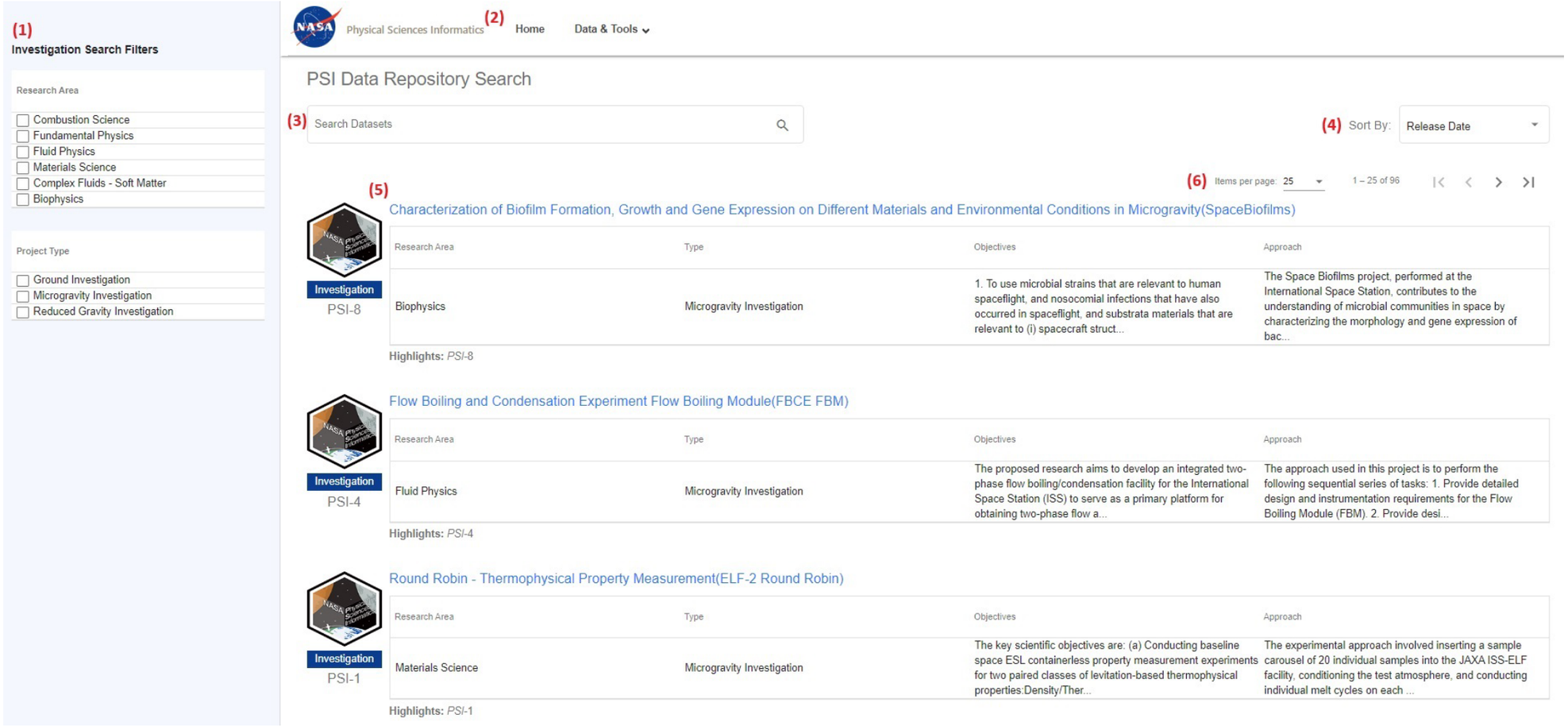
Searching Investigation Data within Physical Sciences Informatics (PSI)

1. **Investigation Search Filters:** Select specific Research Area(s) or Project Type(s) to narrow the list of resulting investigations based on the selected criteria.
2. **PSI Toolbar:** To navigate to the external PSI home page at anytime, click on the NASA logo or Home link. Click "Data & Tools" to navigate to the Submission Portal or Workspace.
3. **Search Bar:** Users can search using keywords (e.g. ethane) and Boolean operators such as “AND”, “OR”, and “NOT”. (e.g. Ethane AND N-Butane)
4. **Results Sort:** Investigations by default are sorted by “Release Date” but can be adjusted to reflect “Title” or “Accession ID”.
5. **Investigation Title (Acronym):** Investigations are displayed as a list. Clicking the Title (Acronym) redirects users to the selected investigation page.
6. **Results Display:** Shows the number of search results available by page. The default display is 25, but this can be adjusted to 50 or 100.



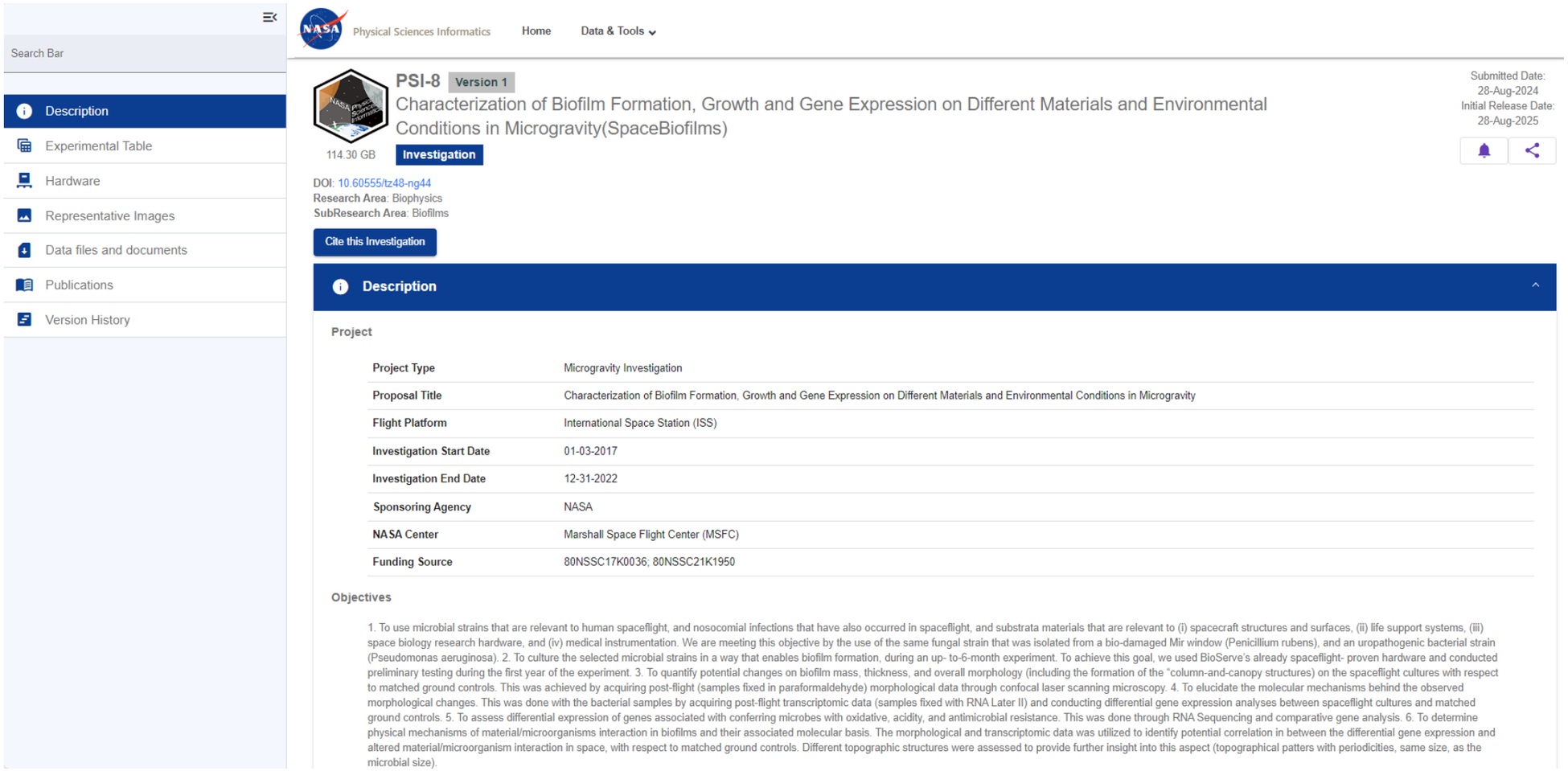
Navigating a PSI Investigation Page

Navigation Panel

On the left of the page is the navigation panel, which allows users to go directly to a specific section of the investigation page.

Overview

The top of the page contains the investigation id (e.g. PSI-8) along with title and acronym, assigned DOI and specifics about the investigations research area.
Clicking “Cite this Investigation” generates the downloadable citation that should be used when referencing this investigation in published materials.



Investigation Description Section

This section contains general details (e.g. Project Type, Start & End Date, etc), the specific Objectives, Approach, Hypothesis and Benefits, as well as investigation contact information.

Description

Project

Project Type	Microgravity Investigation
Proposal Title	Characterization of Biofilm Formation, Growth and Gene Expression on Different Materials and Environmental Conditions in Microgravity
Flight Platform	International Space Station (ISS)
Investigation Start Date	01-03-2017
Investigation End Date	12-31-2022
Sponsoring Agency	NASA
NASA Center	Marshall Space Flight Center (MSFC)
Funding Source	80NSSC17K0036; 80NSSC21K1950

Objectives

1. To use microbial strains that are relevant to human spaceflight, and nosocomial infections that have also occurred in spaceflight, and substrata materials that are relevant to (i) spacecraft structures and surfaces, (ii) life support systems, (iii) space biology research hardware, and (iv) medical instrumentation. We are meeting this objective by the use of the same fungal strain that was isolated from a bio-damaged Mir window (Penicillium rubens), and an uropathogenic bacterial strain (Pseudomonas aeruginosa). 2. To culture the selected microbial strains in a way that enables biofilm formation, during an up- to-6-month experiment. To achieve this goal, we used BioServe's already spaceflight- proven hardware and conducted preliminary testing during the first year of the experiment. 3. To quantify potential changes on biofilm mass, thickness, and overall morphology (including the formation of the "column-and-canopy structures) on the spaceflight cultures with respect to matched ground controls. This was achieved by acquiring post-flight (samples fixed in paraformaldehyde) morphological data through confocal laser scanning microscopy. 4. To elucidate the molecular mechanisms behind the observed morphological changes. This was done with the bacterial samples by acquiring post-flight transcriptomic data (samples fixed with RNA Later II) and conducting differential gene expression analyses between spaceflight cultures and matched ground controls. 5. To assess differential expression of genes associated with conferring microbes with oxidative, acidity, and antimicrobial resistance. This was done through RNA Sequencing and comparative gene analysis. 6. To determine physical mechanisms of material/microorganisms interaction in biofilms and their associated molecular basis. The morphological and transcriptomic data was utilized to identify potential correlation in between the differential gene expression and altered material/microorganism interaction in space, with respect to matched ground controls. Different topographic structures were assessed to provide further insight into this aspect (topographical patters with periodicities, same size, as the microbial size).

Approach

The Space Biofilms project, performed at the International Space Station, contributes to the understanding of microbial communities in space by characterizing the morphology and gene expression of bacterial and fungal biofilms formed in microgravity with respect to ground controls. The project has two big branches, the bacterial and the fungal side. Pseudomonas aeruginosa was used as model organism for the bacterial side and both morphology and transcriptomic (selected samples) studies were performed with bacterial samples, while Penicillium rubens was used as model organism for the fungal side and a morphology study was performed for fungal samples. Bacterial biofilm formation was characterized at one, two, and three days of incubation (37°C) over six different materials: stainless steel 316, passivated stainless steel 316, a lubricant impregnated surface (LIS), catheter grade silicone with and without a linear microtopography, and cellulose membrane. Fungal biofilm formation (mold) was characterized at 10, 15, and 20 days of incubation (25°C) over seven different materials: stainless steel 316, aluminum alloy (Al6061), titanium alloy (Ti-6Al-4V), quartz, catheter grade silicone, carbon fiber, and a superhydrophobic surface "nanograss".
Bacterial samples: 144 flight and 144 ground samples were prepared for the Space Biofilms bacterial experiment. The experiment independent variables were two gravitational regimes (Earth gravity and microgravity), three incubation times (1, 2, and 3 days), six material-media combinations (LBK media was used for samples grown over SS316, pSS316, and LIS; while mAUMg-hi Pi media was used for samples grown over cellulose, silicone, and silicone DLIP), two types of fixative/preservative (PFA and RNAlater), and replicates (four). To provide the necessary levels of containment, each sample was prepared in a Fluid Processing Apparatus (FPA) and eight FPAs were integrated into a Group Activation Pack (GAP). Once in microgravity, samples were activated by introducing the bacterial inoculum into the sterile medium and placing the samples at 37°C for the corresponding incubation time. After the incubation time the samples were terminated by introducing the fixative (for morphology samples) or the preservative (for transcriptomic samples). The morphology samples were stained (one dye for lipids and one dye for nucleic acids) and imaged with a confocal microscope. The resulting 3D images of the biofilms (.nd2 files) were processed and analyzed using the COMSTAT2 software to quantify biofilm mass, biofilm thickness, and biofilm surface area coverage. The transcriptomic samples had their RNA extracted and sequenced. The resulting transcriptomic data files (fastq files) were processed and used for gene expression analysis using DeSeq2.
For more information on the bacterial sample preparation see section 4, and for information about the experiment performance in space see section 5 of the following paper: https://doi.org/10.1016/j.actaastro.2022.07.015 For more information on the bacterial morphology and transcriptomic analyses see the Methods section of the following paper: https://doi.org/10.1038/s41526-023-00316-w
Fungal samples: 288 flight and 288 ground samples were prepared for the Space Biofilms fungal experiment. The experiment independent variables were two gravitational regimes (Earth gravity and microgravity), three incubation times (10, 15, and 20 days), seven material substratum (stainless steel 316, aluminum alloy Al6061, titanium alloy Ti-6Al-4V, quartz, catheter grade silicone, carbon fiber, and a superhydrophobic surface "nanograss"), two types of fixative/preservative (PFA and RNAlater), and replicates (6-12 depending on the specific set). To provide the necessary levels of containment, each sample was prepared in a well of a 24-well plate and sealed with a gas permeable membrane. Additionally, four 24-well plates were integrated into a Plate Habitat (PHAB). Once in microgravity, samples were activated by wetting pads inside the PHAB to increase the environment humidity and by placing the samples at 25°C for the corresponding incubation time. After the incubation time the samples were terminated by introducing the fixative (for morphology samples) or the preservative (for transcriptomic samples)*. *The transcriptomic samples were not analyzed as part of this project. The morphology samples were stained (one dye for chitin and one dye for extracellular matrix proteins) and imaged with a confocal microscope. The resulting 3D images of the biofilms (.nd2 files) were processed and analyzed using the COMSTAT2 software to quantify biofilm mass, biofilm thickness, and biofilm surface area coverage.
For more information on the bacterial sample preparation, the experiment performance in space, and the fungal morphology analyses see section 2 of the following paper:- https://doi.org/10.3390/life13041001

Hypothesis

It is hypothesized that, in comparison to matched ground controls: a) Biofilm mass and thickness in microgravity will be increased for all bacterial and fungal species, growth medium, and substratum material; b) Gene expression will vary as a function of growth medium, substratum material, and gravitational regime; c) A systematic increase in expression of the genes that confer microorganisms with oxidative, acidity, and antimicrobial resistance will be observed in space (becoming more pronounced with time in space); and d) The formation of the "column-and- canopy" bacterial biofilm architecture and the material/microorganism interaction mechanisms in space will vary from one microbial species and material to the other, and will be associated with the differential expression of specific genes.

Research Impacts/Earth Benefits

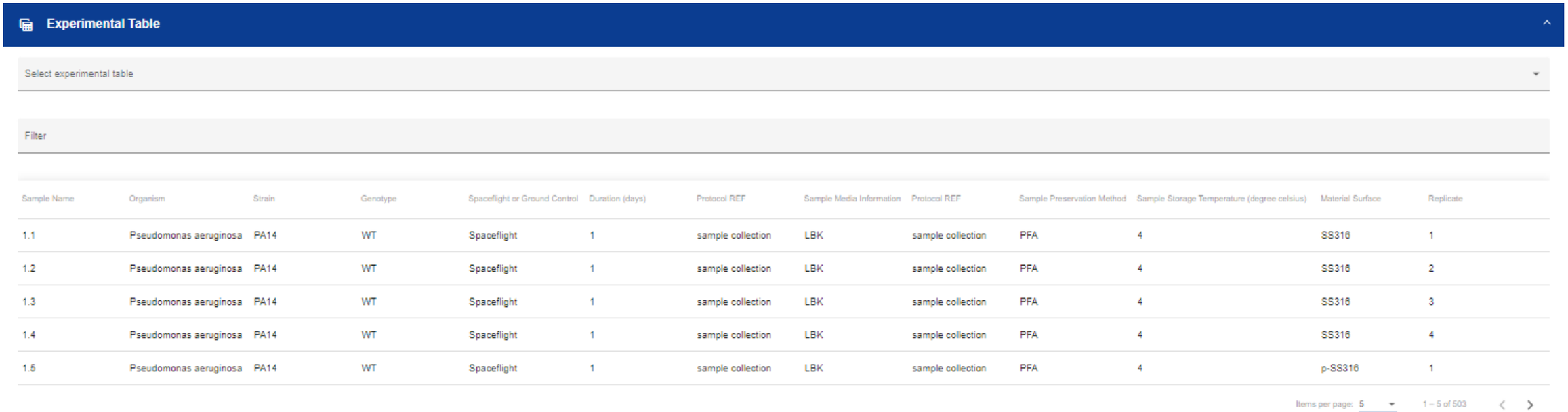
This project is relevant to the space program and the "Biophysics – Biomaterials" emphasis of this NRA as it investigates biofilm formation (which can increase the risk of astronaut infection and equipment failure) on spacecraft-relevant materials. This work is relevant to the Space Biology Program and the Human Research Roadmap as it utilizes human pathology-associated bacterial species (uropathogenic Pseudomonas aeruginosa), growth media (e.g. modified artificial urine media), and materials (e.g. silicone from catheters).The knowledge produced may help address Gaps Micro-01, -02, -03, and -04 by characterizing bacterial and fungal responses to spaceflight, by interrogating the expression of genes associated with drug resistance, and by elucidating the governing mechanisms behind the observed phenomena. Furthermore, due to our proposed approach, the knowledge derived from this project may be translatable to biofilm-associated illnesses on Earth.

Contact(s)

Luis Zea, Pamela Flores, Sid Gorti

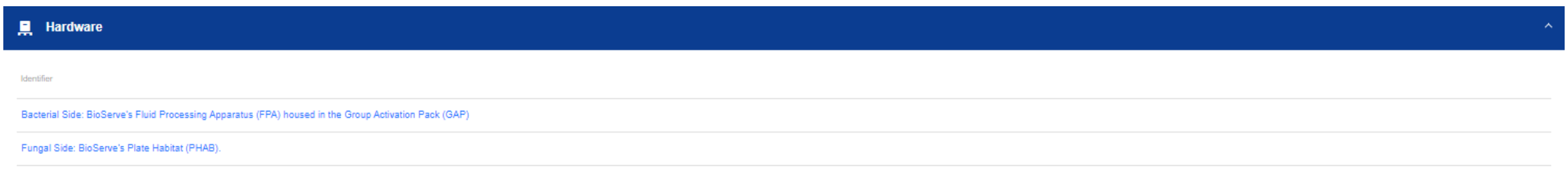
Experiment Table

The section for the Experiment Table provides specific details on the investigation samples and runs. This table is also available to download in the “Data Files and documents” section.



Hardware

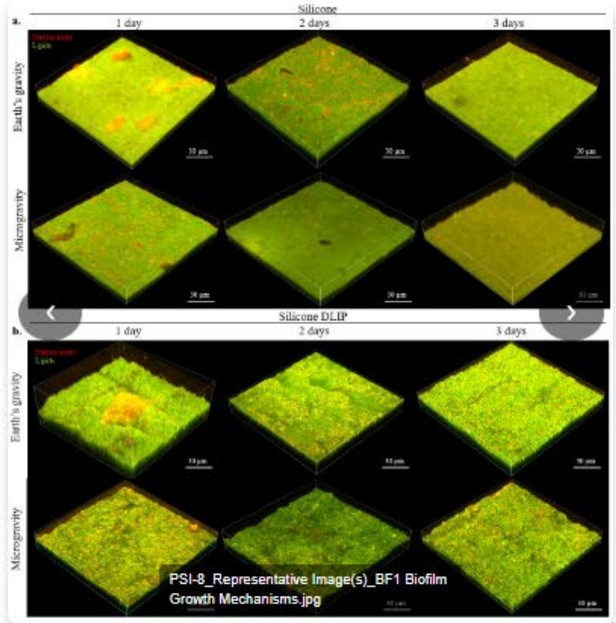
Hardware and experiment facility information is available as clickable external link(s) in the “Hardware” section.



Representative Images

Thumbnails of science and/or other investigation related images identified by PIs appear in this section. Users can navigate through multiple images using the arrow buttons on either side of the image.

Representative Images

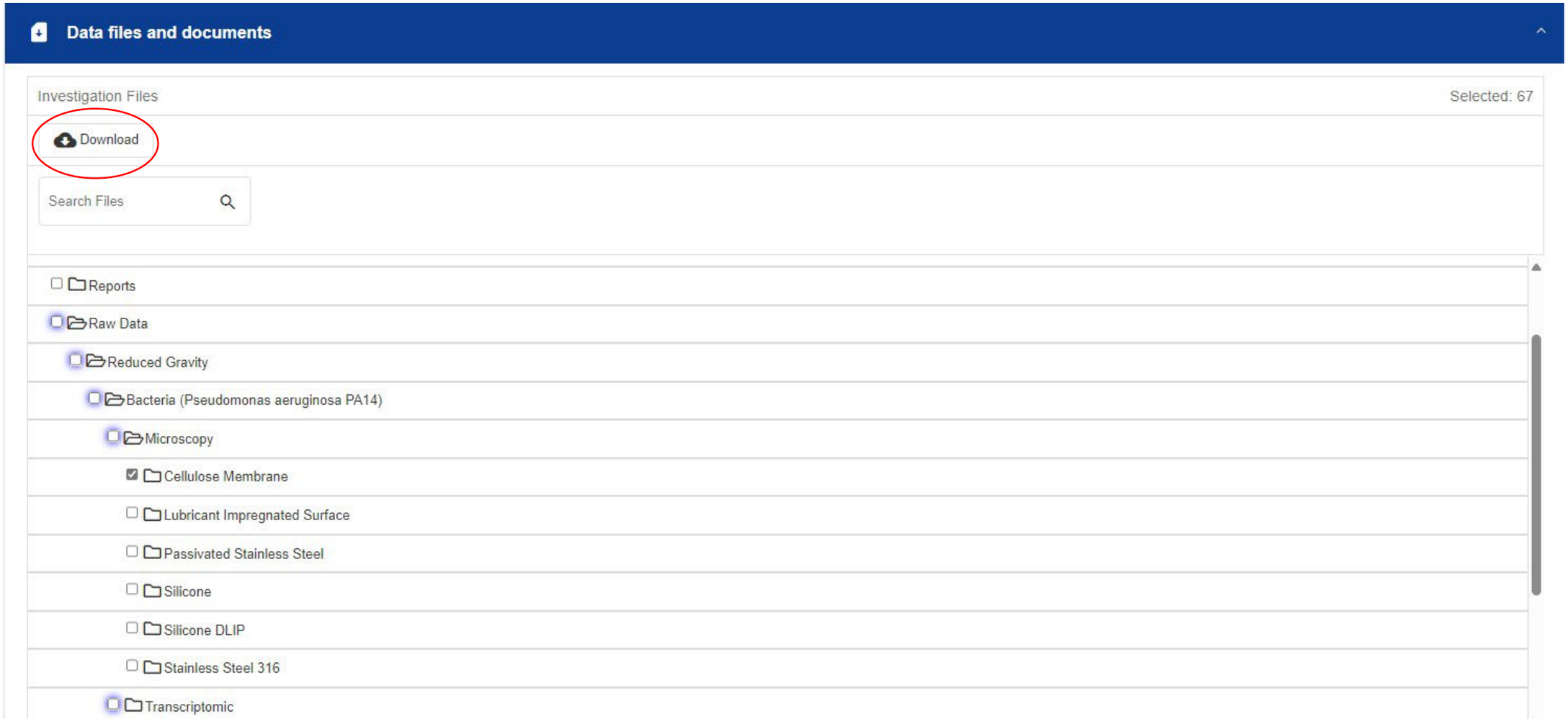


PSI-8_Representative Image(s)_BF1 Biofilm Growth Mechanisms.jpg

Data Files and Documents

The files section provides users with access to investigation datafiles and supporting documentation. Files are organized into separate folders based on file type. Raw and Analyzed Data folders are additionally separated by Reduced or Earth gravity. Additional data subfolders may be present depending on the specific investigation.

To download a specific file or an entire folder, select the corresponding checkbox and click “download” to either view the file in a new window or save it to your local device.



Publications

This section features a list of the publications associated with the investigation. The title of the publication appears as a clickable external link redirecting users to the specific publication.

Publications

Morphology of Penicillium rubens Biofilms Formed in Space
Authors: Hupka Megan, Kedia Raj, Schauer Rylee, Shepard Brooke, Granados-Presa María, Vande Hei Mark, Flores Pamela, Zea Luis
PubMed ID: 37109532
DOI: 10.3390/life13041001

Biofilm formation of Pseudomonas aeruginosa in spaceflight is minimized on lubricant impregnated surfaces
Authors: Flores Pamela, McBride Samantha A., Galazka Jonathan M., Varanasi Kripa K., Zea Luis
PubMed ID: 37587131
DOI: 10.1038/s41526-023-00316-w

Fungal Experiments in Space
Authors: Nielsen Sheila, Schauer Rylee
DOI: 10.1007/978-3-319-50909-9_37-1

Preparation for and performance of a Pseudomonas aeruginosa biofilm experiment on board the International Space Station
Authors: Flores Pamela, Schauer Rylee, McBride Samantha A., Luo Jiaqi, Hoehn Carla, Doraisingam Shankini, Widhalm Dean, Chadha Jasmin, Selman Leah, Mueller Daniel Wyn, Floyd Shannon, Rupert Mark, Gorti Sridahr, Reagan Shawn, Varanasi Kripa K., Koch Christina, Meir Jessica U., Muecklich Frank, Moeller Ralf, Stodieck Louis, Countryman Stefanie, Zea Luis
DOI: 10.1016/j.actaastro.2022.07.015

Potential biofilm control strategies for extended spaceflight missions
Authors: Zea Luis, McLean Robert J.C., Rook Tony A., Angle Geoffrey, Carter D. Layne, Delegard Angela, Denvir Adrian, Gerlach Robin, Gorti Sridhar, McIlwaine Doug, Nur Mononita, Peyton Brent M., Stewart Philip S., Sturman Paul, Velez Justiniano Yo Ann
PubMed ID: 33447811
DOI: 10.1016/j.bioflm.2020.100026

Design of a spaceflight biofilm experiment
Authors: Zea Luis, Nisar Zeena, Rubin Phil, Cortesão Marta, Luo Jiaqi, McBride Samantha A., Moeller Ralf, Klaus David, Müller Daniel, Varanasi Kripa K., Muecklich Frank, Stodieck Louis
PubMed ID: 30449911
DOI: 10.1016/j.actaastro.2018.04.039

Biofilm formation of Pseudomonas aeruginosa in spaceflight is minimized on lubricant impregnated surfaces.
Authors: Flores P, McBride SA, Galazka JM, Varanasi KK, Zea L.
PubMed ID: 37587131
DOI: 10.1038/s41526-023-00316-w

Version History

Version history contains the records of all available versions of the investigation page, including the changes made, dated the version was released and any removal or addition of files.
To access previous versions of the investigation page, click “Show/Hide All Version Information” to view previous version information.
fi