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Excess Water in Astronaut Helmet During EVA on ISS: Mitigations with Flight Demonstrations

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Brief Background…

- Potentially catastrophic release of water into Luca Parmitano helmet during EVA-23, 2013
- Mishap investigation immediately conducted by NASA
- Key items: water quality specs, monitoring, hardware in helmet (HAP and Snorkel) and updated operational responses
- NASA acknowledges that sublimator carry-over could result in “small” amounts of water entering helmet
- EVA-80 March 2022, Matthias Maurer reports lower volume helmet water event
- NASA temporarily halts EVAs on ISS, May 2022 and pursues path to mitigate critical water release within suit
- Investigation begins April 2022
- NASA becomes open to ‘do-no-harm’ solutions requiring some modification to the suit
- Considerations expanded from Helmet bubble to T2 Port, Vent Loop plumbing, and Sublimator CHX within EMU

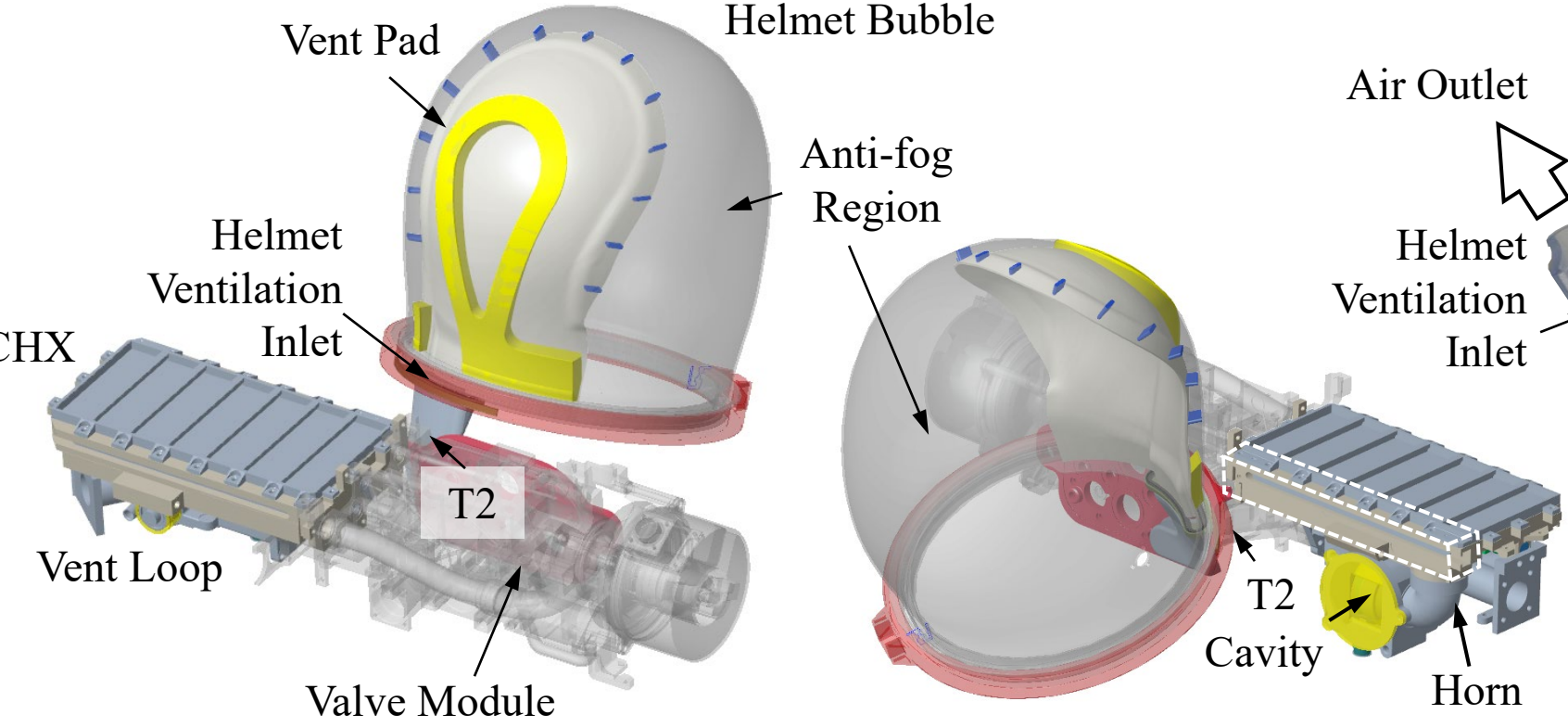
Brief Introduction…

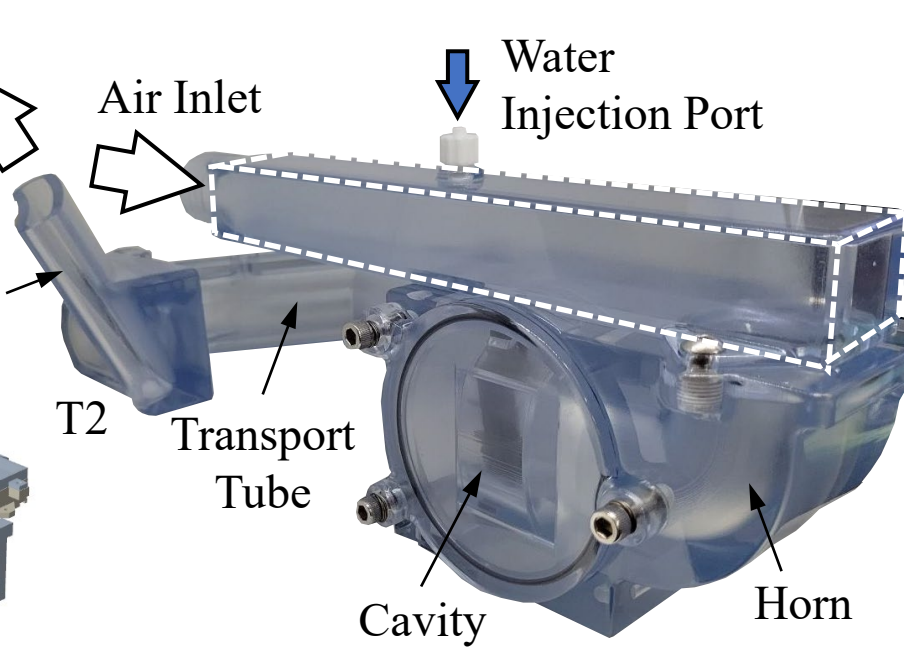
- Due to the novelty of such fluid phenomena, we report efforts from a microgravity fluid physics challenges perspective
- Free water volumes inside helmet increase with EVA duration and crew exertion
- Water volumes estimated as high as 1500 mL can be life-threatening
- We address the significantly lower volume Sublimator CHX of the EMU, < 360 mL.

Brief Contents…

- Description of the flow phenomena from a microgravity capillary fluidics perspective
- Brief review of requirements imposed for the ‘helmet leak’ mitigation investigations
- Highlight salient details of efforts supported by terrestrial research and flight demonstrations aboard ISS
- Conclude with discussion of overall water mitigation performance of integrated system: Helmet, T2 Port, and Vent Loop

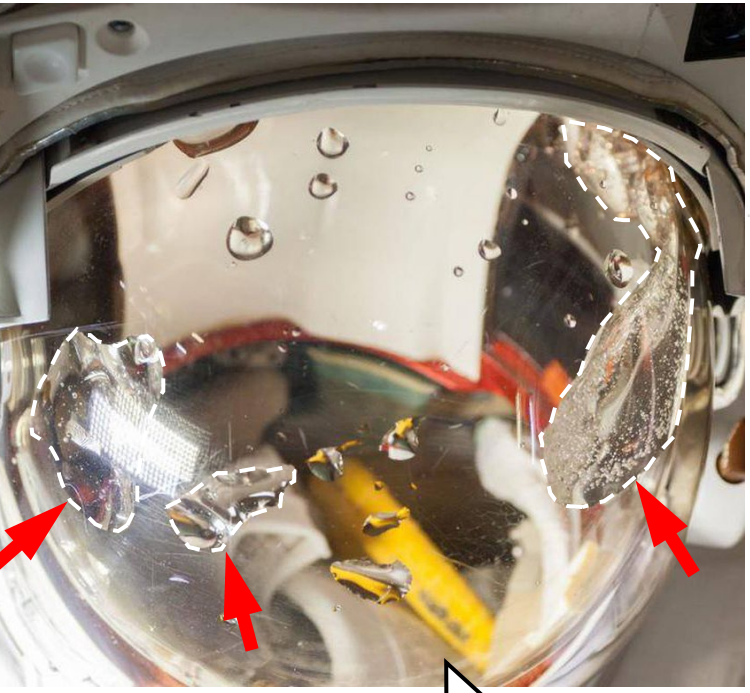
Simplified models of Helmet, T2 port, and Vent Loop

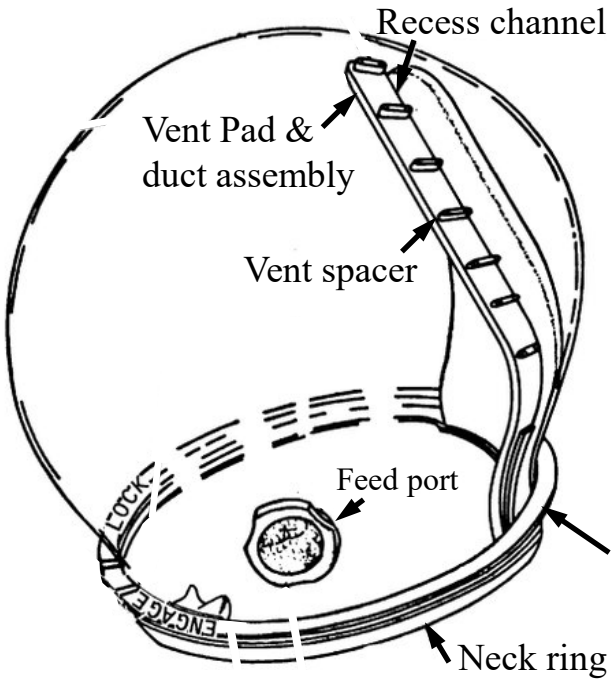


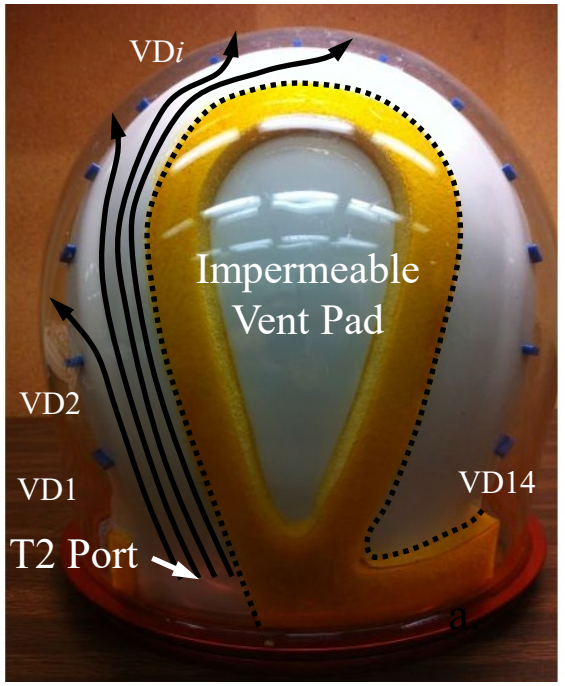


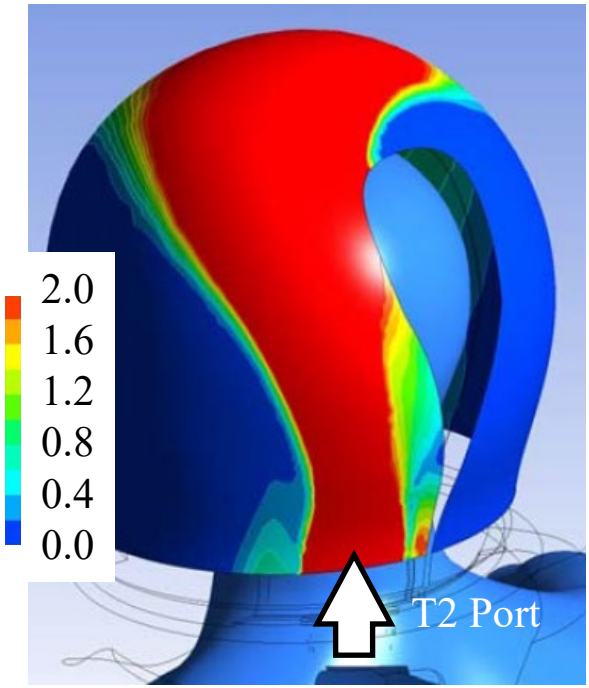
1:1 SLA EVA Geometry Simulator
(EGS; aka Vent Loop model)

EMU Helmet



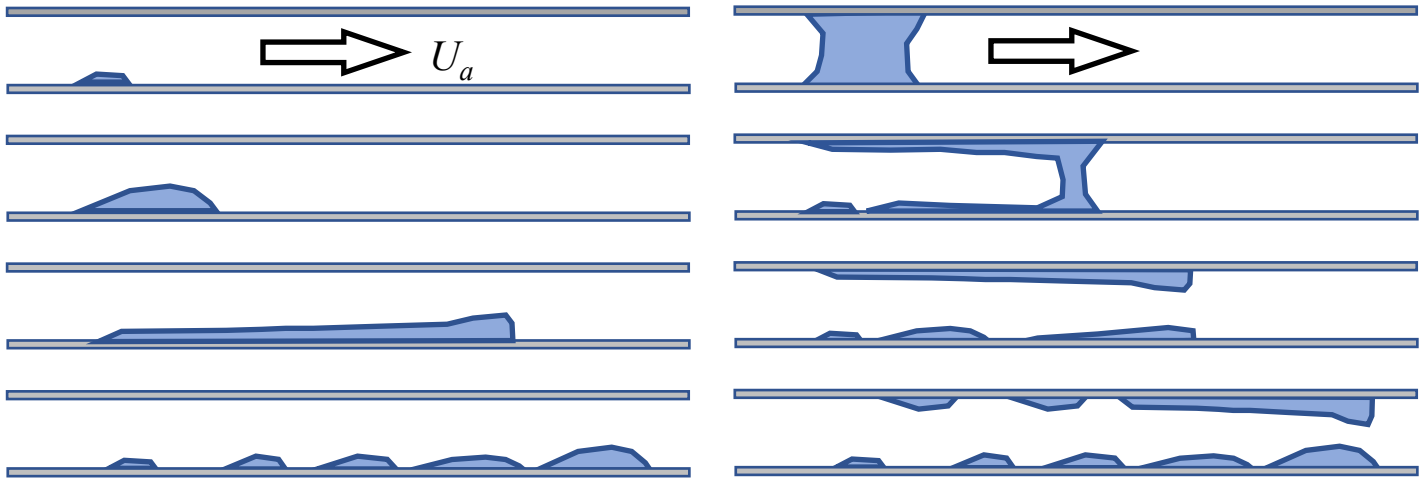


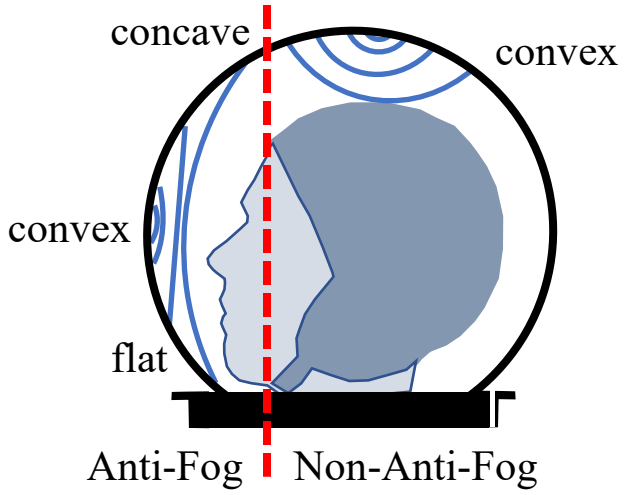


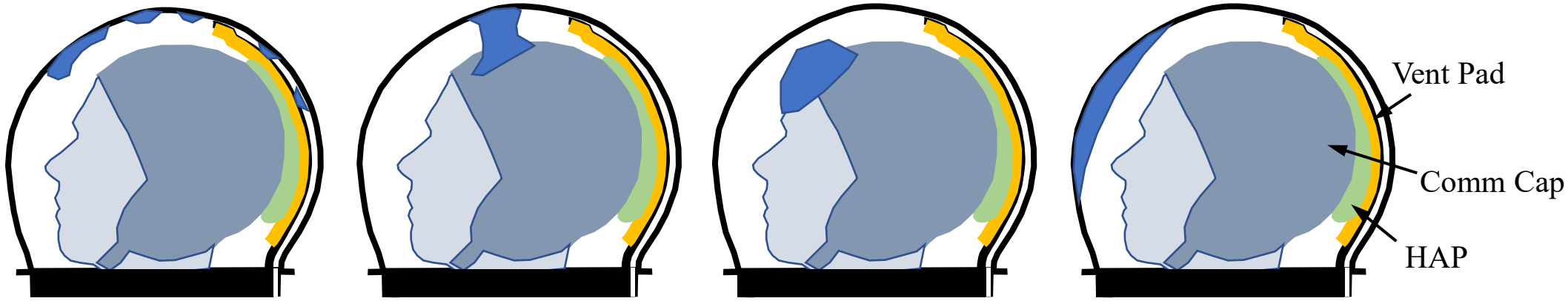


Helmet-bound water droplets with micro-bubble laden large volumes

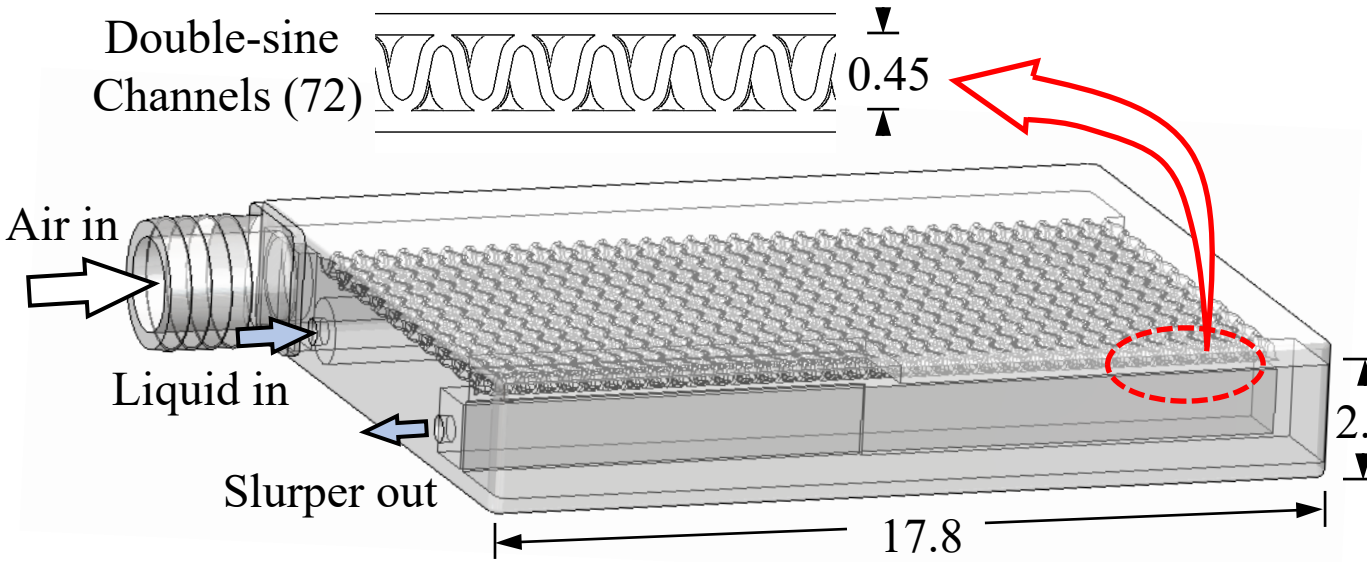
Transient two-phase capillary flow expectations pertinent to Helmet

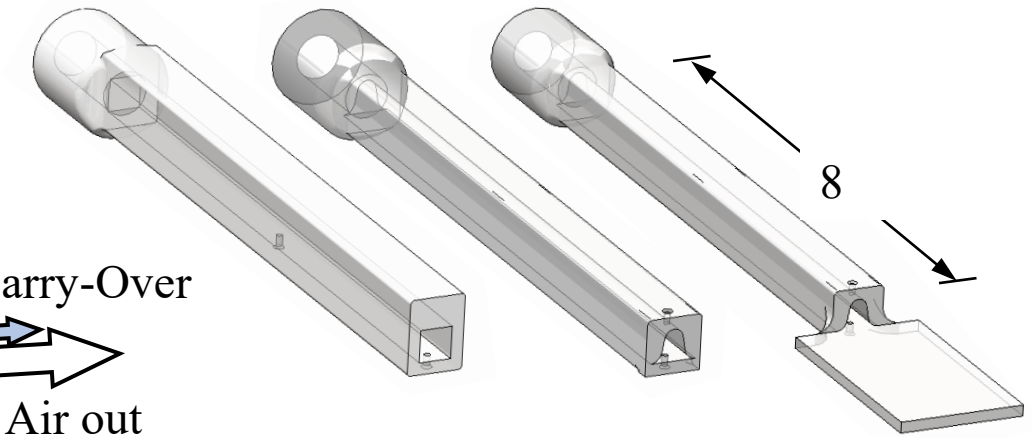


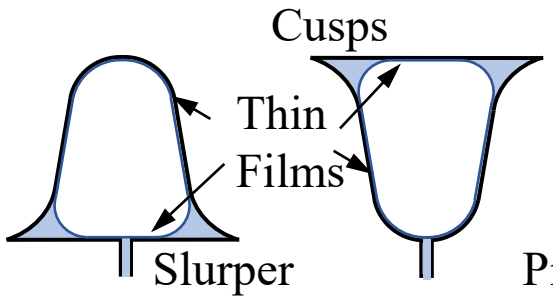


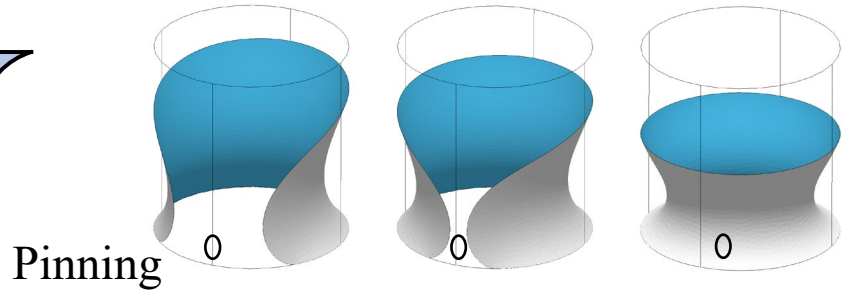


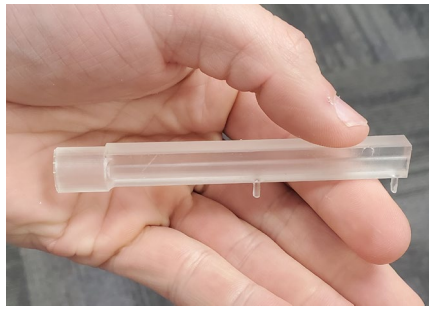
Sublimator CHX model with demonstrations of capillary performance



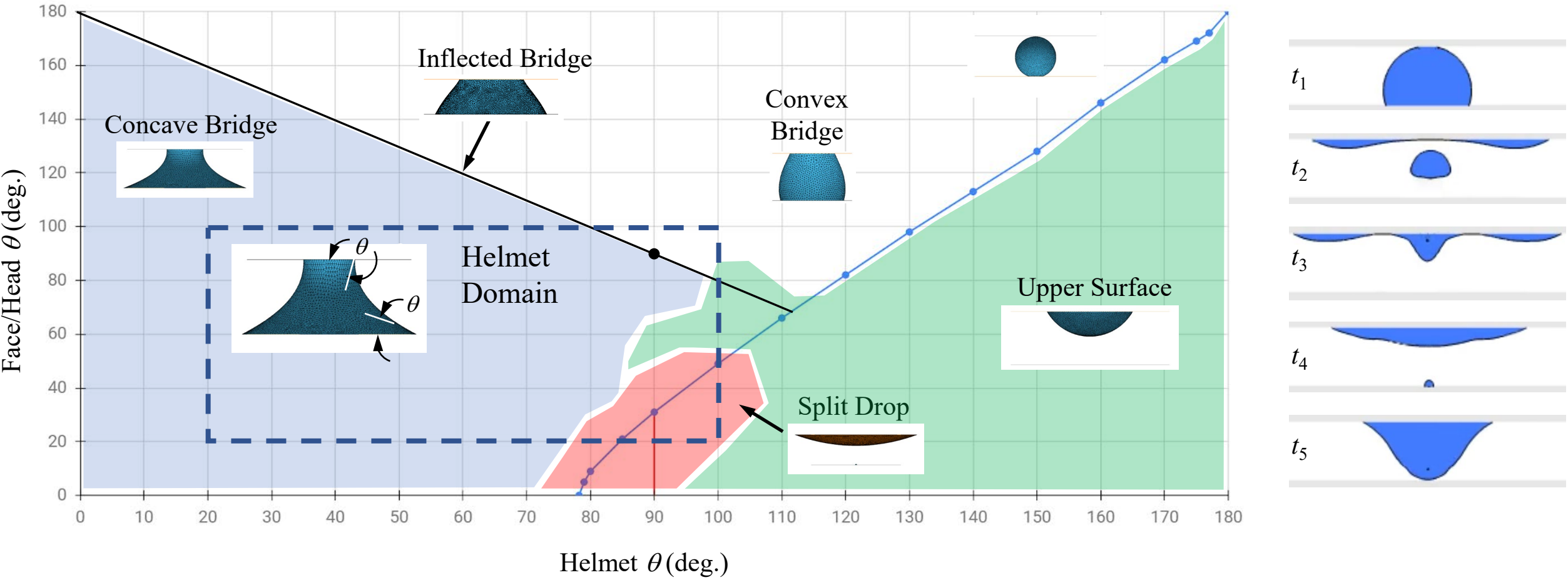




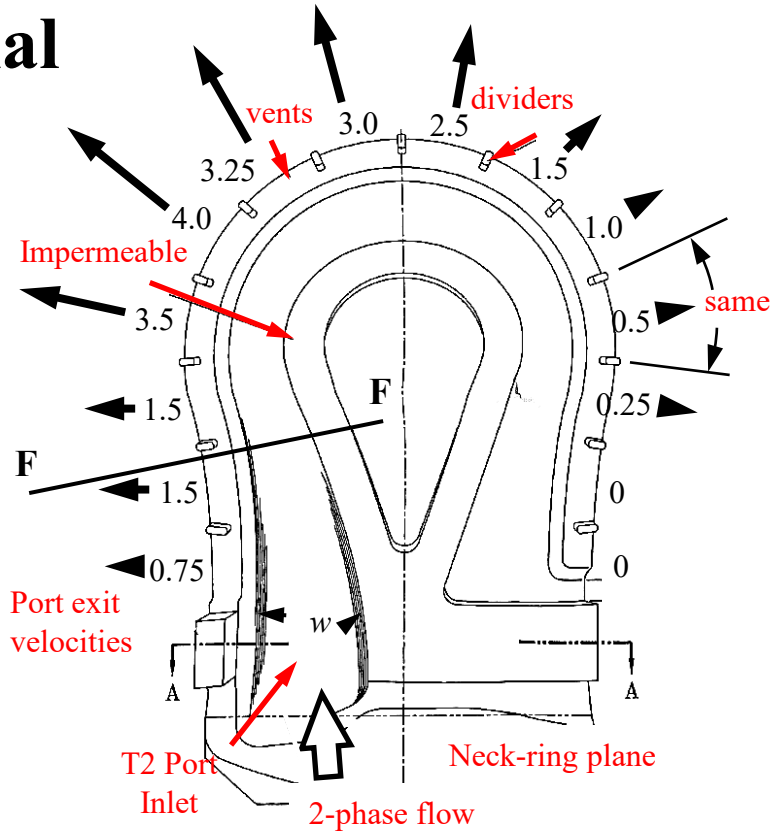


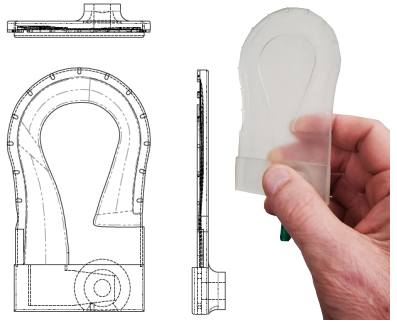


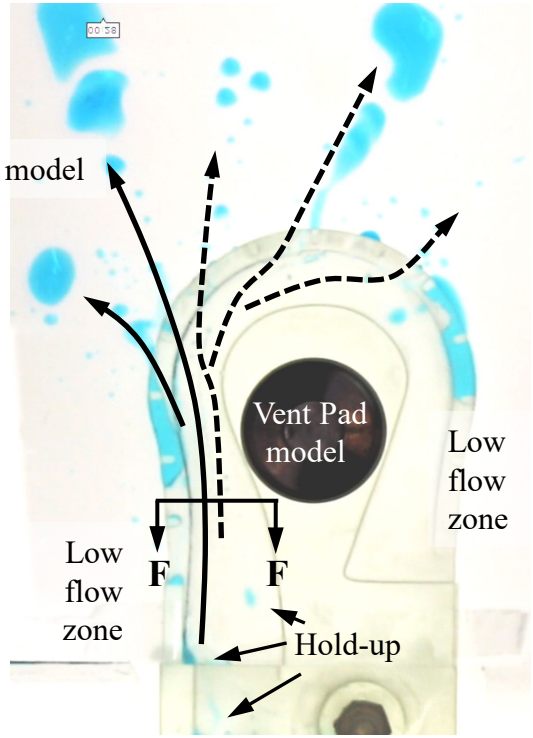
Static SE-FIT & dynamic Basilisk computations of droplets: Helmet, face, head

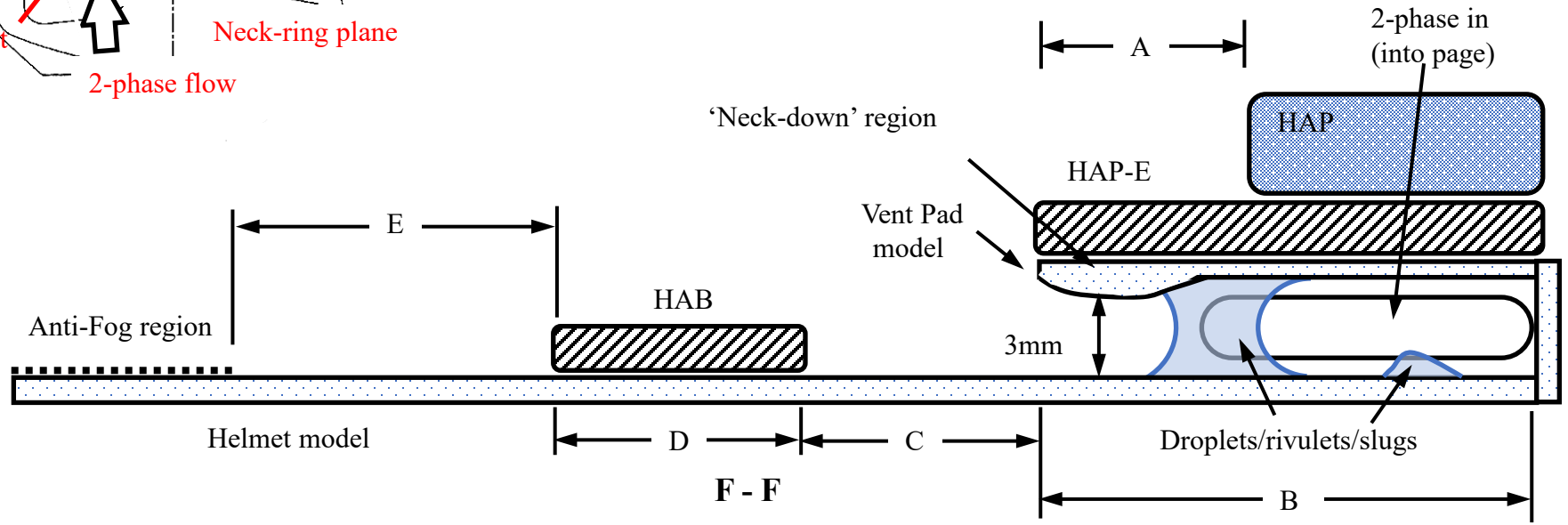


Terrestrial Helmet Model Items



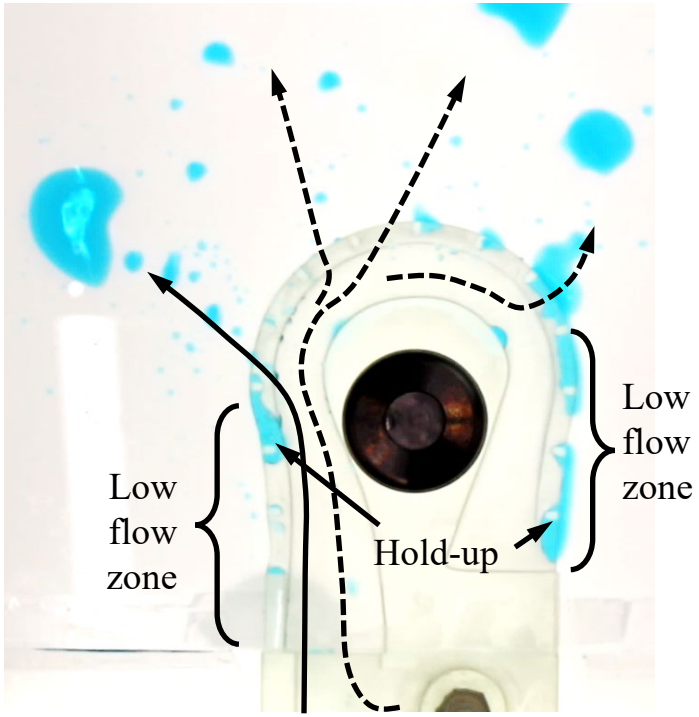




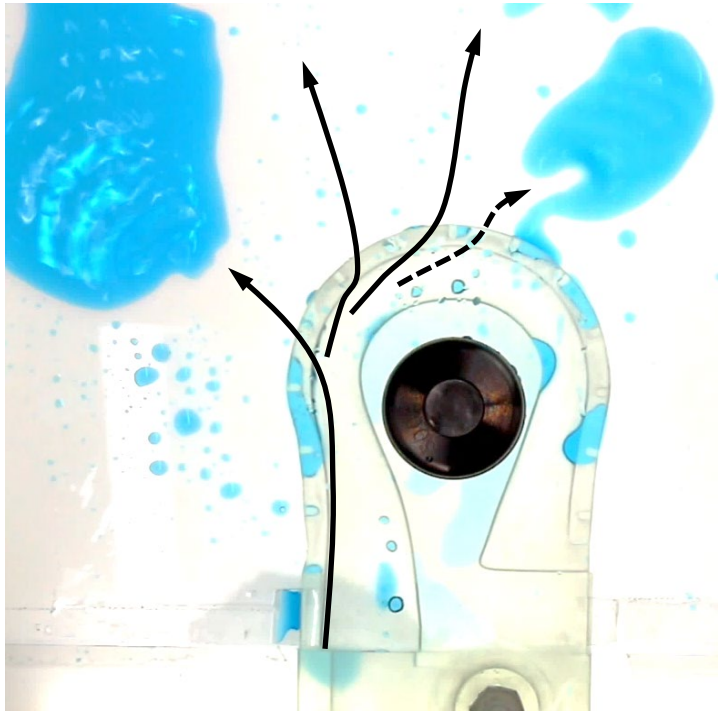


Terrestrial Helmet model demonstrations

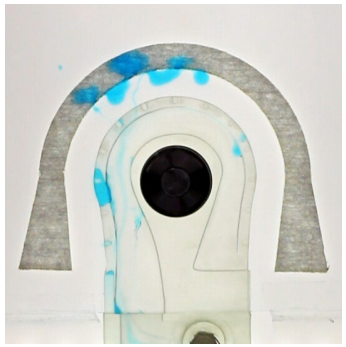
Trickle 5 x 1 mL injections
(5 ea 6 mL inj., 30 mL total)

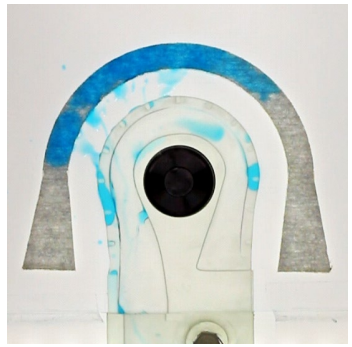


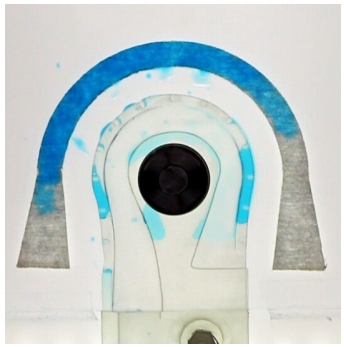
Pulse 4 x 5 mL injections
(4 ea 30 mL inj., 120 mL total)

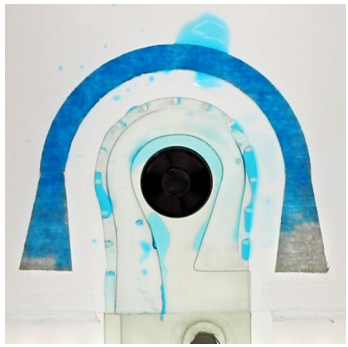


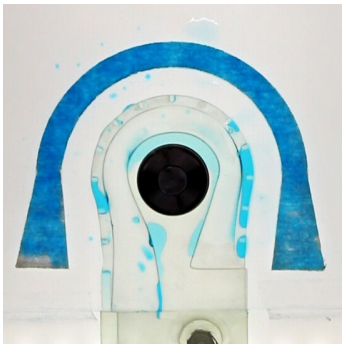
Trickle; ~ 24 mL w/ anti-fog



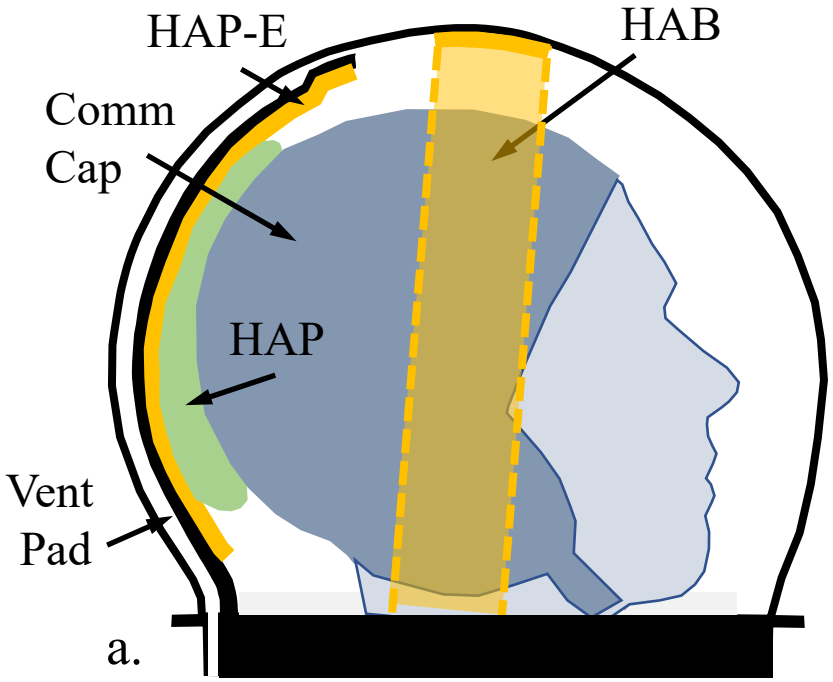


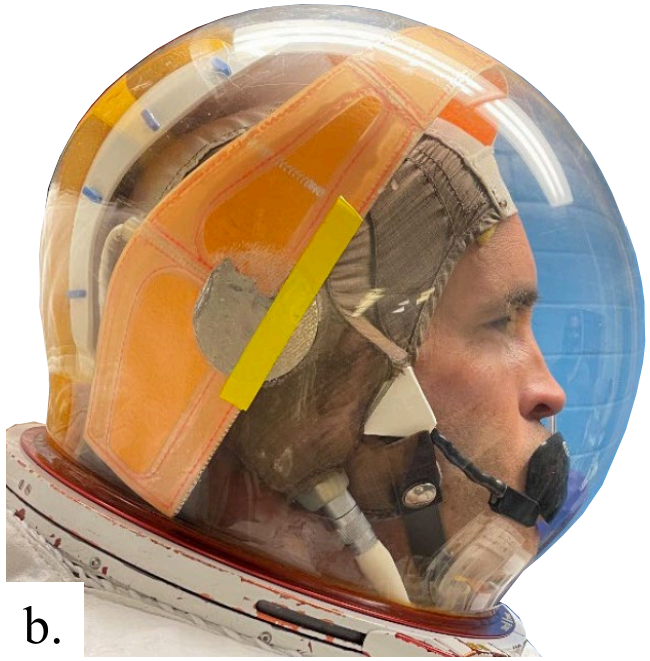


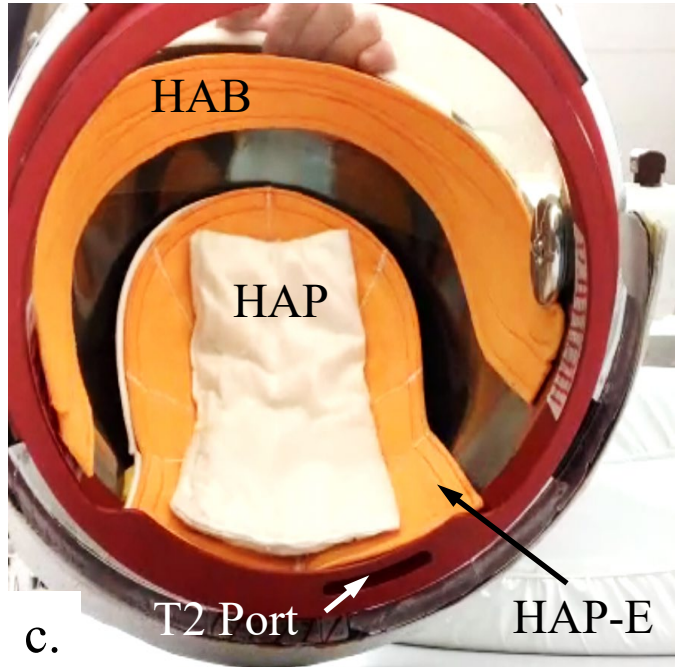




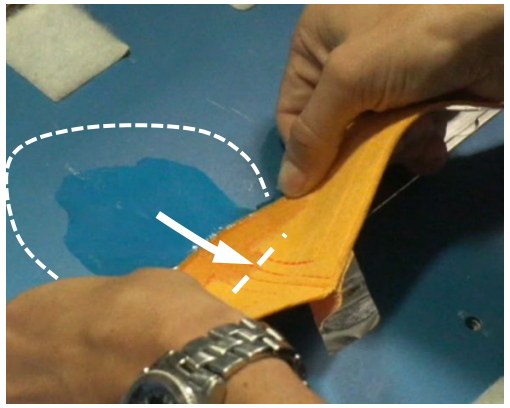
Helmet Mitigations

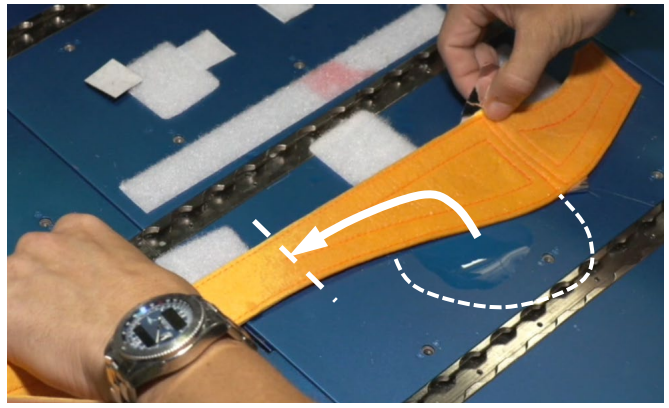


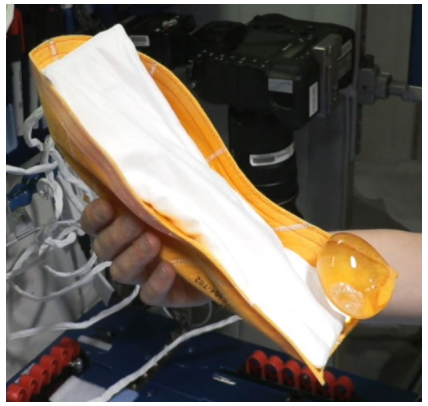


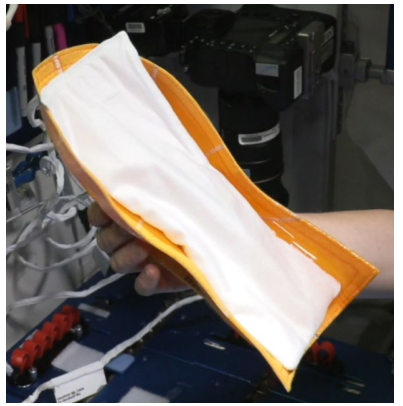


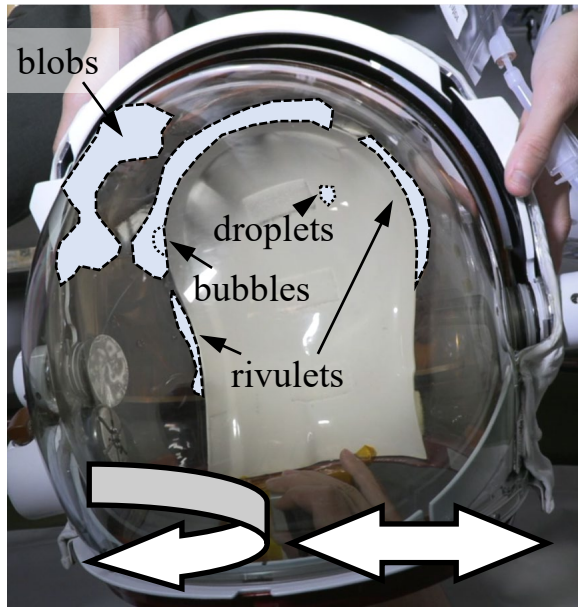
Selection of Helmet Mitigations Demonstrations on ISS



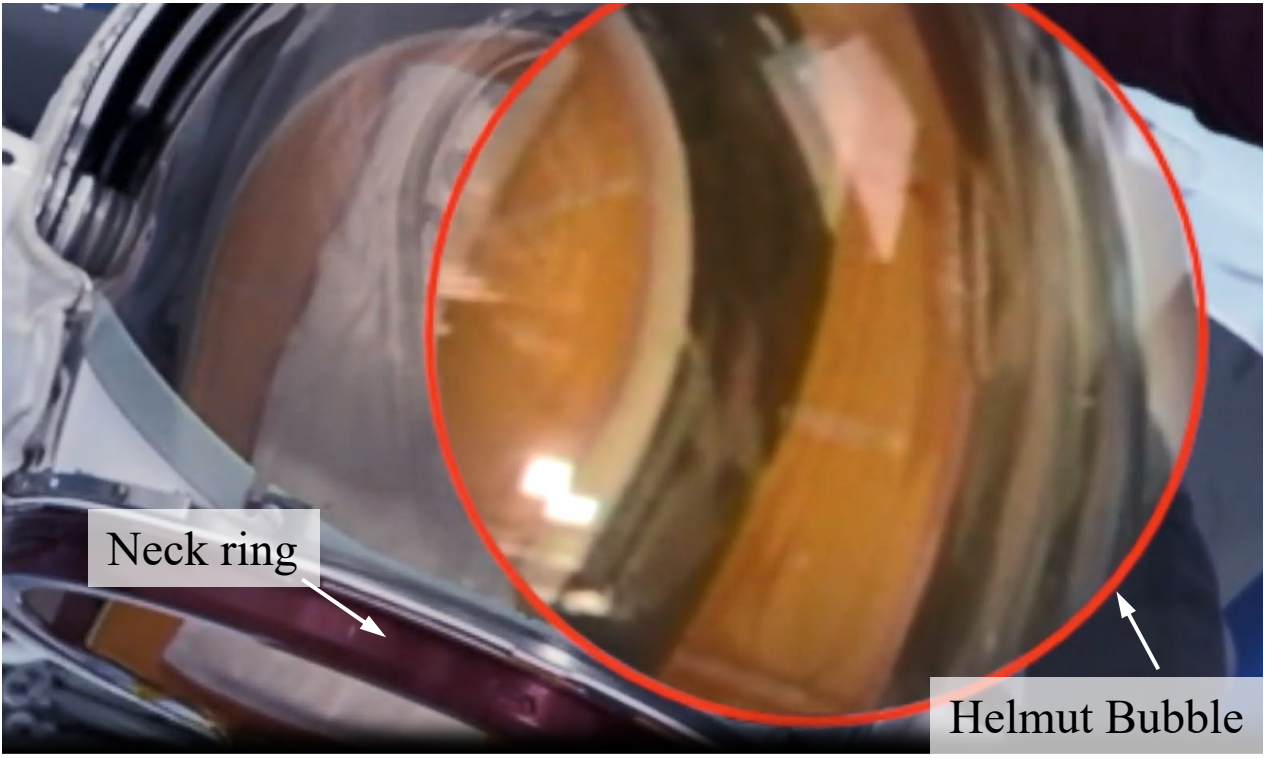


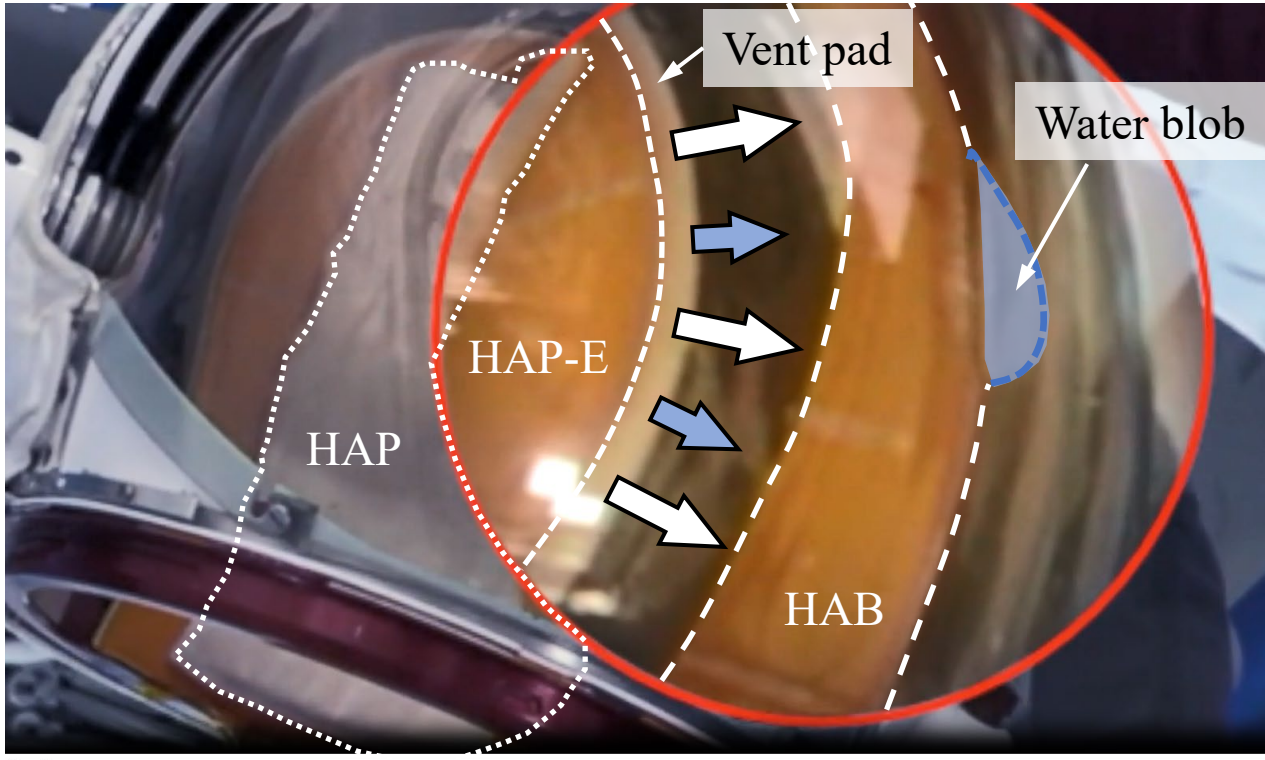




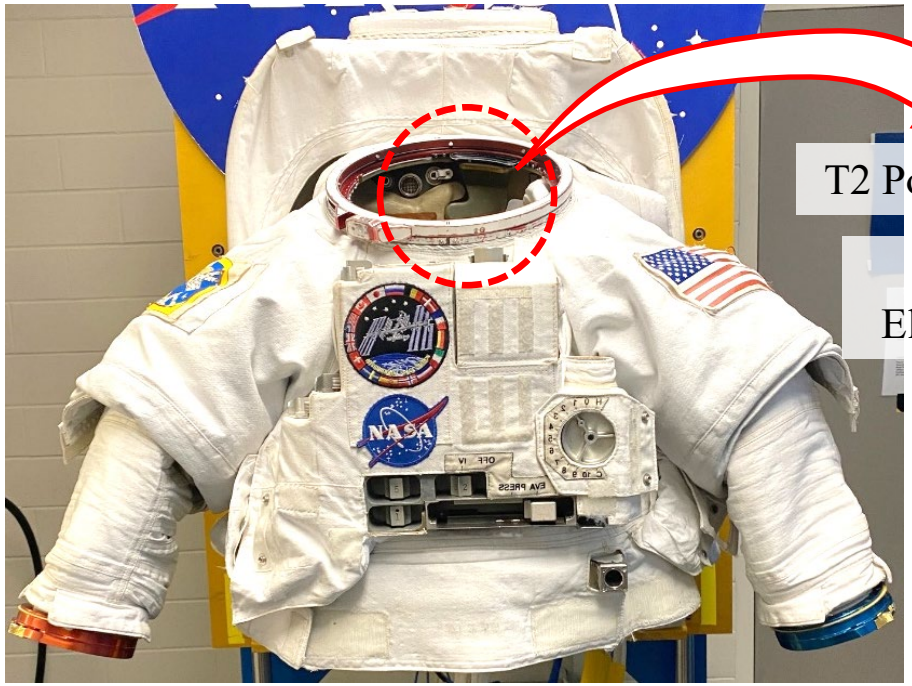


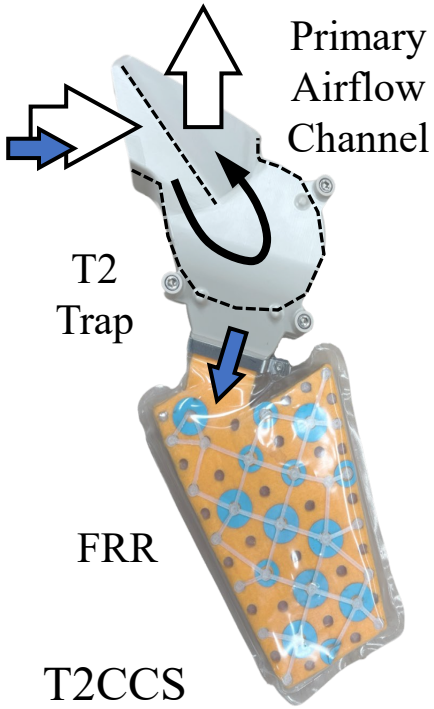
HAP, HAP-E and HAB wicking demonstrations on ISS



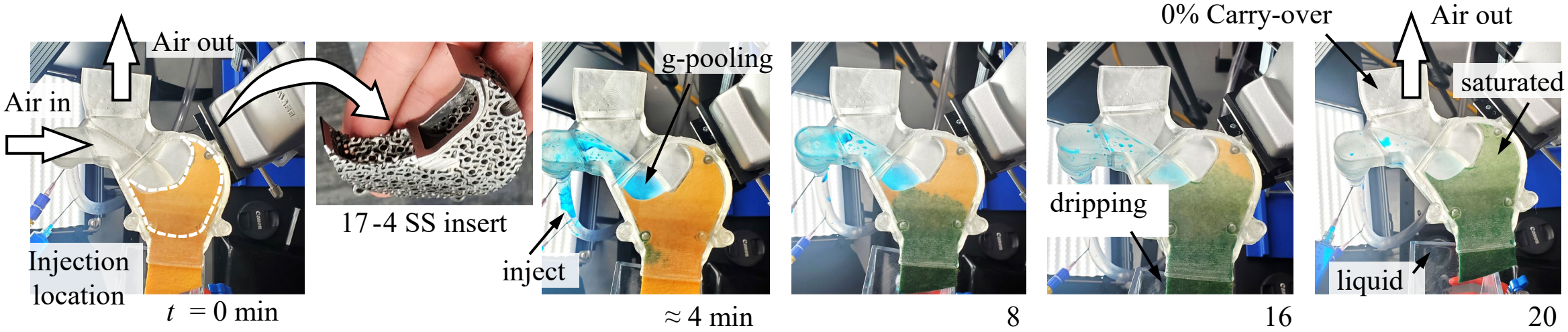


T2 Port Region & T2CCS Modification

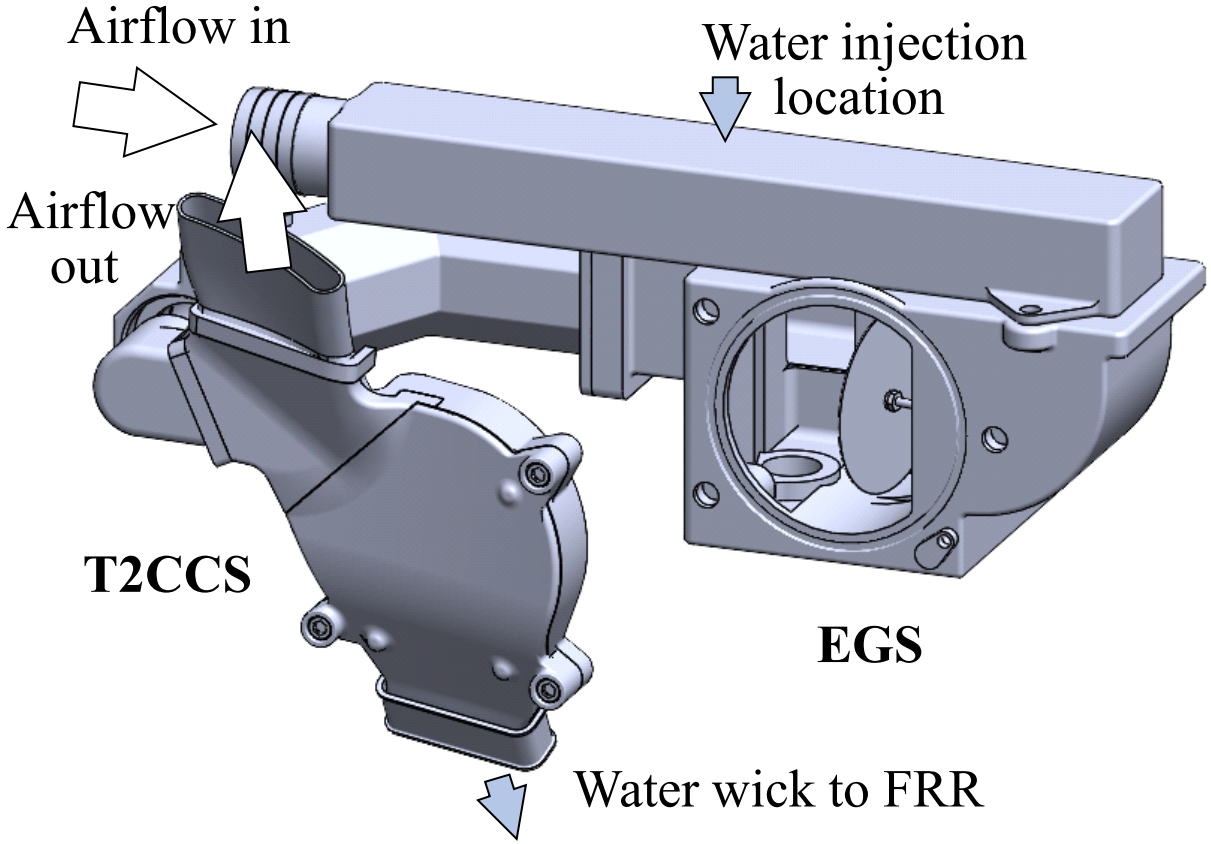


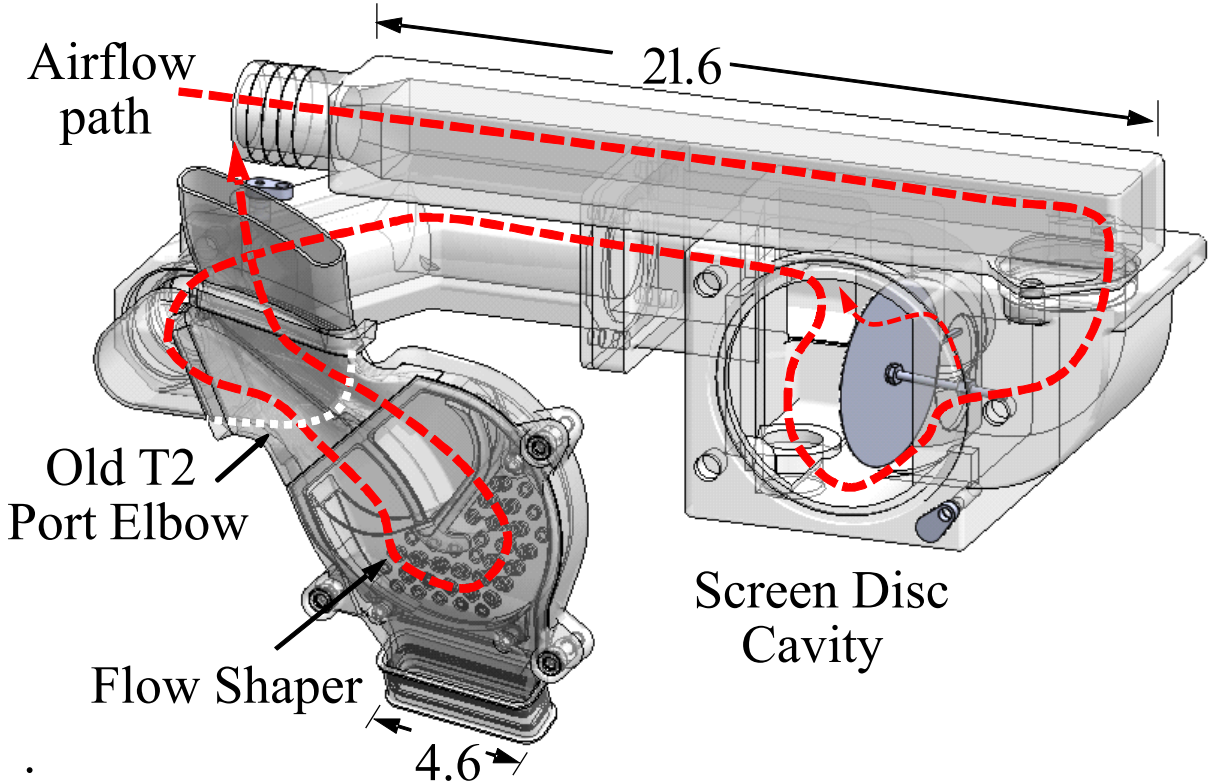


T2CCS Terrestrial Testing

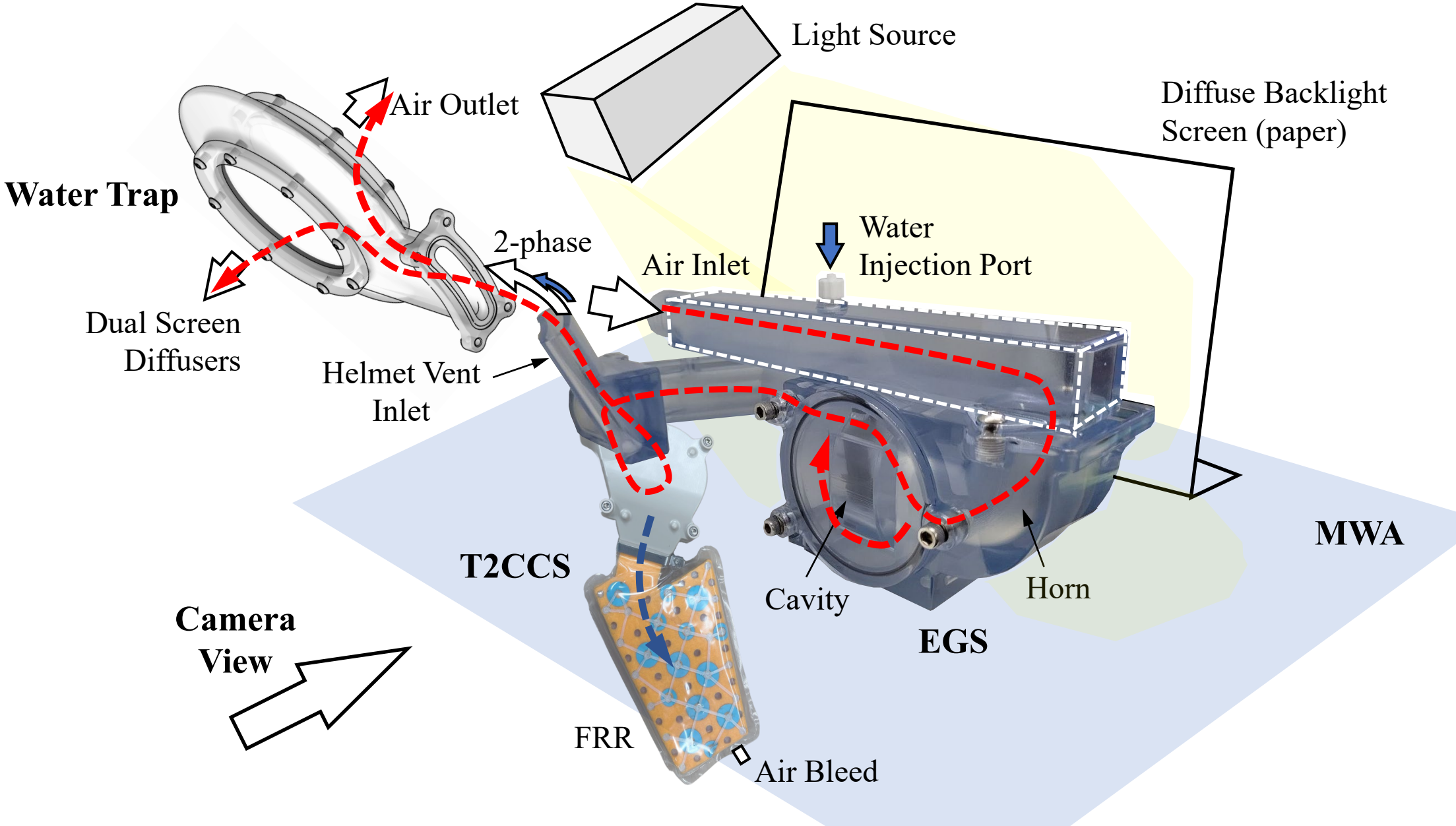


Integrated EGS & T2CCS Assembly

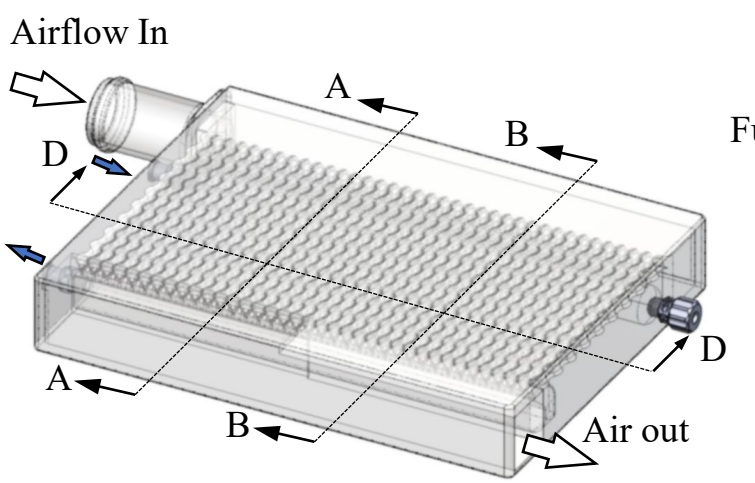


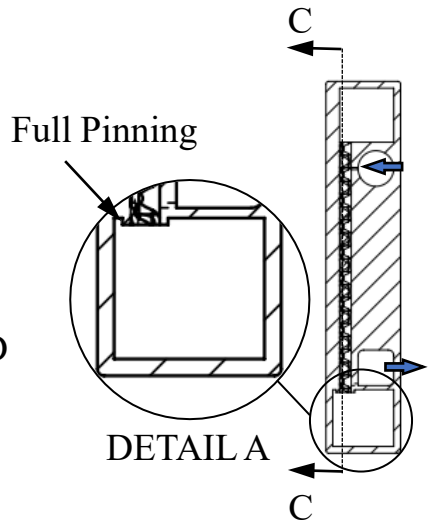


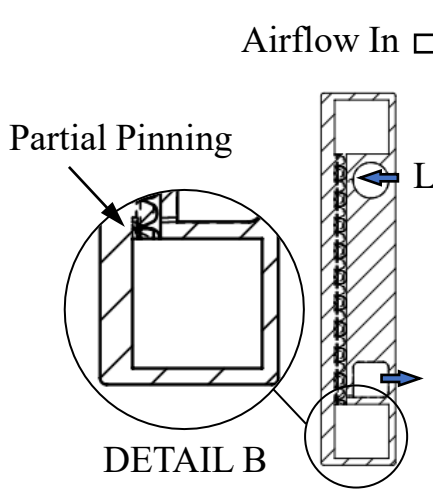
Integrated EGS and T2CCS on MWA (plan)

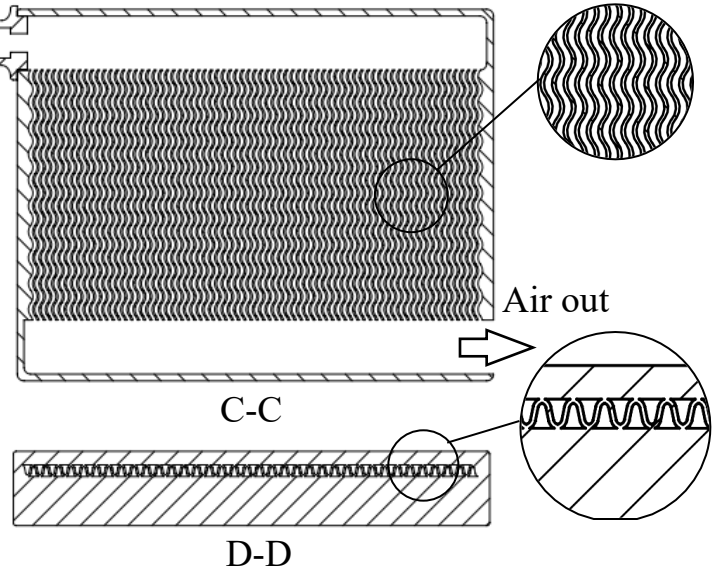


Sublimator Test Unit: CHX Hold-up Demonstrator

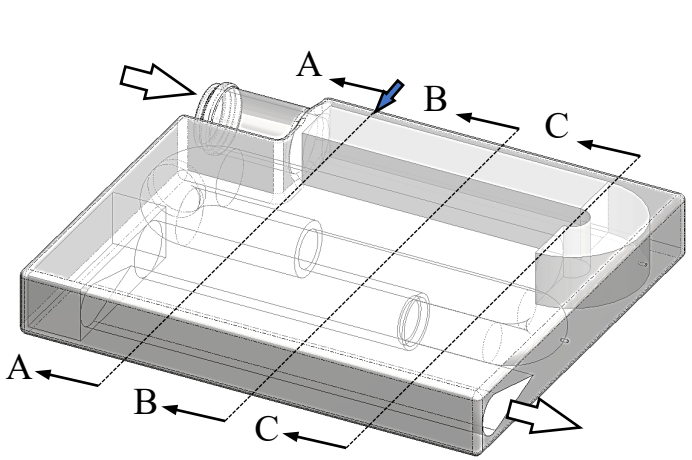


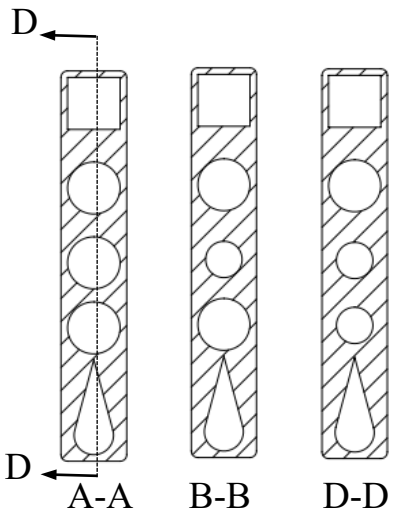


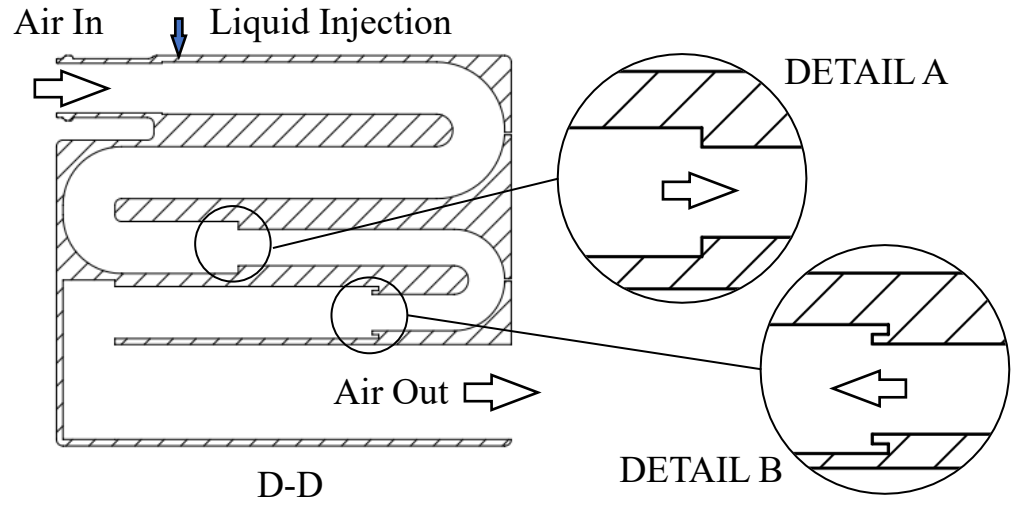




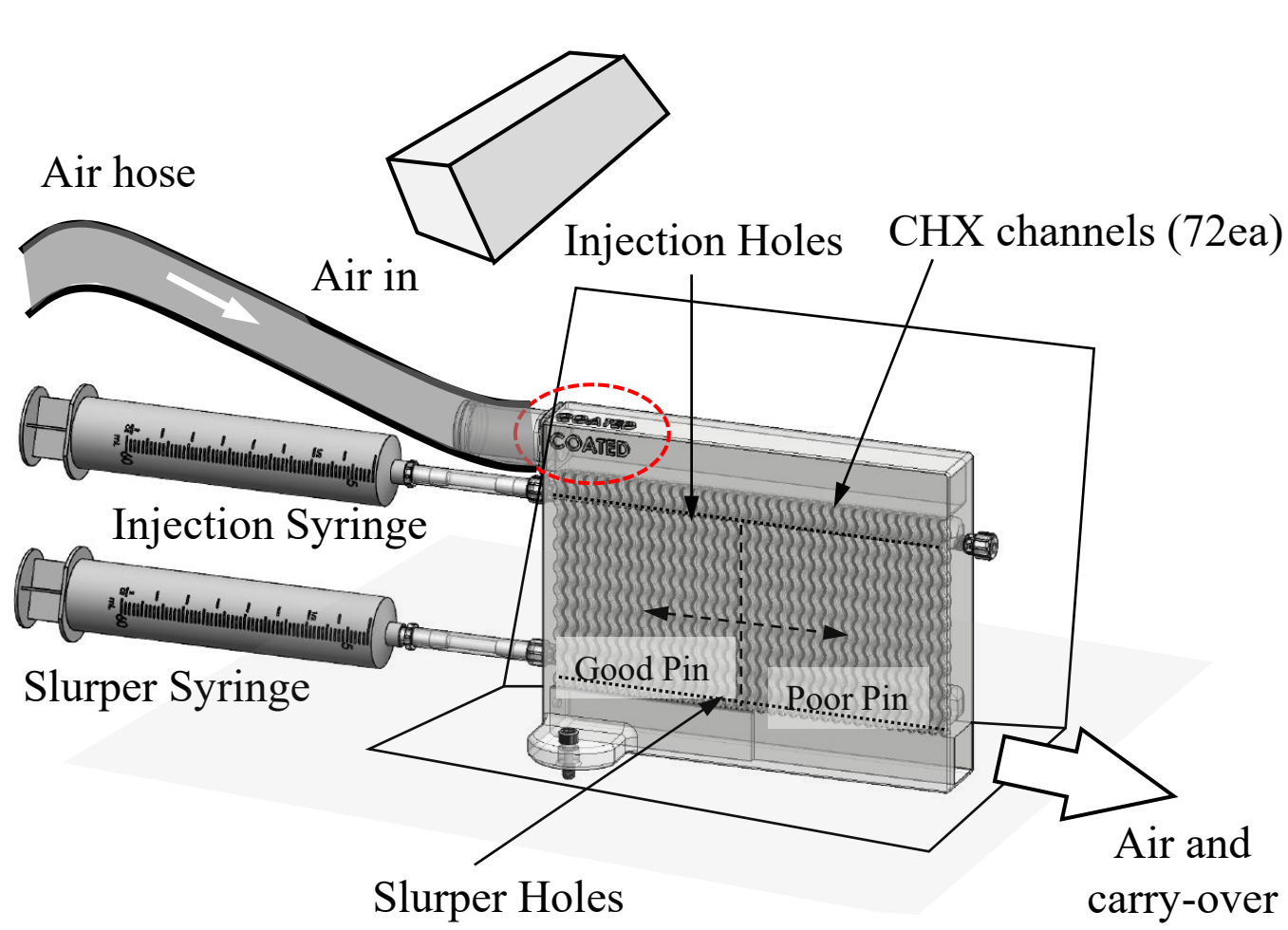
Flow Calibration Test Unit: Calibration Hold-up Demonstrator

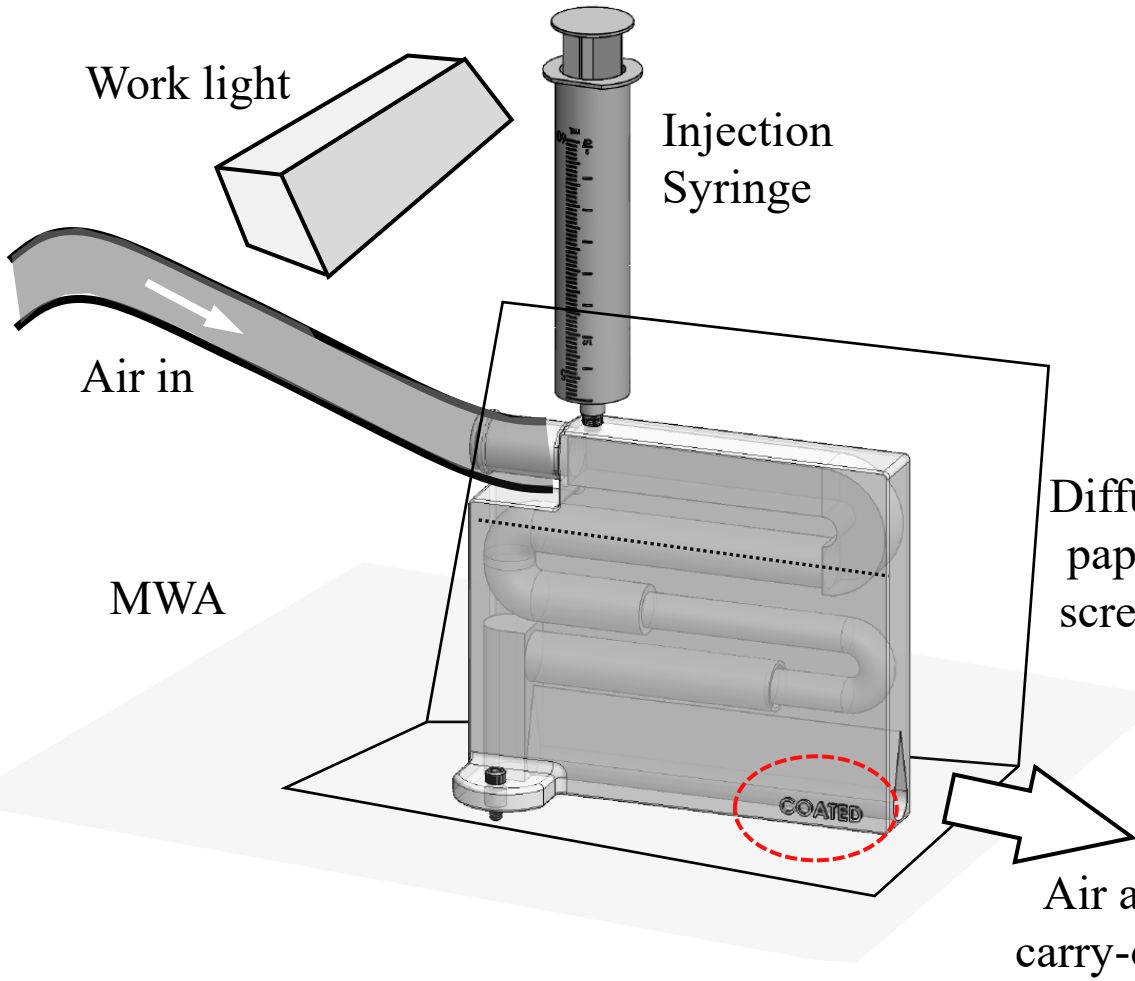






Set-up of Sublimator and Flow Calibration Test Units on MWA (plan)





Summary and Outlook…

- The EMU EVA Helmet water leak mitigations reported herein can meet project requirements:
  - Provide understanding & analyses of unique microgravity fluid behavior
  - Establish & demonstrate leak hazard mitigations
  - Verify & validate all via ISS measurements & demonstrations for EVA & IVA conditions
- Specific analyses & mitigations developed for Helmet, T2 port, & Vent Loop, with first visuals μ-g EMU Sublimator CHX performance
- Successful tests aboard the ISS completed for combined Helmet mitigations HAP, HAP-E, and HAB:
  - Nature of Helmet-bound droplet/rivulet two-phase flow
  - Increased likelihood of water transfers to head/face with increased water release, duh
  - Change in flow configurations when water encounters the antifog region
  - Confirm difficulty of visually estimating increasing liquid volumes within the helmet
  - Rapid absorption of HAB, which significantly resists/prevents water from moving towards visor
- HAB absorbs 2x its internal volume (> 100 mL) for combined ≈ 1000 mL for system
- ISS demonstrations reveal Comm Cap capable of additional 250 mL, while transferring significant liquid to HAP
- T2CCS passive liquid separation device ground tested
  - 100% liquid separations for water leak rates
  - 2 mL/min for as much as 228 mL
  - 2x higher separation rates anticipated in low-g
  - A successful T2CCS renders Helmet mitigations unnecessary
- Plans to demonstrate EGS on ISS in work
- Currently anticipate 100 mL water hold-up within the Vent Loop
- ISS tests for integrated EGS & T2CCS tests to identify: Vent Loop hold-up, hold-up stability due to crew perturbations, T2 Port Hold-up, separation efficiency, stability to perturbations, confirm or refute all model assumptions employed
- Water release volume, rate, and character from the Vent Loop illuminates true entrance conditions for the T2CCS
- Water release volume, rate, and character from the T2CCS illuminates true entrance conditions for the Helmet
- Jan. 18 2023, the EVA and Human Surface Mobility Program (EHP) Mission Implementation Configuration Control Board stopped work on T2CCS project
- Due to maturity of T2CCS design, it may still be flown to ISS for demonstrations as a downstream element of the TAVVID investigation

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