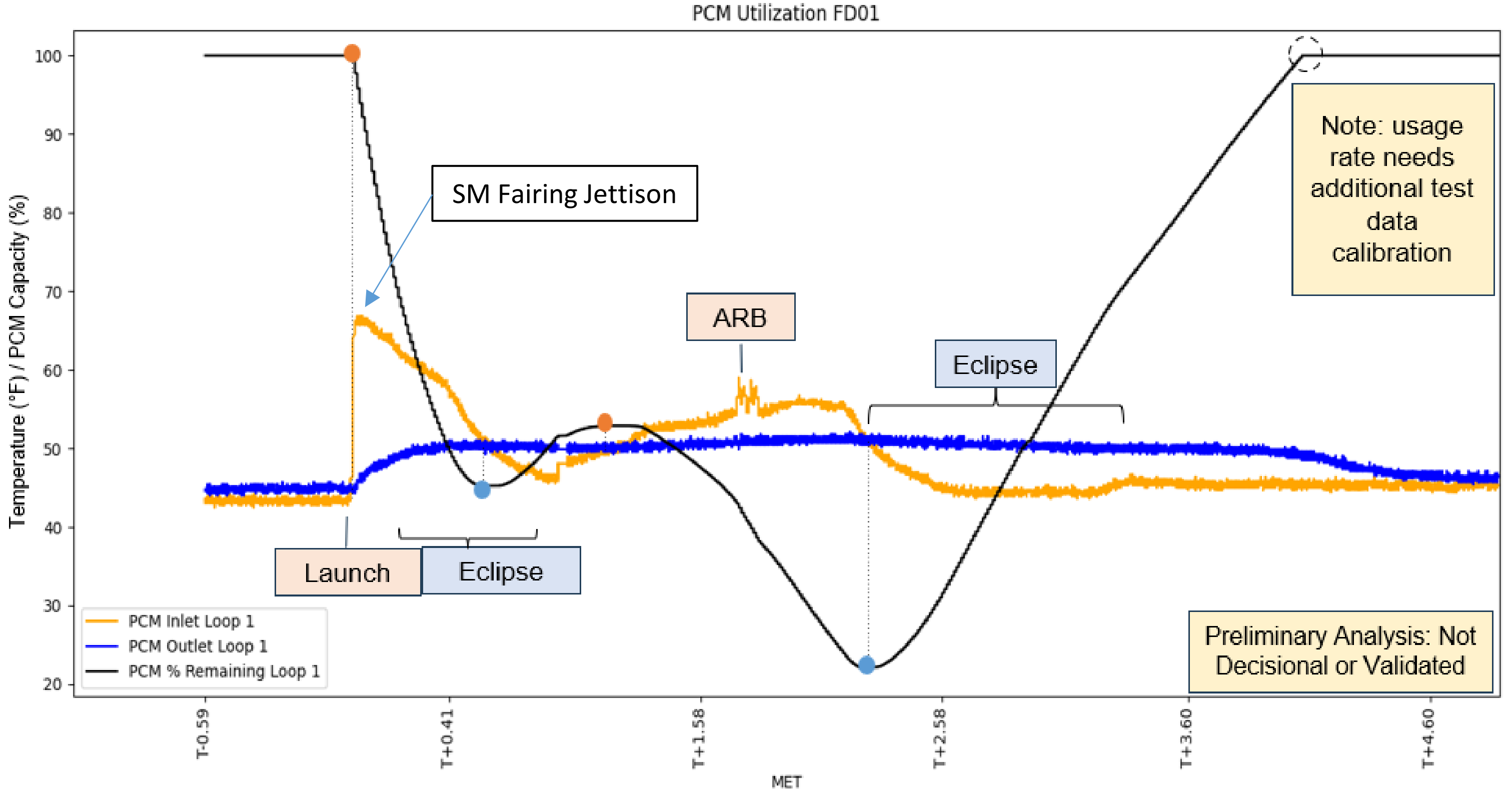






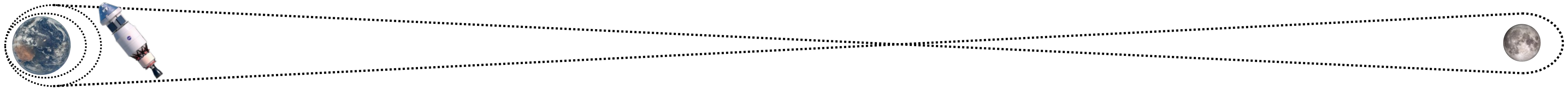
Ascent

- Ground Cooling disconnects just before launch
- Temperatures rise sharply in the radiator loops (not shown) and the IFHX outlet of the PGW coolant loops during ascent heat loads (yellow)
- PCM maintains temperature of coolant loops at 50 degF throughout ascent (blue)
- Radiators start helping to cool after SM-fairing jettison
- AR2 launched in the evening into eclipse (ideal case), recharging PCM
- The ammonia boilers are standing by ready to add supplemental cooling. Up to 7 lbs is budgeted for ascent, but not needed because of AR2 eclipse phasing.
- As we leave Earth behind, the radiators can take the full cooling load

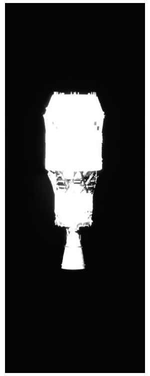


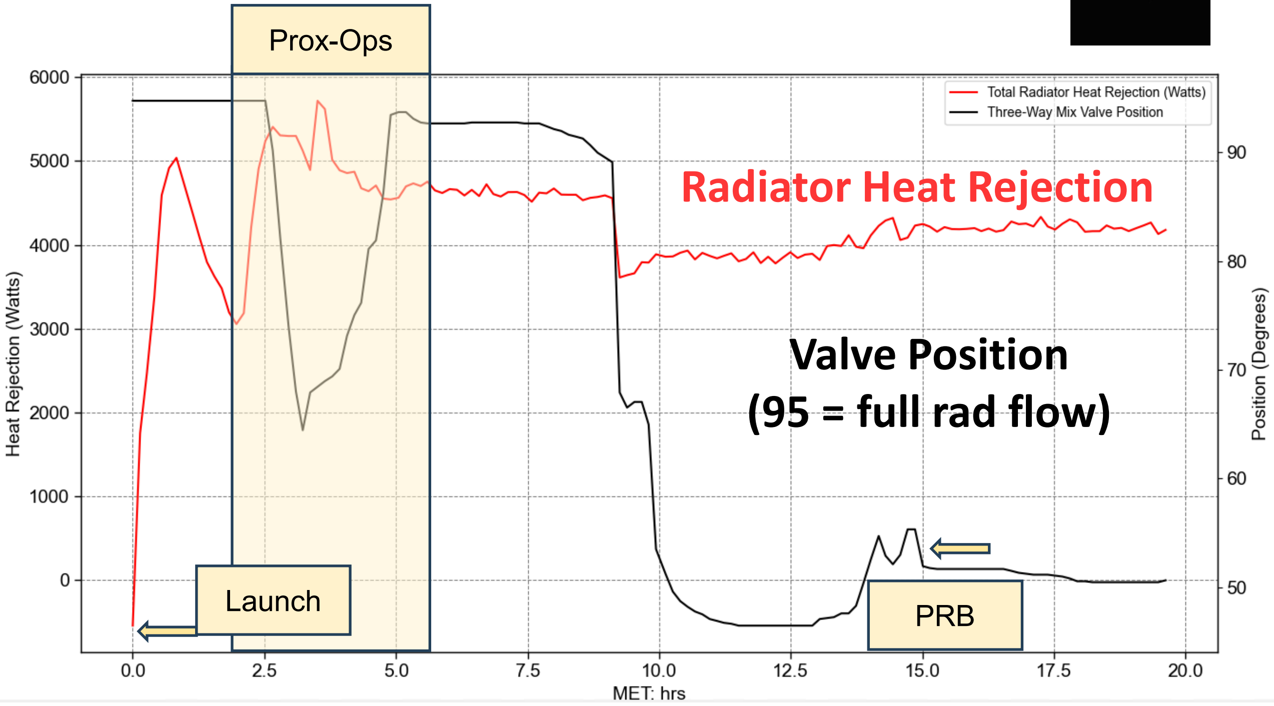
PCM usage during ascent is highly dependent on eclipse timing and is a driving factor in whether or not ammonia is used during this phase.
PCM will always *reduce* ascent ammonia usage.

Earth Orbit (LEO + HEO)



- Proximity Operations (Prox-Ops): manual piloting activities after ICPS separation
- Prox-Ops is a transient phase of flight. Radiator control is sensitive to changing attitudes and view factors



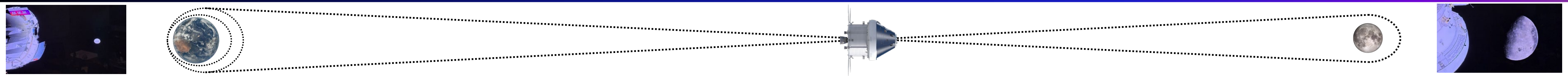


- Crew reported cabin temperatures were colder than desired in the first ~14 hrs of flight. What are some knobs we can turn?

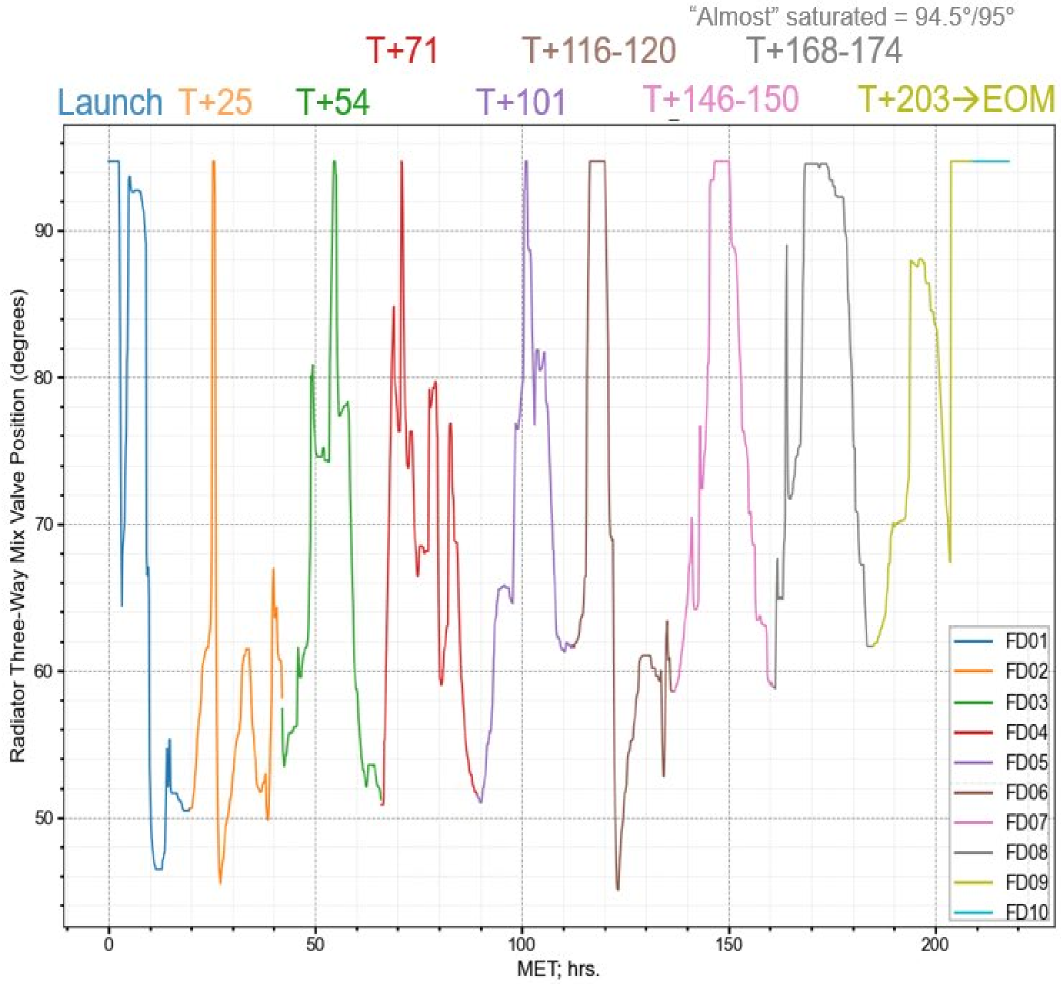
Desire to *Raise* Cabin Temperature

Lower PGW Flow	Actuate FCV	Raise PV Heater Setpoints	Raise Rad Mix Temp Setpoints
Less heat rejected to IFHX = warmer PGW	N/A until FD09 (FCV DFTO)	Increases cabin wall temperature	Raises HFE temps through IFHX
Small impact to cabin temp	AR2 pre-flight mitigations constrain FCV position	PV temps and cabin air temps are well-coupled	Direct impact to PGW temps; limited by PCM state

Lunar Transit

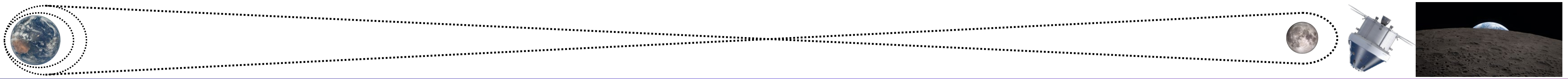


- Lunar transit is a relatively stable phase of flight where radiators drive heat rejection
- Radiator saturation occurs during attitude maneuvers or periods of increased demand
- The PCM acts as a “buffer” for heat load absorption before ammonia is used – PCM holds PGW mix temperature around 50 degF until depleted.

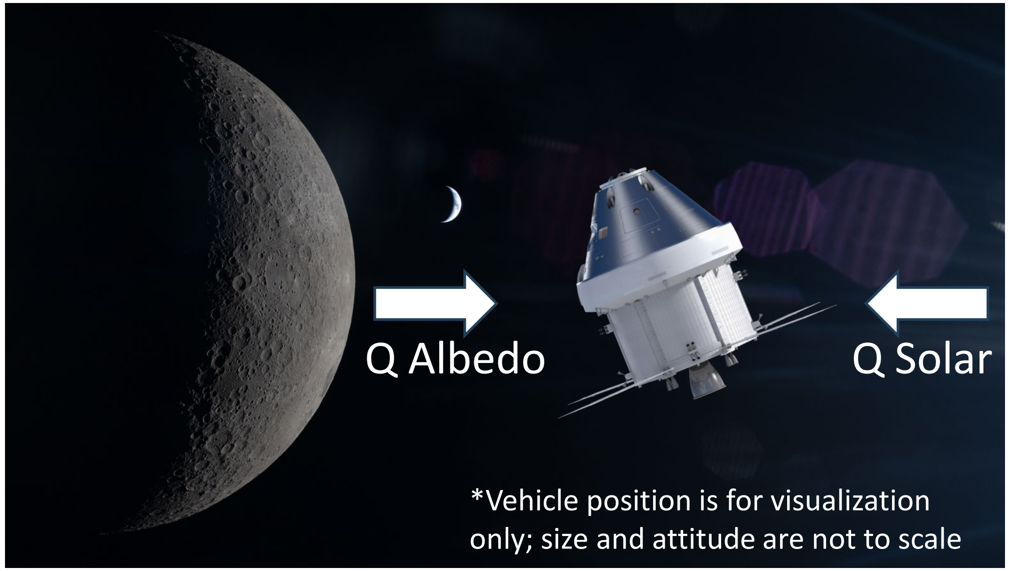


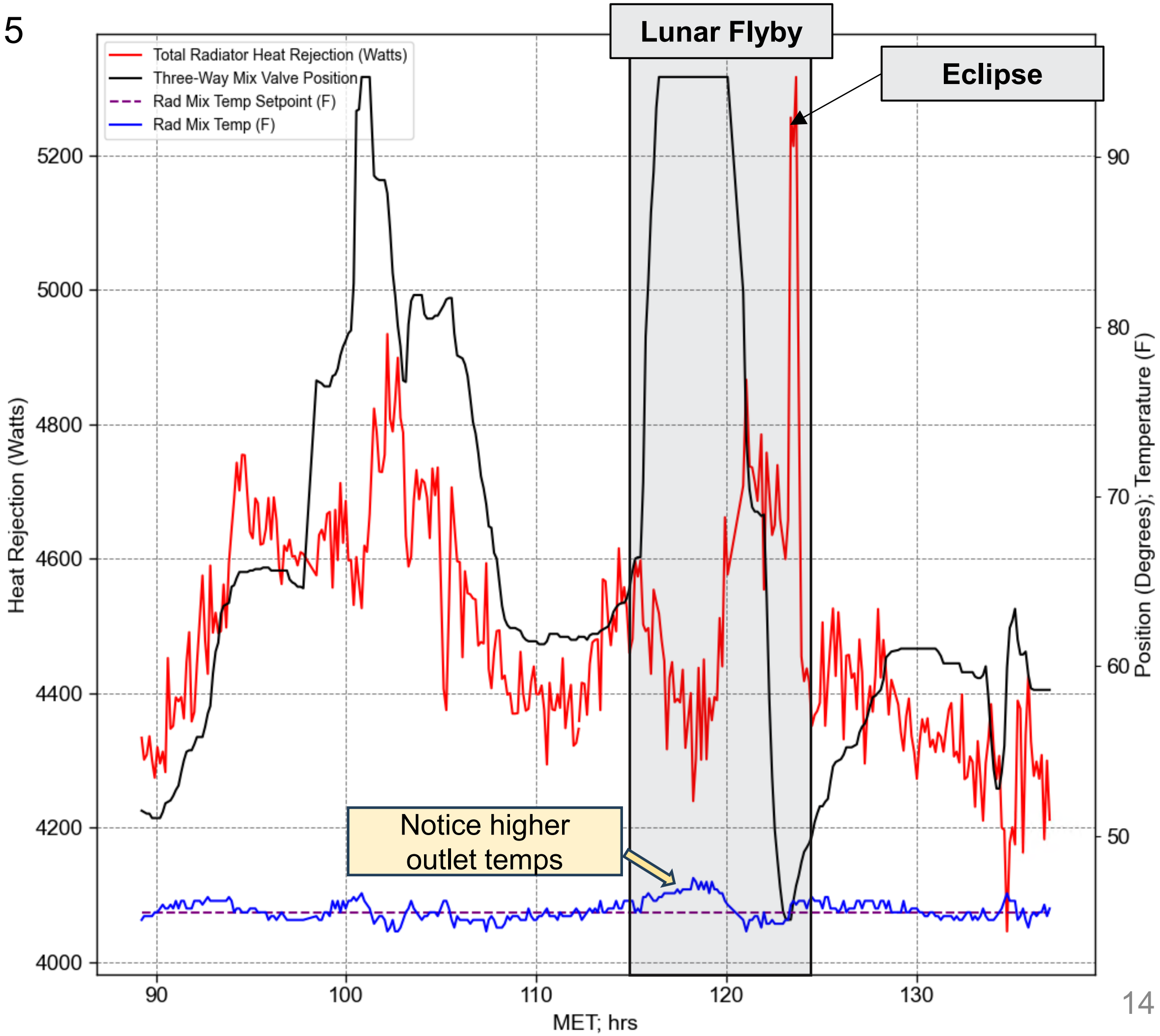
MET	Event
T+25	TLI Completion
T+54	Emergency Com DFTO: Attitude Maneuver
T+71	Exercise following WW Bakeout (66.99-68.72)
T+101	After OTC-3 Burn (100.77)
T+116-120	Lunar Flyby (115.67-123.08)
T+146-150	Exercise following RTC-1 Burn; fan speeds were increased to 9000 rpm
T+168-174	After Exercise (164-168) + attitude maneuvers
T+203 →EOM	Start of DFTO: Rads forced to saturation for CL FCV control

Lunar Flyby

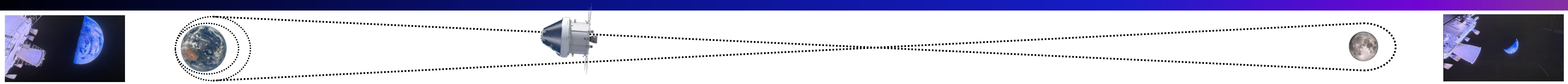


- A major objective: Fly with windows towards the Moon during flyby – around 5 hours Out Of Attitude (OOA)
- Increased demand on the system with lunar albedo + OOA
  - Sun will hit nose, radiators, etc as the vehicle rotates.
- Radiators were fully saturated during most of flyby
- Radiators give great cooling performance during eclipse
- Ammonia boilers available for supplemental cooling, but not used.
  - Analysis allows us to go as close at ~50 nmi (AR2 was around 3500 nmi)

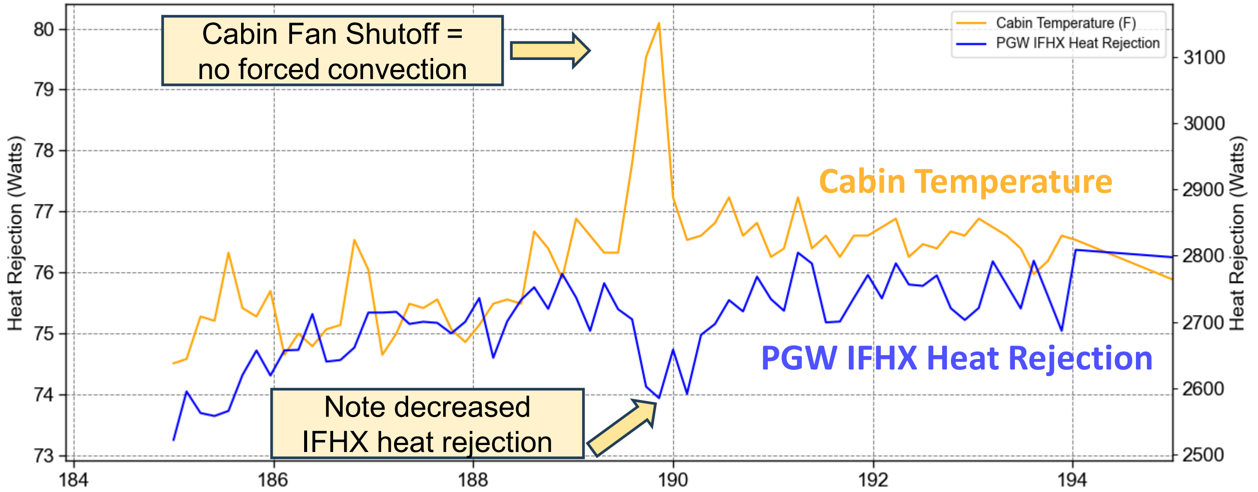


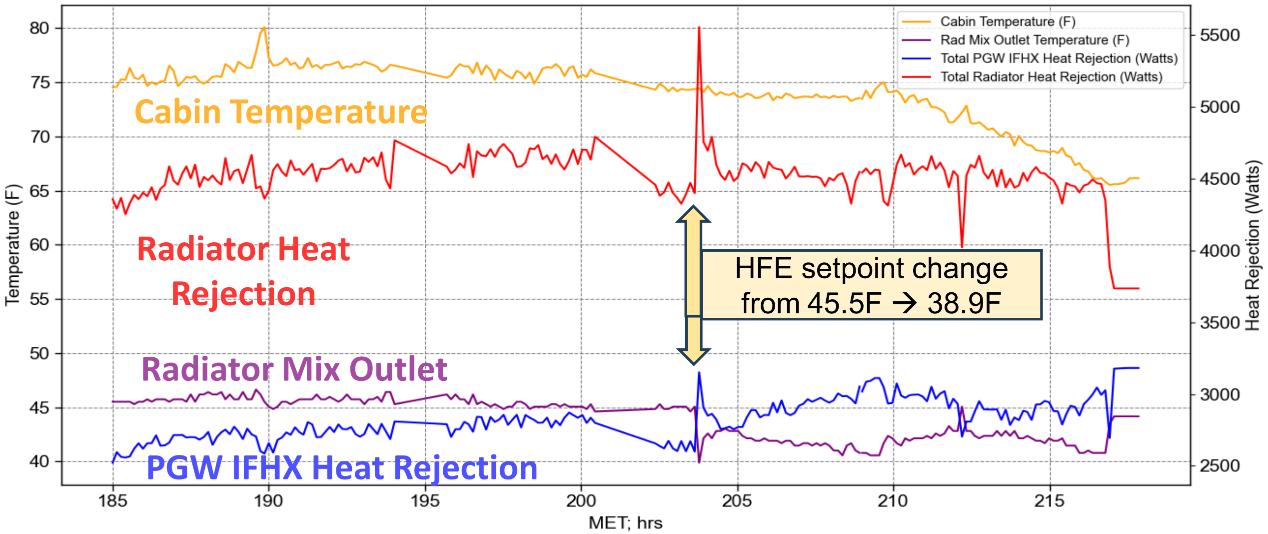


Lunar Transit - Flight Day 9/10

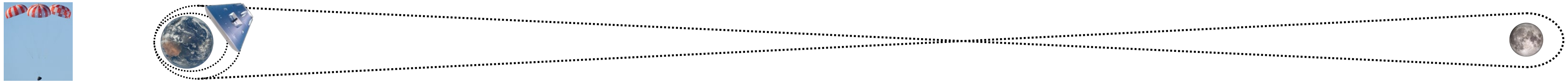


- FD09 was our day to do tests/checkouts before SM separation
- Smoke Detector False Alarm – Automatically Turned Off Cabin and ARS Fans, causing high cabin temperature transients (~80F) – with nearly zero convection on skin!
- Coolant Loop Flow Control Valve – Development Flight Test Objective
  - FCV was activated hours prior to SM separation (low risk exposure time). Nominal radiator mix and coolant mix temperature setpoints implemented. (AR3+ Config)
  - Valve performed as designed and immediately started to control flow to IFHX
- Ammonia Boiler system checkout successfully performed on FD9 since no NH_3 used during launch or flyby

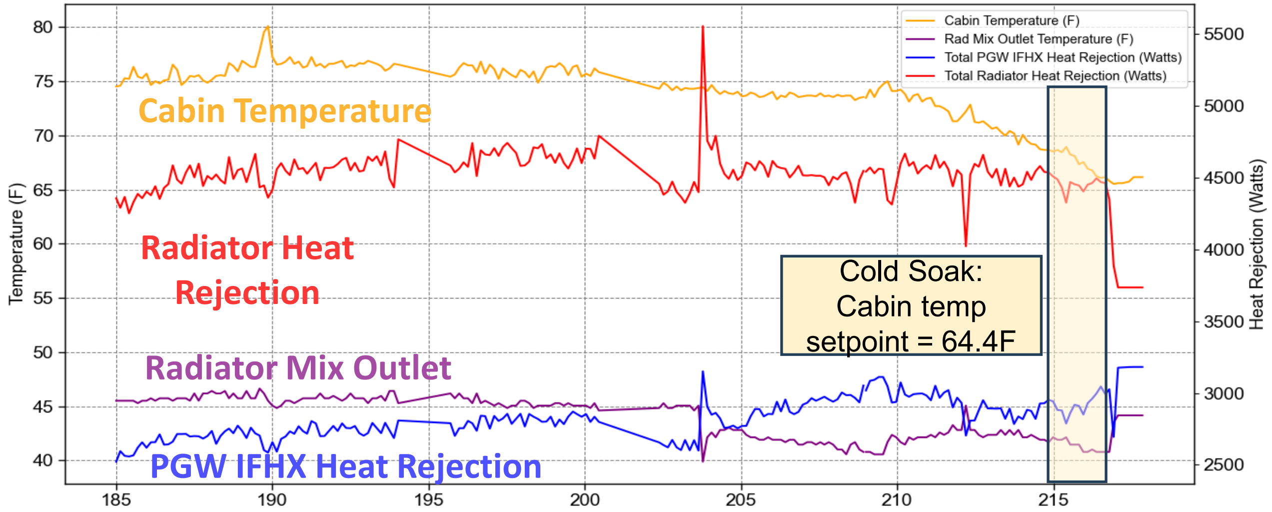


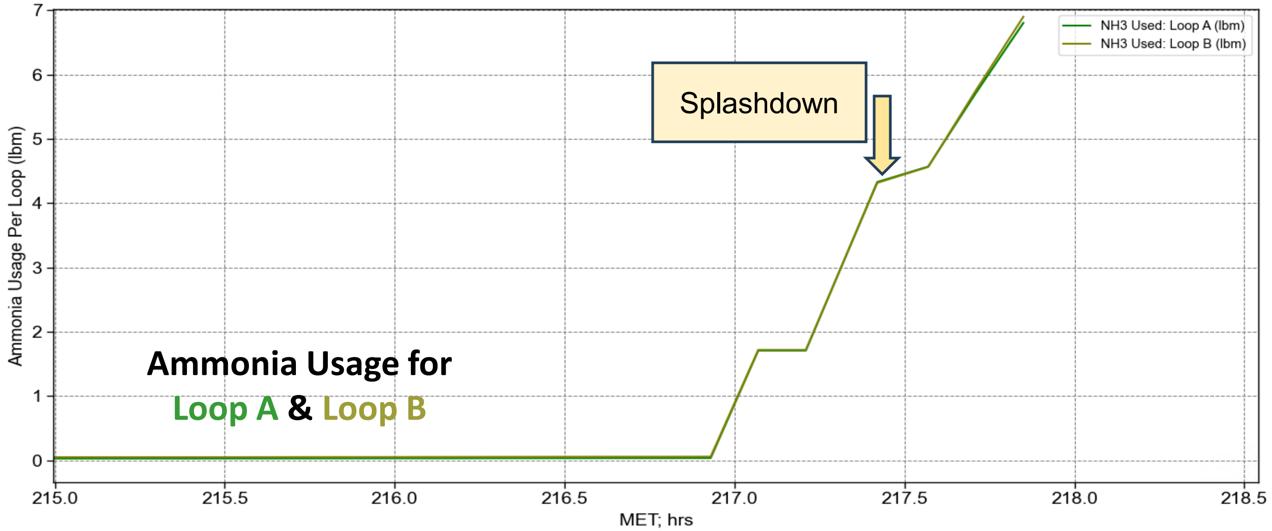


SM Separation and Entry

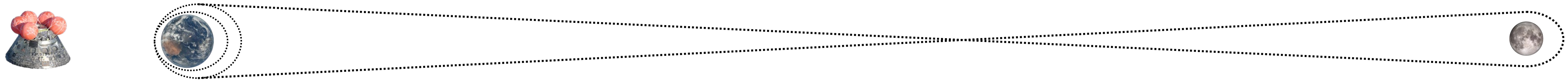


- Pre-SM Separation:
  - Cold soak with radiators to condition coolant loops and cabin for reentry heat loads
- Post-SM Separation:
  - Ammonia boilers handle all Crew Module cooling
    - Feedback loop to hold ABHX outlet temperature at setpoint – 53 degF
  - Entry heat loads are extraordinarily high, but not felt inside the cabin until after splashdown (CM is a well insulated thermos)

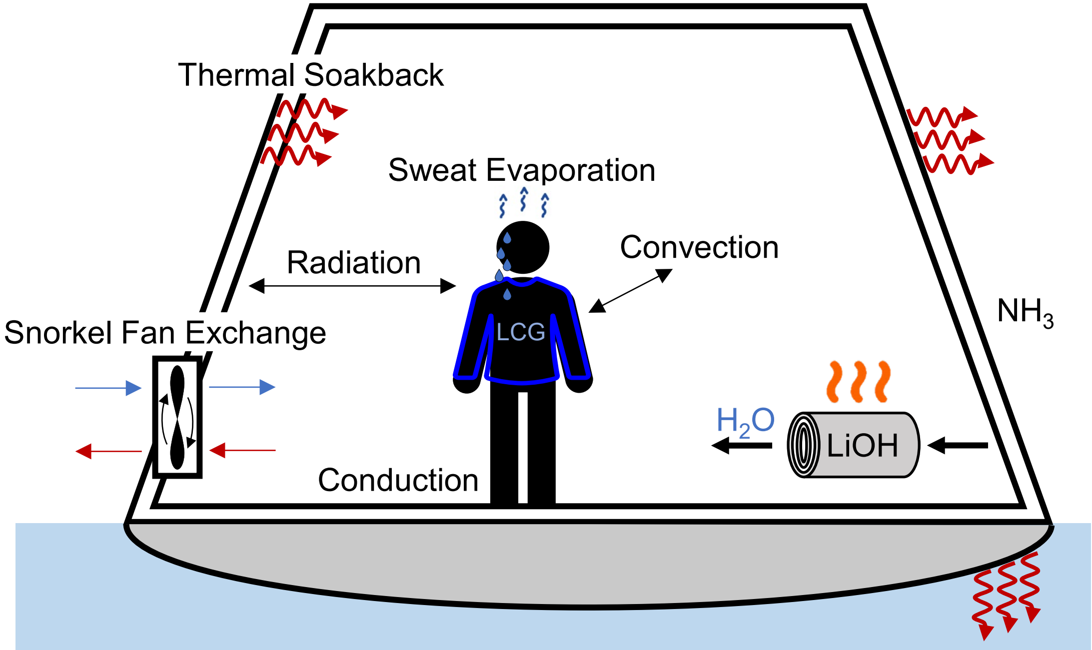




Splashdown



- After splashdown, the crew stays sealed in the crew module for up to 2 hours to wait for recovery forces.
- Ammonia boilers provide PGW and vehicle cooling
  - Human heatloads ~100 watts each
  - Entry heat loads soak into cabin
  - Most electronics shut-off early – cooling to cold plates shut off.
- Crew cooled directly by Liquid Cooled Garments
- Lithium Hydroxide canisters scrub atmosphere (add some heat and humidity)
- If additional time is needed for recovery, ammonia can be turned off, and a snorkel fan engaged to exchange air with the exterior.



Conclusions

- Orion Active Thermal Control had no inflight anomalies! (Perfect Flight)
- Orion is a deep space vehicle with radiators sized for deep space
- A Low Earth Orbit mission for Artemis 3 will be very thermally stressing.

Thank you!

Questions?