MULTIPHASE FLOWS RELATING TO WATER/ WASTE RECYCLE AND THERMAL MANAGEMENT SYSTEMS FOR SPACECRAFT

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- Professor of Chemical and Biomolecular Engineering and Senior Associate Dean for Research and Graduate Studies.
    - At Notre Dame since 1984.
- Department chair for 16 years, "Dean's Office" for past 5 years.
- Associate Editor of *International Journal of Multiphase Flow* for 5 years.
- Active researcher in multiphase flows for ~37 years
    - Research is generally "experiment first", even though we did considerable analysis.
    - Publications on gas-liquid and liquid-liquid flows, "trickle bed" flows, gas-liquid catalytic reactions, heat transfer in gas-liquid flows, absorption of gases with ionic liquids and molecular dynamics simulation of nucleate boiling and ionic liquid transport properties.
- Funding and other associations with NASA since 1990
    - Conferences, Workshops, Reviews of NASA flight experiments.
- From teaching, consulting and commercialization ventures, I have developed a good understanding of the challenges of systems level engineering.

MAIN POINTS

- Expect that the power management/cooling/heating system and the food/waste/recycle systems will have to be designed <u>close to the edge</u> of what is possible given the overall difficulty of the mission

  - Thus: need to be free to design multiphase flow and heat exchange/contacting devices to achieve the <u>maximum</u> performance — these will involve liquids and gases and probably solids flowing together in a variety of configurations.

  - Almost for sure, there will be critical aspects of components or systems for which design will require an "answer", that goes beyond what has ever been needed for other technologies.

  - The following speaker may address this point in more detail, but "largely", the detailed fluid mechanics of <u>specific</u> flow configurations can be successfully addressed.

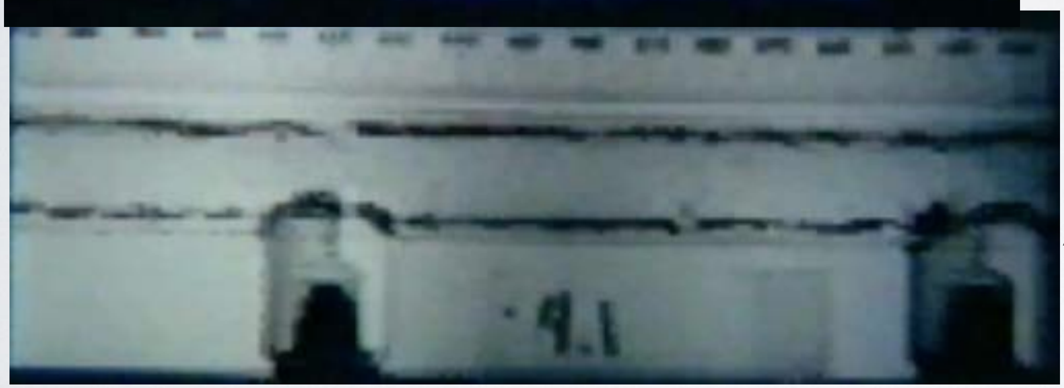
MAIN POINTS

- System level problems are more problematic.
  - Even if detailed flow calculations are correct, confirming performance of the entire fluid/heat handling system may not be possible.
    - accumulation of small errors and dynamic uncertainties.
  - Might need a test of full-size system in μg — and if so, the time scales will be minutes to hours, not 20 seconds.
  - Engineering *experience* will be needed to deal with system scale problems and could mitigate the full-scale testing need to some extent.
  - The only people with first-hand knowledge of actually making fluids devices work in μg did the bulk of this work some years ago.
    - Thus NASA may wish to consider moving forward very soon with the overall ideation and conceptual design of the spacecraft which will provide operating boundaries for the various system components. This will allow the expertise of existing employees be tapped — At some point these people will retire and can't be replaced.

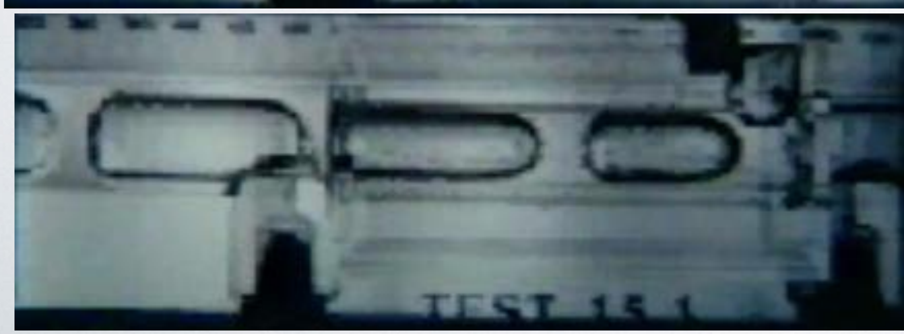
FLOW REGIME: PHASE CONFIGURATION

- In the 1990's John McQuillen of NASA Glenn/Lewis took a really nice set of videos of the flow regimes that exist in the absence of gravity

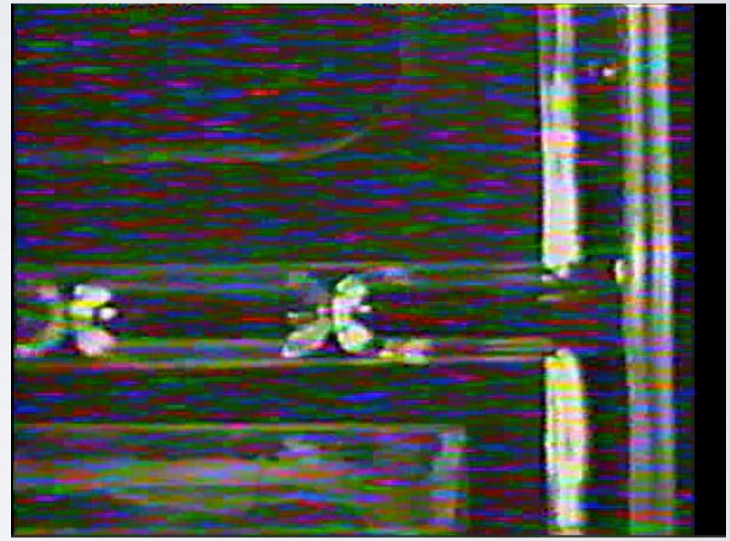
Bubbly



Annular



Slug

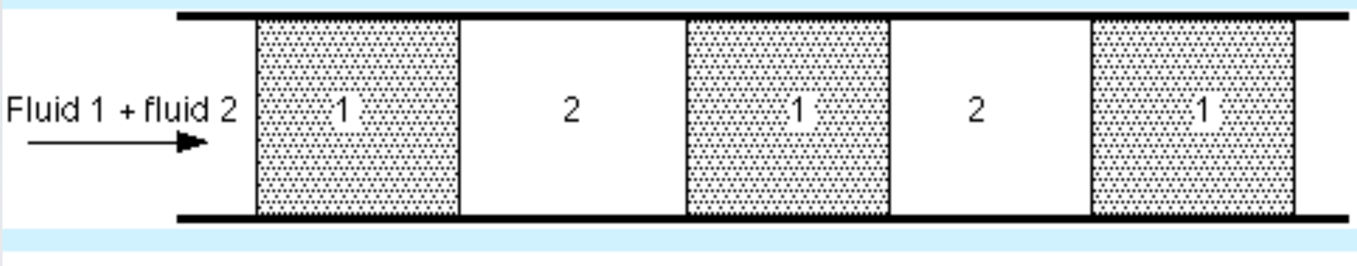


Side Branch

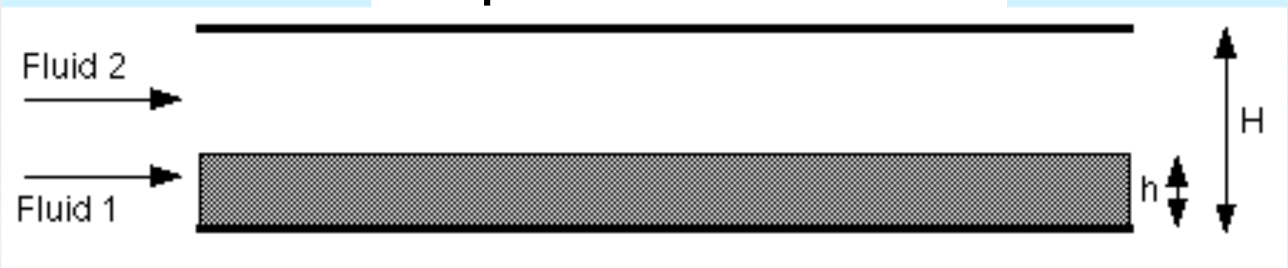
McQuillen, NASA GRC http://microgravity.grc.nasa.gov/6712/2phase_flow/2phase.html

IDEALIZED FLOW REGIMES

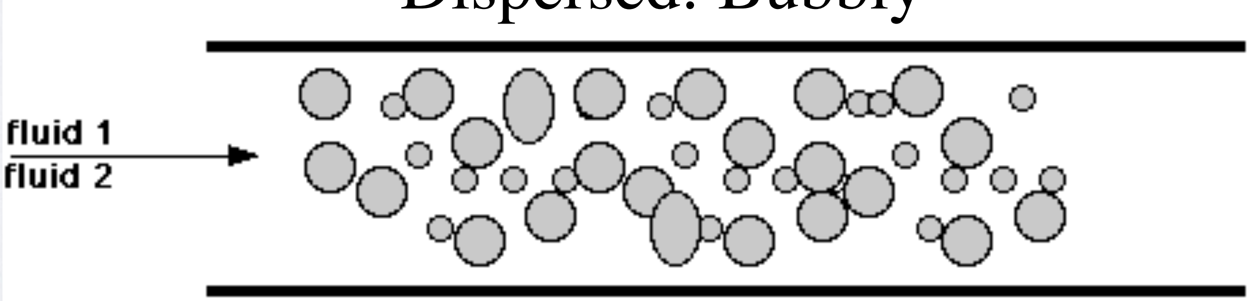
Alternating: Slug



Separated: Annular

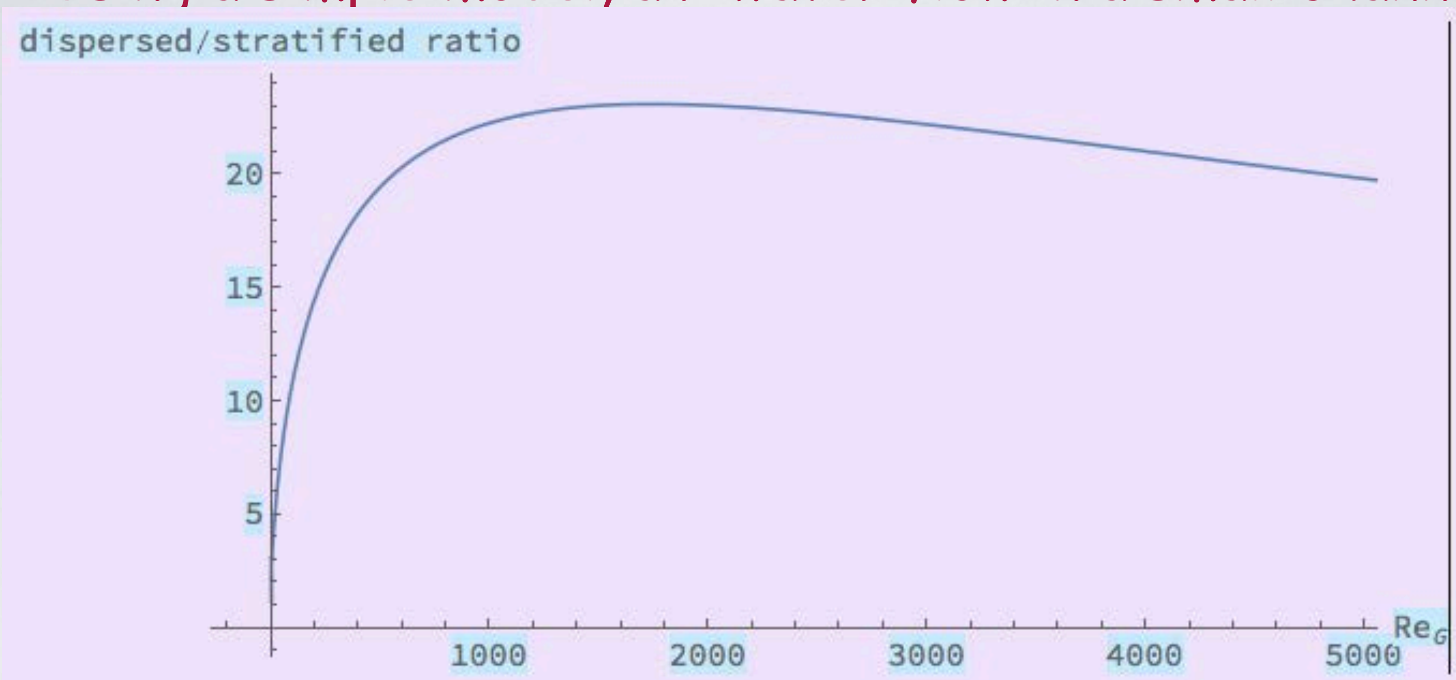


Dispersed: Bubbly

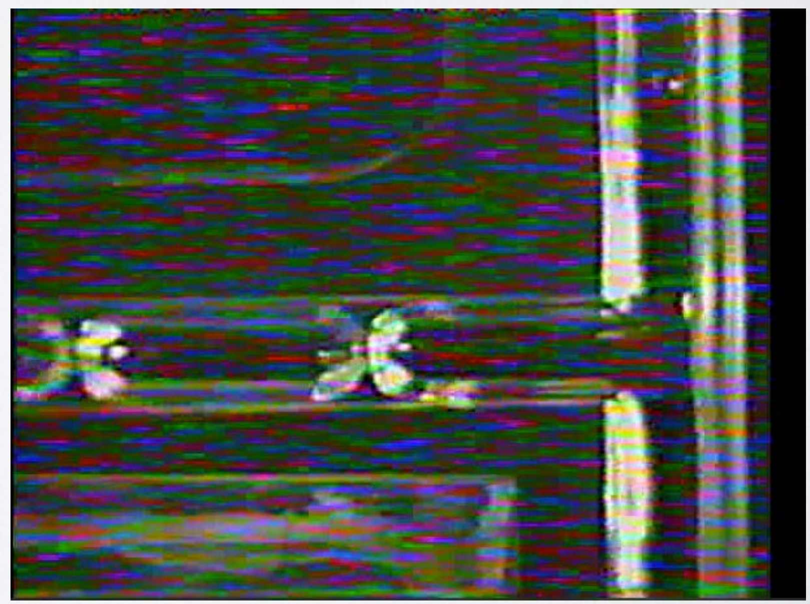


SURPRISING RESULT: PRESSURE DROP RATIO

Using a simple model, air-water flow in a small channel



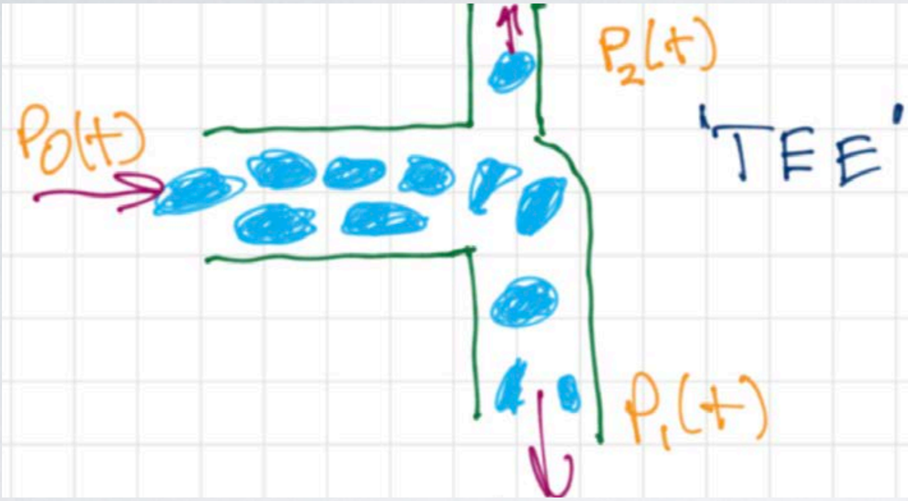
- Similar level of variation for a "T" or other branch



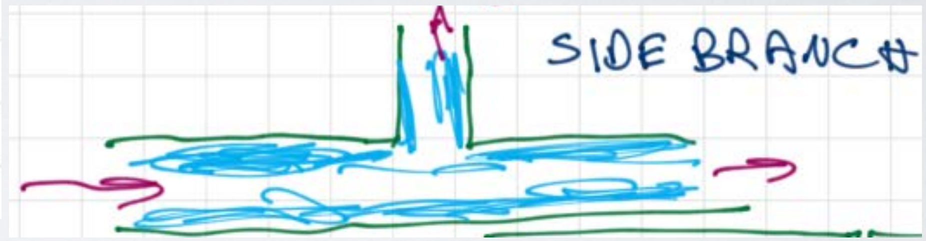
MOST CRITICAL CURRENT ISSUES

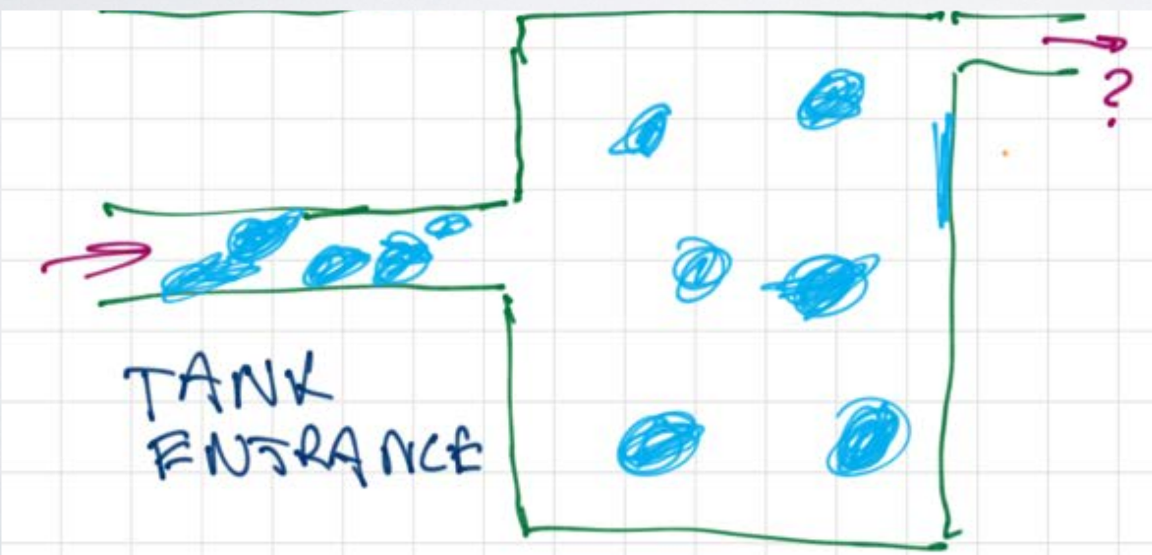
- For these standard "problematic" flow situations, significant computation capabilities exist — if we ask the right question. (Prof Tryggvason, may provide details)
- To know which questions to ask, we need to see conceptual designs of the various systems.

"CLASSIC PROBLEM" SITUATIONS



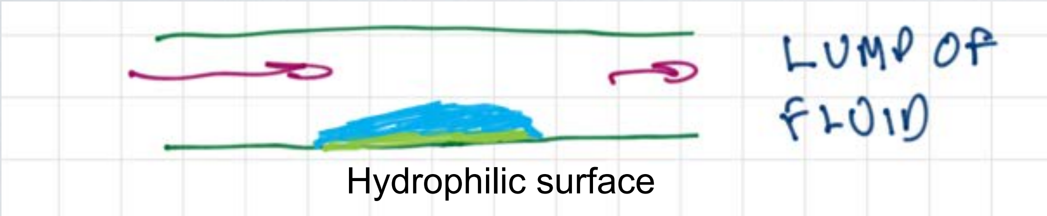
How much liquid and gas in each branch?

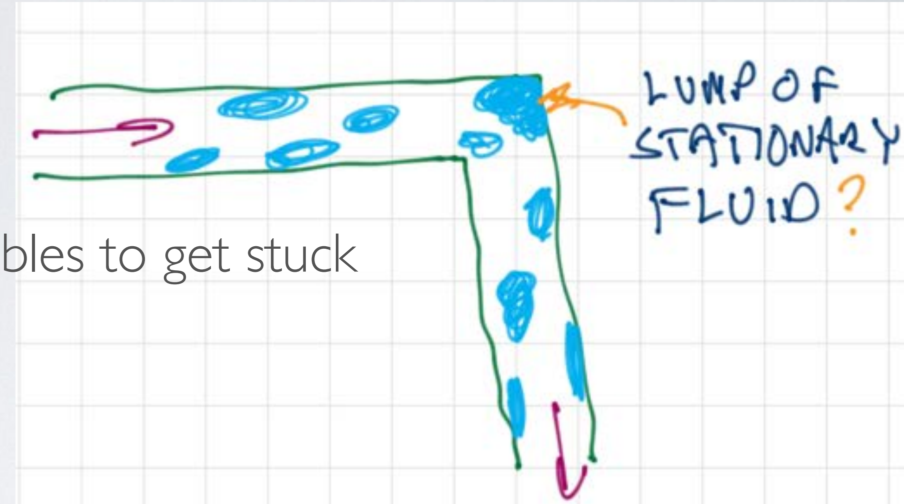




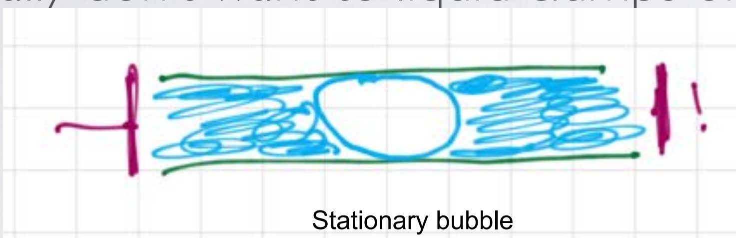
"Where" does liquid go?

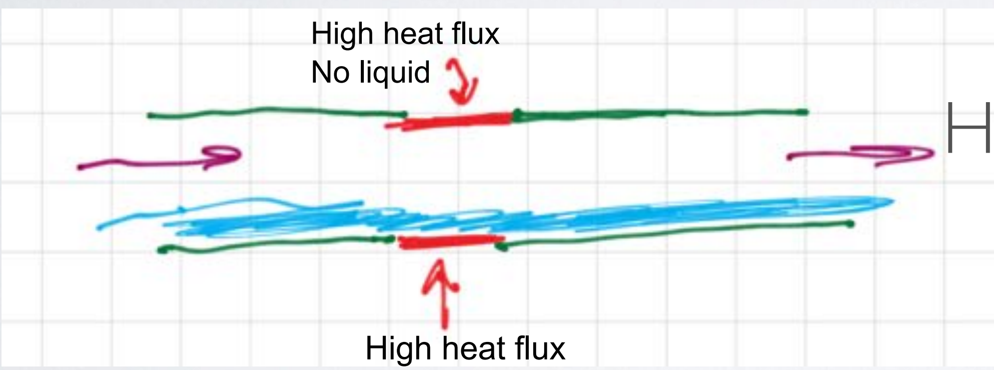
CLASSIC PROBLEM SITUATIONS





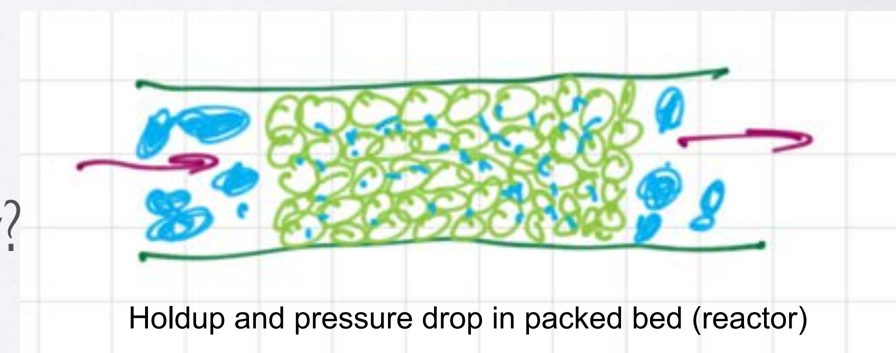
Generally don't want to liquid clumps or gas bubbles to get stuck



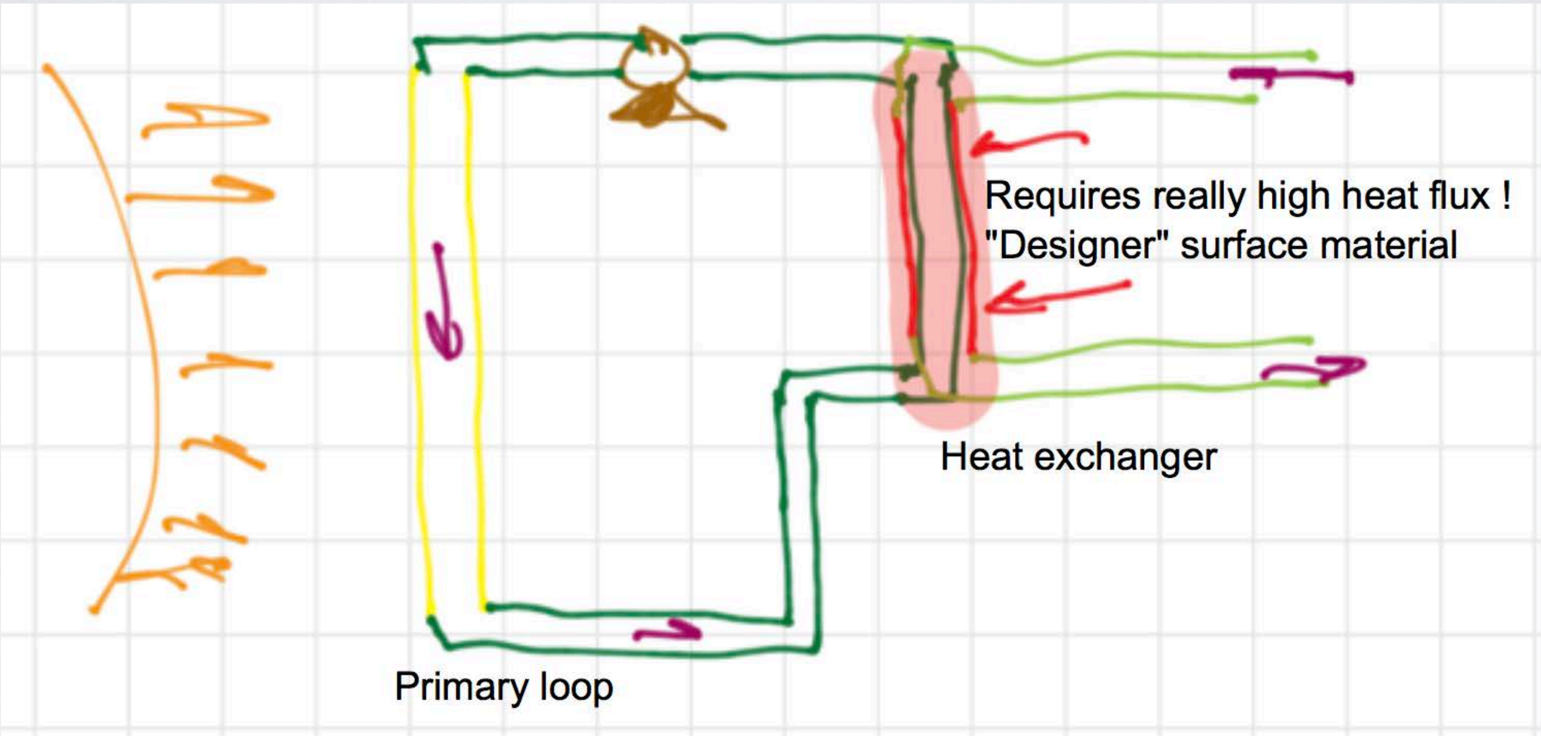


Heat flux for liquid compared to gas?

Flying now?



HIGH PERFORMANCE REQUIREMENT



- Reasonable chance of pushing the envelope on heat exchange
- Still some concern about system performance (pumps may be key)