NASA's Ground-Based Microgravity Simulation Facility

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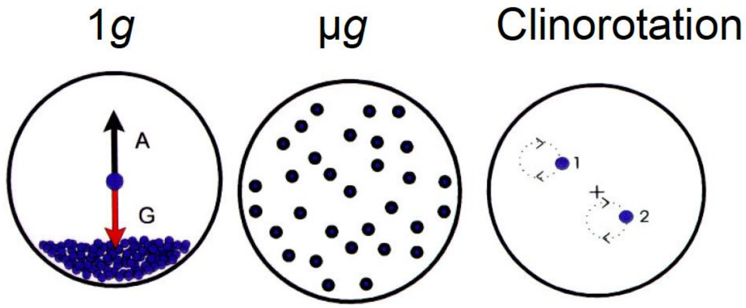
Why Ground Microgravity Simulation?

- **Key points** from recent reviews on ground-based microgravity simulation:
  - While **microgravity simulation devices (MSDs)** do not abolish the 1g force of gravity, they either **randomize the direction of gravity with respect to the sample over time or compensate the gravity force by creating a counteracting force** (for instance by the use of magnetic levitation).
  - **Each type of MSD has its own specific artifacts**, e.g. centrifugal accelerations and vibrations in the case of clinostats or differing magnetic susceptibility of cell components in the case of magnetic levitation.
  - **While true microgravity cannot be achieved with an MSD, it can generate functional weightlessness from the perspective of the organisms or cells** if the provided environment results in physical constraints that are below the known acceleration sensitivities of the biological processes being studied (Briegleb, 1992).
- **Given that microgravity simulation devices have limitations**, **they are valuable tools for (1) preparing spaceflight experiments, (2) conducting ground control studies for spaceflight experiments, and (3) facilitating cost effective ground studies for gravitational research**.



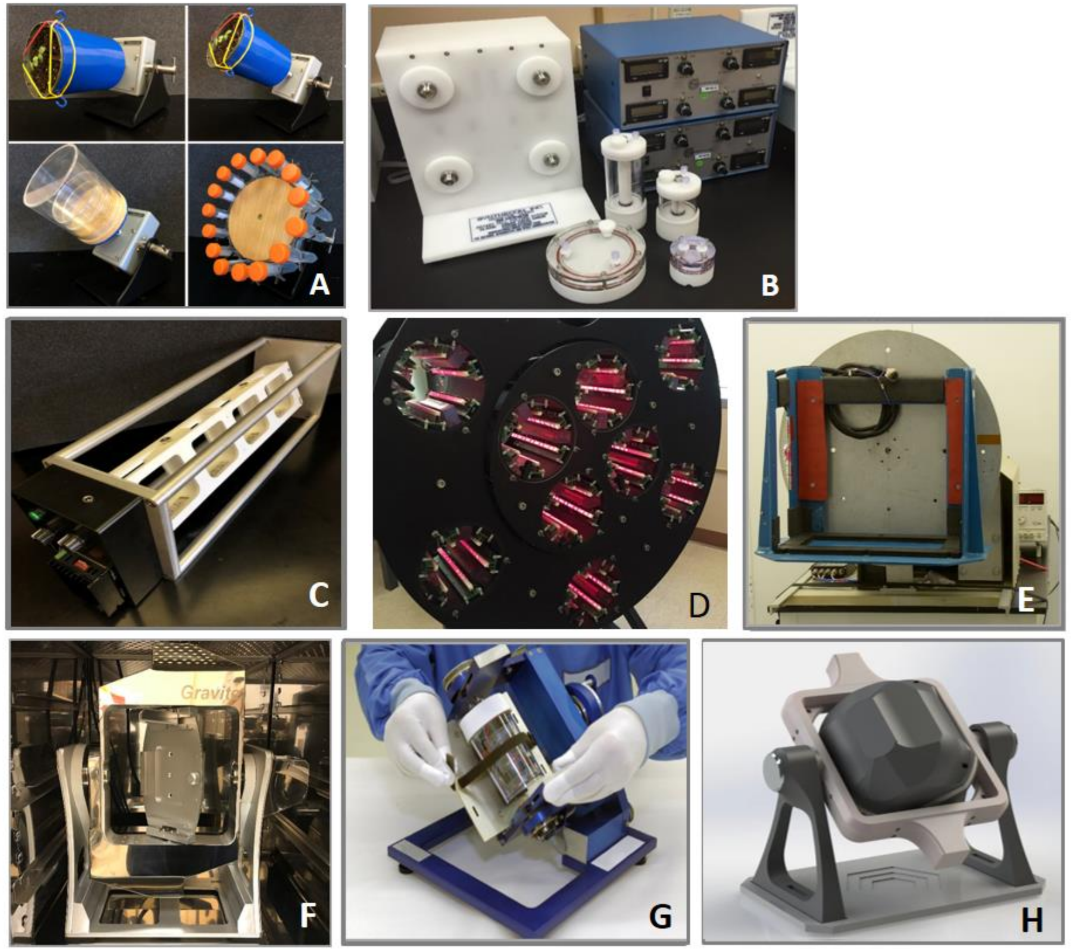
Simulation of Microgravity on Earth using Clinorotation.

Microgravity Simulation Support Facility (MSSF)

The Microgravity Simulation Support Facility (MSSF) at Kennedy Space Center (KSC) was established to support visiting scientists for short duration studies utilizing a variety of microgravity simulation devices that negate the directional influence of the “g” vector

MSDs Currently Available for Use:

- 2-Dimensional (2-D) Clinostats (A, n=6)
- Rotating Wall Vessel Clinostats (Rotating Bioreactors; B, n=2)
- KSC 2-D Clinostat with LED (C, n=2)
- Large 4’ Diameter 2D Clinostat with Light Emitting Diodes (LED) (D, n=1)
- KSC Heavy Load 2-D Clinostat with middeck locker payload (E, n=1)
- Gravite 3-Dimensional (3-D) Clinostat (F, n=2)
- Random Positioning Machine (G, n=4)
- SciSpinner 3-D Clinostat (H, n=2)



Microgravity Simulation Support Facility (MSSF)

Critical Supporting Capabilities

Simulation Devices

2D Clinostats (3 types)

3D Clinostats (2 types)

RPM (n=4)

Synthecon Rotary Cell Culture Systems (RCCs)

Analytical Instruments

Flow Cytometer

Multi-Mode Plate Reader

Real-Time PCR System

NanoDrop™ One

Confocal Microscopy

Fluorescence Stereo-Dissecting Scope

Customized Sample Modules

Sample Container Holders: Tubes, Flasks, Petri Dishes, and Chamber Slides

Dual-Light Cycle Module

Plant Growth Module

Perfusion System

Live-Imaging Microscope Module

Science Support

Advanced Image Analysis

ANSYS CFD Simulation

CAD Design and 3D Printing

Cold Stowage from -150 ˚C to 4 ˚C, and LN2

Logistic Support

Each simulation device has its own pros and cons:

- The way "microgravity" is simulated
- The ability to accommodate different specimen types due to their individual unique constraints.
- The selection of an appropriate simulation method (device and rotation speed for many cases) is driven by the science, the biology, and the experimental objectives.

Microgravity Simulation Support Facility (MSSF)

It requires more than an appropriate simulation method for conducting a reliable microgravity simulation experiment and subsequent data interpretation:

- One of the major constraints that affects the quality of a microgravity simulation experiment is the number of replicates, often limited by the size of the rotating plates.
- The threshold for a biological organism to respond to a directional "g-vector" is determined by its gravity-sensing mechanism and the magnitude and duration of the accelerations.
- In addition, careful planning, adequate logistic support, and high fidelity 1-g controls are some of the most important determinant factors for the success of a microgravity simulation experiment in reducing confounding variables and mitigating non-device-related artifacts.

Strategies being implemented in the MSSF to reduce artifacts:

- Using multiple microgravity research platforms with high fidelity controls.
- Minimizing artifacts mechanically.
- Understanding the localized physical nature around specimens through fluid dynamics modeling.
- Developing customized science modules based on individual experimental requirements.

Using Multiple Microgravity Research Platforms and High-Fidelity Controls

This 2D clinostat was upgraded and a customized holder was designed to support an ISS experiment.

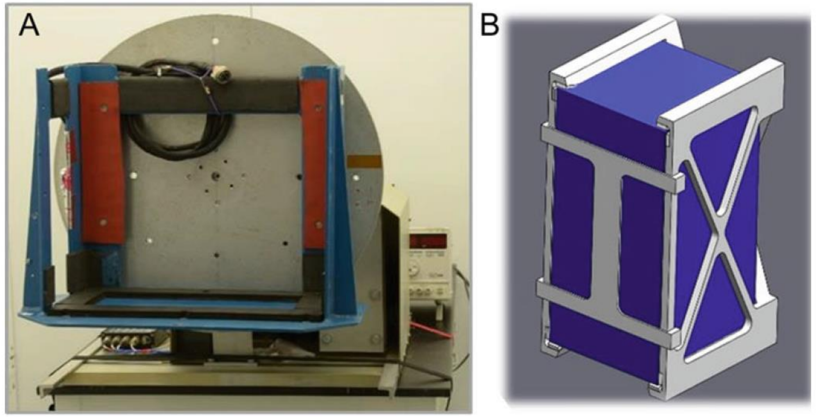


Fig. 2 The design of the bracket for a 2 U container, showing (**a**) the large 2D clinostat without the bracket; and (**b**) the CAD rendering of the bracket that can be installed at the center of the large 2D clinostat

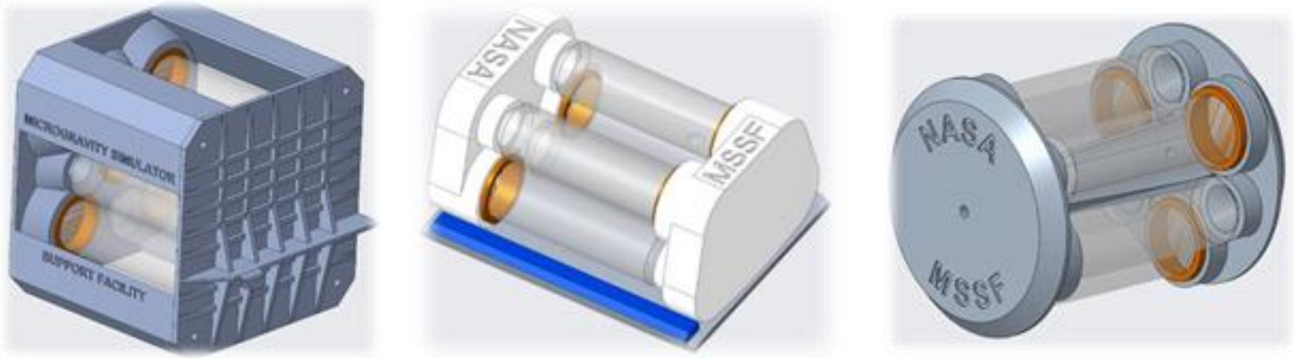
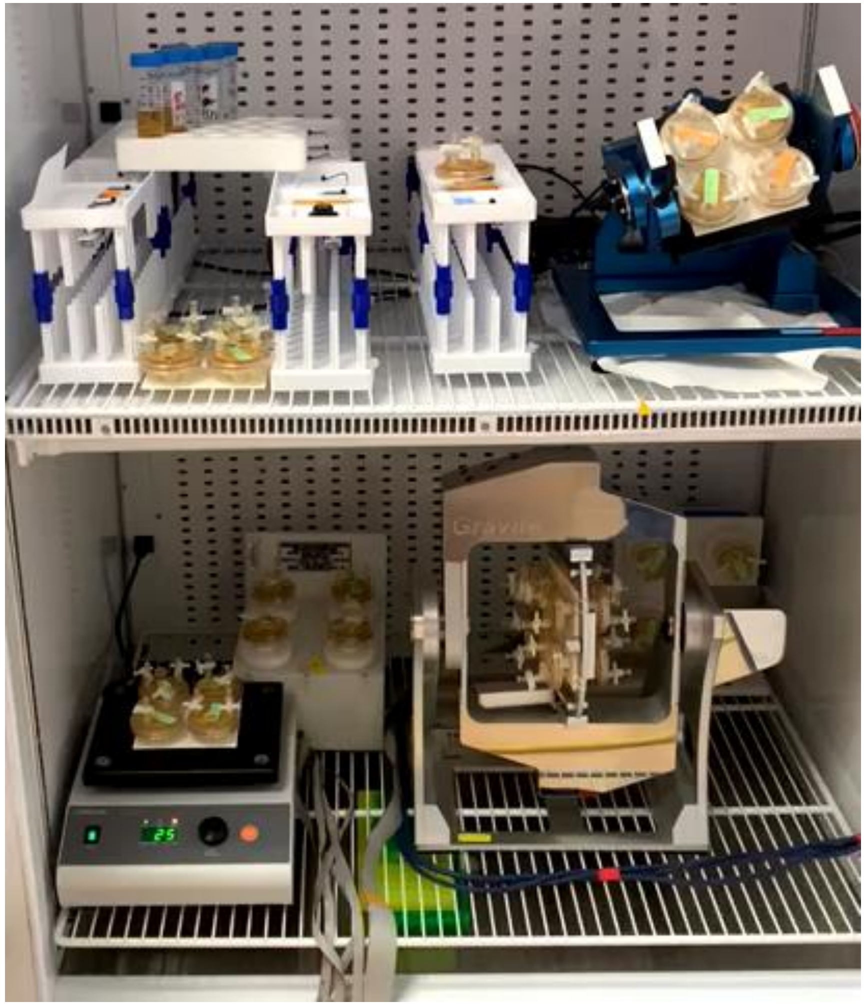


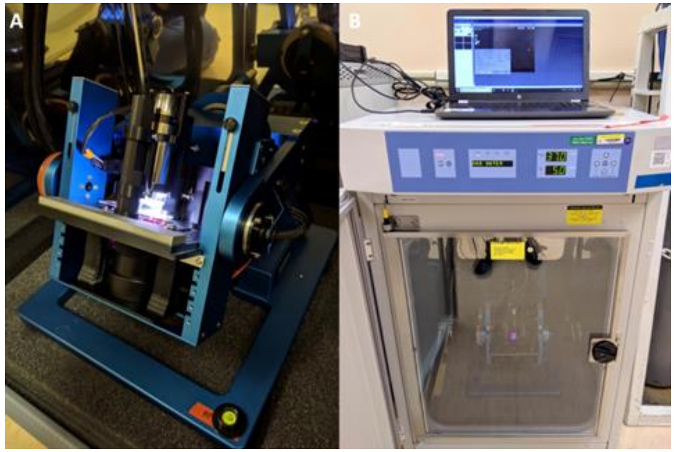
Fig. 3 Tube holders designed for biofilm coupon experiment on (**a**) RPM and (**b**) Gravite



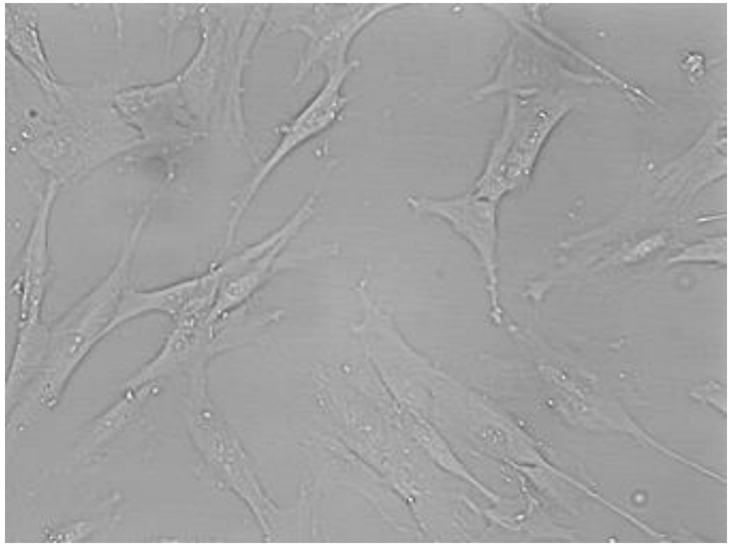
These fixtures were designed to support multiple simulated microgravity platforms for Dr. Rice and Dr. Venkat's projects.

Minimizing Mechanical and Design Artifacts

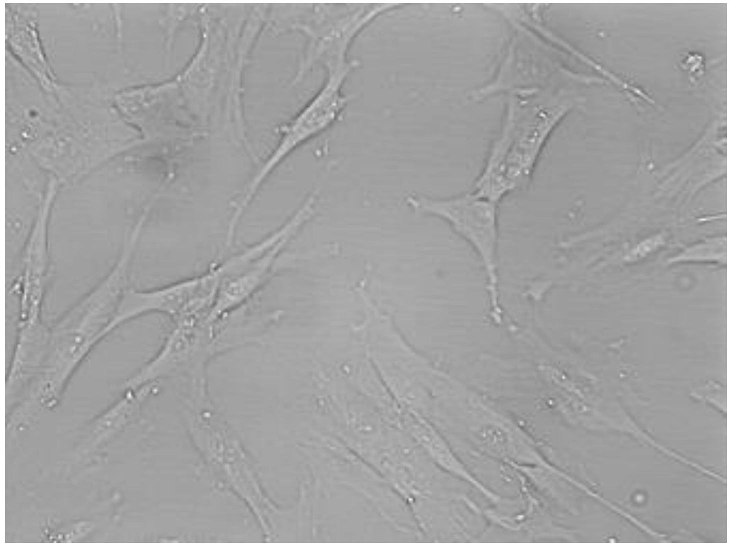
A



B



C

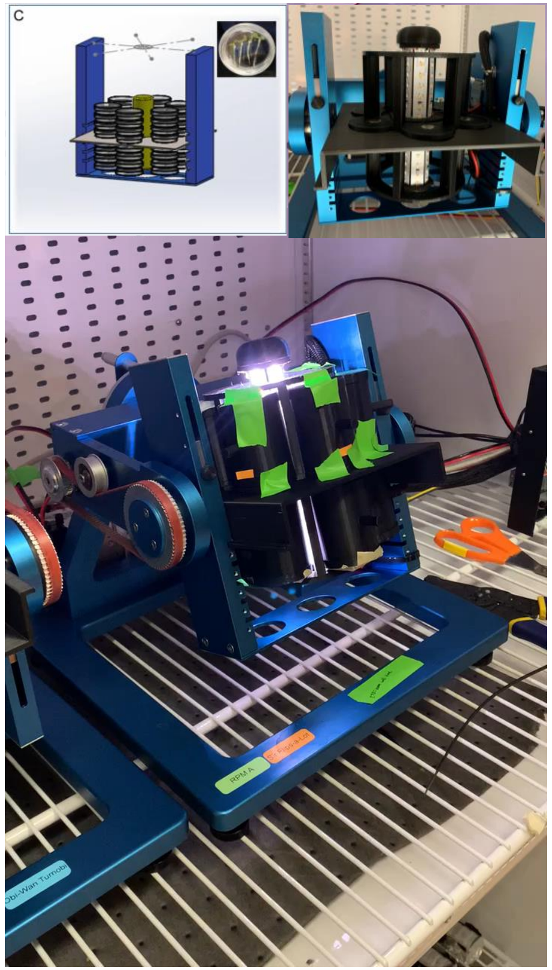


(A) Live cell microscopic imaging module for the RPM; (B) The conjunction of the sample slide with the holder connecting with the RPM frame may have relative movement at the micron scale; (C) Stable time-lapse video after correction.

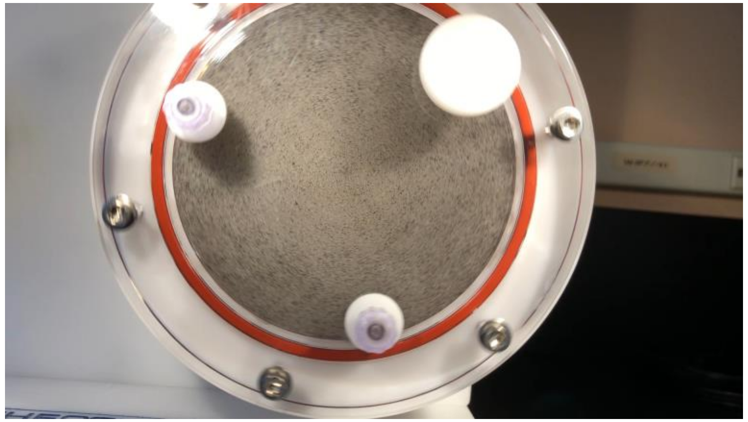
Capabilities for Designing Experiment
Unique Equipment Add-ons

Plant growth chamber designed for
microgreen study and other plant research

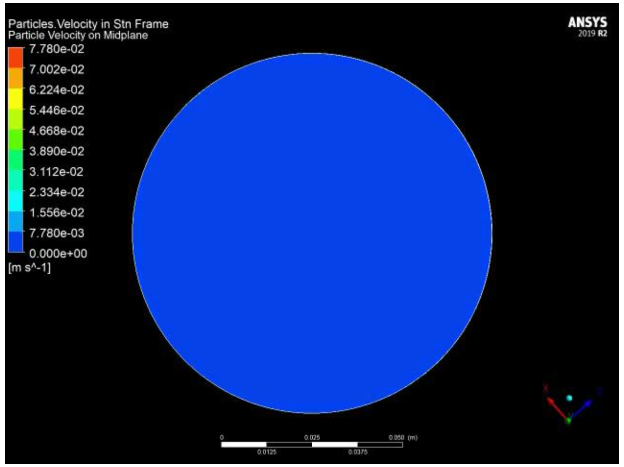
Sample removable module designed for
time-course study such as circadian research



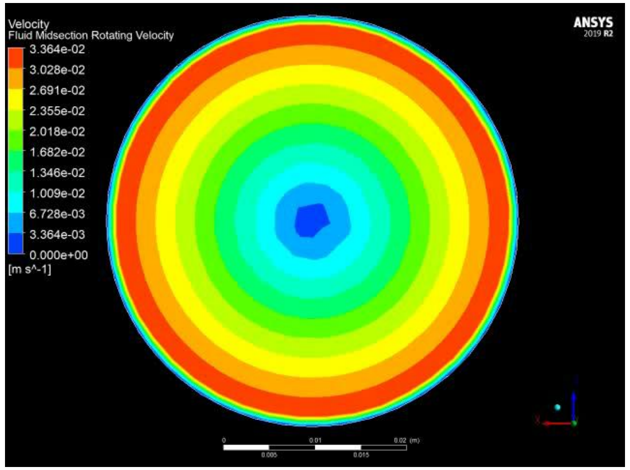
Computational Fluid Dynamic Models



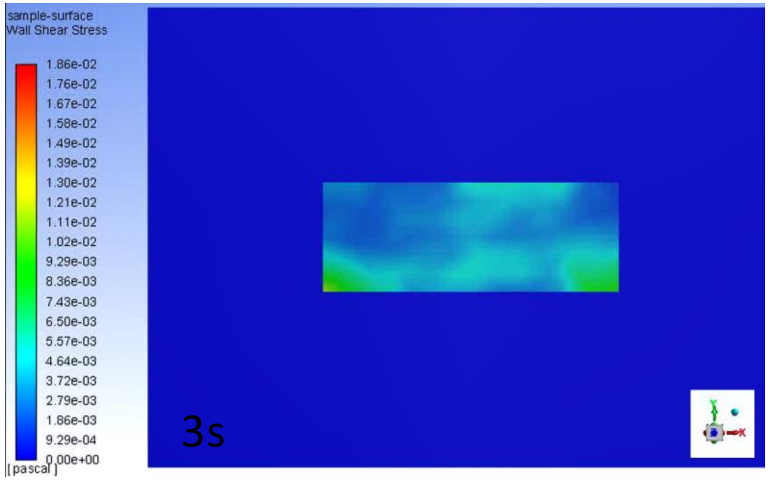
HARV with experimental flakes rotating at 15 rpm for particle tracking

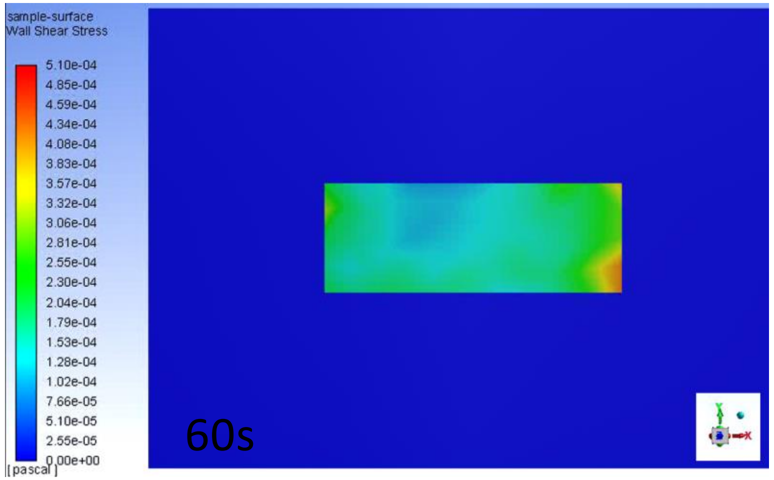


Fluid Velocity Relative to *Stationary* Frame



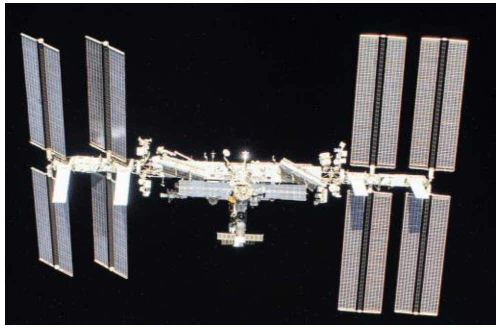
Relative to *Rotational* Frame





Analysis of the potential shear force imposed upon adherent cells on slide chamber surface after exposure to simulated microgravity on a 3D clinostat

Experiments under Simulated Microgravity and True Microgravity Conditions



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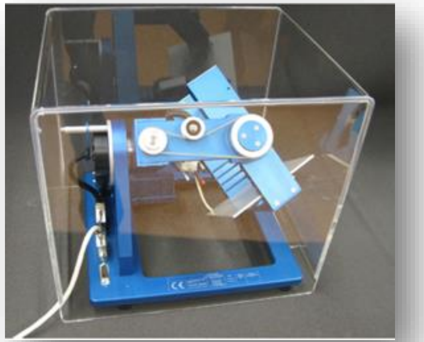


Ground (left_APEX-05) and Static (right) Controls

ISS (left_APEX-05) RPM (right)

APEX-07 RPM (shorter growth period)

APEX-07 ISS Flight

Experiments under Simulated Microgravity and True Microgravity Conditions

		Result of glycome profiling heat map at APEX 03-1	Result of immunolabeling at APEX 03-1		Seedlings grown in Random Positioning Machine (RPM)	
Glycan type	Monoclonal antibody (mAb)	Root	Root Tip	Root-Hypocotyl Junction	Root Tip	Root-Hypocotyl Junction
Non fucosylated xyloglucan	CCRC-M58	Space increased	Space increased	Space increased	No change	RPM increased
	CCRC-M96	Space increased	Space increased	No change	RPM increased	RPM increased
Fucosylated xyloglucan	CCRC-M1	No change. This mAb serves as an internal control.	No change	Space increased	No change	RPM increased
Xylan	CCRC-M140	Space increased	No reaction	Space increased	No reaction	No change
Pectin	CCRC-M34	Was not included on glycome profiling; but, showed big difference on immunolabeling.	No change	Space declined	No reaction	RPM increased
	CCRC-M80	Space increased	Space declined	Space increased	RPM showed more punctate bodies	RPM declined in cell corner middle lamella
	CCRC-M13	Space increased	Space increased	Space increased	RPM showed more punctate bodies	RPM declined in cell corner middle lamella
Extensin	JIM19	Space increased	Space declined	Space declined	RPM showed more punctate bodies	RPM increased but declined in cell corner middle lamella

Dr. Blancaflor's group compared results from an RPM experiment to those from APEX 03-1 ISS experiment.

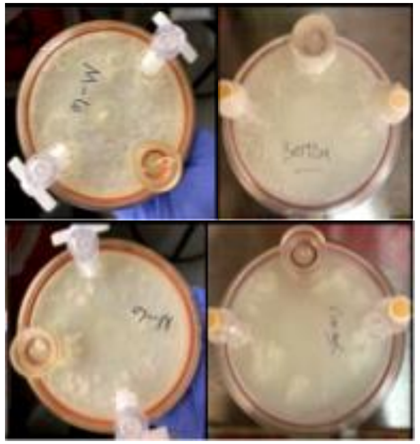
Examples of Biological Studies Using Microgravity Simulators

Suspension Culture of *S. mutans* (Dr. Rice) and Animal-Microbe Interaction (Dr. Foster)

HARV RPM

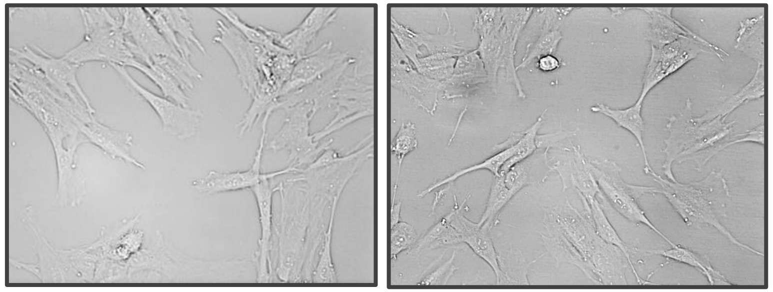
Rotation

Static



Live Cell Imaging of Fibroblast Cells

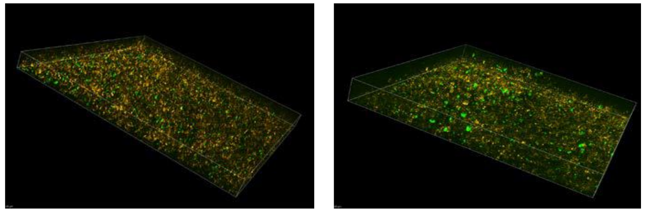
Static RPM



Plant Research – Dr. Gilroy

Biofilm Formation – Dr. Rice's group

Static RPM



Microgreen Research – Dr. Johnson

Other Plant Research

Future Work to Support Science beyond Low Earth Orbit

- For missions beyond LEO, such as those in Lunar orbit, on the Lunar surface, or during Mars transit missions, life will experience the absence of Earth's protective magnetic field, increased space radiation, micro to reduced gravity, and enclosed environments with significant space and resource constraints.
- For the past several decades, microgravity simulation devices have been developed and widely utilized for ground microgravity research, particularly focusing on LEO and changes associated with living in microgravity.
- Studies on combined effects of microgravity and other space-related risk factors are extremely under-represented in space biology investigations and the published literature.
- Because opportunities for conducting deep space biological science are rare, ground studies using microgravity simulation devices at micro g and partial g levels in combination with ionizing radiation exposures relevant to deep space radiation, as well as other risk factors, are promising analog approaches for continuing research beyond LEO.
- These approaches require next level capabilities of ground microgravity simulation based on the extensive experience gained over decades and the large body of knowledge from research onboard the ISS.

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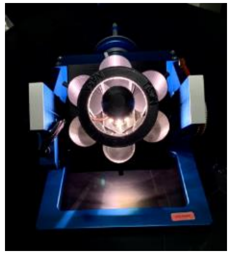
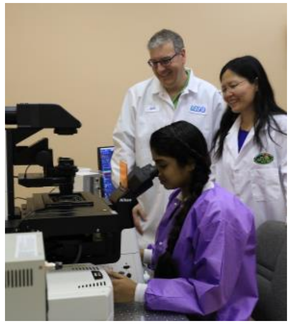
Thank you!





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