Section 21
Developing microgravity tolerance specifications

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<div style="border: 2px solid red; padding: 10px;">

GOAL:

Predict sensitivity of the experiment to the acceleration environment

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- PI must justify *need for microgravity*

- PI must be able to predict *tolerable* (and intolerable) *environments*
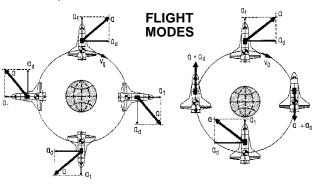
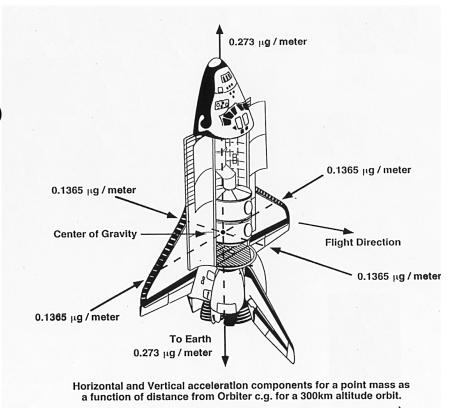## PI's choices (and assignments) affect the quality of the μg environment

For the Shuttle, some variables are:

- *flight mode (attitude of the carrier with respect to the earth)*
- *Deadband (allowable angular displacement from the desired mode)*
- *location* of experiment relative to CG
- *orientation* of the experiment w.r.t. Shuttle body axes
- scheduling of *crew activities*
- operation of *other apparatus* or experiments

FLIGHT MODES

Gravity gradient   Solar inertial

0.273 μg / meter

0.1365 μg / meter

0.1365 μg / meter

Center of Gravity

Flight Direction

0.1365 μg / meter

0.1365 μg / meter

To Earth
0.273 μg / meter

Horizontal and Vertical acceleration components for a point mass as a function of distance from Orbiter c.g. for a 300km altitude orbit.

- Feuerbacher et al. (1988)

Strategy for assessing experiment sensitivity to the μg environment

(1) Identify the *tolerance criterion*

(2) *Correlate acceleration* to the tolerance criterion

(3) Examine *knowledge base* from previous experiments

(4) Perform "simple" analyses to determine *range of sensitivity*

(5) Perform *detailed analysis* in the range of sensitivity and *examine specific microgravity environments*

(6) If necessary and possible, *test hypotheses* with prototypes on ground-based microgravity facilities, e.g., KC-135, drop tower

(7) Develop *detailed μg tolerance specifications*

Choice of tolerance criteria

Tolerance criteria are:

- *subjective*; may be to some extent *arbitrary*
- functions of *many parameters*
    - fundamental physics
    - experiment goal
    - composition of system (thermophysical properties, etc.)
    - geometry of system (aspect ratio, length of test section, etc.)
    - applied boundary conditions (applied thermal or pressure field, velocity of boundaries, etc.)
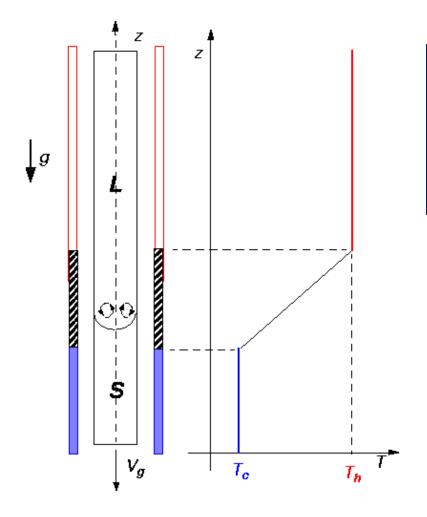
A good tolerance criterion is evaluated in light of the *specific experiment design* and the *specific environment* in which it is placed

Bridgman growth of semiconductor crystals

Tolerance criterion:

5% variation in solute concentration at solid/liquid interface (for example)

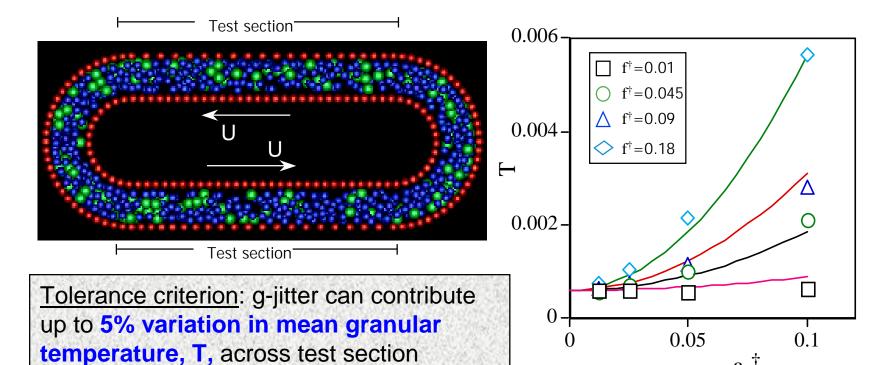$$\xi = \frac{c_{max_{interface}} - c_{min_{interface}}}{c_{bulk}}$$

Correlating acceleration to tolerance criterion

- All experiments will have some dependence on acceleration *magnitude*, *frequency*, *orientation*, and *duration*

- Experimental system *response varies enormously*, e.g.,:

  - may be very sensitive to *specific* frequencies, orientations, e.g., interfaces

  - require examination of *overall* momentum input, especially for bulk flows

  - may need *long recovery* times for short disturbances, especially for flows in which diffusion of momentum is large in comparison to the diffusion of the desired quantity (e.g., Schmidt or Prandtl number)

  - requires an understanding of the *time scales* of the experiment relative to the unsteady accelerations

Microgravity segregation of energetic grains (μgseg)

Test section

U

U

Test section

$f^\dagger = 0.01$

$f^\dagger = 0.045$

$f^\dagger = 0.09$

$f^\dagger = 0.18$

T

$a_z^\dagger$

Tolerance criterion: g-jitter can contribute up to **5% variation in mean granular temperature, T,** across test section
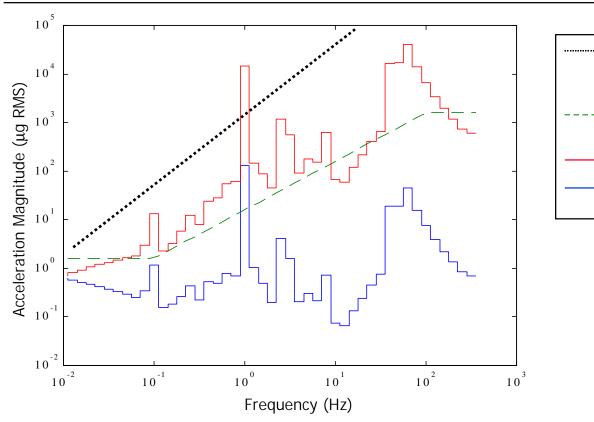
$$T = \tfrac{1}{3}\tilde{u}_i' \cdot \tilde{u}_i'$$

$$T = T_0 + c_i\, f^\dagger a^{\dagger 2}$$

- Jenkins and Louge (1998)

Tolerability limits for μgSEG
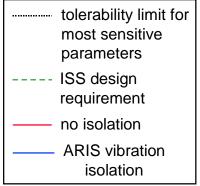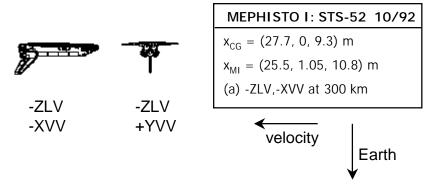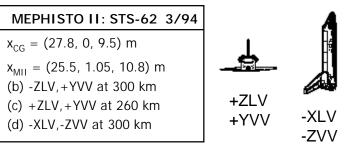

- Jenkins and Louge (1998)

Examine knowledge base: minimize g-jitter effects in directional solidification for MEPHISTO

- Use flight modes which do not require **Shuttle maneuvers** for water dumps, etc. (e.g., -ZLV,+YVV) for long-duration microgravity (>3 days)

- To minimize large accelerations, **specify a flight mode** requiring fewer thruster firings to maintain attitude; **2° deadband** required fewer thruster firings than 1° -- better μg

- Experiments should be **aligned with Shuttle's z body axis** for these flight modes to minimize transient acceleration effects (least transmission of disturbances along this axis)

-ZLV
-XVV

-ZLV
+YVV

MEPHISTO I: STS-52 10/92
x_{CG} = (27.7, 0, 9.3) m
x_{MI} = (25.5, 1.05, 10.8) m
(a) -ZLV,-XVV at 300 km

MEPHISTO II: STS-62 3/94
x_{CG} = (27.8, 0, 9.5) m
x_{MII} = (25.5, 1.05, 10.8) m
(b) -ZLV,+YVV at 300 km
(c) +ZLV,+YVV at 260 km
(d) -XLV,-ZVV at 300 km

+ZLV
+YVV

-XLV
-ZVV

← velocity

↓ Earth

- de Groh and Nelson (1997)

Some microgravity environments

Carriers:
- International Space Station
- sounding rocket
- Space Shuttle
- free flyer
- drop tower
- parabolic flight, e.g., on KC-135

Other distinguishing factors:
- location of experiment on the carrier
- type of rack
- vibration isolation
- disturbances present in the environment: crew exercise, thruster firings, water vents, other experiments

Developing detailed microgravity tolerance specifications

- **Describe the *quasisteady* acceleration limits**
  - upper bound of QS *magnitude* (expect several μg on ISS)
  - desired *orientation* (if choices are available)
  - angular *tolerance* about that orientation (e.g., align experiment with torque equilibrium attitude (TEA) of ISS with a tolerance of ± 0.05°. Maintain g_{qs} orientation to within TEA ± 10°)

- **Identify *oscillatory* acceleration limits**
  - *specific frequencies* at particular magnitudes of concern
  - frequency *cutoffs* (examine both upper and lower bounds)

- **Describe *transient* acceleration limits**
  - *thumbs up/down for identified transients* (based on thruster firings, impulsive crew activity, etc., e.g., 100 μg for up to 2 sec);
  - specify *integrated acceleration input* subject to limits (e.g., 300 μg-sec with magnitude ≤ 150 μg)

Developing detailed μg tolerance specifications (cont'd)

- **Specify *duration* of experimental runs**
    - *typical* length
    - anticipated *maximum/minimum* length
    - expected *number of runs* per 30-day microgravity period
- **Give *thumbs up/down for specific environments*, e.g.,**
    - Shuttle, sounding rocket, free flyer, KC-135, ISS
    - examine possibilities for vibration isolation
        - unisolated rack
        - ARIS vibration isolation
        - passive vibration isolation

        - MIM, g-LIMIT, or other active sub-rack isolation unit

  and *specific disturbances*
    - question experiments that are likely to interfere if run simultaneously (see DeLombard et al., 1998, for an example)

Now let's buzz through some examples: ➡

Studies of Gas/Particle Interactions in a Microgravity Flow Cell

Microgravity justification: A continuation of μgSEG. The previous study was governed by particle-particle interactions. In this experiment, the gas medium (in which the particles move) can also have an impact. Numerical simulations of the evolution of granular temperature in a shear flow between parallel bumpy boundaries were used to determine the microgravity requirements. These simulations were informed by theory and tested in a KC-135

Microgravity requirements:

duration: The minimum duration is governed by the time to reach steady state and by the amount of time to capture sufficient images for image processing and statistical analysis:

$$\theta_\mu > \theta_{ss} + \frac{N_{\min}d}{2U_{\max}} \text{ where } \frac{\theta_{ss}U_m}{Y'} = \frac{42}{\sqrt{T_{ss}^*}\left[1+4G(v)\right]G(v)}$$

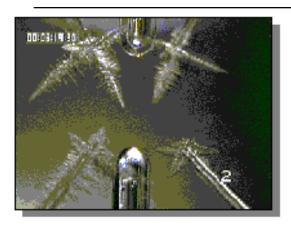quasisteady, oscillatory and transient: similarly specific equations are developed

Tables of two choices of candidate materials are given which give values to the above parameters
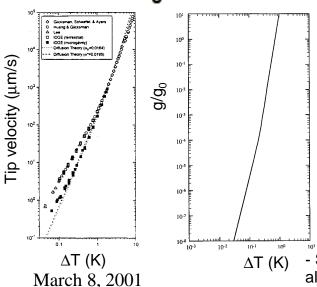
- Louge and Jenkins (2000)

Equiaxed Dendritic Solidification Experiment (EDSE)

Tetrahedron Arrangement of Dendrites

Microgravity justification: Bulk convection has significant impact on dendritic growth on earth at an undercooling ΔT<1.5K. At this ΔT, morphological details are very fine (<1µm); tip speed is high; and interactions are limited to distances of < 200 µm. Related experiment was able to obtain diffusion-controlled growth on the Shuttle for ΔT=0.2-1K, which provided grounds for optimism.

Microgravity requirements:

duration: 30-1000s

quasisteady: 30,000 µg for ΔT=0.3K; 760 µg for ΔT=0.2K; 2.3 µg for ΔT=0.1K

oscillatory: maximum 100 µg at f<0.5 Hz; maximum 1000 µg at f>0.5 Hz

Measure accelerations in vicinity of experiment with minimum bandwidth of 0-100 Hz with accuracy ±20%; time-tagged notification of accelerations outside specified levels

- Sensitivity to g provided by Lee et al. (1996)

- Beckermann et al. (1998)

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Physics of Colloids in Space (PCS)

Microgravity justification: Growth of binary colloidal crystal alloys is driven purely by entropy; complexity of alloy structure places severe demands on the growth conditions.

• Extended duration is required for the growth process.

• Matched index of refraction between particle and medium required for diagnostics. On earth, density matching to avoid sedimentation effects is also necessary, which places a severe limitation on candidate materials.

• As fractal colloidal aggregates become more tenuous, they are increasingly fragile and are susceptible to shear forces, as well as collapse by their own weight. Order-of-magnitude estimate that 10 μg and below will ensure that yield stress no longer limits cluster size.

Microgravity requirements:

duration: app. 1 year

quasisteady: 1000 μg

oscillatory: most sensitive to low frequency, gives example of diagnostic to determine sensitivity during experiment. Cites previous successful colloidal crystal growth on the Shuttle

transient: maximum 10,000 μg for a second or two

- Weitz and Pusey (1997)

Coarsening in solid/liquid mixtures (CSLM)

Microgravity justification: Sedimentation places a lower limit on the allowable volume fraction of solid particles on earth. Below the critical volume fraction, a skeletal structure will not develop and the particle sedimentation distance is governed by Stokes law. Investigation by scaling analysis and using various model systems shows that reducing particle sedimentation distances to acceptable levels on earth is nearly impossible. Five hours of microgravity time is a realistic expectation of the required duration.

Microgravity requirements:

duration: 5 hours

quasisteady: less than 1000 μg with no preferred direction

oscillatory: less than 10 μg over f=0.1-20 Hz

transient: less than 1000 μg for no longer than 0.1 sec, with total integrated firing times less than 1.8 sec during the 5-hour period

- Voorhees et al. (1994)

Solid Inflammability Boundary at Low Speed (SIBAL)

Microgravity justification: Theoretical analysis shows that flame spread and extinction in sub-buoyant low-speed flow (less than 20 cm/s) are fundamentally different from higher-speed flow typically encountered on earth. The scientific understanding of these phenomena, especially material flammability, is incomplete without investigating this low-speed regime. Examination of low-speed flow on flames at 1g is impossible.

Microgravity duration must be long enough for the flame to reach steady state, approximately 16s. Further, quench limit determination requires a gradual approach to the limit through a succession of steady states, requiring at least a minute. Residual acceleration must be small enough so that the flames are not perturbed by the induced flow.

Microgravity requirements:

duration: 16 sec to several minutes

quasisteady: below 100 μg

KC-135 test was compromised at 10,000 μg. Free-floating the payload on the gave promising results at 100 μg, but the duration was too short. Drop tower experiments also suffered from short duration.

- T'ien and Sacksteder (1995)

Smoldering Combustion Experiment in Space

Microgravity justification: Smoldering combustion is poorly understood. Its complexity requires many modeling approximations and (ground-based) experimental compromises. Microgravity can simplify the problem greatly by minimizing buoyancy-driven instability and problems related to sedimentation and collapse of fuel and char.

- In 1D, opposed smolder air velocities of 3 mm/s and more weaken the reaction by convective cooling. Forward smolder air velocities that can overcome buoyancy can cause flaming of the material.

- Extreme sensitivity to **g** at smoldering occurs at porous solid/gas interface under many conditions

- Sensitivity of this naturally weak combustion reaction to heat losses and oxygen availability.

- Possible applications to fire safety

Microgravity requirements:

<u>duration</u>: at least 1000s

- Fernandez-Pello (1992)

<u>Recap</u>: Strategy for assessing experiment sensitivity to the μg environment

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Where to go for help online

Browse through the microgravity sites to find experiments with similar physics:

- Fluid physics, materials science, combustion: **http://microgravity.grc.nasa.gov/new/expermnt.htm**

- Life sciences: **http://lsda.jsc.nasa.gov, http://www.spaceline.usuhs.mil**

- ESA microgravity database: **http://www.esa.int/cgi-bin/mgdb**

- Microgravity Research Experiments database (MICREX): **http://mgravity.itsc.uah.edu/microgravity/micrex/micrex.stm**

- For NASA civil servants and contractors, try Aeronautics & Space Access Page (ASAP): **http://www.sti.nasa.gov ASAP**

- NASA Technical Reports Server: **http://techreports.larc.nasa.gov/cgi-bin/NTRS** (especially RECONSelect)

- Microgravity Effects on Experiments Database to be online this summer (check **http://cml.grc.nasa.gov/nelson** for updates)

Note: for a good science dictionary, see **http://www.harcourt.com/dictionary**

Bibliography

Abbaschian, R. *"Bismuth-tin crystal growth."* Science Requirements Document (March, 1993).

Beckermann, C., H.C. de Groh III, I. Steinbach and A. Karma. *"Equiaxed dendritic solidification experiment (EDSE)."* Science Requirements Document (February, 1998).

Berg, R.F. and M.R. Moldover. *"Critical viscosity experiment."* Science Requirements Document (199?).

Chaikin, P.M., W.B. Russel, and J.S. Ling. *"Physics of hard spheres experiment (PHASE)."* Science Requirements Document (1994?).

Colwell, J.E. *"Collisions into dust experiment - 2"* Science Requirements Document (January, 1999).

De Groh, H.C. and E.S. Nelson. "*On residual acceleration during space experiments.*" **ASME HTD-Vol 290**, pp 23-33 (1994).

DeLombard, R.K., K. Hrovat, and K. McPherson. *"Experiment-to-experiment disturbance of microgravity environment."* **AIAA-99-0576** (Also NASA TM-1998-208847) (1998).

Demel, K. "*Implications of acceleration environments on scaling materials processing in space to production.*" In Measurement and characterization of the acceleration environment on board the Space Station. NASA/MSFC and Teledyne Brown. Aug 11-14 (1986).

Dodge, F.T. *"Liquid motion in a rotating tank experiment (LME)."* Science Requirements Document (August, 1994).

Fernandez-Pello, C. *"Smoldering combustion experiment in microgravity."* Science Requirements Document (November, 1992).

Feuerbacher, B., H. Hamacher and R. Jilg. *"Compatibility of microgravity experiments with spacecraft disturbances."* **Z Flugwiss Weltraumforsch 12:**145-151 (1988).

Bibliography (cont'd)

Louge, M. and Jenkins, J. *"Studies of gas/particle interactions in a microgravity flow cell."* Science Requirements Document (May, 2000).

Jenkins, J. and M. Louge. "*Microgravity Segregation of Energetic Grains*." Science Requirements Document (1998).

Matthiesen, D.H. *"Diffusion processes in molten semiconductors."* Science Requirements Document (June, 1996).

McKinley, G.H. *"The extensional rheology experiment."* Science Requirements Document (February, 1997).

Ronney, P.D. *"Structure of flame balls at low Lewis number (SOFBALL)."* Science Requirements Document (October, 1994).

T'ien, J.S. and K.R. Sacksteder. *"Solid inflammability boundary at low speed (SIBAL)."* Science Requirements Document (1995).

Voorhees, P.W. *"Coarsening in solid-liquid mixtures."* Science Requirements Document (June, 1994).

Weitz, D.A. and P.N. Pusey. *"Physics of colloids in space."* Science Requirements Document (July, 1997).