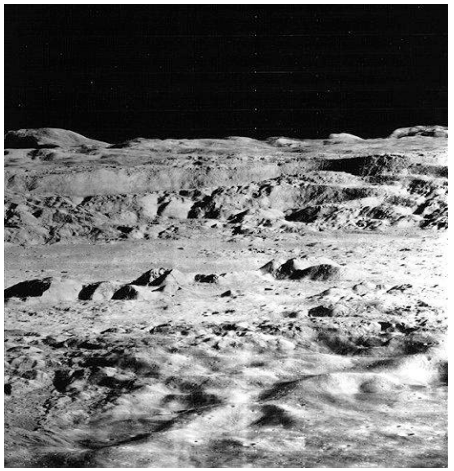
BACKGROUND

- WHAT IS MICROGRAVITY?
- EARLY HISTORY
- FIRST RESEARCH FACILITIES AND TOPICS DROP TOWERS, AIRCRAFT, SOUNDING ROCKETS, TOPICS INCLUDED FLUID MANAGEMENT (FOR LIQUID FUEL ROCKETS), THERMAL CONTROLS (SINGLE PHASE COOLING SYSTEMS) APOLLO AND SKYLAB
- NAS/NAE AND NRC CONFERENCES DEFINED RESEARCH AREAS DISTINCT DISCIPLINES SUGGESTED AND INITIALLY FOLLOWED
- ESTABLISHED OPEN SOLICITATIONS AND EXTERNAL PEER REVIEW-

  PRIORITIES AND TIME CONSTRAINTS WERE TO FLY OFF EXISTING PROJECTS, ESTABLISH GROUND BASED PROGRAM
- FLIGHT OPPORTUNITIES ON SHUTTLE- MIDDECK, CROSS BAY, SPACELAB; FIRST OPPORTUNITIES FOR FOLLOW ON EXPERIMENTATION AND MORE SOPHISTICATED HARDWARE DEVELOPMENT
- ISS PREPARATION AND ONGOING INTERCHANGEABLE EXPERIMENT MODULES, MORE SOPHISTICATED ON ORBIT DIAGNOSTICS, SCIENTISTS INVOLVED IN HARDWARE DEFINITION AND DEVELOPMENT

FLUID PHYSICS

- **Gravity** plays a major role in the behavior of fluids and thereby impacts chemical reactions, thermal control systems, life support systems, rocket fuel management and much more. Intrinsically involved in almost all other disciplines. RESEARCH LEADS TO NEW THEORIES, THEORETICAL ADVANCEMENTS, ENABLING NEW TECHNOLOGIES AND MANUFACTURING PROCESSES, SIGNIFICANTLY IMPACT WAY RESEARCH IS DONE HERE ON EARTH
  - low gravity environment allowed studies in the importance of shape and surface tension on the flow in and handling of fluids. (these insights have made significant contributions as nanotechnologies and microfluidics progress from scientific curiosities to applications as well as chemical engineering systems using surfactants)
  - MGM studied soil dynamics in loosely compressed soils which can suddenly lose their load bearing capability such as in an earthquake. Important for moon, Mars where soils weigh significantly less.
  - GFFC used an electric field inside a dome shaped container to test models for gas flows inside stars and gaseous planets. Able to reproduce flow patterns observed in gaseous planets for analysis and physical interpretation.
  - Boiling experiments have lead to understandings that will allow use of much more efficient thermal control systems on future space missions (two phase).

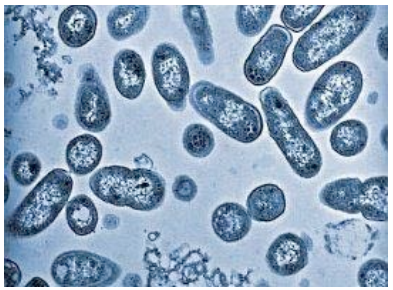


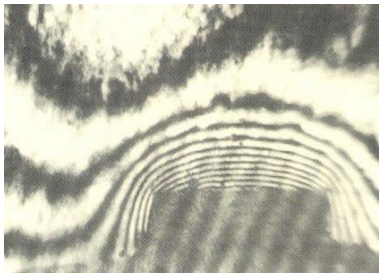
MATERIALS

- **Buoyancy and sedimentation** lead to inhomogeneities and defect formation in metals and semiconductors as they are fabricated or processed. IMPROVE THEORY, MANUFACTURING PROCESSES, ENABLE NEW TECHNOLOGIES AND IMPACT SIGNIFICANLTY WAY RESEARCH IS DONE ON EARTH
  - Low gravity experiments strongly influenced scientific understanding and technologically important areas such as control of homogeneity and structural defects in semiconductors (use of magnetic fields), production of industrial materials by sintering and precipitation hardening, accurate thermophysical properties such as surface tension, viscosity, diffusivity required for process modeling.
  - Space experiments in liquid phase sintering showed that deformation in space was considerably more than on earth. Improved understanding lead to significant impact on $1.8B industry.
  - Understanding dendrite growth experiments lead to widely improved physical understanding and mathematical models of pattern formation in solidification.
  - Studies on the formation of a defects called freckles lead to almost universally accepted practice of rotating samples during processing.

BIOTECHNOLOGY

- **Buoyancy and sedimentation** have significant impact on organic molecular separations, cell culturing, protein crystal growth and other biotechnology processes. RESEARCH HAS SIGNIFICANTLY IMPACTED WAY RESEARCH IS CARRIED OUT ON EARTH
  - Electrophoresis studies (biological separation process) determined influence of sedimentation and buoyancy that lead to an industry standard for separations here on earth. Further studies discovered an electrohydrodynamic instability leading to refinements of terrestrial processes.
  - Rotating wall bioreactor invented to maintain viability before and after other space operations but proved useful for providing low shear environment that allows cell and tissue culture problems. Bioreactor has been used to culture cells to high degrees of differentiation (close to tissue) large mass growth on STS 107 but lost. Has been used to study propagations of viral infections in vitro and lead to new insights into the roles of fluid stress and mass transport in cell culture.
  - Protein crystal growth important in understanding the structure of molecules (proteins and DNA) involved in biological functions. Most require laborious trial and error experimentation. Space studies gave some spectacular results (1000X larger and highest resolution of a virus to that time and some crystals that had never been grown on Earth but others wouldn't grow at all). Lead to understanding the physics of problem and understanding of the role of buoyancy.
  - Gene expression is space is significantly different than on the ground, due to gravitational effects

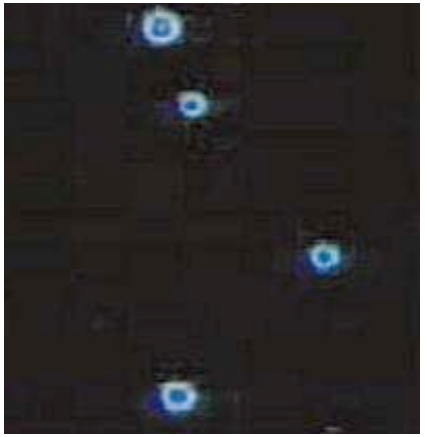




COMBUSTION

- **Combustion** is controlled by source of fuel, oxidizer and heat. In a great many processes (about 85% of energy in US economy is from burning hydrocarbon fuels) gravity plays a critical role. In space fires ignite and spread differently. RESEARCH ENABLES NEW TECHNOLOGIES, THEORETICAL ADVANCEMENTS AND IMPACTS MANUFACTURING PROCESSES
  - Shuttle research has given understanding of ignition, propagation and suppression of fires in space. Soot particles are larger and usually not detectable by sensors used on Shuttle. Results being used to design research on ISS leading to new generation of fire detection and suppression hardware for space exploration including ISS.
  - Droplet burning results lead to development and confirmation of comprehensive modeling capability that is used by engine builders such as GE and Pratt and Whitney to optimize designs.
  - Study of very weak flames near the flammability limit gave insights into efficient design for hydrogen burning engines that may help meet need for clean transportation technologies.

A candle flame in normal gravity. A candle flame in microgravity.



FUNDAMENTAL PHYSICS

RESEARCH TO TEST FUNDAMENTAL THEORY

Renormalization group theory is a Nobel Prize winning theory that can be scaled to cover topics as large as global weather or small as pattern formation at atomic levels in metals and ceramics or the charge radius of an electron. It is also used to describe phenomena as a fluid approaches it's critical point (a set of pressures and temperatures where the fluid is neither a liquid nor a gas in other words the two phases become indistinguishable) where the thermophysical properties converge to a singularity. On earth, the compressibility of the fluid causes the properties to be smeared and measurement is generally an averaging of the properties on both sides of the singularity. Space experiments measuring thermal conductivity and viscosity have verified the applicability of RNG and given theorists more confidence in its application to an even broader set of problems.

LESSONS LEARNED

- Know your customer
- Flexibility allows following agency policy
- Failure is not an option- Risk vs Cost
- Spin is okay but lies are lethal
- External community support essential
- Internal support just as vital