N86-28417

U.S. GRAVITY UTILIZATION OF TETHERS ACTIVITY

Ken Kroll
Johnson Space Center, NASA

I'm going to talk about three things: the ongoing study on fluid transfer that Martin-Marietta is doing right now, our future planning, and some of the issues we have in gravity utilization.

The first thing you need to know about tether orbital refueling is that it's for basically one reason: to settle fluid, overcome the surface tension forces that we see in space with the gravity level (see Figure 1). This allows us to have an earth-like environment where the liquid is over an outlet and the gas is over a vent so that we can perform as normal.

It also allows us to have a separation, when we are on the Space Station, from contamination and also from explosion hazards, though that's not as great a hazard as the contamination.

The important thing here for the acceleration to overcome the surface tension is its dependence upon the fluid properties, the acceleration level and the tank diameter, which is defined by the bond number.

And, if you look at Figure 2, which shows the acceleration in tether length versus different propellants, which is what we are looking at here, you will notice that there is quite a difference. It is very sensitive to tank diameter. The cryogenic propellant tank diameters are fairly large because of the large propellant quantities, and it's very good for settling with a tether gravity. Because both the use of this propellant and the opportunity to use a tethered depot will come later than an IOC Space Station, and also because of the technical reason that it settles well, we are concentrating on the cryogenic propellants for settling with the tether.

Once we settle the propellants, the most important thing is the fluid slosh (Figure 3). We can't cover the vent or uncover the propellant outlet. And, for a single disturbance, we can increase the tether length in order to increase potential energy of any slosh motion and we can change tank shape. Typically, we will have a conical bottom to provide the best tank shape. Now, for multiple disturbances, we have to damp this slosh motion. Typically, we would use a ring-type baffle to do that.

It turns out that the major impact, or the major issue, on the tether for a propellant depot is going to be the impact on the Space Station (Figure 4). The actual settling of the propellant and the slosh control are fairly easily done.

Going on to planning, we see that in the coming two years we are planning on doing a gravity laboratory study (Figure 5). Here, I define micro-gravity as trying to get the minimum disturbance level, and low gravity as purposely providing a gravity level, just to get the nomenclature across. We are looking at both types of laboratories, and also want to look at the low gravity processes to try and identify some so that we can understand what type of laboratory we do need, and the type of technology we would like to look at. Gravity level instrumentation is on top of the list. The crawler mechanism is a means of going from one end of the tether to the other. We would like to look at this both for logistics reasons, and also for an experiment using different gravity levels. Also very important is the disturbance-damping tether. Disturbances are damped very well laterally, but actually it is much more uncertain. We would like to look at the different tether weaves and combinations to see if we can dampen disturbances in the axial direction.

Currently we are planning a demonstration of gravity utilization using a TSS type of deployer (Figure 7). I am currently thinking of having the end satellite perform a fluid transfer to demonstrate a low-g application, and then having a crawler on the tether itself, moving around trying to position itself with the CG and performing gravity measurements as it goes along the tether.

And, as for a low gravity laboratory itself (Figure 8), my thinking is currently that a TSS-type of device on the Space Station itself would be best because it allows a long-term experiment and reduces the number of times that we have to bring up the deployer.

Getting into issues (Figure 9), the first thing in this particular area is the fact that we can't trade capital costs for operating costs. We are going to have to look at how much it's going to cost us extra, period, to have the tether. And the benefits that we get out of it, in terms of gravity utilization, will have to make that worthwhile.

The second point is the fact that we are going to be impacting the Space Station itself, especially for permanently deployed platforms like a transfer depot. This would be in terms of induced gravity, which would move the zero gravity point off the Space Station if it was the only platform. And also operational complexities, especially in terms of proximity operations. How do you supply those platforms? And how do you dock to the Space Station? And things like that.

Another point is, some of the platforms may want to be temporarily deployed, and some permanently. As we get more tether platforms up there, we are going to be wanting--providing--more permanent deployent. But, initially, we should be able to get away with some temporary ones.

Should we be remotely or manually controlling experiments or operations on the platform itself? This is important in terms of how much the astronaut has to EVA, if it's manual. If it's not, we have to try some remote method to keep the cost down, and keep the experiment as simple as possible. Another important point is that a Space Station doesn't appear to lend itself to medical experiments. Because with medical experiments, we have to start spinning the tether. How do we implement this in terms of a total Space Station that will be having a spinning tether as a free-fly or whatever?

And the last point. If we are going to have a lot of tether applications utilized simultaneously, I'd like to make the point that we could probably save some money if we integrate the tether systems together. This is to allow for more competitiveness with its conventional alternatives, since all these concepts do have conventional alternatives. It will allow us to share the cost of the tether control systems, and the cost of the additional hardware and operational development that we have to have with a permanently deployed tether.

Another important thing is micro-gravity. Because as I said before, if we have a tethered platform on a Space Station, it's going to move the micro-gravity point off of the station. We may want to do the micro-gravity still on the Space Station, because the modules will already be there. So we might have to balance different tether applications, one on each side of the Space Station. Or, we just might want to move everything to the micro-gravity laboratory on the tether itself. It also allows us to simultaneously use multiple tether applications. If we don't have an integrated concept, we can only use one at a time. In fact, some of these applications can complement each other, especially the electrodynamic tether. It can provide power into the platforms and whatever.

That completes my presentation.

U.S. GRAVITY UTILIZATION OF TETHERS ACTIVITY

KEN KROLL

NASA, JOHNSON SPACE CENTER

OCTOBER 15, 1985

TETHERED ORBITAL REFUELING STUDY

OBJECTIVE

- EVALUATE FEASIBILITY, REQUIREMENTS, AND LIMITATIONS OF FLUID TRANSFER ON A TETHERED SYSTEM

PURPOSE

- SIMPLIFY FLUID TRANSFER
  - TETHER ACCELERATION SEPARATES FLUID PHASES
  - LIQUID OVER OUTLET
    - LIQUID ACQUISITION IN RECEIVER TANK
  - GAS OVER VENT
    - VENT PRESSURE IN RECEIVER TANK
    - REDUCE CONTAMINATION BY VENTING GAS TO SUPPLY TANK

- IMPROVE SAFETY
  - TETHER LENGTH SEPARATES HAZARDS FROM SENSITIVE AREAS
  - PROPELLANT CONTAMINATION REDUCED
    - LEAK OR VENT HIGHLY LIKELY
  - EXPLOSION HAZARD REDUCED
    - OVERPRESSURE OR DETONATION HIGHLY UNLIKELY
  - TETHER BREAKAGE IS NEW HAZARD
    - DEBRIS IMPACT OR TETHER DEGRADATION MODERATELY LIKELY

NASA-S-84-05269

Fluid Settling

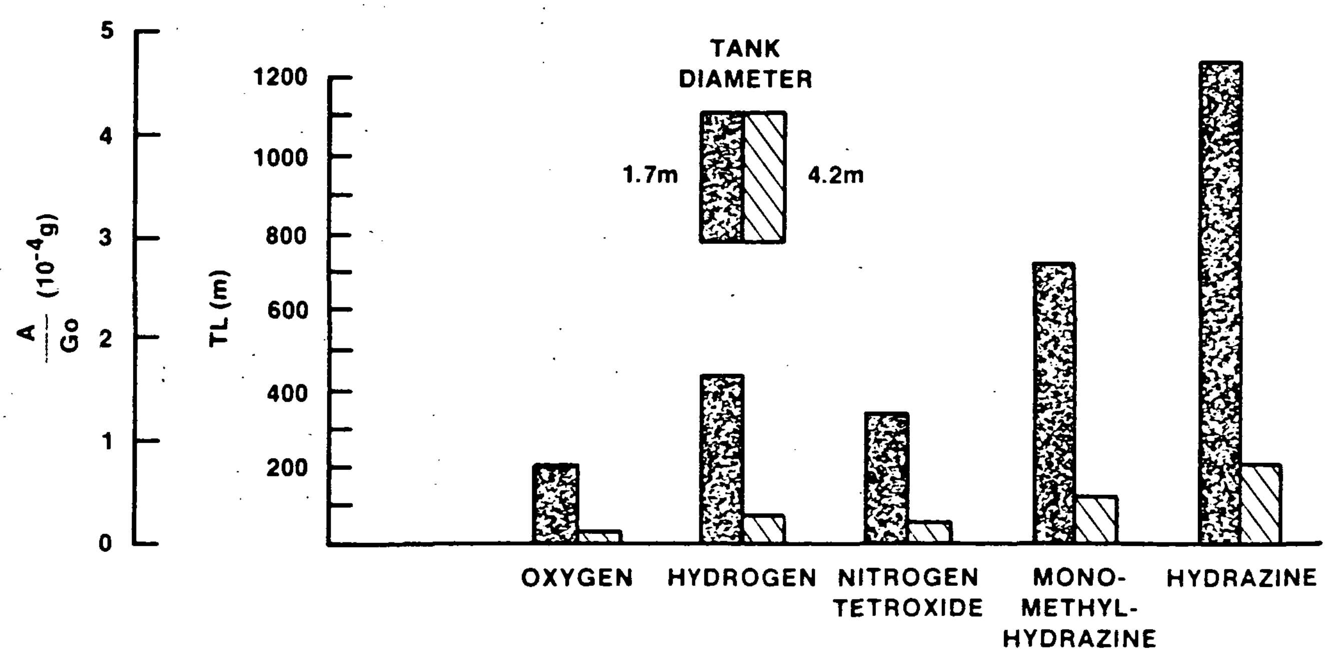
- **SETTLING REQUIREMENT**
  - **GRAVITY DOMINATE SURFACE TENSION**
- **FLUID SETTLING PARAMETER IS BOND NUMBER (Bo)**

$$Bo = \frac{\rho^* A^* D^2}{4^* \sigma}$$

ρ = FLUID DENSITY
σ = SURFACE TENSION COEFFICIENT
D = TANK DIAMETER

- **FLUID SETTLES IF Bo $>$ 10**
  - **Bo = 50 CHOSEN TO BE CONSERVATIVE**

PROPELLANT SETTLING ON A STATIC TETHER (Bo = 50)



FLUID TRANSFER

- TRANSFER METHODS
  - CRYOGENIC PROPELLANTS - AUTOGENOUS PRESSURIZED TRANSFER
  - STORABLE PROPELLANTS - PUMPED TRANSFER
  - BACKUP - GRAVITY FEED TRANSFER
- FLUID SLOSH
  - SLOSH CAN UNCOVER OUTLET AND COVER VENTS
  - LARGEST DISTURBANCE IMPULSE IS DOCKING WITH SPACE SHUTTLE
  - LIQUID POTENTIAL ENERGY CAN ABSORB DISTURBANCE ENERGY
    - TETHER LENGTH - 1 KM
    - TANK SHAPE - CONICAL BOTTOM
    - SINGLE DISTURBANCE
  - INTERNAL BAFFLES DAMP ENERGY
    - MULTIPLE DISTURBANCES
    - LITTLE CHANGE TO INITIAL AMPLITUDE

SPACE STATION IMPACTS

- REFUELING FACILITY PERMANENTLY DEPLOYED
  - CONTAMINATION CONCERNS
  - LARGE DEPLOYMENT MASS
  - CROWDING OF SPACE STATION PROPER
- LARGE SHIFT IN CENTER OF GRAVITY
  - ACCELERATION ON MICROGRAVITY LABORATORY
  - PLACE MICROGRAVITY LABORATORY ON TETHER
  - COUNTERBALANCE WITH ANOTHER TETHER APPLICATION
- PROPULSIVE FERRYING OPERATIONS WILL BE COMPLICATED
  - FERRY VEHICLES, MATERIALS, AND MEN
  - PROPULSIVE FERRYING WILL REQUIRE ORBITAL TRANSFER MANEUVERS
  - PROPULSIVE FERRYING WILL REQUIRE FAST DOCKING
  - FERRYING ALONG TETHER (CRAWLER) PROBABLY PREFERABLE
- REMOTE RATHER THAN MANUAL CONTROL OF OPERATION
  - REMOTE LOCATION
  - ACCELERATION ON EVA PERSONNEL

PLANNING RECOMMENDATIONS
GRAVITY LABORATORY STUDY

- FISCAL YEAR 1986
  - MICROGRAVITY LABORATORY
    - DETERMINE REQUIREMENTS AND LIMITATIONS
      - SPACE STATION AT CENTER OF GRAVITY
      - LABORATORY CRAWLER AT CENTER OF GRAVITY
    - DETERMINE COST AND BENEFITS
  - LOW GRAVITY PROCESSES
    - DETERMINE CANDIDATE PROCESSES FOR RESEARCH
    - DETERMINE CANDIDATE PROCESSES TO INVESTIGATE MICROGRAVITY BOUNDARY
    - DETERMINE CANDIDATE PROCESSES FOR INDUSTRIAL USE

- FISCAL YEAR 1987
  - LOW GRAVITY LABORATORY
    - DETERMINE REQUIREMENTS AND LIMITATIONS
      - LABORATORY AT TETHER END
      - LABORATORY CRAWLER
    - DETERMINE COST AND BENEFITS

PLANNING RECOMMENDATIONS
TECHNOLOGY

- 0 FISCAL 1987 TO 1989
- 0 GRAVITY LEVEL INSTRUMENTATION
  - 0 DETECT DISTURBANCE LEVELS
  - 0 CONTROL POSITION RELATIVE TO THE CENTER OF GRAVITY
- 0 CRAWLER MECHANISM
  - 0 PROVIDE MICROGRAVITY LABORATORY POSITIONING
  - 0 PROVIDE LOW GRAVITY LABORATORY POSITIONING
  - 0 PROVIDE FERRY CAPABILITY ALONG TETHER
- 0 DISTURBANCE DAMPING TETHER
  - 0 REDUCE EFFECT OF AXIAL TETHER DISTURBANCES

PLANNING RECOMMENDATIONS
DEMONSTRATION

- O FY87 - DEMONSTRATION DEFINITION
- O FY88 - 91 - DEMONSTRATION DEVELOPMENT
- O FY92 - DEMONSTRATION FLIGHT

- O DEMONSTRATION ELEMENTS
  - O TSS DEPLOYER
  - O FLUID TRANSFER EXPERIMENT ON END SATELLITE
    - O DEMONSTRATE FLUID TRANSFER
    - O VERIFY FLUID AND SYSTEM DYNAMICS
    - O TETHER LENGTH FROM CENTER OF GRAVITY GREATER THAN 8 KM
  - O CRAWLER
    - O DEMONSTRATE CRAWLER
    - O VERIFY CRAWLER DYNAMICS
    - O VERIFY PLACEMENT ACCURACY AT CENTER OF GRAVITY
    - O DETERMINE DISTURBANCE LEVEL AT CENTER OF GRAVITY

PLANNING RECOMMENDTIONS
LOW GRAVITY LABORATORY

- 0 FY88 - DEFINITION STUDY
- 0 LOW GRAVITY LABORATORY ELEMENTS
  - 0 SPACE STATION BASED
    - 0 LONG TERM EXPERIMENTS
    - 0 SINGLE SHUTTLE FLIGHT
    - 0 MULTIPLE EXPERIMENTS
  - 0 BASED ON TSS
    - 0 USE ON IOC SPACE STTION
    - 0 DEPLOYABLE TO MINIMIZE SPACE STATION IMPACT
  - 0 PROCESS EXPERIMENTATION ONLY

ISSUES

- IS A TETHER WORTH THE EXTRA COST?
- HOW IS IMPACT TO SPACE STATION TO BE HANDLED?
  - INDUCED GRAVITY
  - OPERATIONAL COMPLEXITY
- SHOULD PLATFORMS BE TEMPORARILY OR PERMANENTLY DEPLOYED?
- SHOULD EXPERIMENT AND OPERATIONS ON PLATFORMS BE REMOTELY OR MANUALLY CONTROLLED?
- HOW SHOULD GRAVITY LEVEL MEDICAL EXPERIMENTS BE CONDUCTED IN A SPACE STATION SYSTEM?

CASE FOR AN INTEGRATED TETHERED SPACE STATION

- 0 INTEGRATED TETHER SYSTEM CAN SHARE COSTS
  - 0 ALL TETHER APPLICTIONS HAVE MORE CONVENTIONAL ALTERNATIVES
  - 0 COST FOR TETHER AND CONTROL SYSTEM
  - 0 HARDWARE AND OPERATIONS COSTS OF PERMANENTLY DEPLOYED TETHER

- 0 PROVIDE MICROGRAVITY LABORATORY REQUIREMENT WITH PERMANENTLY DEPLOYED TETHER
  - 0 BALANCED TETHER APPLICATIONS
  - 0 MICROGRAVITY LABORATORY ON TETHER

- 0 SIMULTANEOUS USE OF MULTIPLE TETHER APPLICATIONS
- 0 TETHER APPLICATIONS CAN COMPLEMENT EACH OTHER