OMNI-GRAVITY HYDROPONICS FOR SPACE EXPLORATION

ICES PAPER 2019-242

NASA Glenn Research Center
Tyler Hatch
John McQuillen

Portland State University
Rihana Mungin
Mark Weislogel

OMNI-GRAVITY HYDROPONICS

Hydroponic system capable of functioning in a variety of gravity environments.

- ‘Gravity dominated’ mode
- ‘Capillary fluidics’ mode mimicking gravity

MOTIVATION

Supporting human exploration beyond LEO

- Limited resupply
- Nutrient degradation
- Weight & volume of stored food
- Favorable crew response
- Etc.

PLANT WATER MANAGEMENT

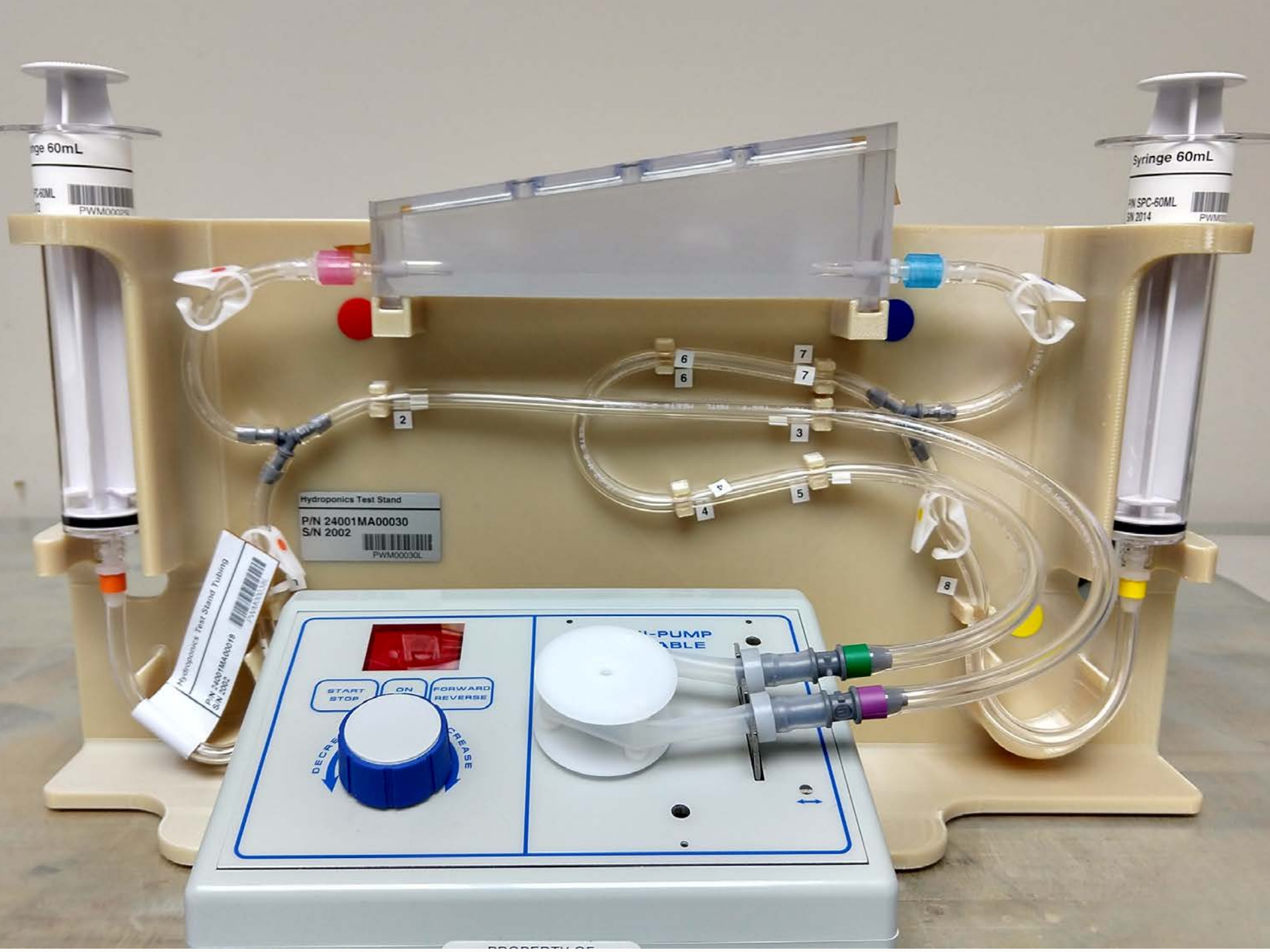
- Investigation of the application of capillary fluidics for liquid management
- Coop. agreement between PSU, GRC, and KSC
- Six novel water delivery devices
  - (1) Omni-gravity hydroponics (PWM – H)
  - (2) Breathable ‘geometric soil’ (PWM – S)
  - (3 & 4) Specified and under contract
  - (5 & 6) Early development

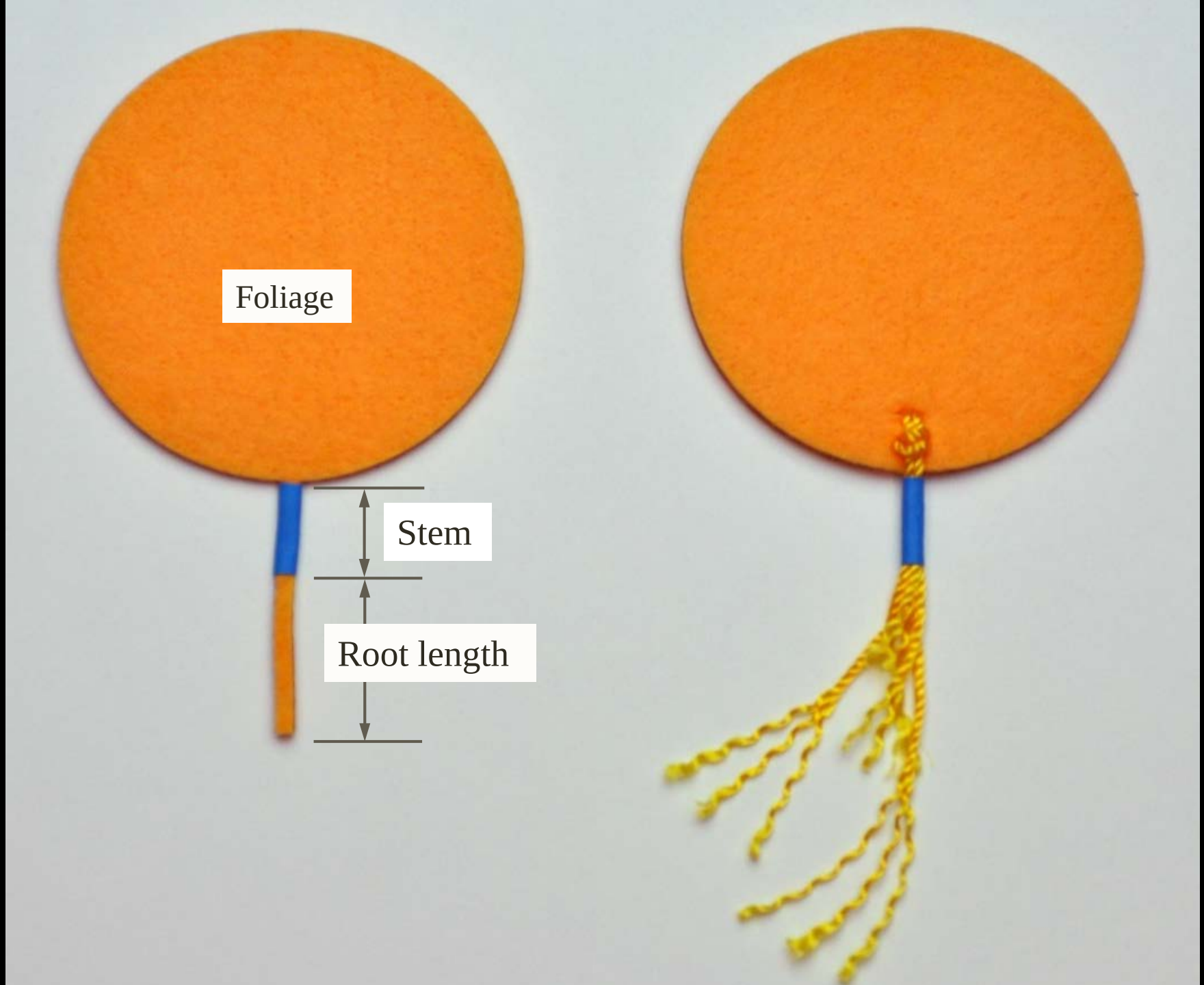
OBJECTIVES

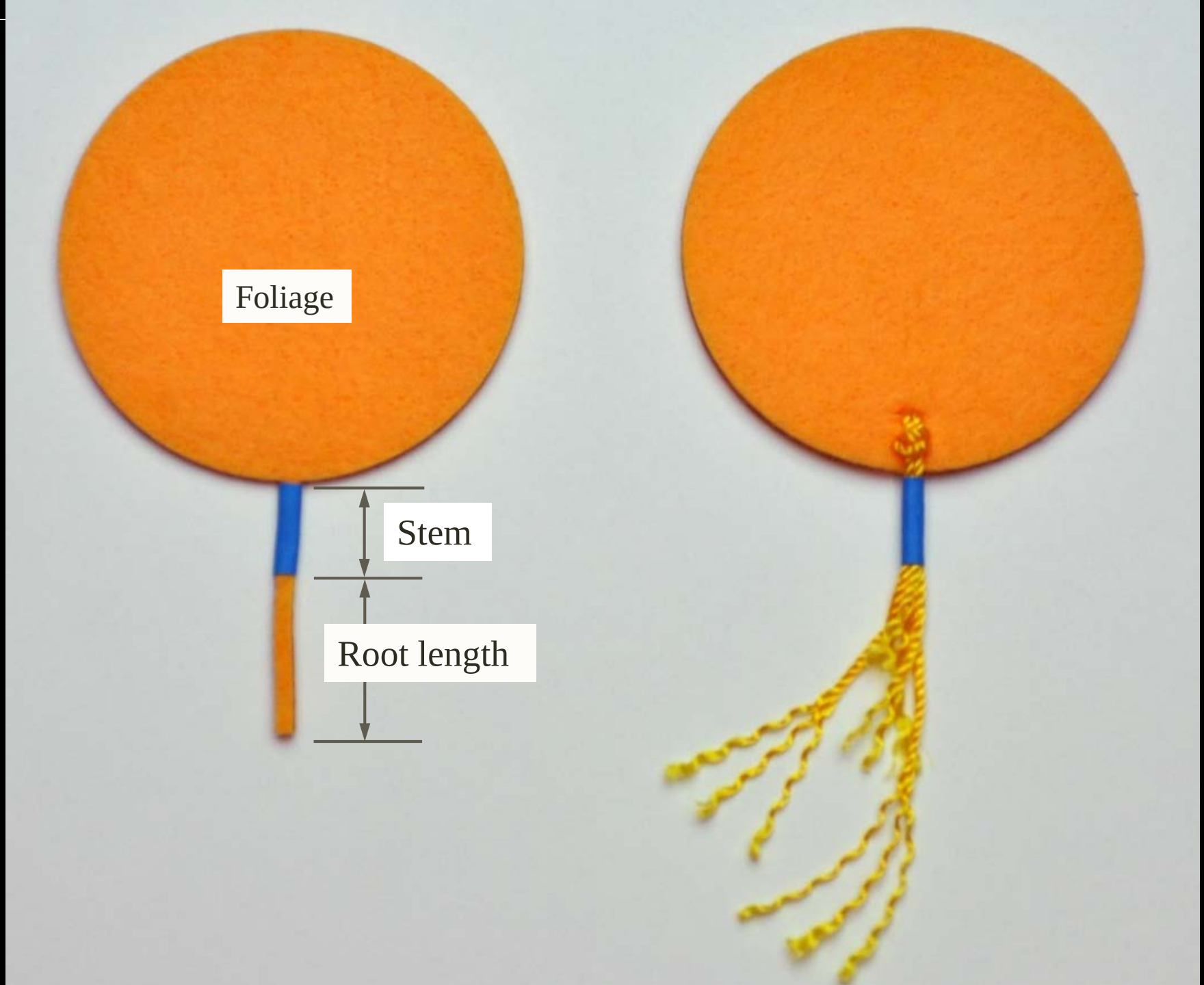
- Demonstrate omni-gravity function
- Passive hydration, aeration, and nutrient supply during simulated plant maturation process
- Passive liquid stability and control in open and semi-open containers with plant models
- Demonstrate practical system performance: i.e., prime, start-up, shutdown, safing, restart, ect.
- Considerations for germination, harvesting, plant removal, autonomous function, etc…

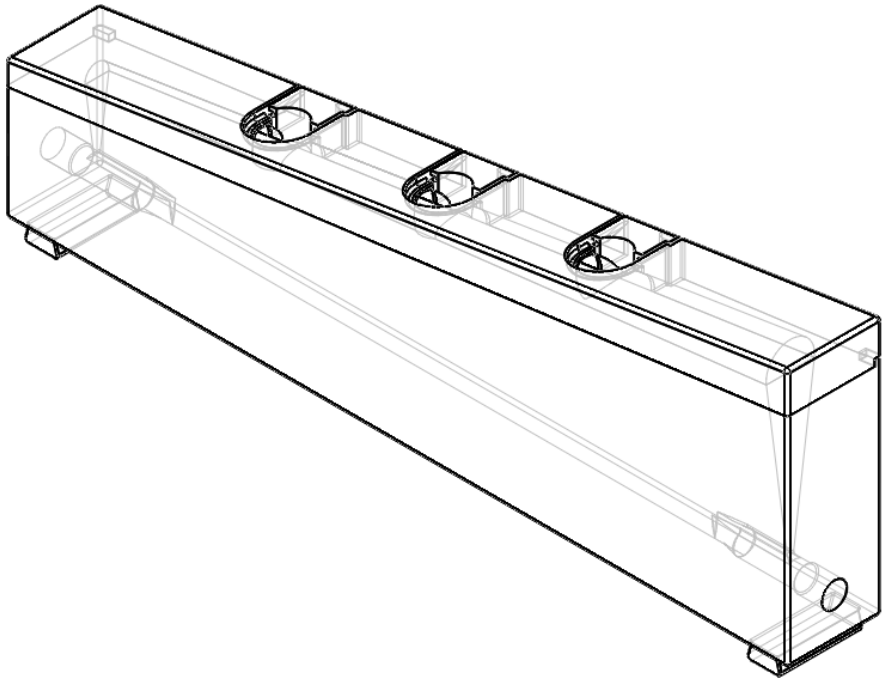
PLANT WATER MANAGEMENT CHARACTERISTICS

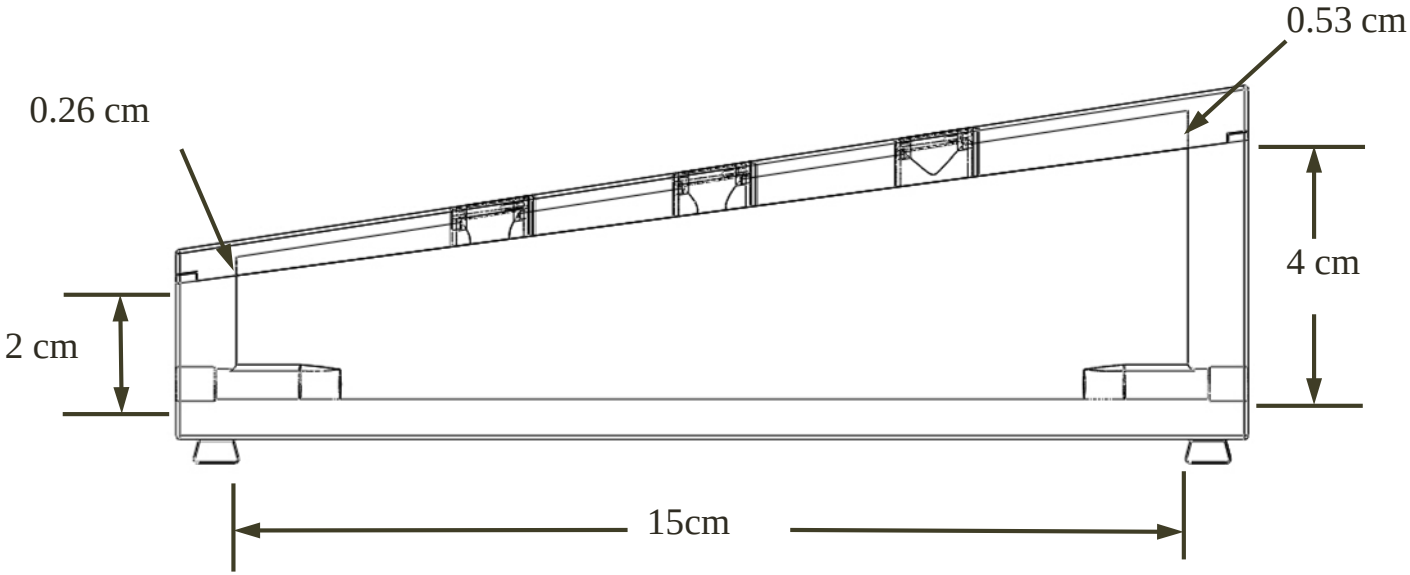
- Simple
- Inexpensive
- Fast-to-flight
- Low ISS resource utilization
- Task listable
- No crew training
- Open capillary containment of TOX 0 fluid: i.e., open cabin on MWA
- High data rate from single RTDL HD camera
- Variety of plant models: root, stem, and foliage
- And more

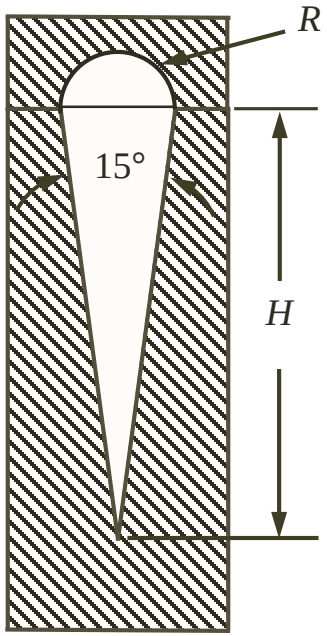

Syringe 60mL
Hydroponics Test Stand
P/N 24001MA00030
S/N 2002
PWM00030L
START STOP
ON
FORWARD REVERSE
2
3
4
5
6
7
8

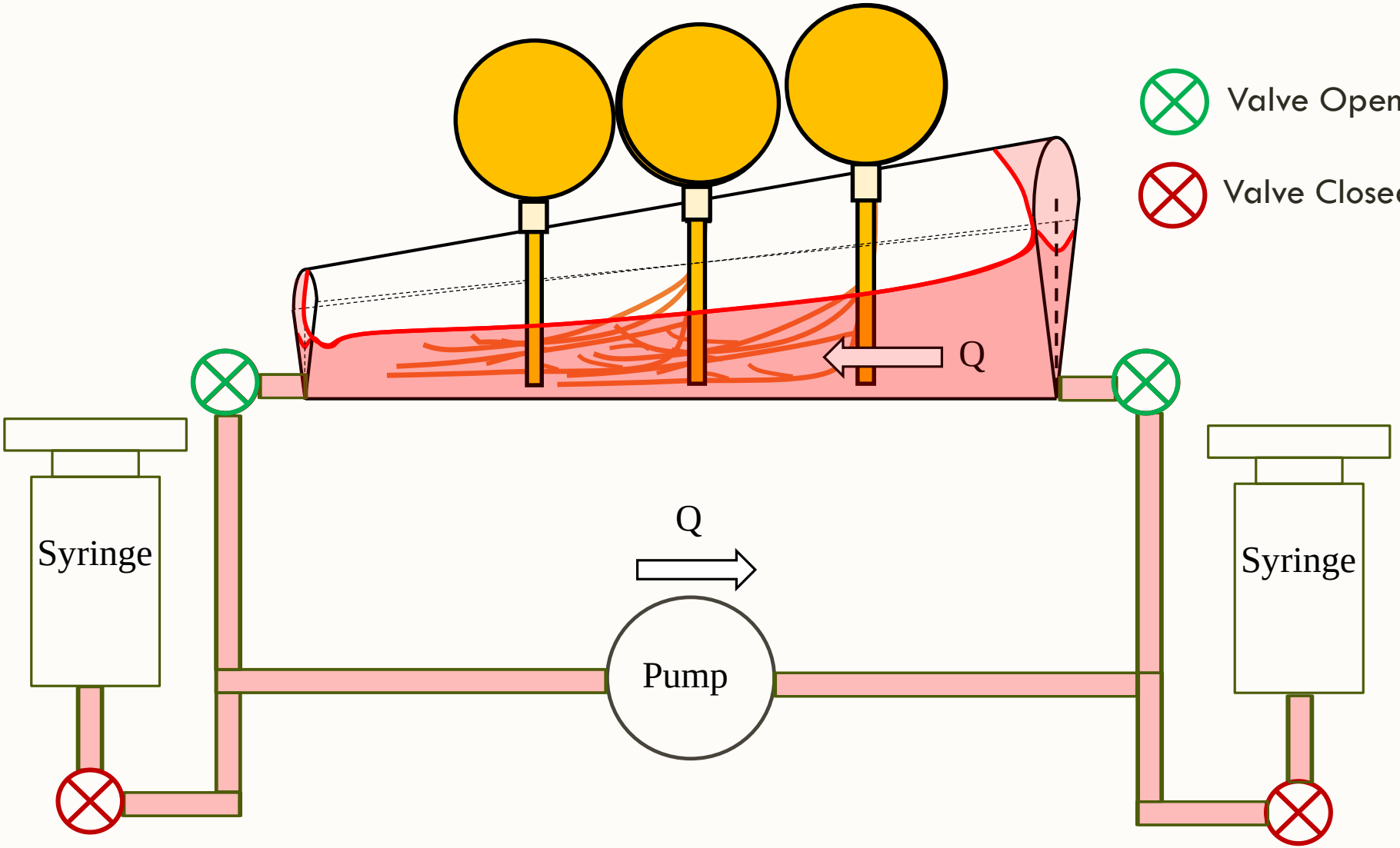

Foliage
Stem
Root length


Foliage
Stem
Root length




0.53 cm
0.26 cm
4 cm
2 cm
15cm

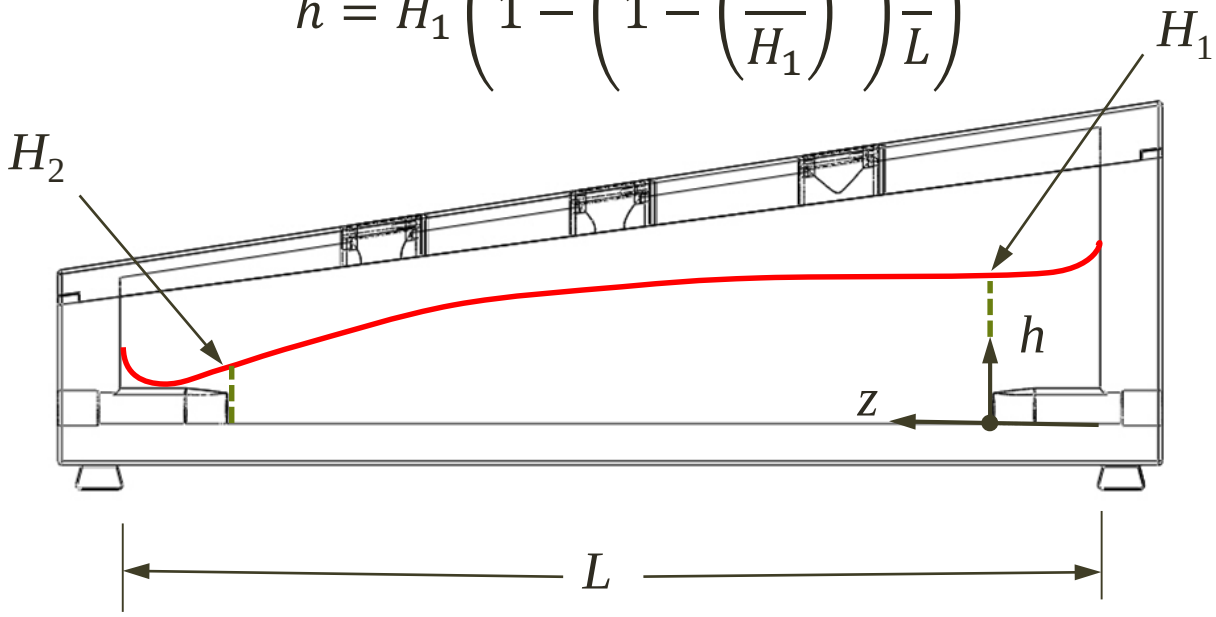

R
15°
H


Valve Open
Valve Closed
Q
Q
Syringe
Pump
Syringe

INTERFACE POSITION

For known H_1 and H_2 the free surface profile can be determined by

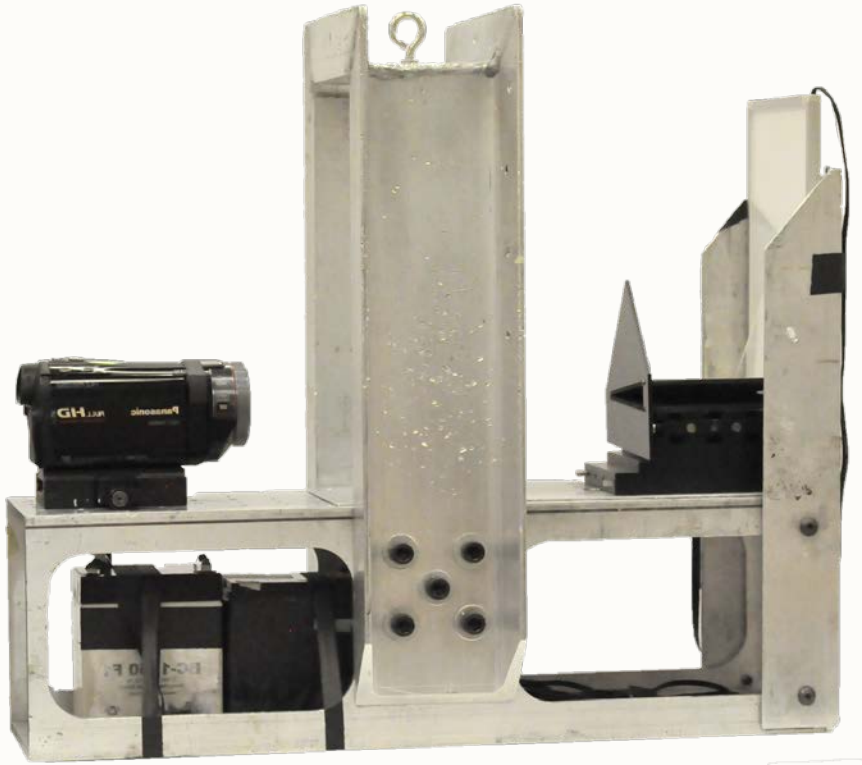
$$h = H_1\left(1-\left(1-\left(\frac{H_2}{H_1}\right)^3\right)\frac{z}{L}\right)^{1/3}$$

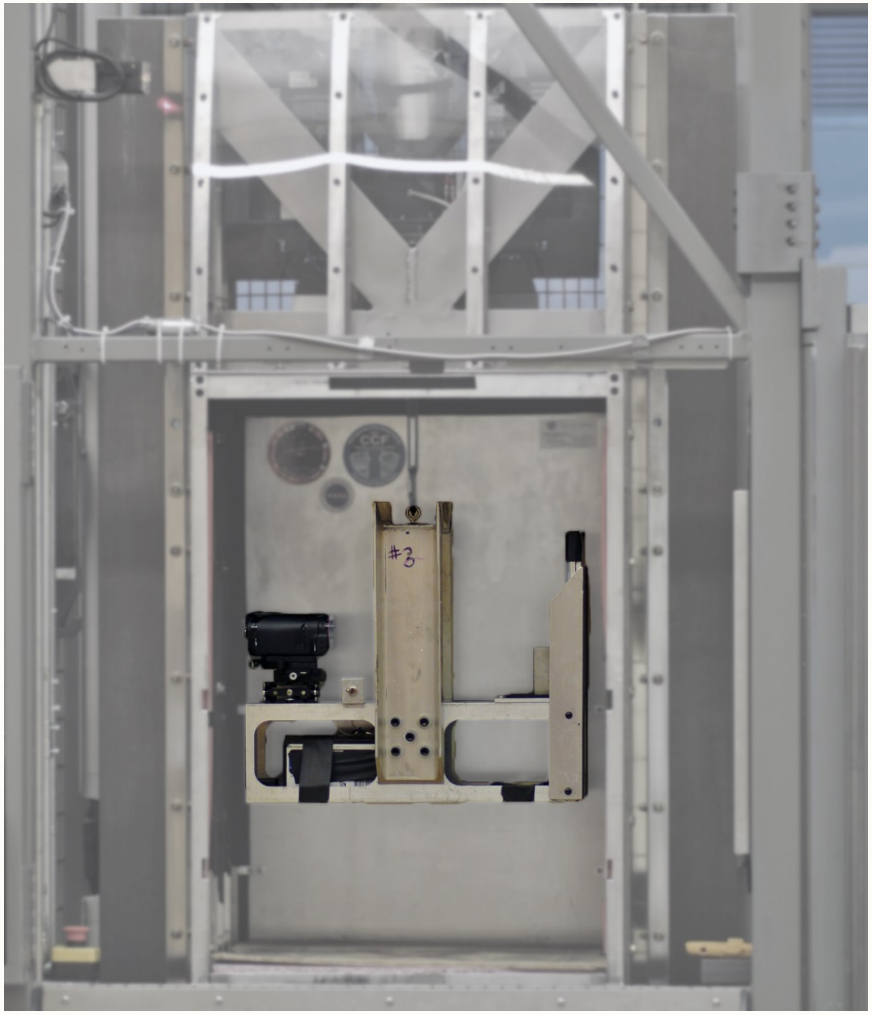


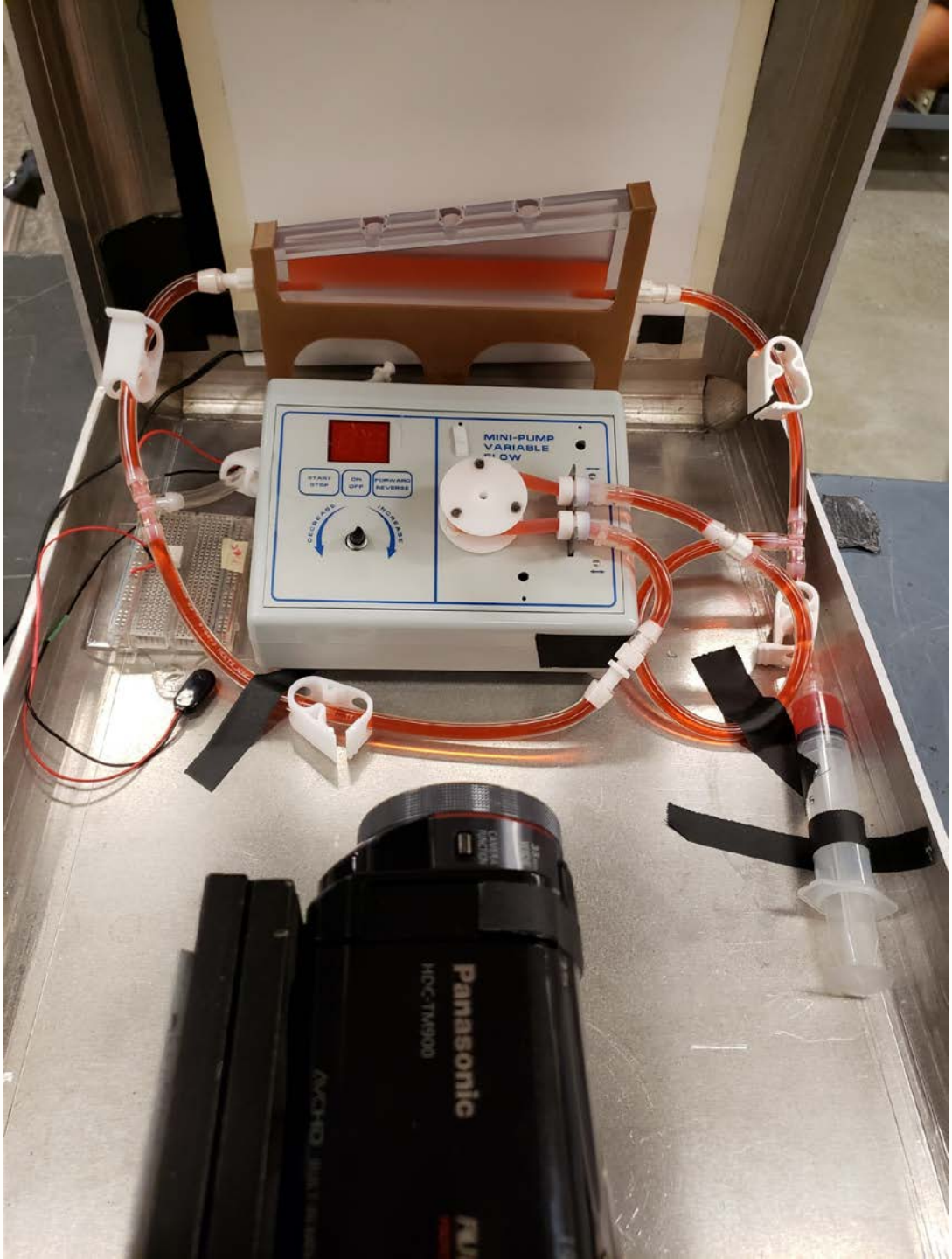
Want to see the math???

Dynamics of Massively Parallel Open Capillary Channel Flow….

Tomorrow @ 2pm in Brandeis/Holmes



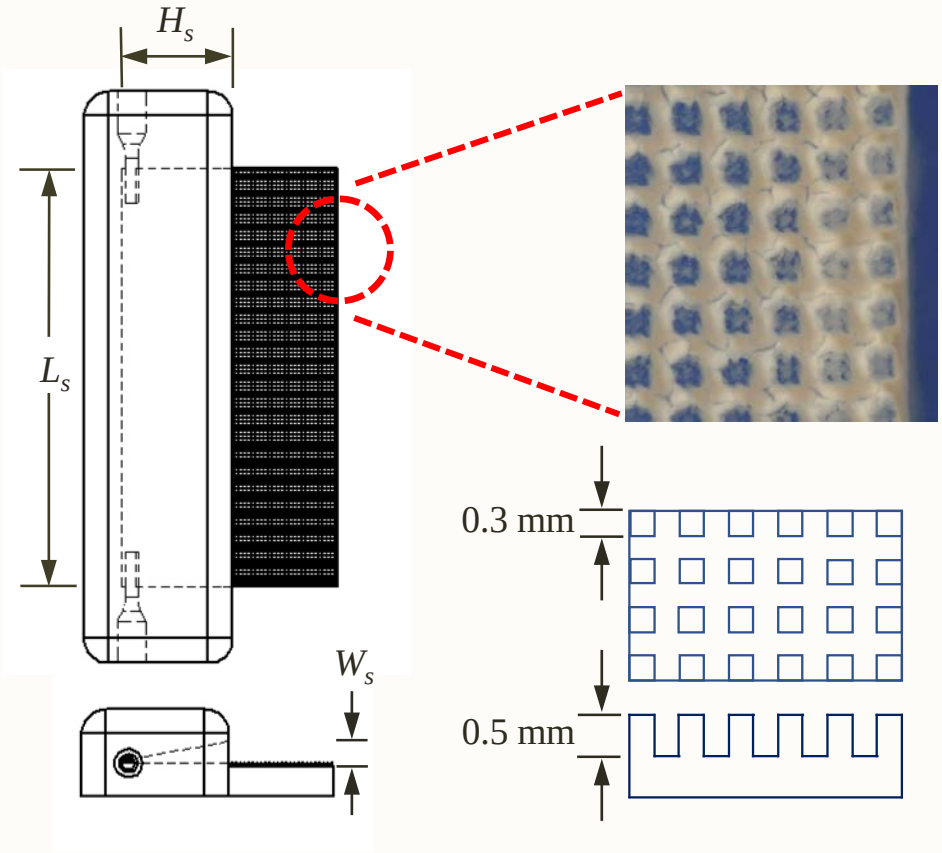

#3

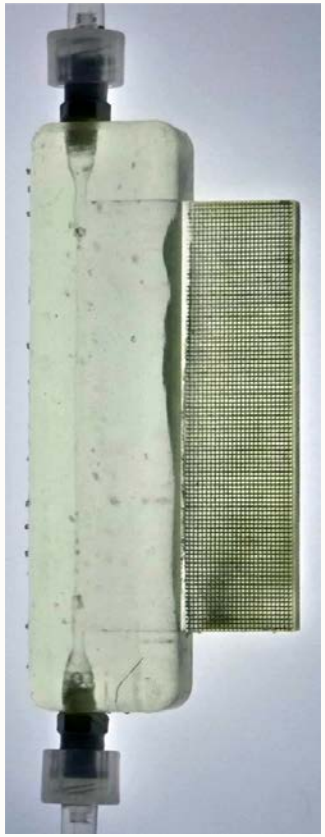

MINI-PUMP
VARIABLE
START
STOP
ON
OFF
FORWARD
REVERSE
DECREASE
INCREASE
Panasonic
HDC-TM900

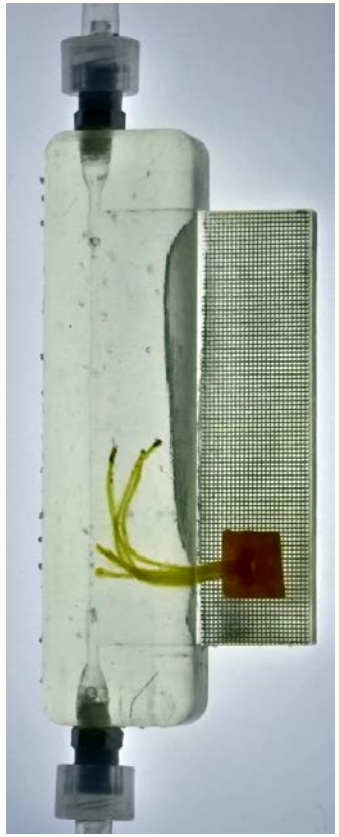

MINI-PUMP
VARIABLE
Panasonic
FULL HD
900M

Capillary dominated when Bo << 1

$$Bo = \frac{Gravitational}{Capillary} = \frac{\rho g {W_s}^2}{\sigma}$$







FLOW REGIMES

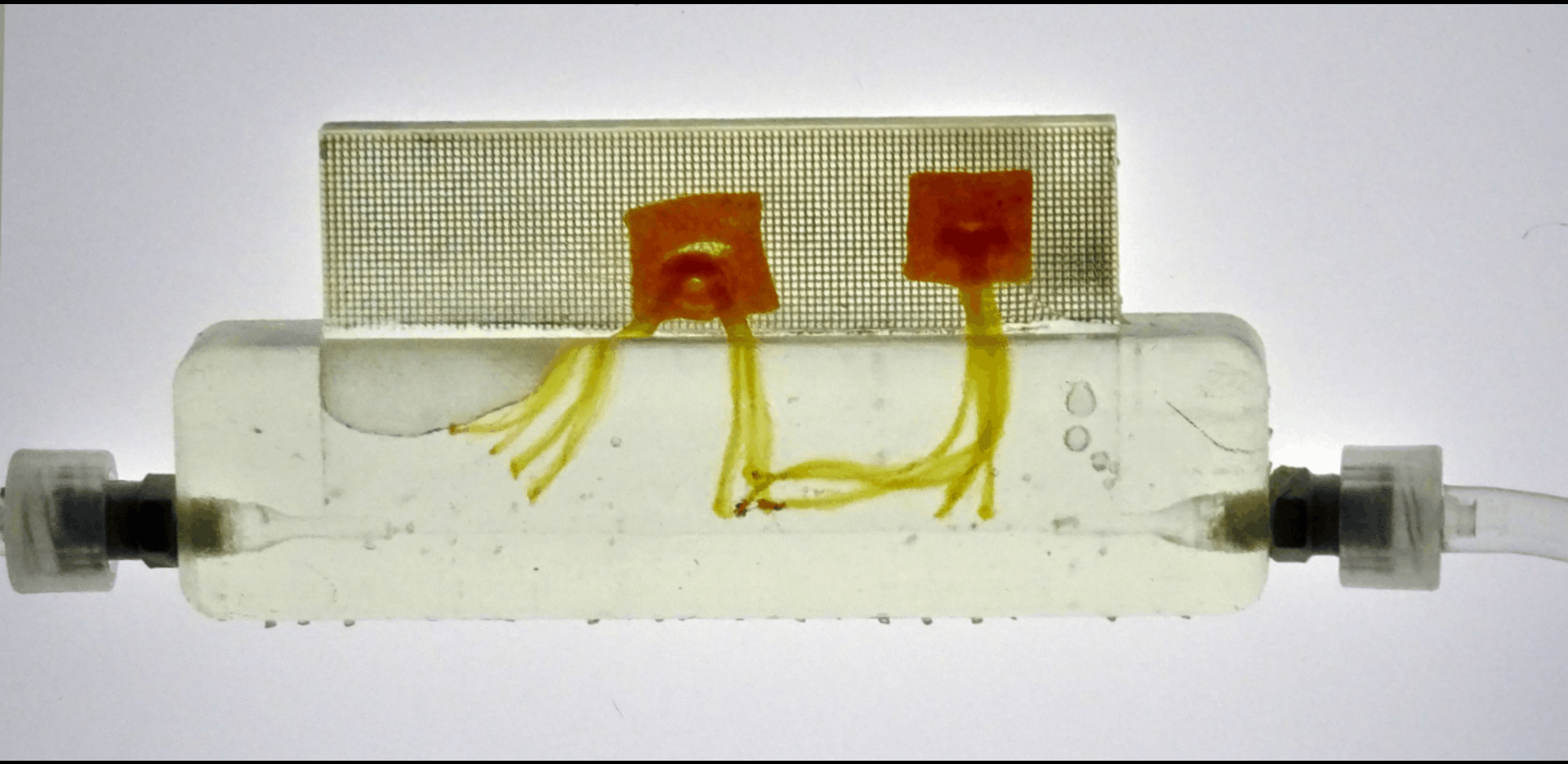
- **Stable:** Continuous liquid stream at outlet, $Q_{max} \sim 0.4$ ml/s
- **Ingestion:** Gas ingested at outlet
- **Embolism:** Accumulation of liquid at inlet
- **Ejection:** Liquid droplet ejection from channel

STABLE

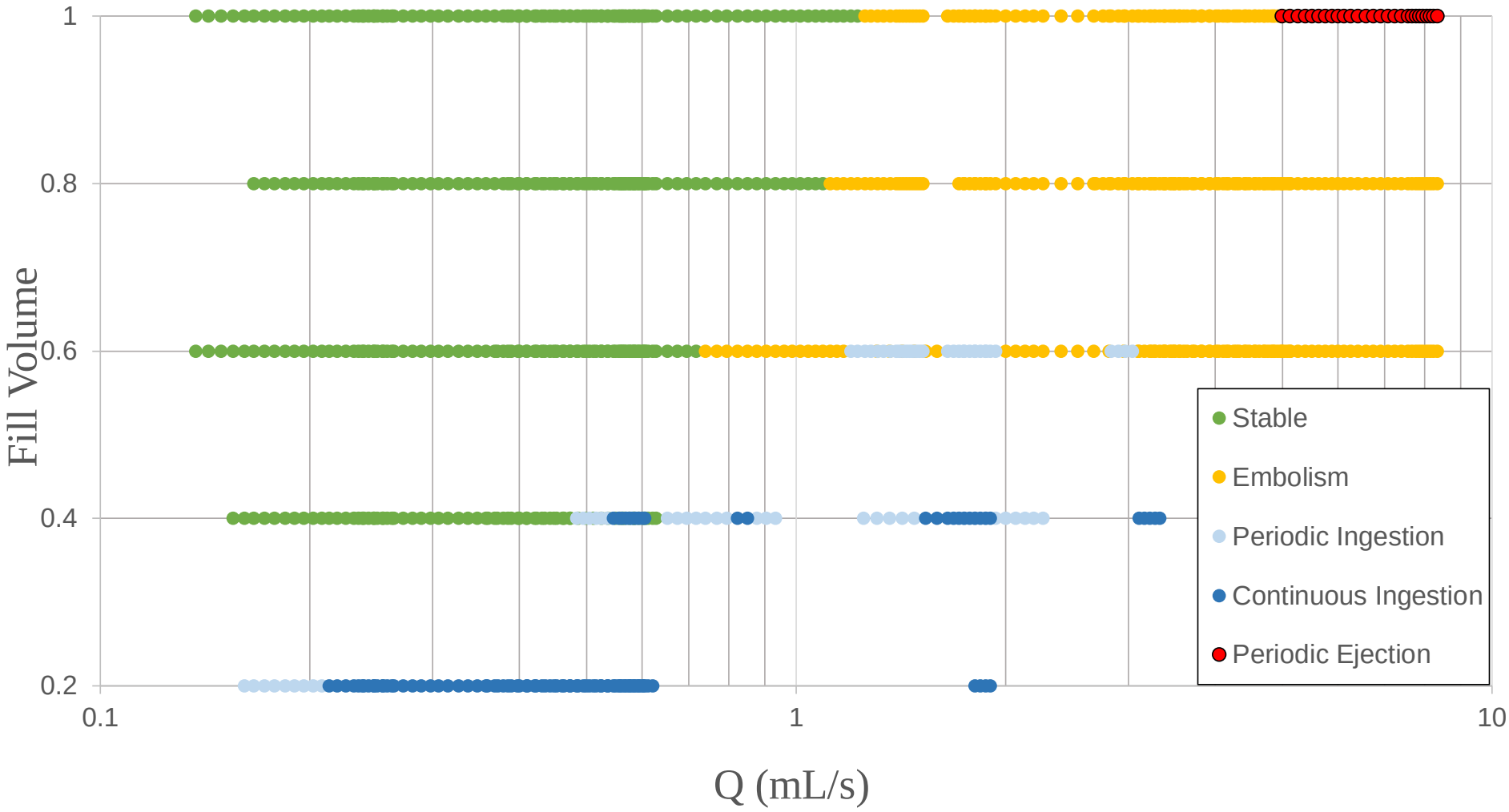
INGESTION

EMBOLISM & EJECTION

LONG DURATION



SINGLE TAP ROOT



ACCOMPLISHMENTS TO DATE

- Omni-gravity hydroponics designed, fabricated, and tested in collaboration with KSC plant physiologists
- Flight hardware shipped for launch
- Successful terrestrial 1-g, Terrestrial low-g, and low-g drop tower demonstrations
- Flow regime maps established with 1/30th model
- 6 regimes identified including steady periodic bubble ingestion providing passive aeration to root zone

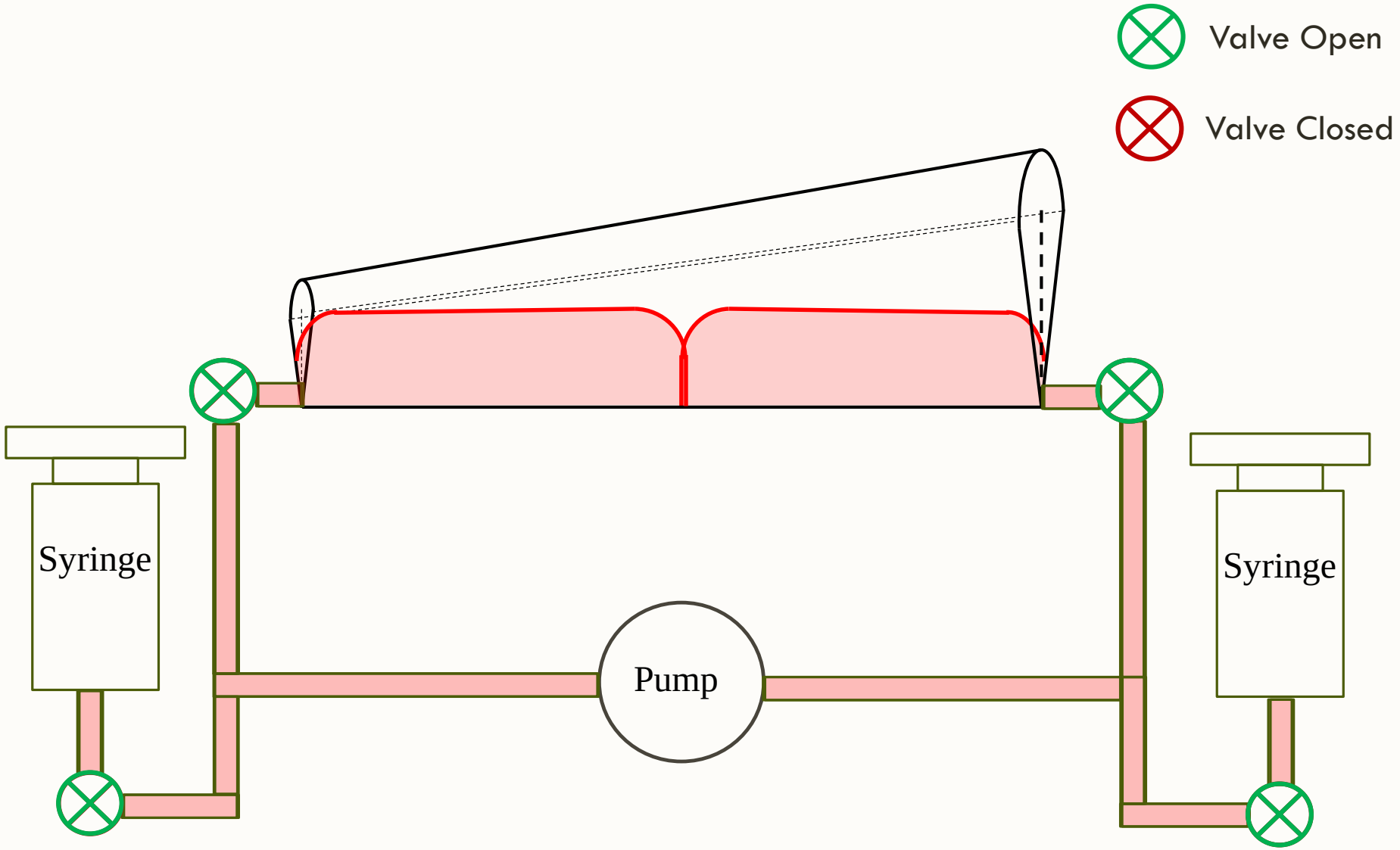
STATUS & NEXT STEPS

- Provisional patent filed
- PWM-H and PWM-S scheduled to fly on SpaceX-18 July 21, 2019
- Ops August – September 2019
- Test cells 3 & 4 specified and under contract
- Experimental 1-g, drop tower, and numerics investigation continues
- Publication(s) forthcoming

ACKNOWLEDGEMENTS

- Funded in part by the NASA Cooperative Agreements 80NSSC18K0436: GRC CoTR J. McQuillen
- NASA KSC plant physiologists: Tom Dreschel, Ralph Fritsche, Gioia Massa, Oscar Monje and Ray Wheeler, et al.
- PSU undergraduate researcher: Tara Prevo
- Zin Technologies

Backup Slides

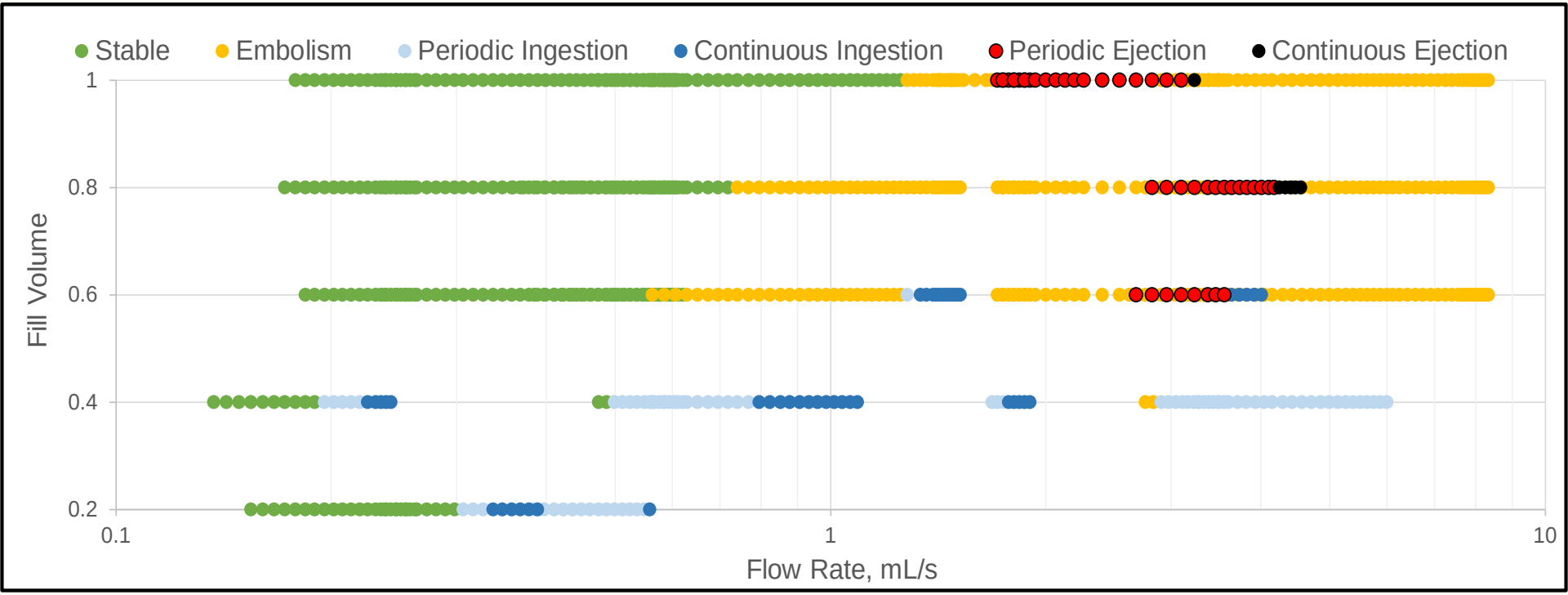

Valve Open
Valve Closed
Syringe
Pump
Syringe

CSELS: CAPILLARY STRUCTURES FOR EXPLORATION LIFE SUPPORT

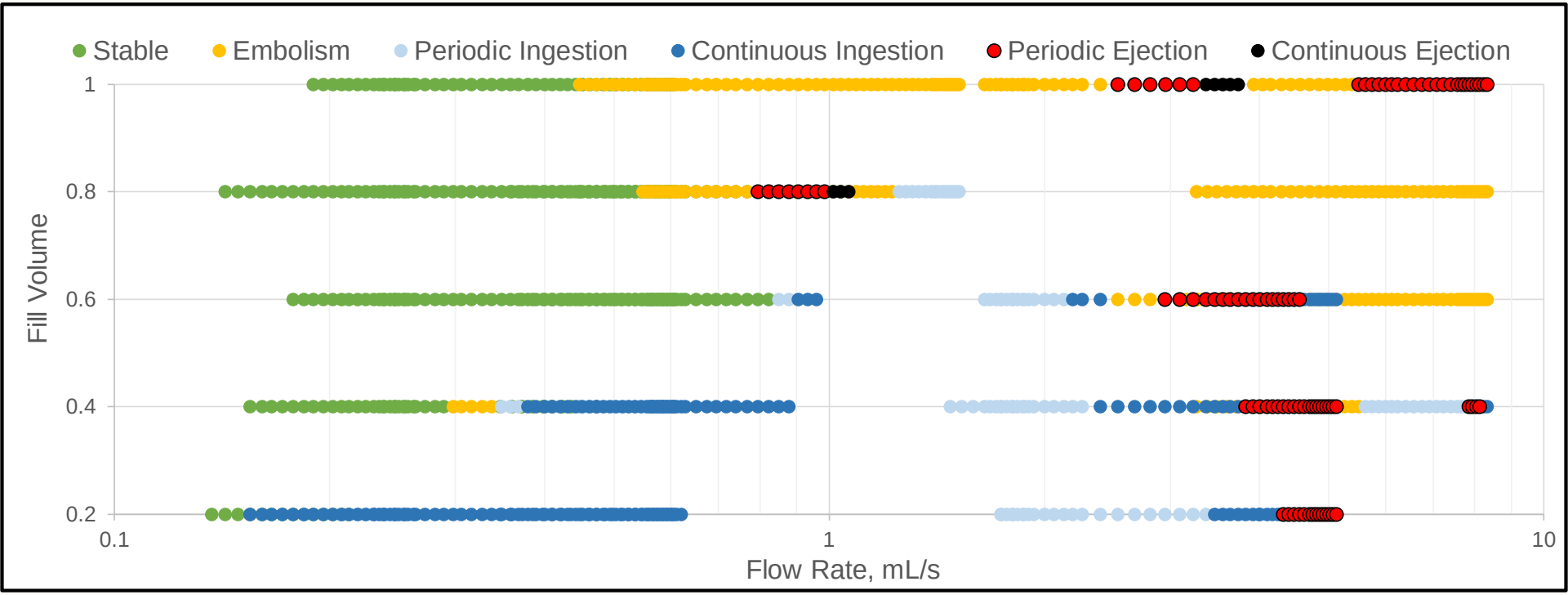
Investigating capillary phenomena in microgravity for the development of life-support technologies

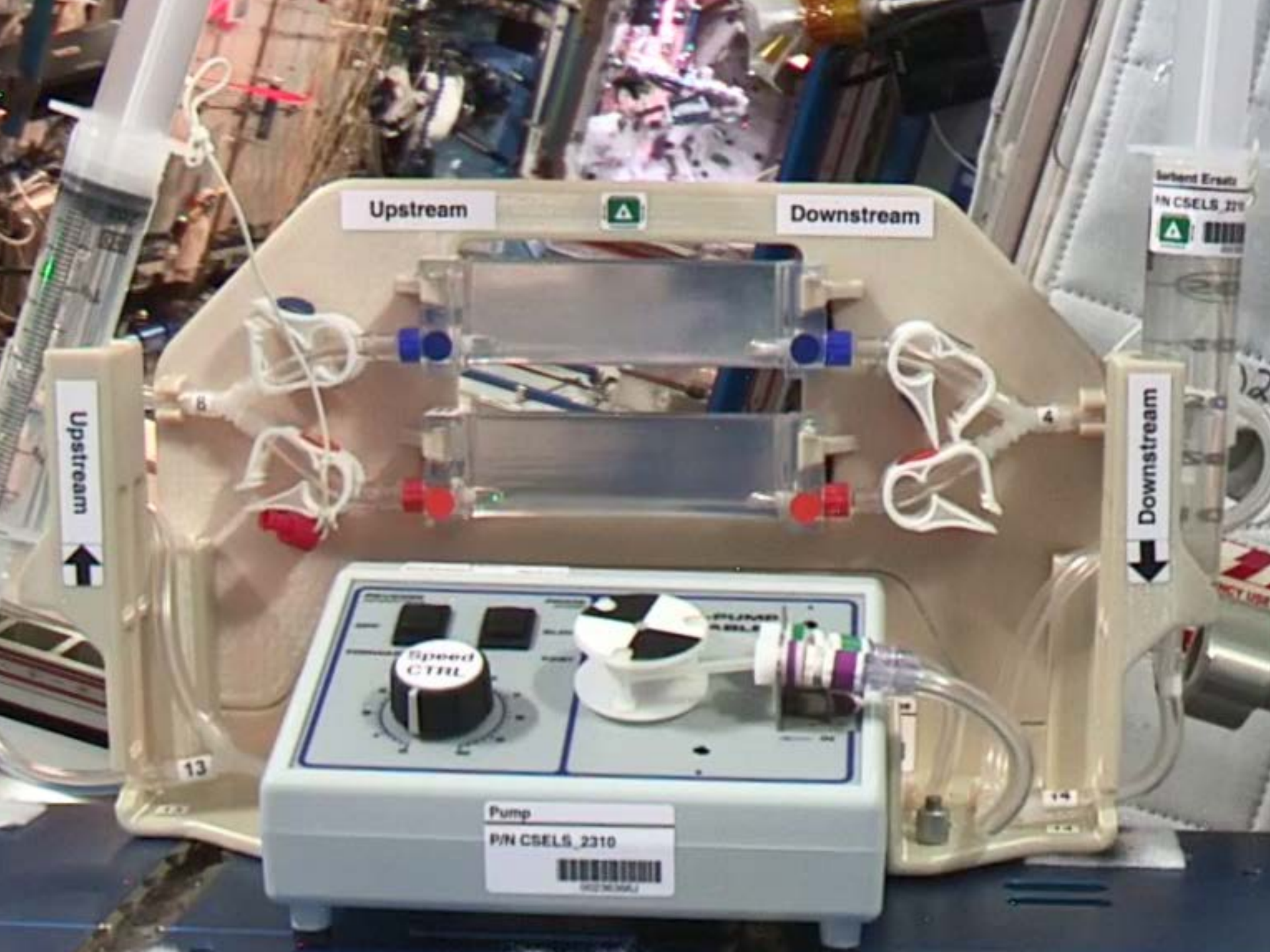
- Capillary Evaporator (CapEvap)
  - Microgravity evaporation rates
  - Wastewater processing
- Capillary Sorbent (CapiSorb)
  - Parallel open channel corner flows
  - CO_2 removal from air

NO PLANTS


Stable
Embolism
Periodic Ingestion
Continuous Ingestion
Periodic Ejection
Continuous Ejection
Fill Volume
1
0.8
0.6
0.4
0.2
0.1
1
10
Flow Rate, mL/s

SINGLE STRING ROOT




Upstream
Downstream
Upstream
Downstream
Speed CTRL
Pump
P/N CSELS_2310

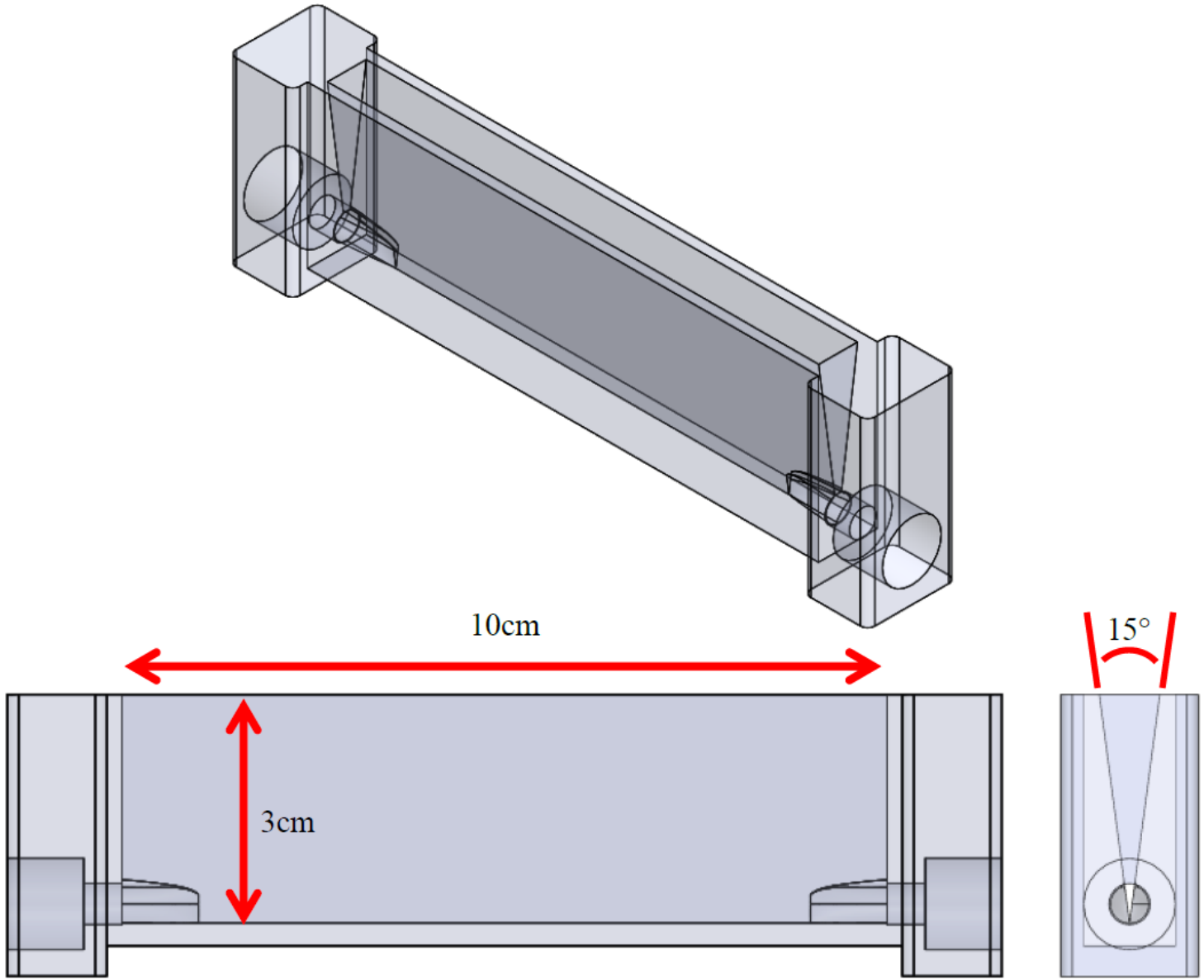
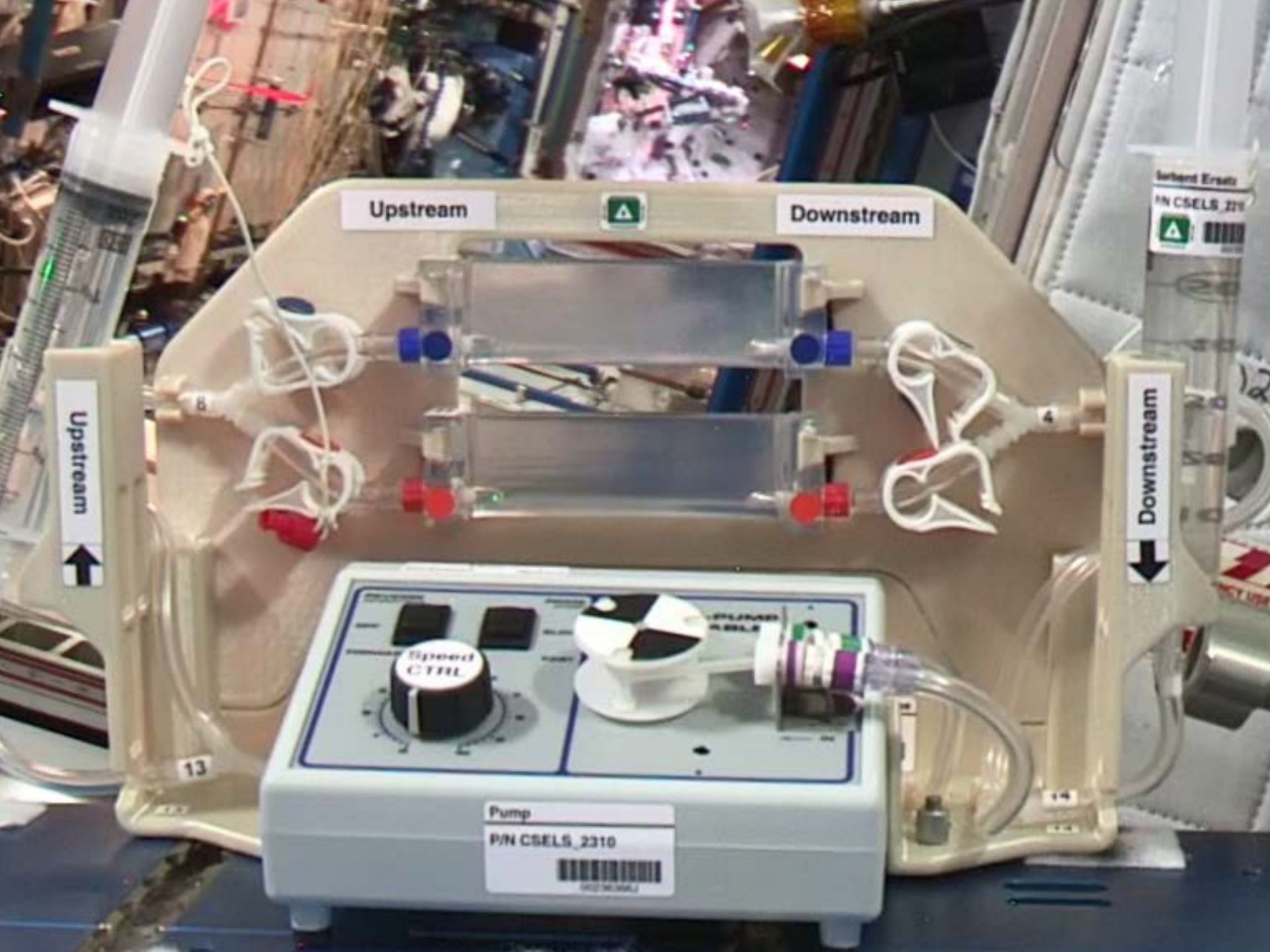
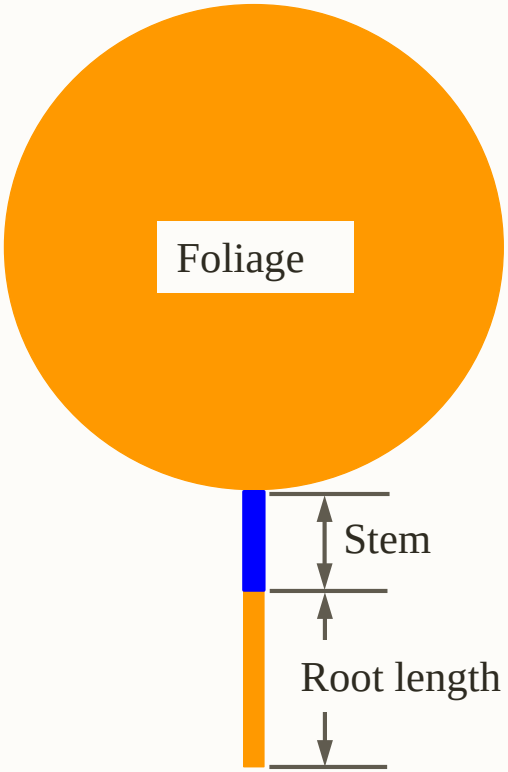


PHOTO: FINAL REPORT FOR CAPILLARY STRUCTURES FOR EXPLORATION LIFE SUPPORT (CSELS) FLIGHT EXPERIMENTS


Upstream
Downstream
Upstream
Downstream
Speed CTRL
Pump
P/N CSELS_2310


Foliage
Stem
Root length