



**THE
NATIONAL
CENTER
FOR
MICROGRAVITY
RESEARCH**

**A COOPERATIVE VENTURE
between
NASA GLENN RESEARCH CENTER
UNIVERSITIES SPACE RESEARCH ASSOCIATION
and
CASE WESTERN RESERVE UNIVERSITY**



MICROGRAVITY RESEARCH

AN AGENCY-WIDE ASSET

Using NASA-Generated Knowledge to Solve Its Own Problems



- Many NASA facilities and enabling technologies involve transport phenomena whose behavior is unknown at reduced g
- NASA is limited to low-earth orbit human operations by primitive technologies (at enormous cost for resupply)
- Need self-generating and self-sustaining technologies to be efficient under unprecedented conditions in alien environments

No Knowledge Bases For Such Designs



**MICROGRAVITY RESEARCH SCIENTIFICALLY
IMPORTANT AND ALSO ESSENTIAL FOR DESIGN
AND DEVELOPMENT OF ENABLING ADVANCED
TECHNOLOGIES AND FACILITIES**

- Fluid and Thermal Sciences are the CORE for both research and applications



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NCMR
FLUIDS AND COMBUSTION

Research for Design

Current Situation

- **The technologies required to exit from low-earth orbit do not exist**
 - **Lack of microgravity knowledge bases to design advanced technologies**
- **Mission Planners and Research Scientists are not working together early enough to bring about needed advances**
 - **Technical interchange between designers and researchers enhances engineering creativity and increases opportunities to develop enabling technologies and significantly maximizes life cycle cost savings**



Original List of R4D Candidate Topics

Cryo Fluid Management

- In-tank heat exchanger/in-space and surface
- Fluid behavior/mixing
- Impacts of varying g-level and tank size
- Liquefaction
- Thermal diode cooler-tank
- Fluid gaging
- Liquid acquisition

TCS

- 2 Phase Flow
 - Evaluation of developing length necessary for “fully developed two-phase flows”
 - Pressure drop characterization for fittings quick-disconnects, elbows, tees, manifolds, etc.
 - Instability issues for two-phase flows in manifolds
 - Development of mechanistic scaling techniques for two-phase systems (e.g., Earth-g system to zero-g system)
 - Development of advanced instrumentation (e.g., void fraction and film thickness sensors) for use with refrigerants or ammonia
 - Expand two-phase database for zero-g and partial-g with different size tubes and different fluids (enables validation of models and scaling techniques)
 - Engineering models/correlations for use in two-phase system design and verification

Power

- Regen fuel cell operating over varying g-level
- Surface reactor heat transfer
- Heat rejection system-viability of 2-phase and/or heat pipes
- Liquid metal reactor startup

Fire Safety/Combustion

- Extinguishment – use CO₂?
- Detection
- Transhab materials testing



Original List of R4D Candidate Topics

ECLSS

- Unsaturated flow in porous media (mass transfer)
 - Plant Growth
- Environmental control (temperature, humidity, dust)
 - CO₂ removal
 - Methods to control CO₂ to low concentrations (below 0.3% by volume)
 - Reduced power
- Trace contaminant control system
 - Regenerable sorbent materials
 - Investigations of catalyst poisoning/upsets
- Gas/liquid separators
- Sensors
 - O₂, CO₂, humidity, combustible gases, organic contaminants
 - Dust control methods
- Water tank/radiation shield
 - Hydrophilic/hydrophobic membranes
- Flow through catalytic reactors
 - 2 Phase flow modeling
 - Oxygenation (single phase)
 - Temperature/pressure effects

- Micro-g compatible bioreactors
 - Oxygenation/O₂ mass transfer
 - Product gas separation
 - Biomass management
 - Flow rate measurement
 - Dissolved oxygen measurement
 - Methods to reduce channeling of packed bed bioprocessors
- Membrane Separation
 - Biofilm control/fouling prevention
 - 2 Phase/3 Phase separation of process stream
 - Oxygenation of aqueous streams
 - Wicking properties for evaporative systems
 - Management of air/water vapor mixtures (vis-à-vis, condensing heat exchange)

ISRU

- Phase separation
- Liquid-Liquid separation
- Micro-channel flow
- CO₂ acquisition at low pressure
- Gas/dust separation
- Thermal processing of Mars atmosphere and soils



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Research for Design

Fluids and Combustion Microgravity Research Relevance to Space Exploration Activities

	Interfacial Phenomena	Multiphase Flow and Transport	Phase Change Heat Transfer	Combustion	Phase Separation	Granular Materials
Power Generation and Storage	Ö	Ö	Ö	Ö	Ö	
Propulsion	Ö	Ö	Ö	Ö	Ö	
Life Support	Ö	Ö	Ö	Ö	Ö	
Fire Safety				Ö		
ISRU	Ö	Ö	Ö	Ö	Ö	Ö
Construction and Maintenance	Ö	Ö				Ö
Cryogenics Fluid Management	Ö	Ö	Ö		Ö	
Thermal Management	Ö	Ö	Ö			



Glenn Research Center



National Center for Microgravity Research on Fluids and Combustion “Value Added Tasks”

Research for Design

Objective of Research for Design

Develop the knowledge for the design and development of self-sustaining technologies by involving fluids and combustion scientists and technologists directly with mission analysis/system designers in early space exploration project definition, design and development

Unique Features

- Customer driven (close coordination with the developer)
- Research done to a schedule – answers to specific questions in a timely manner
- Develops unique knowledge databases
- Brings to bear wealth of microgravity knowledge developed by NASA
- Solves enabling problems





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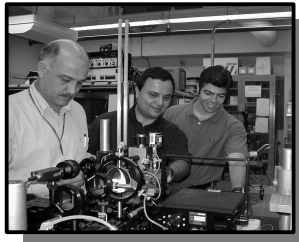
**Control of Flow and
Nutrients to Plant Roots
Under Microgravity and
Variable Gravity**



Understand the physical transport phenomena in porous media to be able to control the air, water and nutrient transport to root zone for successful plant growth in microgravity.

**Zero Boil-Off Pressure
Control of Space Propellant
Tanks**

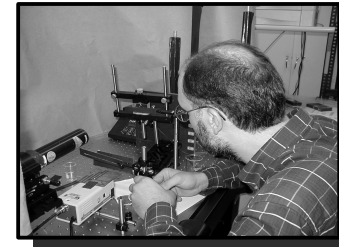
Investigate ways of preventing boil-off of cryogenic propellants during long duration



interplanetary missions which could include stops at the moon.

Research for Design

**Control of Two-Phase Flow
in the Microchannel of
Proton Exchange
Membrane Fuel Cells**



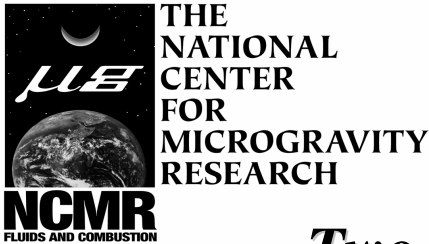
Predict the flow of air and water in the microchannel of PEM fuel cells to design a gravitationally independent device.

**Effect of Reduced Gravity
on the Soldering Process**



Develop a quantitative understanding of the effect of a low-gravity environment on the soldering process

*R4D
Pilot
Projects*



Characterization & Control of Two-Phase Flow in Microchannels (PEM Fuel Cells)

Objectives:

- assist NASA in developing a gravitationally insensitive, regenerative fuel cell
- quantify low-Bond number, non-inertial, 2-phase flows in complex geometries
- use scientific results to develop design tools for predicting liquid holdup, phase separation and mixing in complex channels for various wetting conditions and geometric configurations
- ability to predict behavior of non-fully-developed two-phase flow; such as flow through fittings and short channel lengths
- assist in developing predictive tools for designing flow passages for fuel cell stacks and manifolds

Applicability and Impact:

- Low-temperature, regenerative fuel cells hold great promise for providing renewable power for human exploration of both low-Earth orbit and interplanetary space missions.
- Research is applicable to miniature fuel cells as replacement to batteries in portable electronic devices for terrestrial and/or microgravity applications.
- Research is applicable to high throughput screening applications; such as bioreactors, proteomics, genomics, and protein crystallization.

Approach:

- systematic microchannel experiments to investigate 2-phase flow in fuel cell channels; varying gas/liquid ratios, flow rates, aspect ratio, entrance conditions, and geometries
- comprehensive computational study of microchannel experiments
- macrochannel experiments using low-gravity test rig on KC-135; testing two-phase flow behavior in manifolds and in various fittings typical of fuel cell stack manifolds

Team:

Principal Investigator(s): J. Allen, M. Kassemi/NCMR, J. McQuillen/GRC

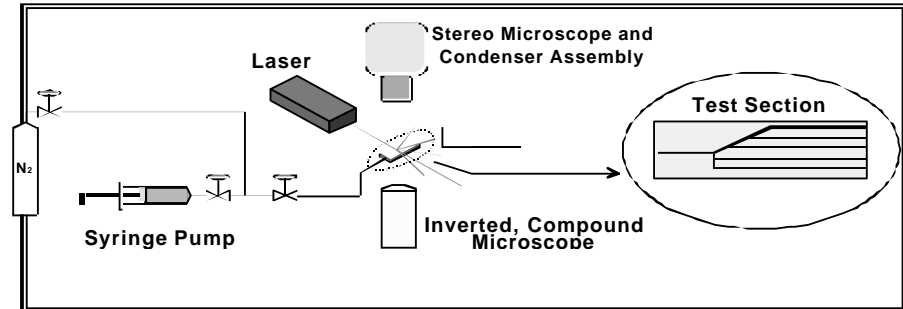
Primary Customer: William Hoffman/JSC

post doctoral researcher: S. Son/NCMR

contracted diagnostics: Prof. K. Kihm/Texas A&M and 2 graduate students

summer faculty fellow: Prof. L. Sumner/Mercer Univ.

undergraduate students: E. Driscoll/ Univ. Dayton, S. Wood/Texas Tech



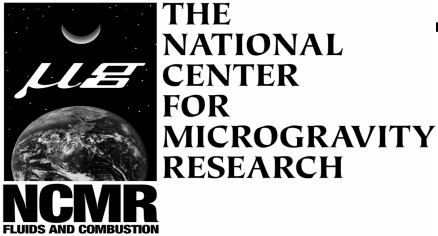
Task Schedule

- Microchannel Studies
- KC-135 Macrochannel Studies
- Develop/Validate Two-Phase CFD Model
- Design Tools for Fuel Cell Optimization
 - phase separation/mixing in microchannels
 - two-phase flow scaling analysis
 - video library of two-phase flow transients
 - two-phase flow in manifolds

		FY02				FY03				FY04			
		Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4
Microchannel Studies		[Task bar spanning Q1-Q4 FY02, Q1-Q4 FY03, Q1-Q4 FY04]											
KC-135 Macrochannel Studies		[Task bar spanning Q1-Q4 FY02, Q1-Q4 FY03, Q1-Q4 FY04]											
Develop/Validate Two-Phase CFD Model		[Task bar spanning Q1-Q4 FY02, Q1-Q4 FY03, Q1-Q4 FY04]											
Design Tools for Fuel Cell Optimization		[Task bar spanning Q1-Q4 FY02, Q1-Q4 FY03, Q1-Q4 FY04]											
Phase separation/mixing in microchannels		[Task bar spanning Q1-Q4 FY02, Q1-Q4 FY03, Q1-Q4 FY04]											
Two-phase flow scaling analysis		[Task bar spanning Q1-Q4 FY02, Q1-Q4 FY03, Q1-Q4 FY04]											
Video library of two-phase flow transients		[Task bar spanning Q1-Q4 FY02, Q1-Q4 FY03, Q1-Q4 FY04]											
Two-phase flow in manifolds		[Task bar spanning Q1-Q4 FY02, Q1-Q4 FY03, Q1-Q4 FY04]											

Accomplishments to Date:

- collaborations established with Texas A&M, Texas Tech, Mercer Univ. & Univ. Dayton
- new diagnostic techniques developed for studying two-phase flow in microchannels:
 - » micro-particle image velocimetry (μPIV)
 - » molecular tagging fluorescence velocimetry (MTFV)
 - » Fizeau interferometry for measuring liquid film profile around a gas bubble in microchannels
 - » backscattering interferometer for non-intrusive pressure measurements
- developing technique for inexpensive fabrication of complex microchannel passages



Research for Design (R4D)

“NASA has long recognized the need to use its scientific resources to advance the technology it needs for the space program”

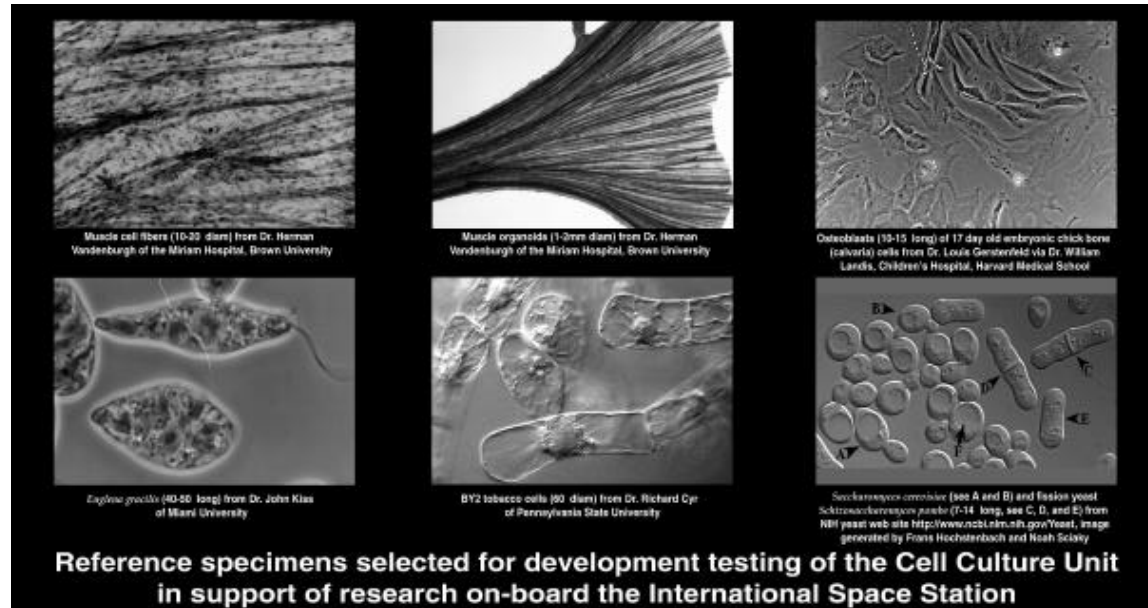
“However, there was no institutional method for proceeding with specific cooperative investigations”

“The NCMR, through its R4D effort is reminding NASA how this can be done. NASA should strongly encourage this initiative by the NCMR--- because the basic method is right, and will surely help NASA learn how to develop the science-technology connection which it lacks, but which may well be the key to NASA’s future success”

“The Administrator should recognize the agency-wide significance of R4D and support it directly” (not from the research budget)

Cell Culture Unit design goals

CCU must accommodate diverse cell types, diverse responses to gravity changes, diverse needs of scientific community



- Can this culture system provide the nutrient and gas exchange required for optimal growth without exposing the cells to forces greater than the microgravity?
- How do we develop systems with comparable mass transport in different gravitational environments (1-g Earth control, *m*-g, centrifuged CCUs up to 2-g on ISS)?

Other NASA Technologies

Conduct other research in direct support of NASA's technology programs.

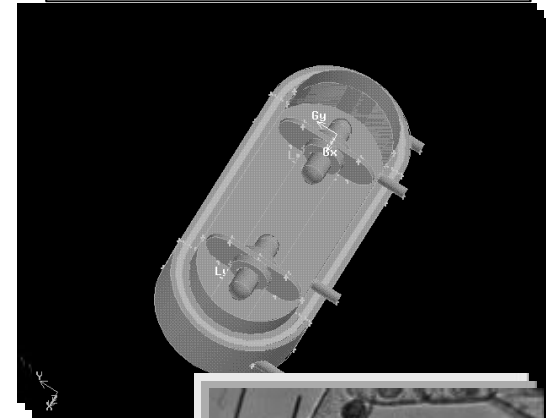
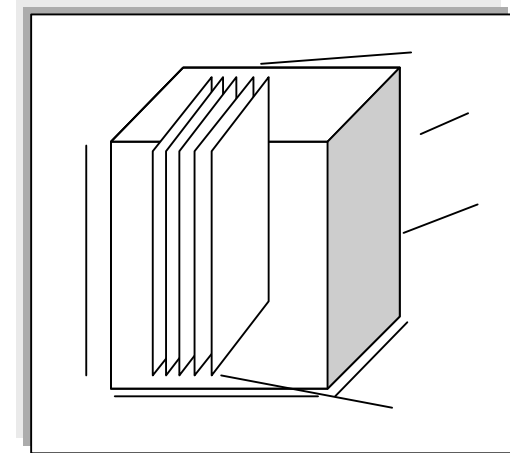
- **Lithium-Based Polymer Battery Program Funding Source (NASA GRC)**
 - Analytically demonstrate that thermal dissipation (Joule heating) is a limiting factor in terms of predicting life cycles in polymer based battery
- **Cell Culture Unit Funding Source (NASA ARC)**

Research Scientist: John Kizito

Application Area: Fluid physics, Computational Fluid Dynamics, Fundamental Space Biology

Impact

- NASA is about to spend \$1.0 Billion dollars on Biology and Biotechnology in space. We are assisting in designing meaningful interdisciplinary biological space experiments by offering predictive tools related to transport issues in Microgravity



Rodent Urine Management for the Advanced Animal Habitat in Microgravity

Application Area

Veterinary services in microgravity

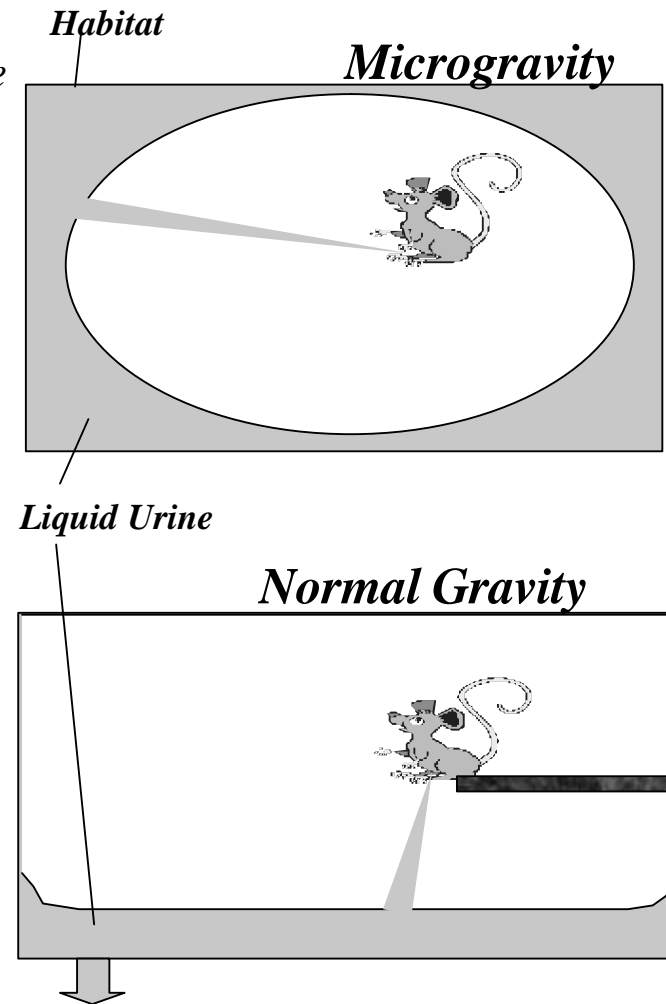
- render expert advice to *STAR Enterprises, Inc.* and *Space Hardware Optimization Technology, Inc.* to the design of the Advanced Animal Habitat-Centrifuge for *NASA Ames Research Center* which will house rats and mice on the International Space Station.

Nature of the Problem

- Existing habitat design results in accumulation of rodent urine on walls
 - Rodent proximity to the wall result in wicking the urine onto the fur or hair causing hypothermia
 - Existing fan design causes liquid evaporation and urea crystallization resulting in pungent smell
- Rodent mother and baby interaction

Impact

- Animal tests are essential for experimental and medical trials a prerequisite long duration manned exploration missions

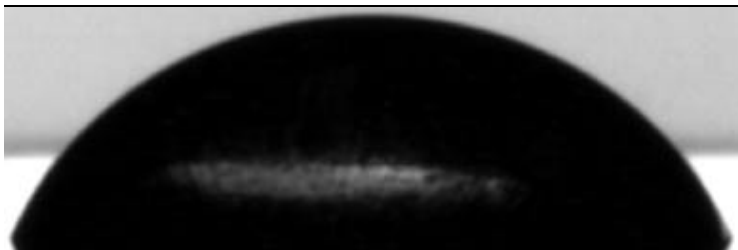


Research Scientists: John Kizito and Jeff Allen

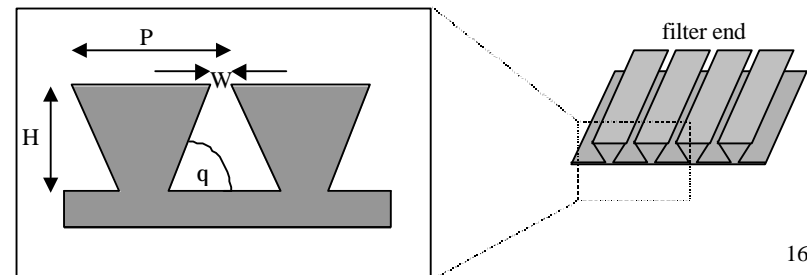
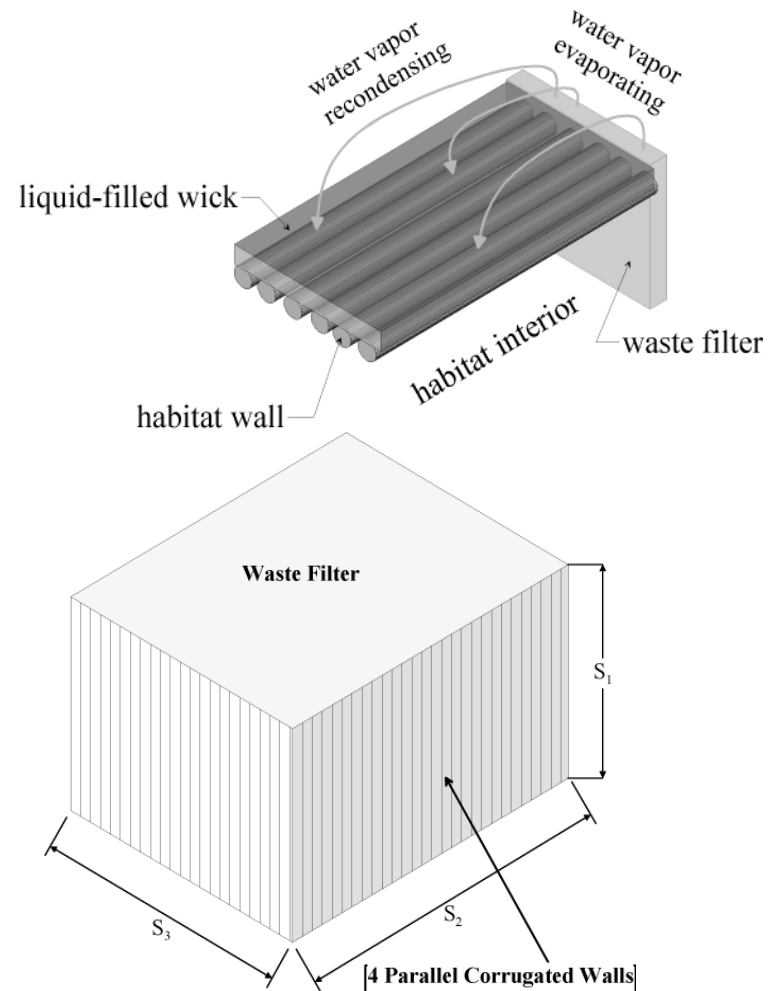
Application Area: Fundamental Space Biology

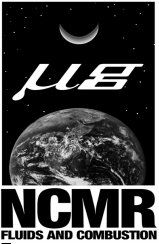
Results

1. Measured 301 data points of transport properties of rodent urine,
2. Developed concepts of managing fluids within the specimen chamber such that:
 - the animals remain suitably dry,
 - fluids within the specimen chamber are directed to the primary waste filter and/or liner for containment and/or evaporation,
 - fouling of the lighting subsystem, the camera lenses, and sensors within the specimen chamber is minimized,
 - liquid is deterred from entering air outlet, and
3. Developed a plan for concept verification.



Male rat urine on untreated aluminum. Contact Angle, $\theta \approx 67.0^\circ$





Conclusions

“NCMR is a vital and successful operation, effectively supporting NASA’s program in many ways beyond technical monitoring. NCMR is supplying leadership for certain new initiatives important to NASA’s future. NASA might regard NCMR as kind of a small laboratory of innovative research management, and should support it generously”