NASA's Microgravity Materials Science Program – A Review of Experimental Investigations

materialsLAB Workshop
15 April 2014
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Historical Reference

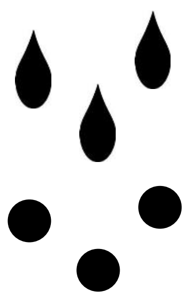
NASA was not the first to understand and utilize the benefits of processing materials in a microgravity environment.

That honor likely goes to William Watts of Bristol, England who in 1753 built a "drop tower" to process molten lead into uniformly spherical shot for firearms

Boughton Shot Tower
Chester, England
1799, 168' tall

Molten lead is poured

Through a sieve



Uniform drops freefall (microgravity), buoyancy effects are minimized

Surface tension dominates forming uniform spheres

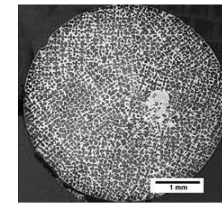
Solidified shot lands in a cushion of cooling water

Phoenix Shot Tower
Baltimore, MD, 234' tall
1828, tallest structure in US
2.5 million pounds shot/year

Micrograviity and Physical Phenomena

Gravity drives thermal and solutal convection

- Detrimentally impacts solidification microstructures
- Compromises diffusion studies



Gravity responsible for sedimentation/buoyancy

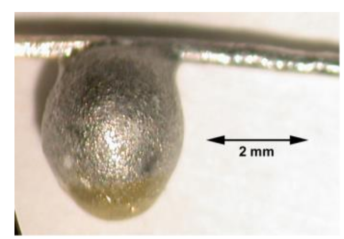
- Promotes non-uniform particle distributions

Gravity necessitates, usually, a container to process/study liquids

- Compromises accurate study of material properties such as viscosity
- Compromises nucleation/undercooling studies

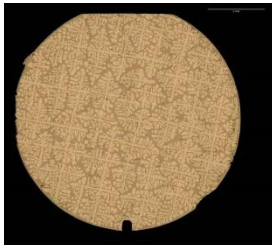
Gravity overwhelms subtle physical features

- Thermocapillary effects, surface tension are masked



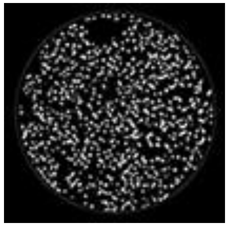
Microgravity and Physical Phenomena

Microgravity minimizes thermal and solutal convection



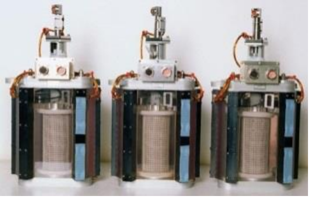
- Promotes diffusion controlled growth and uniform solidification microstructures

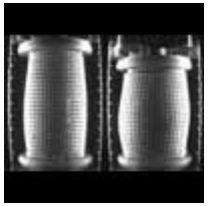
Microgravity minimizes sedimentation / buoyancy



- Promotes uniform particle distributions
  → Advances our understanding of coarsening and sintering

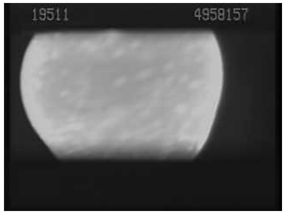
Microgravity minimizes pressure heads





- Reduces defects in semiconductor materials
- Allows study of granular materials

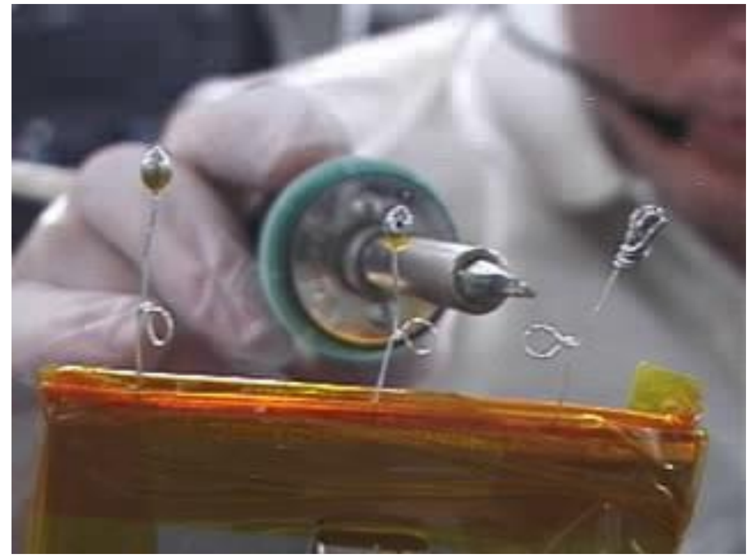
Microgravity eliminates a container to process / study liquids



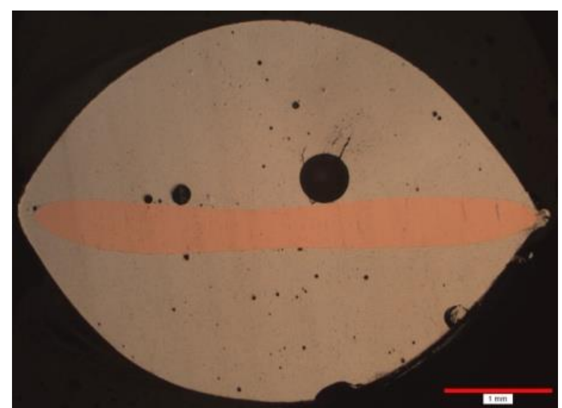
- Improves accuracy of material properties measurements such as viscosity and surface tension
- Facilitates nucleation studies

Microgravity allows observation of subtle physical phenomena

- Thermocapillary effects, surface tension are now dominant



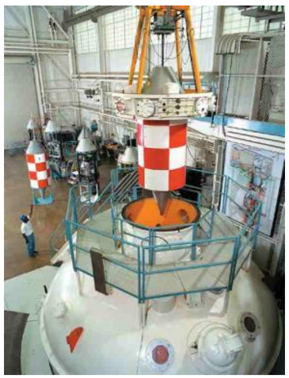
	Large Bubble (0.53mm)	Small Bubble (0.36mm)
Measured Velocity	5.6 mm/s	4.1 mm/s
Calculated Velocity	5.6 mm/s	4.4 mm/s

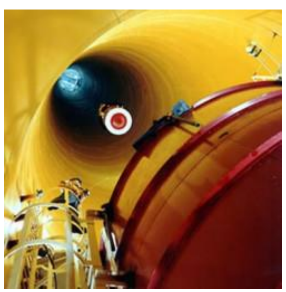


ISS Microgravity, Solder Sample Cross-Section

Microgravity "Platforms"

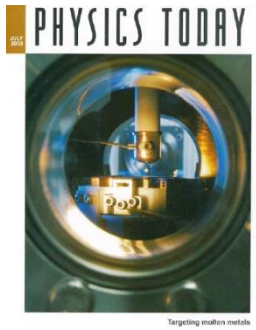
Drop Towers



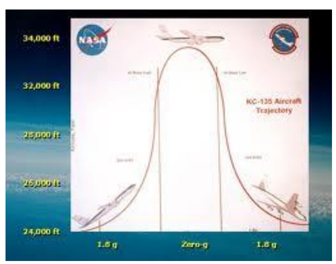


Glenn Research Center
432'
~5.2s μ*g*

Levitators

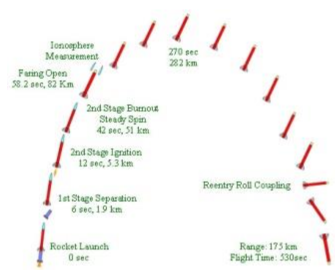


Parabolic Aircraft



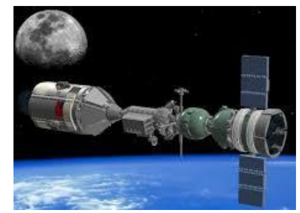
~30s μ*g*

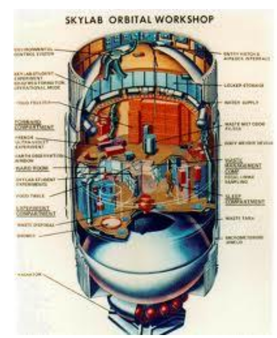
Sounding Rockets



15-25 min μ*g*

Space Vehicles / Stations





Long duration μ*g*

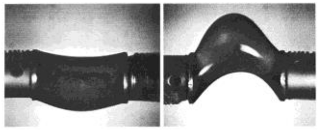
Long Duration Microgravity Physical Sciences Research	
Foundational Era 1950's to 1980	Shuttle Era 1980 to 2000
Mercury / Gemini / Apollo / Soyuz Spacecraft / Skylab	STS and MIR

Soyuz 6 1969 1st Welding Experiment
Apollo 14 1971 Composite Casting
Skylab 1973-1979

Skylab Materials Processing Facility
Multipurpose Furnace System

Apollo Furnace

Skylab



Skylab: "such tests proved that the processing of metals without using containers is feasible in space".

TECHNOLOGY

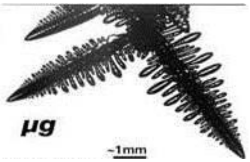
D008	RADIATION IN SPACECRAFT
D024	THERMAL CONTROL COATINGS
M415	THERMAL CONTROL COATINGS
M479	ZERO-g FLAMMABILITY
M512	MATERIALS PROCESSING FACILITY
M551	METALS MELTING
M552	EXOTHERMIC BRAZING
M553	SPHERE FORMING
M555	GALLIUM ARSENIDE CRYSTAL GROWTH
M516	CREW ACTIVITIES / MAINTENANCE STUDY
M518	MULTIPURPOSE FURNACE SYSTEM
M556	VAPOR GROWTH OF II-VI COMPOUNDS
M557	IMMISCIBLE ALLOY COMPOSITIONS
M558	RADIOACTIVE TRACER DIFFUSION
M559	MICROSEGREGATION IN GERMANIUM
M560	GROWTH OF SPHERICAL CRYSTALS
M561	WHISKER-REINFORCED COMPOSITES
M562	INDIUM ANTIMONIDE CRYSTALS
M563	MIXED III V CRYSTALS GROWTH
M564	METAL AND HALIDE EUTECTICS
M565	SILVER GRIDS MELTED IN SPACE
M566	COPPER-ALUMINUM EUTECTICS
T003	IN-FLIGHT AEROSOL ANALYSIS
T025	CORONAGRAPH CONTAMINATION MEASUREMENT
T027	ATM CONTAMINATION MEASUREMENT
T053	EARTH LASER BEACON

STS3 1982 Latex Spheres
STS9 1983 Spacelab 1
STS17 1985 Spacelab 3
STS51B 1985 Spacelab 2
STS61A 1985 Spacelab D1
STS40 1991 Spacelab LS1
STS42 1992 IML1
STS50 1992 USML
STS46 1992 EUREKA
STS47 1992 Spacelab-J
STS55 1993 Spacelab D2
STS57 1993 LEMZ
STS60 1994 CLPS
STS62 1994 USMP2
STS65 1994 IML2
STS73 1995 USML2
STS76 1996 QUELD LPS
STS77 1996 CFZF SEF
STS78 1996 LM2
STS94 1997 MSL
STS87 1997 USMP4

STS3
Latex
Spheres

STS9
InP
THM

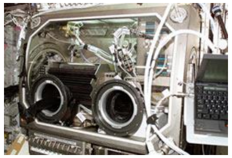
IML1
Hg I
VCG



USMP2
IDGE

Long Duration Microgravity Physical Sciences Research	
ISS Era 2000 to 2024	Exploration Era 2024 to -
STS and ISS	Moon / Mars / Others

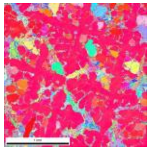

MSRR

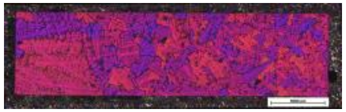

MSG


MWA

STS107 2003 Columbia

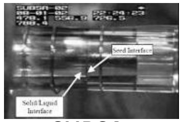
ISS Assembly
- Destiny Lab – MSRR
  - MICAST
  - ICDGSC
  - GTCS
  - DSI
  - SETA
  - METCOMP
  - CETSOL
  - SiSSI
  - GEDS
  - FOGS
  - FAMIS
- μg Science Glovebox
  - CSLM
  - PFMI
  - SUBSA
- Maintenance Workbench
  - ISSI
- Columbus Laboratory – ESL
  - THERMOLAB
  - QUASI
  - PARSEC
- Russian Lab
- Japanese Module JEM


MICAST


CETSOL


CSLM


PFMI


SUBSA


ISSI

In-Situ Resource Utilization

In Space Fabrication and Repair

Summary

Microgravity materials science arguably began in 1753

First long duration μ*g* experiments were Apollo, Soyuz, MIR, Skylab

- Much Russian welding work
- Wide range of Skylab materials experiments

Spirited period of μ*g* materials science was during the Shuttle age

- Many dedicated flights
- Generally good documentation of results
- Advances made in our scientific understanding
  - → Metals processing, semiconductors, crystal growth, dendritic growth, nucleation

Hiatus due to Columbia tragedy, ISS construction

Microgravity materials science initiated on the ISS

- Generally good results, still a long line of experiments