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24. SPACE STATION DYNAMICS

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ABSTRACT

Structural dynamic characteristics and responses of the Space Station due to the natural and induced environment are discussed. Problems that are peculiar to the Space Station are also discussed. These factors lead to an overall acceleration environment that users may expect. This acceleration environment can be considered as a loading, as well as a disturbance environment.

I've tried to re-orient this briefing to emphasize some of the micro-g aspects that everybody's been talking about. We've been hearing a lot about the requirements for the Space Station and how to measure that environment. What I'd like to talk about is what we at the Johnson Space Center think we can expect on Station. The reason is because it really has a very significant effect on the configuration. The requirements that I've heard over the last few days seem to have a very wide range, and will have a dramatic impact on the Space Station configuration. Yet we're very uncertain as to whether 10^{-3} or 10^{-8} g's are needed. 10^{-5} is our current requirement, and remember those exponents are orders magnitude and as such have a large effect on Space Station design. I want to encourage both the user side and the Station performance side that we need to really work together to make sure that we understand exactly what we need. These requirements don't come cheap and we have an $8 billion budget to bring this thing in under.

The configuration can't solve this entire problem. It seems like every speaker at this workshop has put a note in my notebook about another problem with micro-g materials processing, and frankly it seems that the work of the user community in this area is really just beginning. There seems to be a lot of different problems and I think the best we can do as far as Space Station is concerned is to try to present an environment that will be benign to your conditions, because you're going to find out that you never really understand it until you do get on orbit. So from a configuration standpoint, we'll just try not to do anything stupid that will really aggravate a situation that is already a very difficult engineering problem. To that effect we've changed from the power tower (which had featured modules at the bottom of a long beam) to the dual keel, primarily because of this micro-g requirement.

There seems to be a whole host of other problems, including dynamic effects and things like that. Another thing to consider is Owen Garriott's speech about a free-floating type of experiment that may release us completely from the configuration issue, in the sense that the free flyer becomes its own spacecraft and we don't have to worry about it quite as much. Again, I want to emphasize that we really need to work together to resolve this issue because it's an important thing to the Space Station configuration. We need to nail these things down and work toward resolving what those real requirements are.

Work Package 2 represents work that is going on at the Johnson Spacecraft Center (in our own dynamics area), Rockwell in Downey, and McDonnell Douglas in Huntington Beach.

Space Station dynamics separate into rigid and flex, and I'm going to talk about what the characterization and the different disturbances are in each of these areas and what we've been trying to address.

Now one of the major configuration issues is the flight mode, and some of this has been opened up recently again to try to study the solar inertial and Local Vertical, Local Horizontal (LVLH) modes (Figures 1 through 3). The solar inertial flight mode essentially points at the Sun. The reason for doing this is because Space Stations are solar powered, and you can look at it like it's a giant payload on the Station that has to be pointed at the Sun. The issue is whether or not you point the rest of the Station at the Sun, or whether you point the rest

SPACE STATION FLIES WITH PRINCIPAL AXES IN ORBIT PLANE

- All Points On Structure Have Drag Acceleration Opposite To V-Bar (250 NM <0.7 μG's)
- Points On Structure Above Or Below SS CM WRT Earth Have A Component Of Acceleration Force Towards CM Parallel To The Earth Radius Vector
- Points To Side Of Orbit Plane Have A Component Of Accelerations Force Away From Orbit Plane
- Points In Front Or Behind CM Along V-Bar Have A Component Of Acceleration Force Away From CM And Parallel To V-Bar, Which Adds To The Drag Acceleration

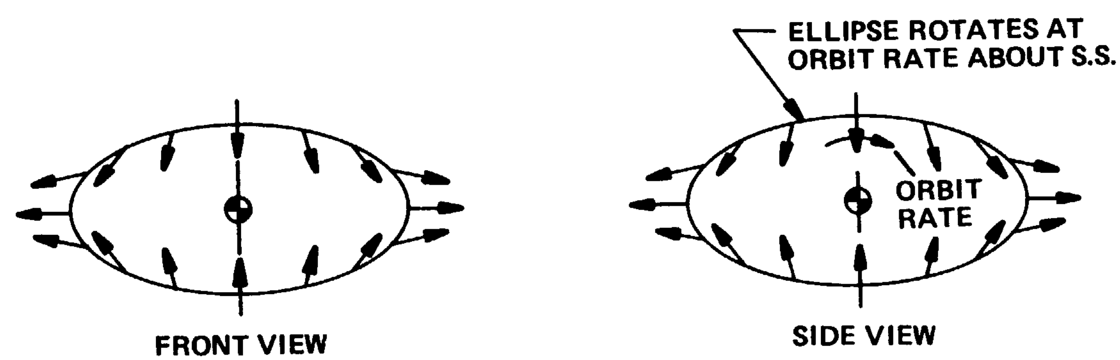


FIGURE 1. SOLAR INERTIAL FLIGHT MODE

LVLH FLIGHT MODEL

- Space Station (SS) Assumed To Rotate About Perpendicular To Orbit Plane
  - All points on structure have a drag acceleration opposite to V-Bar (@ 250 NM <0.7 μGs)
  - Points on structure above or below SS CM have a component of acceleration force towards CM parallel to the earth radius vector
  - Points to side of orbit plane have a component of accelerator force away from orbit plane

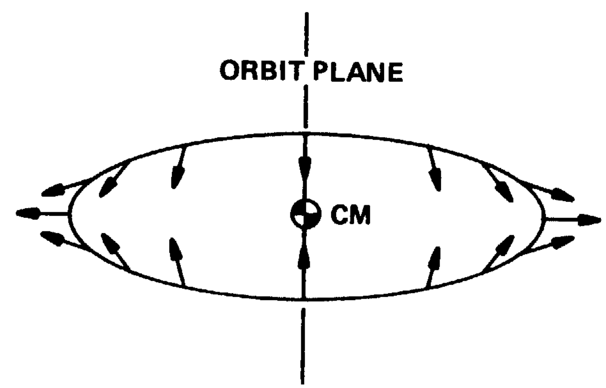


FIGURE 2. LVLH FLIGHT MODE/MICRO-GRAVITY ENVIRONMENT

of the Station at the Earth. The solar inertial flight mode is a very cost-effective way to go. You can eliminate many of the articulating systems and thereby simplify the dynamics issues and analysis. But if we have to go to the LVLH mode from a micro-g standpoint, or from an Earth-viewing standpoint, then we have to do it, but we want to know what the cost is and identify those things and know what the benefits are.

- **CONCLUSIONS:**
  - **BOTH SI AND LVLH FLIGHT MODES HAVE THE SAME μG ACCELERATION COMPONENT PERPENDICULAR TO THE ORBIT PLANE**
  - **THE COMPONENT OF ACCELERATION PARALLEL TO THE RADIUS VECTOR FOR THE LVLH FLIGHT MODE IS APPROXIMATELY 50 PERCENT GREATER THAN FOR THE SI FLIGHT MODE**
  - **THE μG COMPONENTS OF ACCELERATION IN THE ORBIT PLANE FOR THE SI FLIGHT MODE AVERAGES OVER THE ORBIT TO $<1.0\ \mu$G**

FIGURE 3. CONCLUSIONS

Figure 4 shows a reference configuration that is being studied at the Johnson Space Center. This Station configuration has been studied both from the solar-oriented standpoint and from a local vertical, local horizontal configuration. One of the features that is different from the reference dual keel is the lack of the keels. A major benefit of this is that it allows the Space Station to be very compact, and that yields very advantageous dynamics effects.

I was asked to show some of the isogravs, a word that I think we made up at JSC. Figure 5 shows the isogravs on a solar inertial station. You get constant gravity just like you do on the LVLH station as you come out of the orbit plane. The five micro-g circle is the outer one, two and a half the inner. In-plane isogravs are a set of ellipses (Figure 6) and they will rotate with respect to the body, or vice versa.

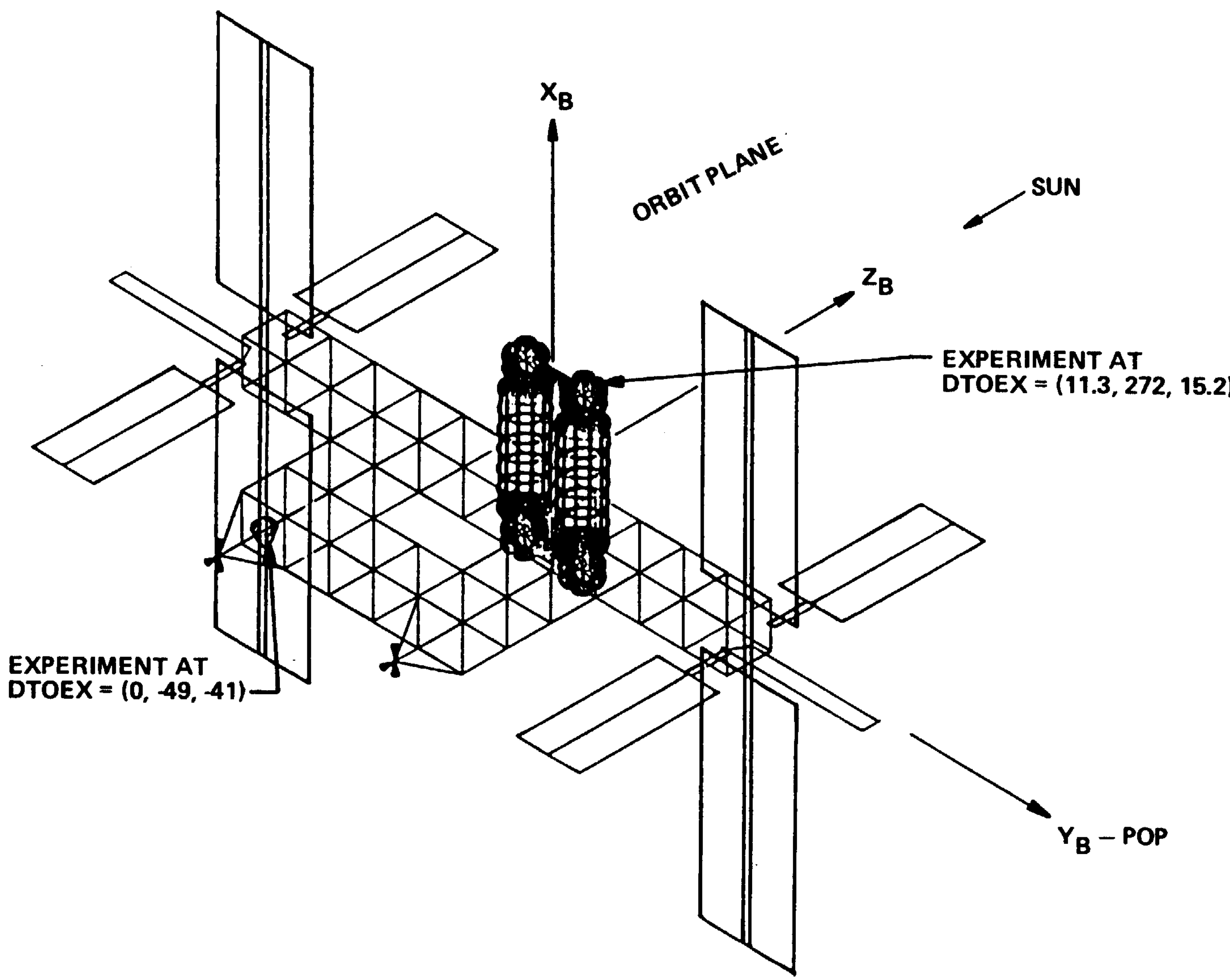


FIGURE 4. SOLAR ORIENTED SPACE STATION

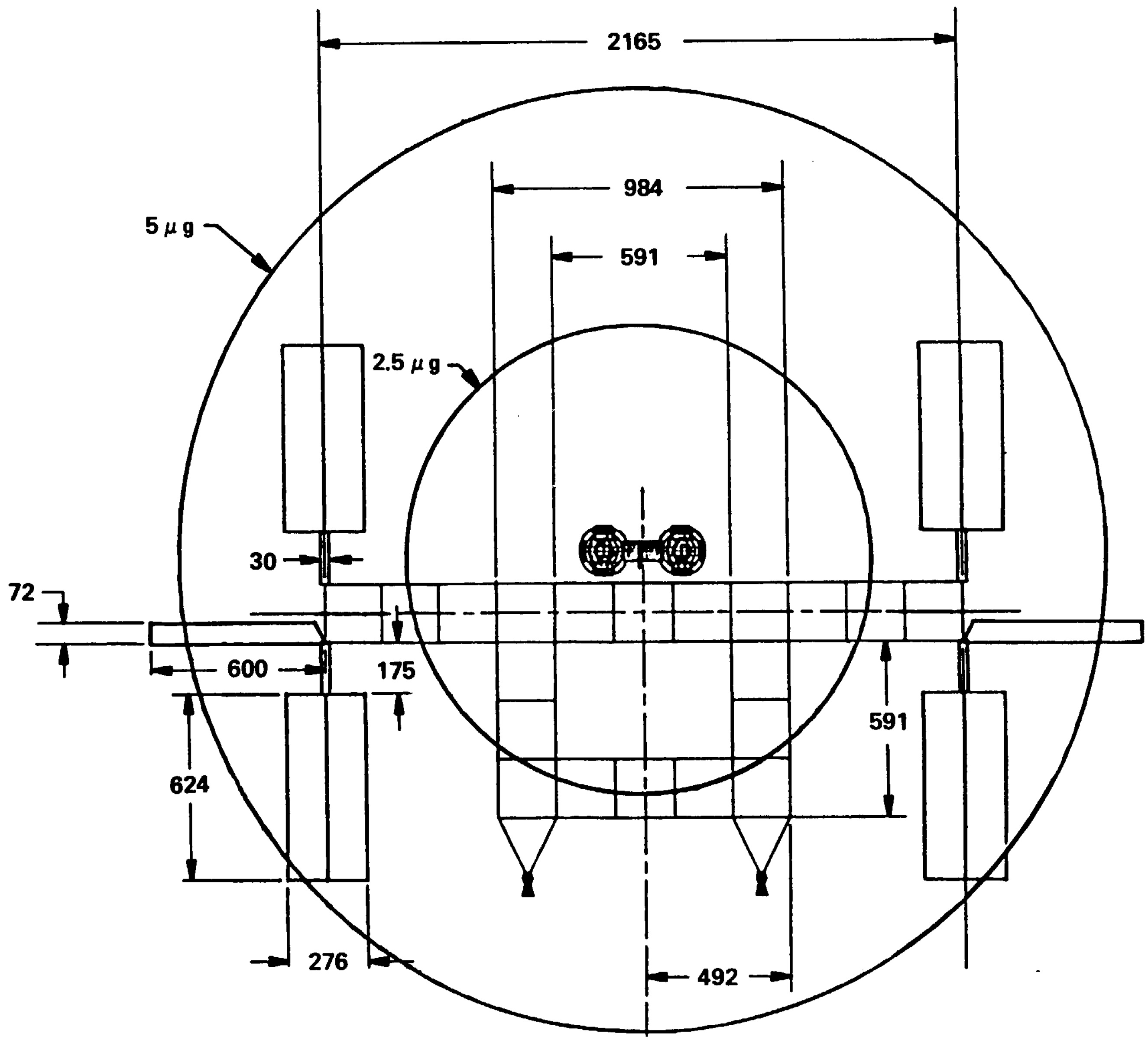
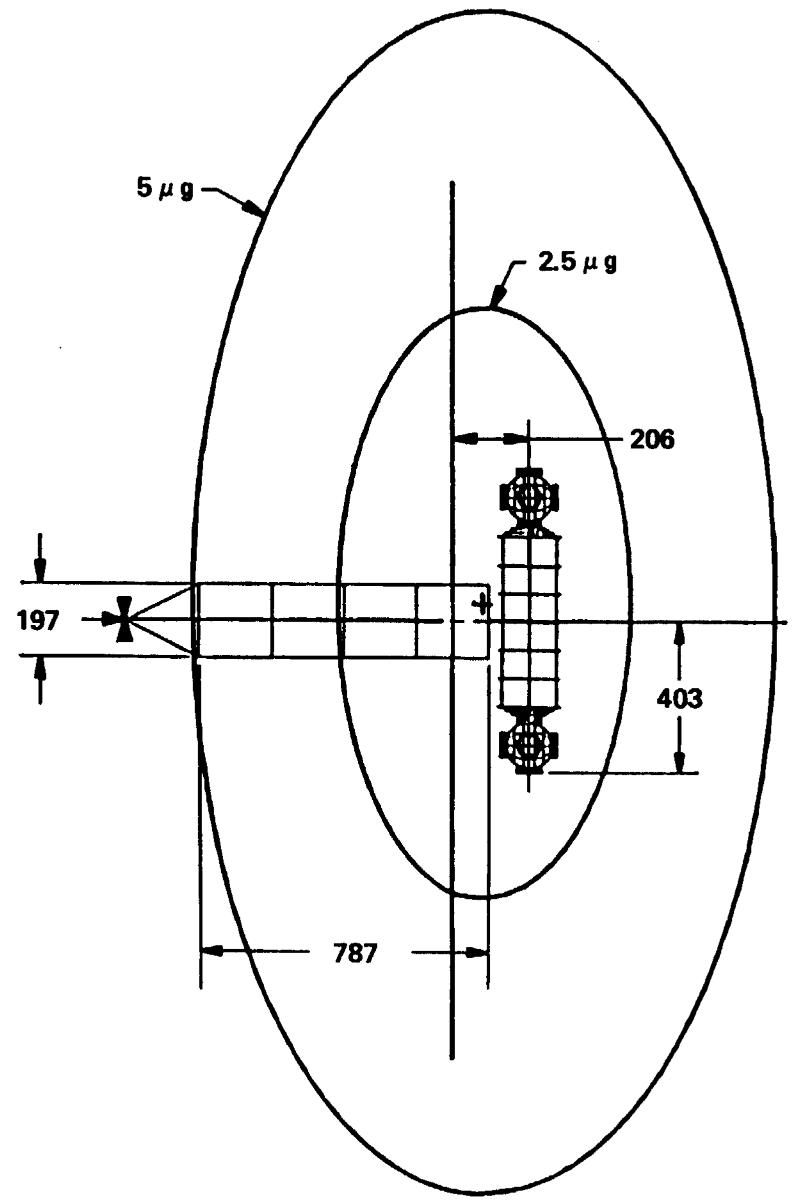


FIGURE 5. SOLAR INERTIAL FLIGHT MODE, TOP VIEW



NOTE: MICROGRAVITY (μg) CONTOURS CLOCK AROUND STATION AT ORBITAL RATE, FOR POP S.I. FLIGHT MODE

FIGURE 6. SOLAR INERTIAL FLIGHT MODE, SIDE VIEW

This characteristic has caused some people in this materials processing community some concern. We're just trying to explore that, and as dynamicists we try to identify the environment and then try and get user's reaction to it.

Figure 7 shows isogravs in the LVLH mode.

Figure 8 shows rigid body accelerations of the two flight modes. This figure tries to address what the actual magnitude of that acceleration is. The number 4 curve includes the aero effects, but I'd like to point out that the model really varies a great deal over whatever assumptions you make in terms of solar cycle so you have to be really careful. It's a difficult thing to quantify. This example is a rather extreme atmosphere, but I think it's the case that's been consistently analyzed. The number 5 line shows a magnitude that results from a solar inertial flight mode on this particular station. It is consistent with respect to atmospheric drag. You would see the same thing if this were on the dual keel or a power tower or anything else. You're going to get a reduction in magnitude from the solar inertial standpoint, but also some fluctuation. On the LVLH mode, you get a constant type of acceleration and it's going to be a little larger. The cycle period is going to be somewhere around half of an orbit, and whether or not a materials processing experiment can respond in 45 minutes to this cycle is questionable. An experiment will get a reduced amount of acceleration in the SI mode, but it's going to be changing a little bit.

Bob Naumann mentioned yesterday the possibility of rotating experiments. Those things have to be investigated because, from the configuration standpoint, we can only present an environment that is amenable to the solution of the problem, we're not going to be able to solve the whole problem. There's still going to have to be something done at the point of the experiment, but from the other problems that I've heard about over the last few days, I think you're going to have to do that anyway. The kind of environment that we can expect from the solar inertial flight mode is reduced, but not constant.

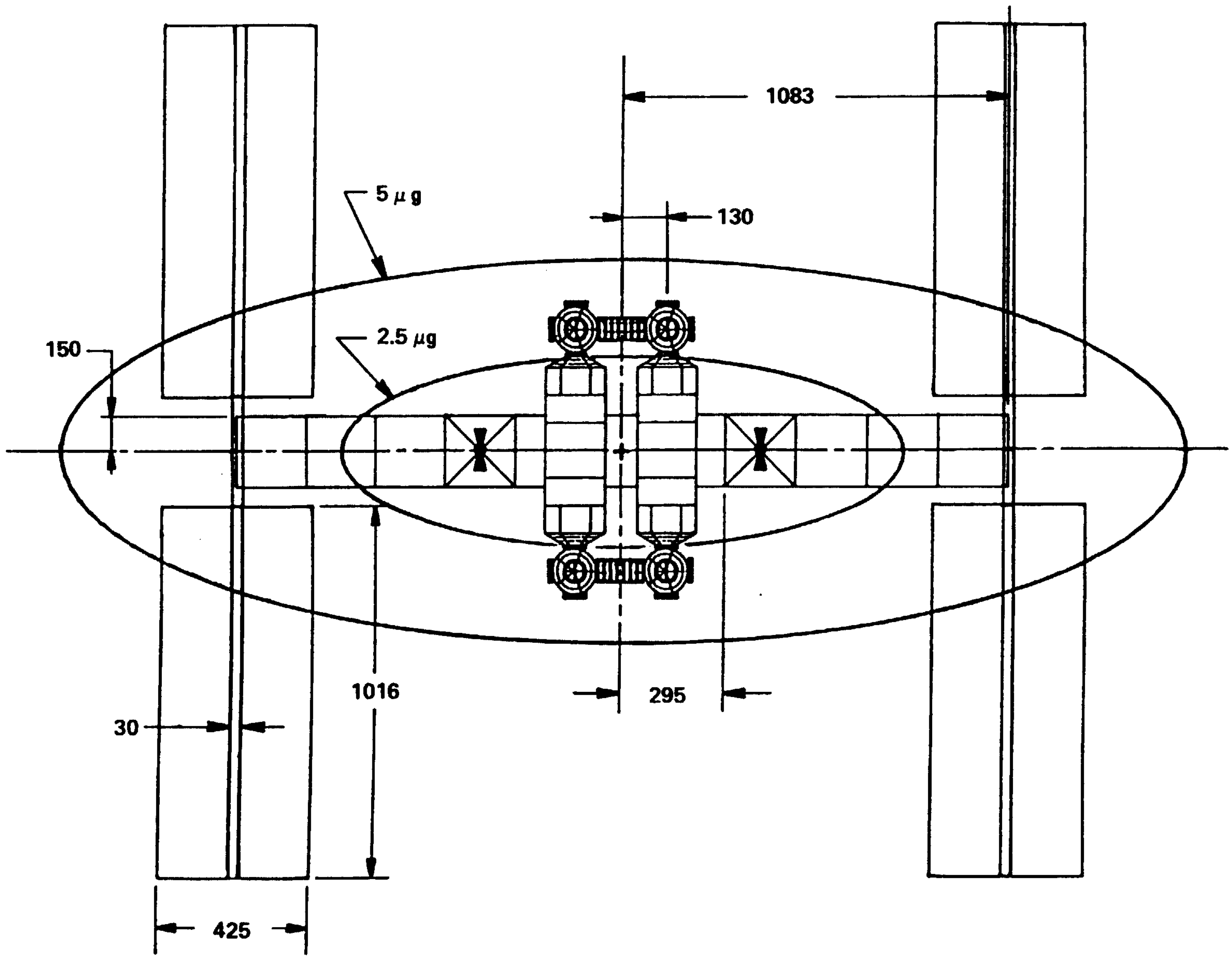


FIGURE 7. LVLH FLIGHT MODE, SIDE VIEW

H = 250 NM, INCL = 28.5, YAW = 0, PITCH = 0, -49, -41

SOLAR BOOM POP

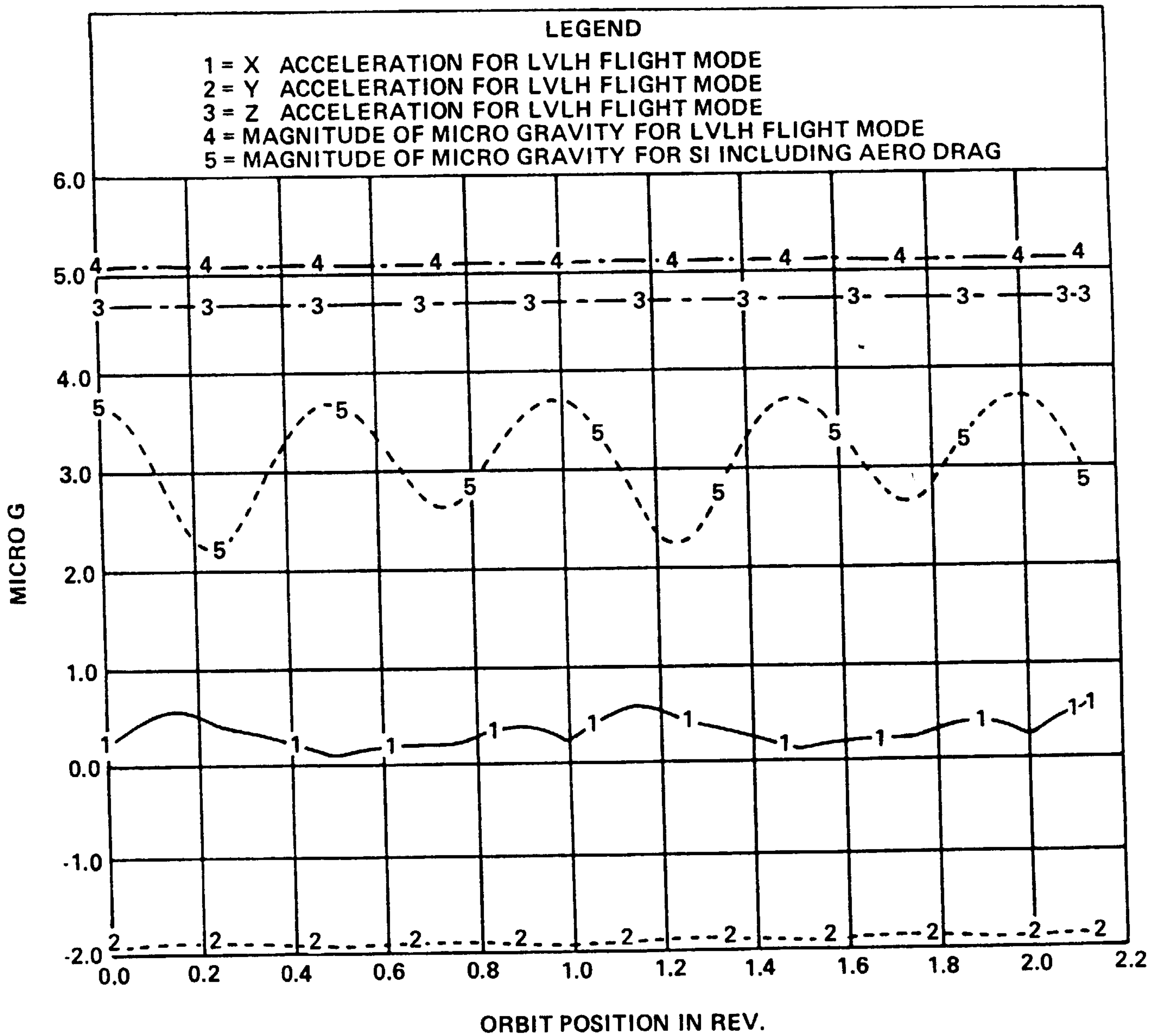


FIGURE 8. RIGID BODY ACCELERATIONS

Figures 9 through 10 show a breakdown of the magnitude value into its components. You do get a sinusoidal activity that has a 45-minute period. There is phasing difference as a function of the position. Line 4 shows the aero disturbance. The thing that I'm trying to learn, with reference to what I heard yesterday about the worst kind of thing, is a steady state acceleration, but I don't know whether this may be too low a frequency. We need to explore that a little more, but certainly as you integrate this as an average (reference again to Dr. Naumann's presentation yesterday) you're going to get a very low net acceleration.

The flight mode is really a very basic and fundamental issue to the configuration. It's probably the first fork in the road. When we start solving micro-g problems from the first fork in the road, we cascade that into an impact on a lot of other systems. So as we try to do the systems engineering on the Space Station, what happens at the very top level can have a very dramatic effect on what happens later on. And that's the concern about the impact of micro-g on flight mode: its significance to the configuration.

Now the conclusions that we're drawing from the analysis is that both the solar inertial and LVLH flight modes have the same micro-g acceleration components out of the orbit plane. It's only in the orbit plane that it shows a difference. If somebody wants a steady-state value, you can locate an experiment at the center of mass and out of the orbit plane leading to a higher static or steady-state value. I'm getting the impression that's probably not a good way to go because the component of acceleration parallel to the radius vector for the LVLH flight mode is approximately 50 percent greater than the solar inertial flight mode. That was what the first chart was trying to demonstrate. Micro-g components of acceleration in the orbit plane for the solar inertial flight mode average over the orbit to less than a micro-g because of the sinusoidal components. We want to hear what impact that has on the materials processing. That is, how you really feel about this difference in flight modes.

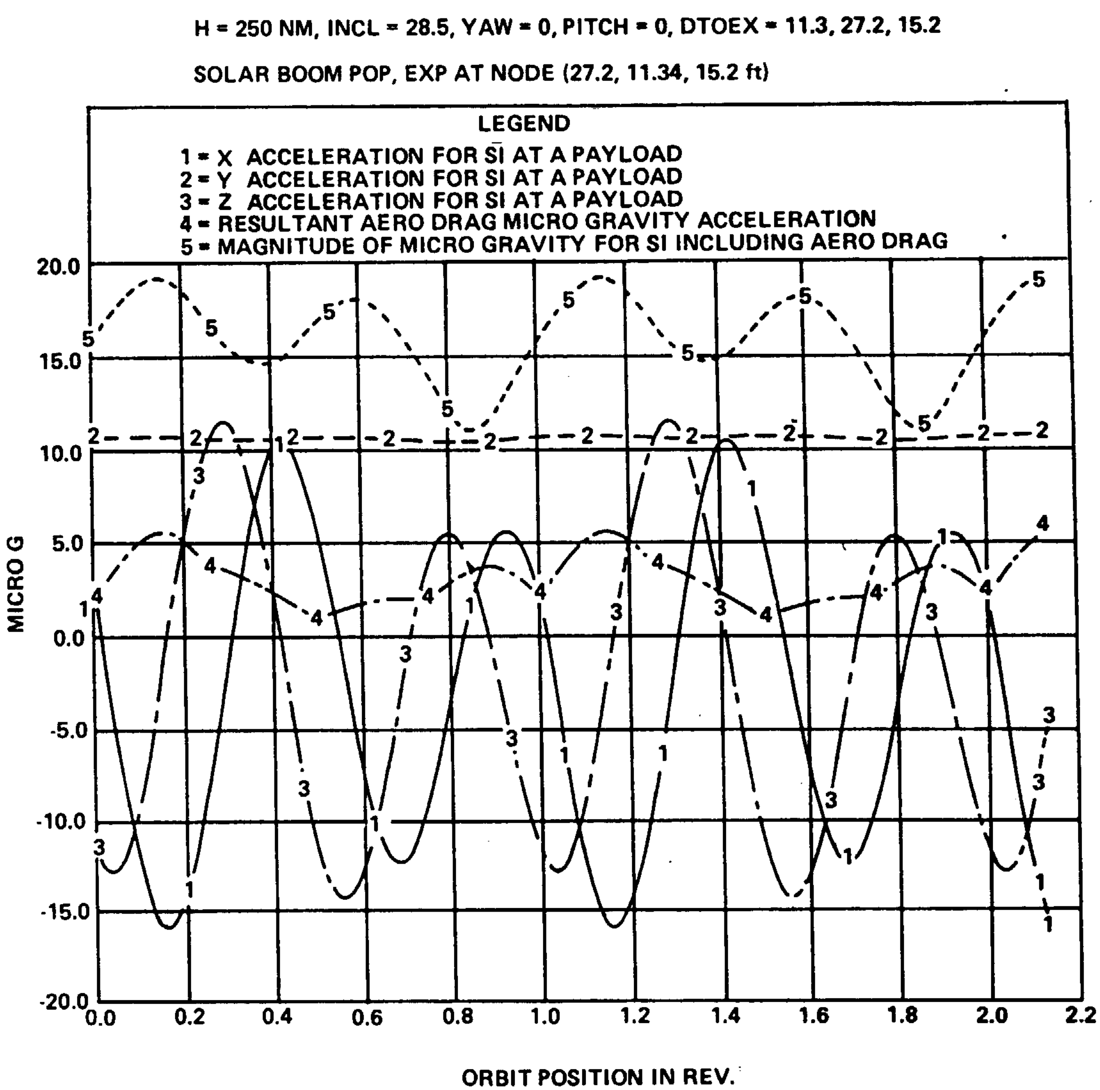


FIGURE 9. COMPONENTS OF ACCELERATION AT A PAYLOAD

H = 250 NM, INCL = 28.5, YAW = 0, PITCH = 0, DTOEX = 0, -49, -41

SOLAR BOOM POP

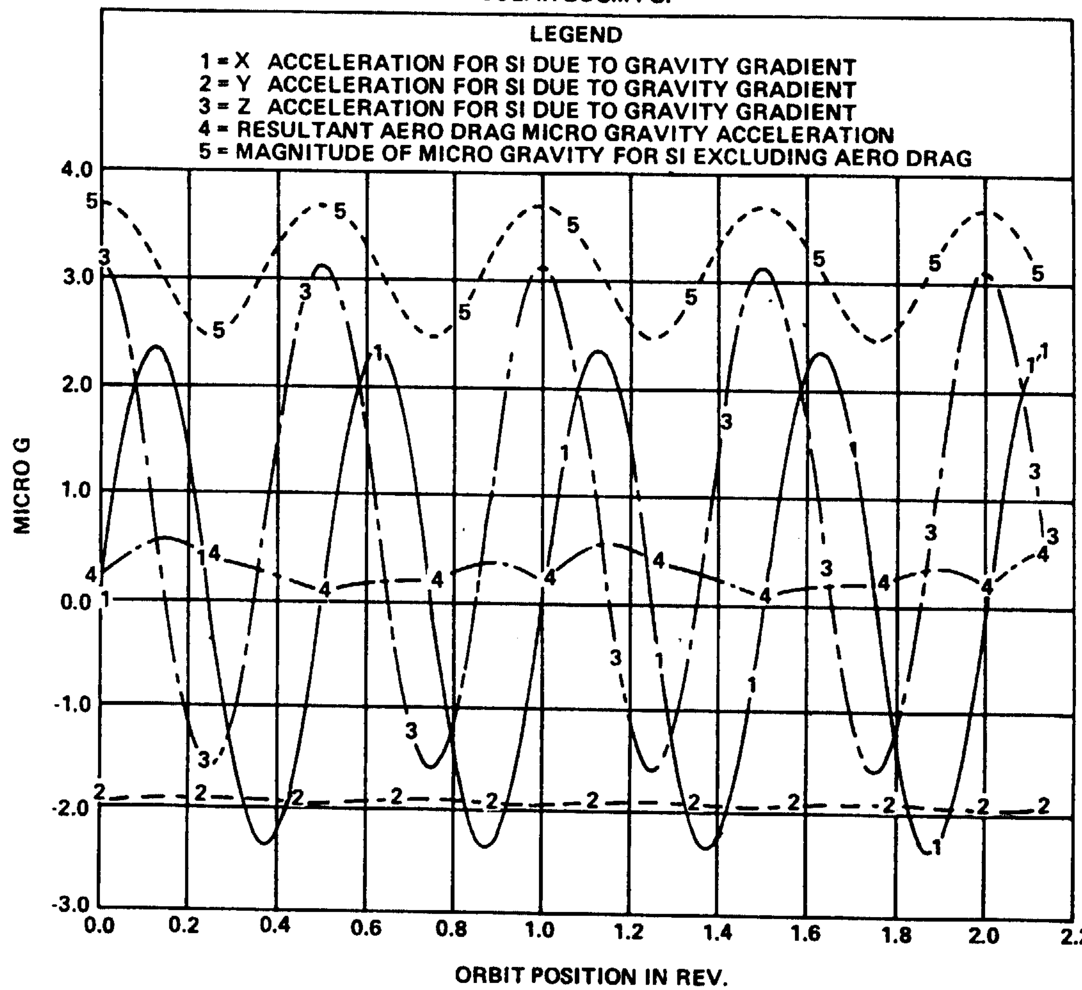


FIGURE 10. GRAVITY GRADIENT COMPONENTS

The operational impacts of orbital rate have become very dramatic from a rigid body standpoint, because there's a lot happening on the Station besides micro-g materials processing experiments. This is what cascades from a very early systems decision, there will be effects that may have been otherwise unexpected. As an example, on the dual keel we ran into several problems conserving angular momentum, moving masses from the upper boom down toward the modules. If you take something out of the orbiter (docked in the middle) and move it out to the upper and lower booms, you've got to conserve a great deal of momentum because in the LVLH flight mode, we have an orbital rate to contend with. The whole system has a certain angular momentum that has to be conserved. Now this has resulted in an impact to the mobile service center, the old MRMS. It now has about 2 feet per minute maximum speed given the design condition of a 30,000-lb payload. Torque equilibrium must be conserved, a gravity gradient torque on the vehicle must counter that angular momentum change. The speed that the mobile servicing center moves is roughly 20 times slower than the mobile launch platform at KSC. This leads to operational impacts. If you go to a solar inertial mode, you don't have angular momentum that has to be conserved, and mass can be moved about the station in a much more expeditious fashion. This, therefore, is one of the impacts that we're concerned about. The mass management for an SI mode can be served by more compact geometry (Figure 11). Inertia changes can be minimized because it's an MX^2 function. We are trying to drive the configuration to be more mass compact. The LVLH modules and the solar inertial power system complicate the rigid body dynamic analysis. There are many problems with coupling the alpha joint control system to the attitude control system. We can provide the LVLH attitude, but it's going to cost and on an $8 billion station budget we need to make sure that we're getting what we pay for. We recently talked with Bob Naumann at MSFC as one of the respondents to a poll. We were trying to get more of a feel for what the user community was looking for in terms of flight mode. The poll came out and interviewed about 18 or so people in the materials science area to get their flight mode preference. It's not a fair question, granted, but in that poll, just over half of the respondents said they had no preference. Of the people that did, the majority of those preferred LVLH flight mode, as you might expect. However, there was some solar inertial preference as well. When I got that information, I asked all my dynamics friends, and they overwhelmingly supported the solar inertial mode as you might understand. So we are on both sides of the fence of this flight mode issue and I just want to try to start a dialogue such that we can work out these problems.

LESSONS LEARNED:

OPERATIONAL IMPACTS OF ORBITAL RATE (LVLH)
- **ANGULAR MOMENTUM MUST BE CONSERVED DURING MASS MOVEMENTS**

MASS MANAGEMENT SERVED BY COMPACT GEOMETRY
- **MINIMIZES INERTIA CHANGES AND CG MOVEMENT**

LVLH MODULES/SOLAR INERTIAL POWER SYSTEM COMPLICATES RIGID BODY DYNAMIC ANALYSES.

FIGURE 11. RIGID BODY DYNAMICS

The flex body dynamics of the station are very interesting. The Station is a very peculiar thing to analyze because about every day somebody walks in with something different they want to do on station and adds to our disturbance environment. Figure 12 shows a very short list here, but it gets longer by the day. I'm very concerned, not about the growth in loading conditions, but the spontaneous way that different loading conditions can pop up. Here the disturbances are crew motion, machinery, payload slewing, and mobile servicing center (MSC) operations. The Space Station peculiarities include changing mass properties as things move about the station. The mass properties are changing, and thereby change the modes and frequencies. That's something we're just going have to live with on the Space Station. We can make some configuration changes by keeping the geometry compact, but we're going to have to live with these problems on an operational station. A solar array rotation, on the other hand, is something that really complicates the modal analysis. We can solve all these problems, that's not the question, it's just whether or not we should. To get in under an $8 billion budget, we need to be eliminating those problems not solving them. The coupled control system is another issue that must be solved from a dynamics standpoint, that is, dynamic interaction between adjacent payload pointing systems. Alpha joint and attitude control is another interaction that we have to consider on an LVLH station.

CHARACTERIZATION: FLEX MODES AND FREQUENCIES

DISTURBANCES: OPERATIONAL
- CREW MOTION
- MACHINERY
- PAYLOAD SLEWING
- MSC OPERATIONS
- CONTROL TORQUES/RATES

NON-OPERATIONAL
- REBOOST
- ASSEMBLY
- BERTHING (ORBITER, OMV)

SPACE STATION PECULIARITIES: CHANGING MASS PROPERTIES
- SOLAR ARRAY ROTATION
- COUPLED CONTROL SYSTEMS

FIGURE 12. FLEX BODY DYNAMICS

Figure 13 shows the dual keel power tower with hybrid power. This station is built up of truss work which contributes to the stiffness rather substantially. There are a lot of pieces on this station, and you can see that the center part is the LVLH part and the outboard parts are the solar inertial aspects of the station. With a large num-

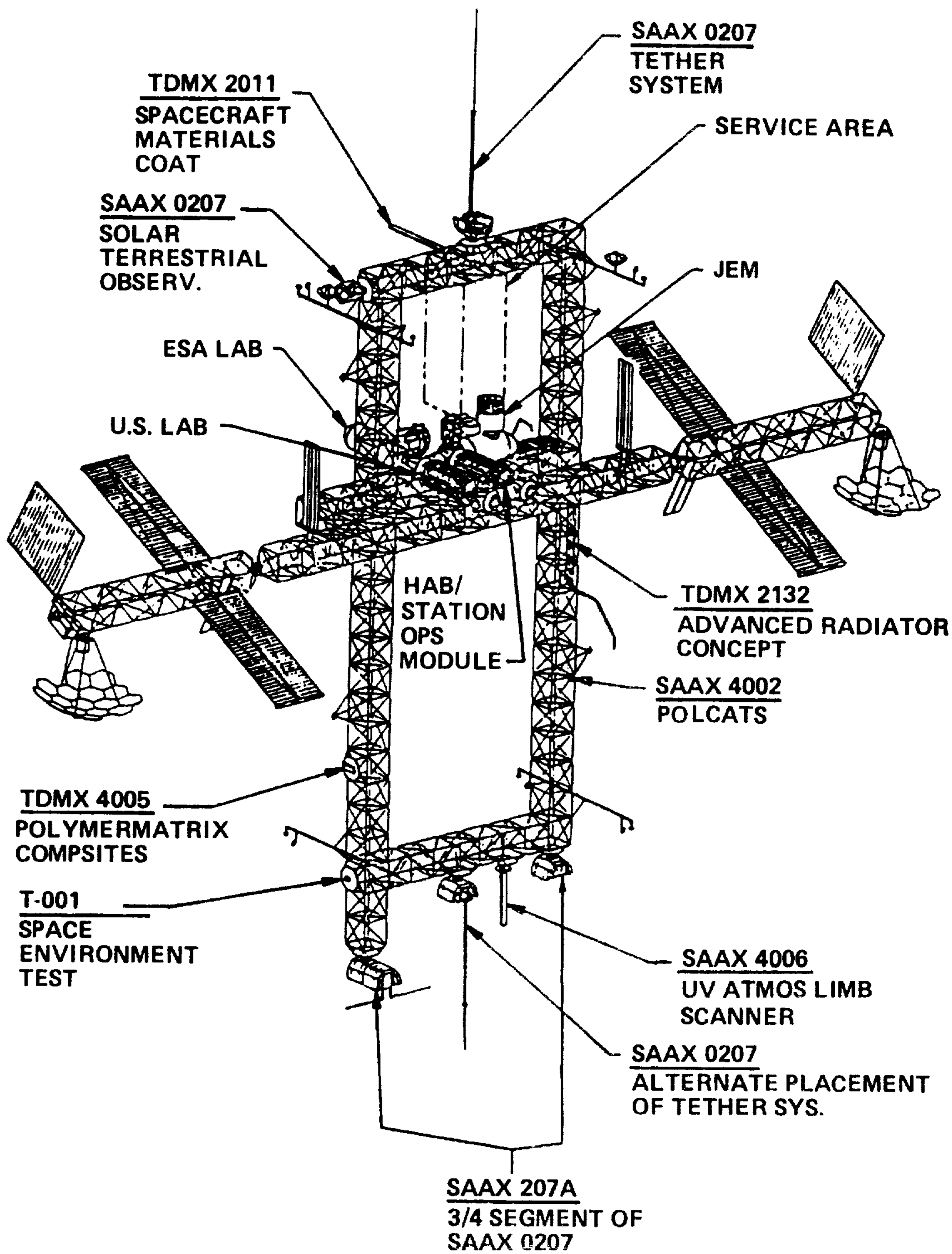


FIGURE 13. INTERNATIONAL SPACE STATION CONFIGURATION

ber of cantilevers like that, there are always a lot of opportunities for little cantilever modes. The mode set is very clustered and quite complicated with this configuration, and the more you put things on it and introduce other flexibilities, the more modes you get.

Assembly is another key loading environment for the Space Station. I guess we're not going to have the micro-g conditions during assembly (Figure 14). The Orbiter's primary reaction control system can overload a large beam very easily. We are baselining use of the vernier reaction control system during assembly; however, we would like to have some kind of back-up capability. The primary system is such an adverse loading environment that we can very easily break some of the truss members. Figure 15 is a growth model, and if you stare at it long enough I'll guarantee it will start moving. Look closely and you can see the first bending mode of the solar transverse booms. These growth versions are a real challenge from the dynamics standpoint.

Next I'd like to talk about the acceleration responses to the loading. I want to point out that we try to separate the environments between an operational and a non-operational environment. We're trying to work the micro-g problem in the context of the operational environment, crew motion and that sort of thing, and not worry about it too much during a reboost condition or Orbiter docking.

We've already hit this Station and looked at the responses (which violate 10^{-5}) and, therefore, we may need isolation on the system (Figure 16). I'm not real sure we do, because if it's peaked one way and peaked the other the average over time may be acceptable. Impulse forces acting on the Station can get significant attenuation and reduce that g-level. It's simply an experiment that's been modeled and located in the lab module and the response to the crew motion. But again we're leaning toward isolation, which means that we're spending money on isolation systems. And we need to know if we need isolation. It looks as though we do, because we're violating 10^{-5}, but we're spending money as we talk, and we'd certainly hate to walk downstream developing isolation systems that we can't use because we didn't define the requirements properly early on.

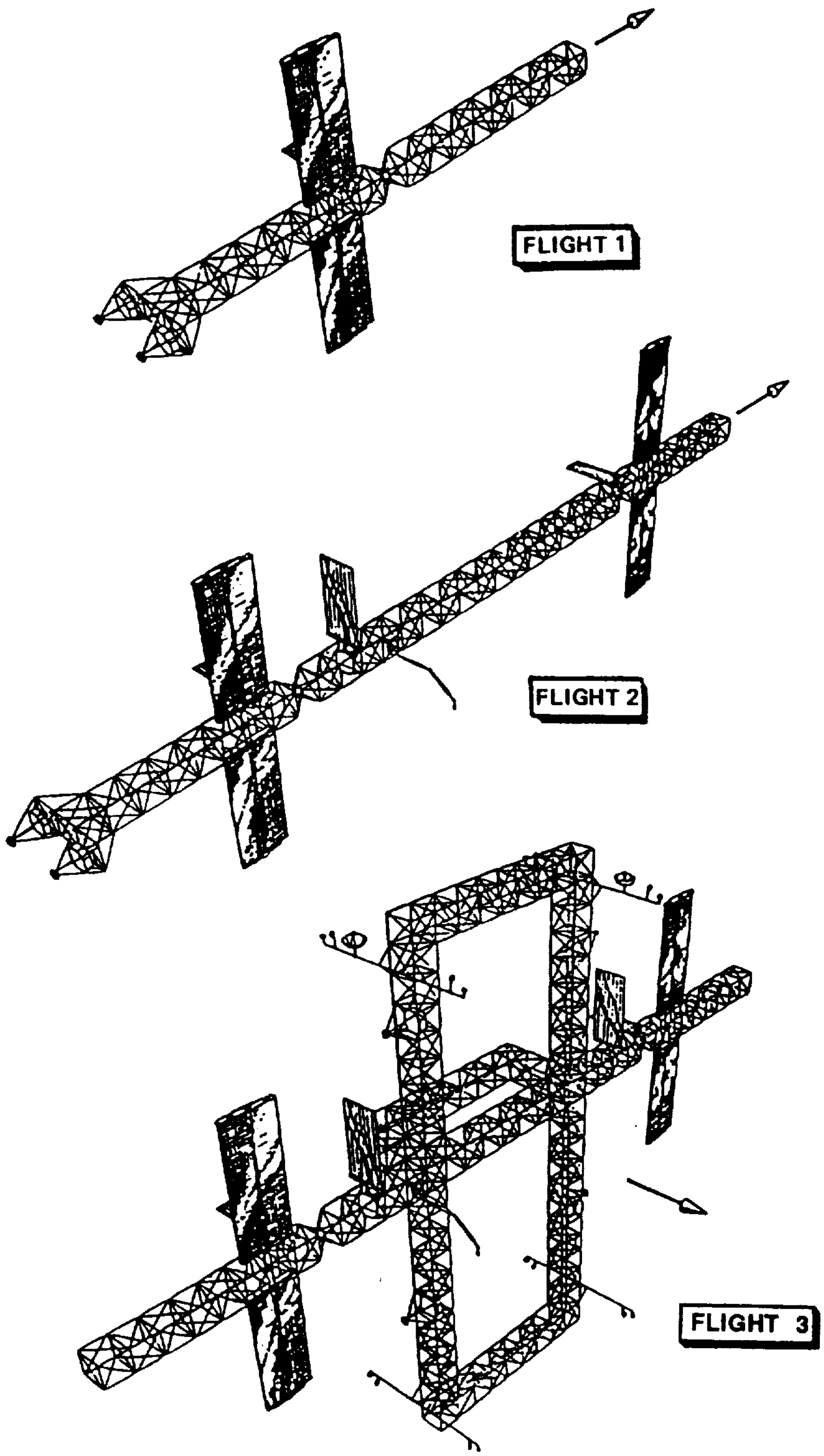


FIGURE 14. FLIGHT ASSEMBLY CONFIGURATIONS

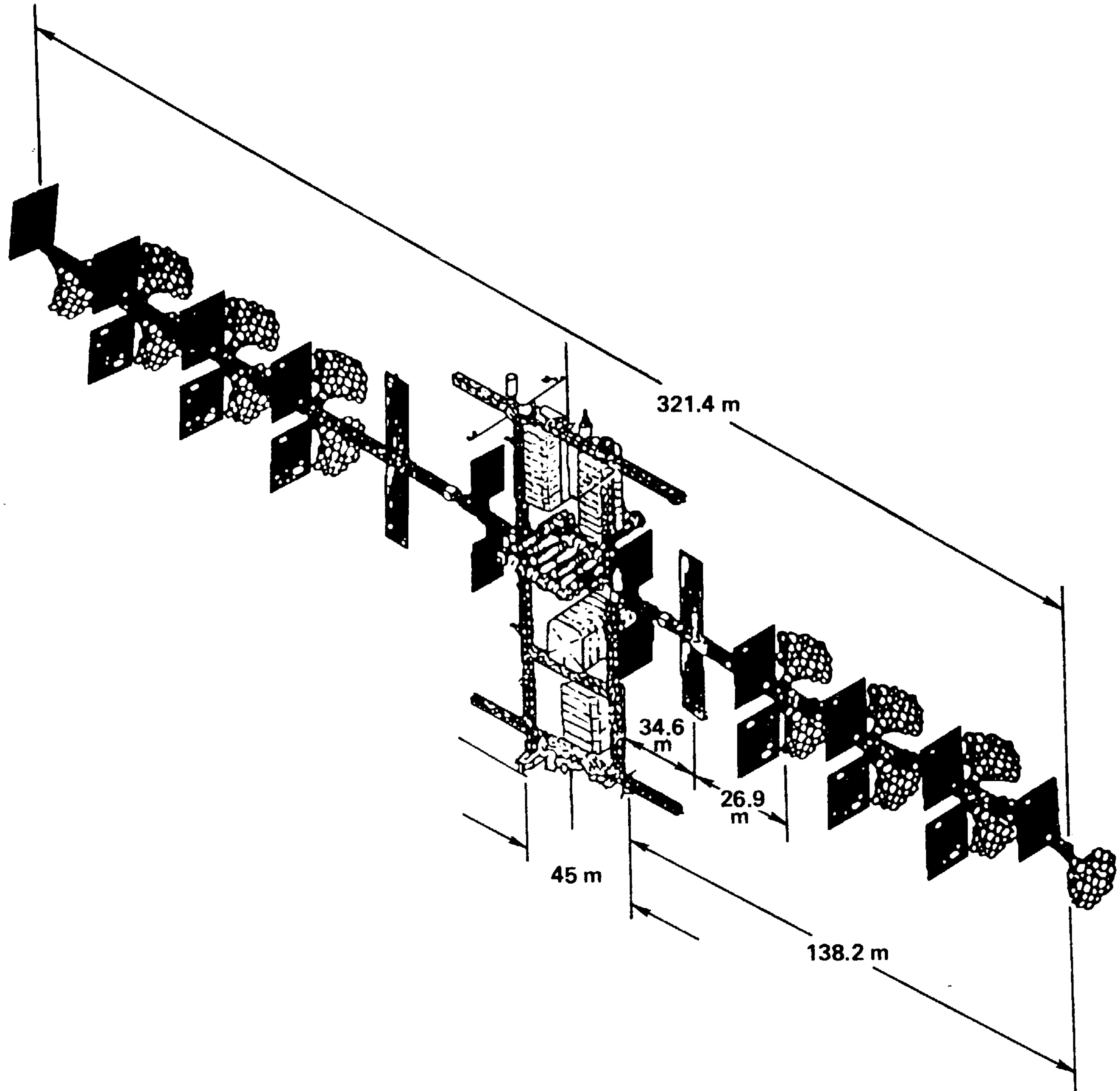


FIGURE 15. DUAL KEEL HYBRID GROWTH MODULE

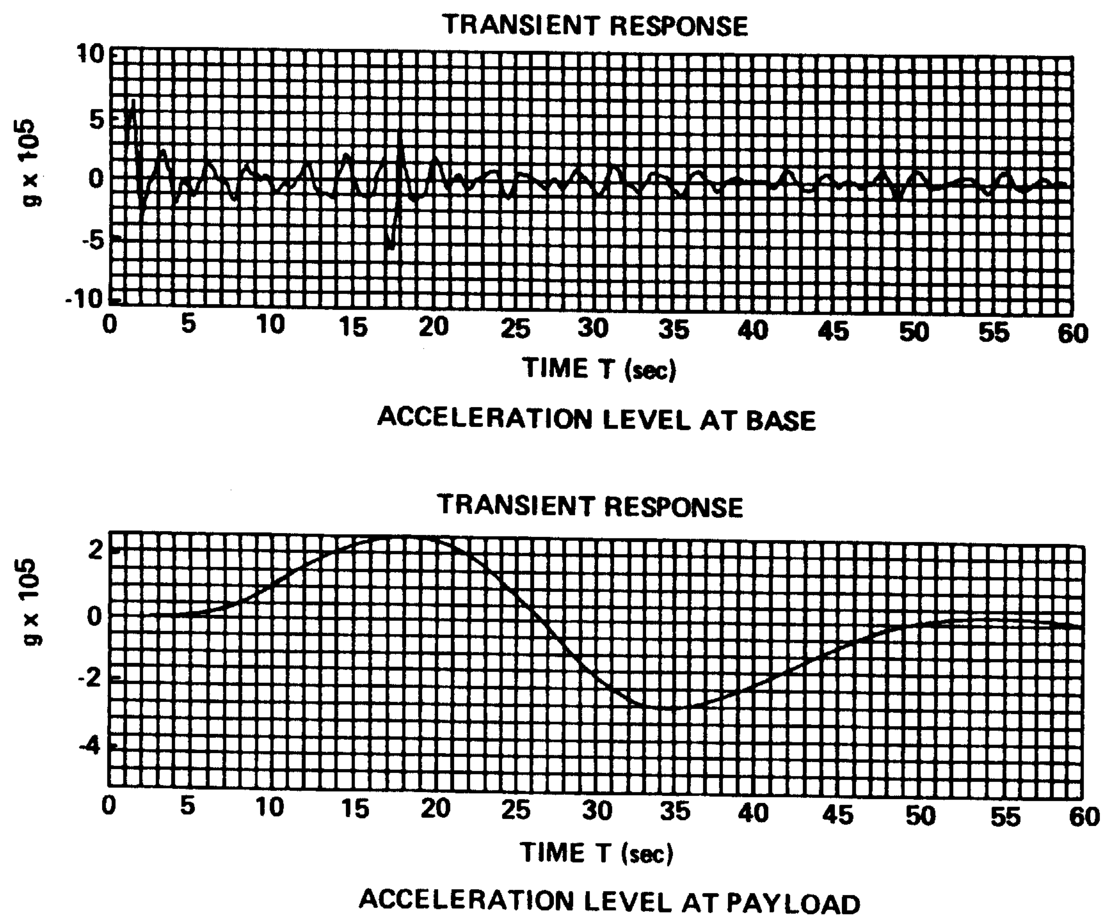


FIGURE 16. ISOLATOR REDUCES CREW DISTURBANCE G-LEVEL

The low-frequency content of the reboost forcing function makes attenuation difficult. I don't think anybody can count on maintaining a micro-g environment during reboost (Figure 17).

Another issue is that dynamicists, if given enough rope, will try to design the most perfect linear system possible. The concern that many of us have is that we might go off and design a completely predictable and linear space station -- tight joints and tight interfaces and all the rest -- and then somebody pushes off a wall and the thing rings like a tuning fork for a day and a half. We don't want to back ourselves into a corner that way and so we're trying to consider different ways of passive damping. We've had concepts for putting in different shock absorbers, where they can go, and what kind of passive damping systems might be employed. Oddly enough, a study of the closed-loop system using a completely tight linear structure showed that all the distributed control systems that weren't put on for damping, but to point payloads and to control the alpha joint, contribute to the damping fairly well. When the controllers have 70% damping, even at some of these frequencies, there is an effect of these distributed control systems as they start to damp out some of the vibration.

The other concern that we had was that in this low frequency system, these big beams with masses at the ends the thing starts to shake as our projector screen did a moment ago. We were very concerned that there was going to be a sea-sickness condition for the crew on board. So we did a study to try to determine what level of acceleration and frequency could be tolerated by the crew so that we didn't give somebody a sailing boat lesson in orbit. Figure 18 shows a result of that. When you see the acceleration requirement 640×10^{-5} that's with respect to the crew-allowable; it's not a micro-g condition. But you can see here how fast things are starting to damp out because of the distributed controllers. I must admit that you have to be a little careful about that as to whether or not you can rely on it. I don't think this solves the problem because any distributed system that's put on there for other reasons certainly can't be counted on in different configurations.

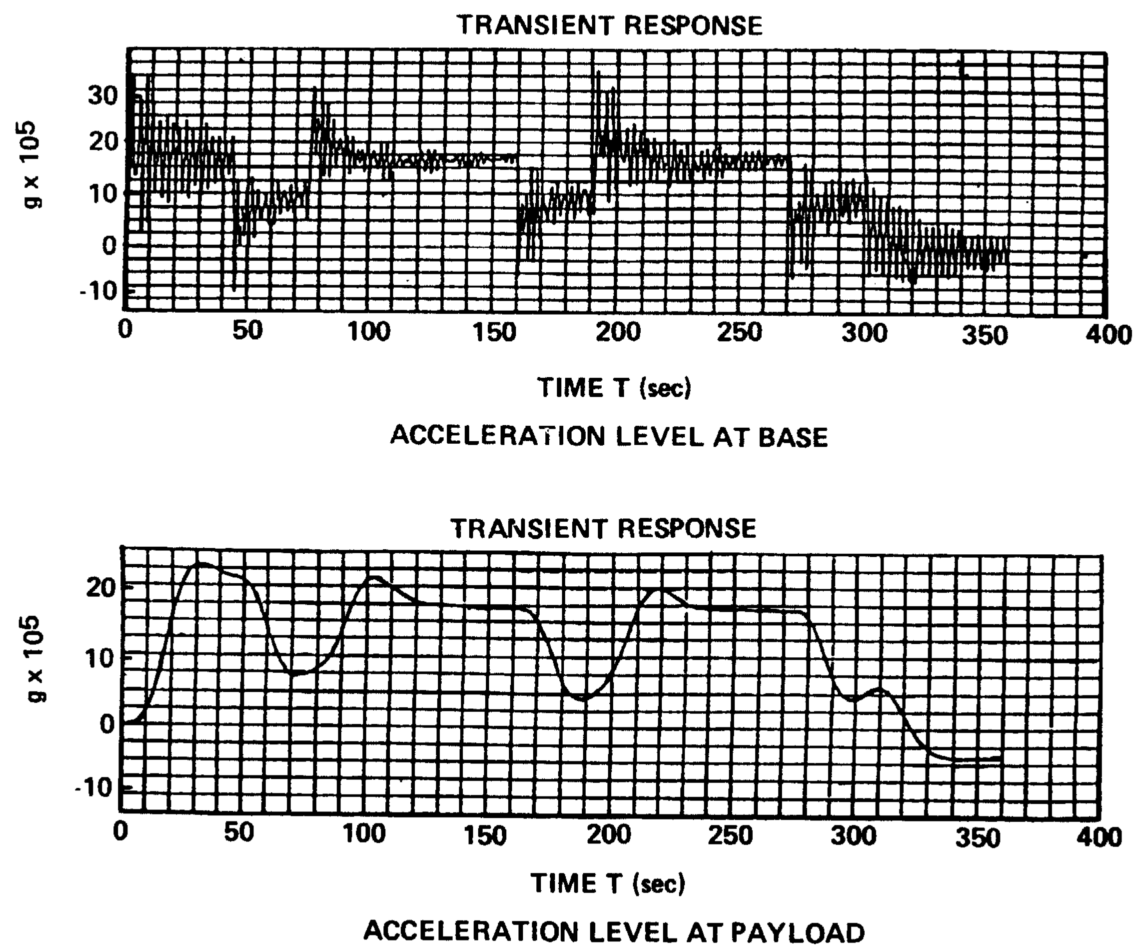
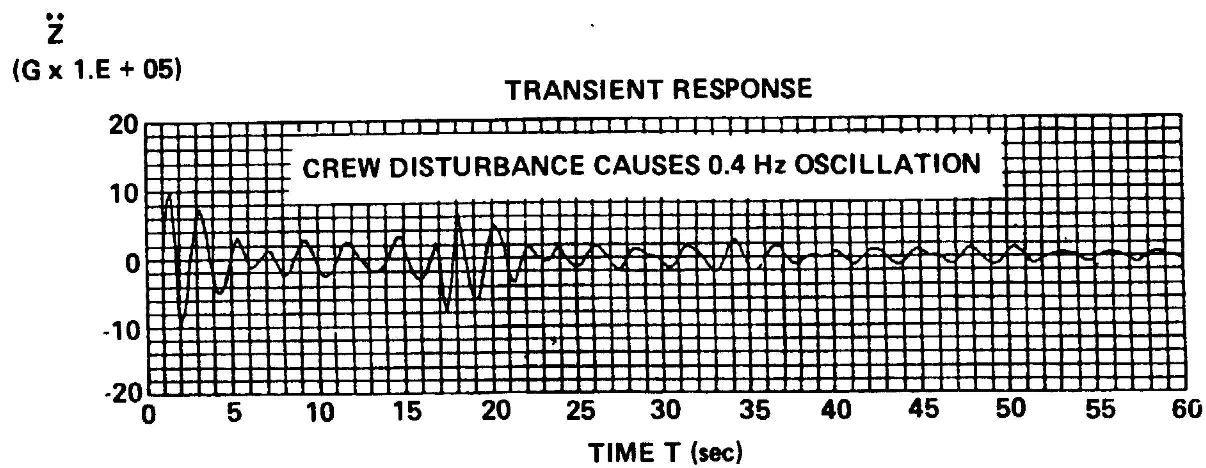


FIGURE 17. MICRO-G ENVIRONMENT CANNOT BE MAINTAINED DURING REBOOST



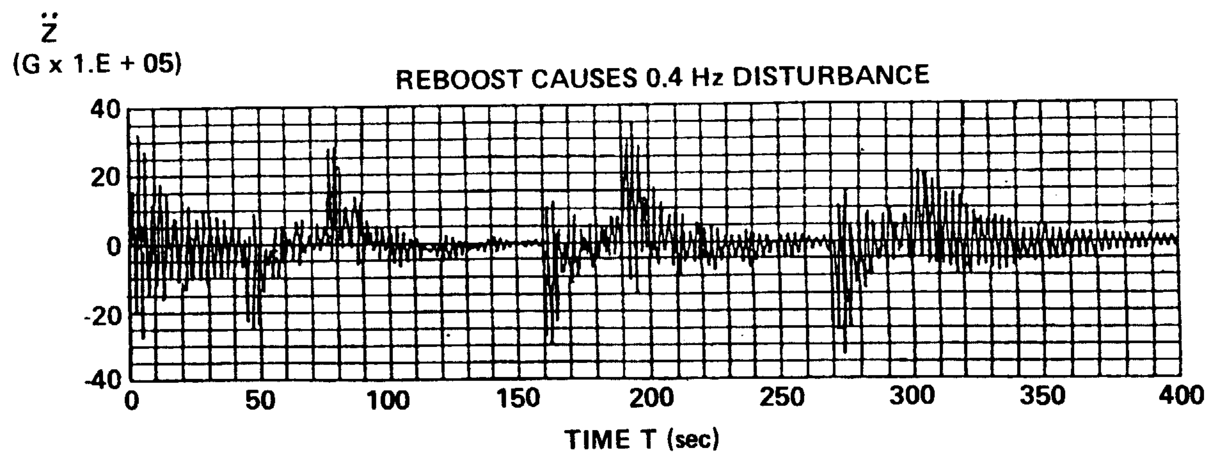
- MODAL DAMPING CAUSED BY STRUCTURAL DAMPING AND CONTROL DAMPING EQUALS 7%
- ACCELERATION REQUIREMENT IS 640×10^{-5} gs
- PEAK ACCELERATION IS 10×10^{-5} gs
- ACCELERATIONS DO NOT EXCEED HABITABILITY REQUIREMENT
- TRANSIENT DAMPS TO HALF AMPLITUDE IN 3 sec

FIGURE 18. CREW DISTURBANCE ACCELERATION LEVEL IS ACCEPTABLE AND TRANSIENT DAMPS TO HALF AMPLITUDE IN 3 SECONDS

The same thing can be said about the reboost transient (Figure 19). Four percent damping to a structures analyst is a lot of damping. So we've come a long way in the damping, and from looking at this, we've learned that we are getting some contribution to the damping effects from the distributed controllers. But I still want to hold the door open on whether we need some passive damping at this point. I think we can provide some damping by designing viscoelastic joints.

I'd like to summarize the micro-g aspects from the flex body standpoint. The micro-g is a design driver since it limits the applied loads. When we try to decide how fast the mobile servicing center can move, we need to accelerate it. When we try to accelerate, it means a force. The force level that we can have comes under our operational category of loads. So when it's under that operational category, we try to maintain the micro-g, and therefore we backed into what the amount of loads can be. As people were saying yesterday, the most benign loadings can violate a 10^{-5} g limit. There are these limits to the amount of loads that can be put into the MSC or how we can slew a payload that determines the different design conditions. The accelerations for most disturbances exceed the 10^{-5} value which is a very small level of acceleration. If that becomes a problem we need to consider isolation very carefully.

Now do periodic or transient disturbances offer relief (Figure 20)? The requirements need to specify this because we're not going to be able to respond with anything in the dynamics area, whether it's flight mode or Space Station configuration, unless it's in terms of the requirements. So we need to narrow the requirements down from between 10^{-3} and 10^{-8} and really be sure of ourselves. Isolation appears necessary, but we are certainly willing to rethink that. That should be done right away, and in earnest (Figure 21).



- MODAL DAMPING CAUSED BY CONTROLS EQUALS 4%
- ACCELERATION REQUIREMENT IS 640×10^{-5} gs
- PEAK ACCELERATION IS 33×10^{5} gs
- ACCELERATIONS DO NOT EXCEED HABITABILITY REQUIREMENT
- TRANSIENT DAMPS TO HALF AMPLITUDE IN 8 sec

FIGURE 19. REBOOST TRANSIENT ACCELERATION LEVEL IS ACCEPTABLE AND TRANSIENT DAMPS TO HALF AMPLITUDE IN 8 SECONDS

- MICRO-G IS A DESIGN DRIVER SINCE IT LIMITS APPLIED LOADS.
- ACCELERATIONS FROM MOST DISTURBANCES EXCEED 10 MG.
- DOES PERIODIC OR TRANSIENT DISTURBANCES OFFER RELIEF?
  - SPACE STATION SPELLS RELIEF.

"R E Q U I R E M E N T S"

- ISOLATION APPEARS NECESSARY
- PROBABILISTIC APPROACH BEING INVESTIGATED.
  - ACCELERATION THRESHOLD CROSSING PROBABILITY.

FIGURE 20. MICRO-G ASSESSMENT SUMMARY

LESSONS LEARNED:

DYNAMIC ISOLATION REQUIRED.

MICRO-G LIMITS OPERATIONAL ACTIVITY.

APPENDAGES LEAD TO CLUSTERED MODES.

DISTRIBUTED CONTROL SYSTEMS CONTRIBUTE TO SYSTEM DAMPING.

LVLH MODULES/SOLAR INERTIAL POWER SYSTEM COMPLICATES FLEX BODY DYNAMIC ANALYSES.

FIGURE 21. FLEX BODY DYNAMICS

Another thing that came up yesterday was the probabilistic nature of the crew disturbance. I'd like to address that. The way that we're looking at solving this problem is from a probabilistic standpoint, which is a method of determining the probability of exceeding certain limits by doing a threshold analysis. For fatigue analysis, the amount of time that stress in a part exceeds a certain stress level generates a stress cycle curve. That same approach can be used to analyze the acceleration environment. A constant acceleration, like 10^{-5}, can be used as the threshold. Then, what is the probability of crossing that threshold? Without isolation, let's say that value is 50%, that means that 50% of the time it might be above this value, then we may need to go to isolation systems. Maybe, with isolators, we can raise that level of probability from 50% to say 95%. The way the analysis is done and the requirements are set is, as Ken Demel said yesterday, doesn't fit to a PSD in terms of units. We can work some more in that area, but we're trying to do this from a probabilistic standpoint. Issues can be raised about stationarity and ergodicity with this approach and it needs more attention. That's our approach to the problem. We are treating it from a probabilistic and not a deterministic standpoint.

The dynamic isolation system now looks necessary. The micro-g acceleration requirement is the limitation to our activity in the design of many systems. The appendages are going to lead to clustered modes. The distributed control systems are contributing to the system damping. I'd like to hear some more interchange. Give me a call sometime. We're really interested in understanding more about this.

Owen Garriott, EFFORT, Inc.: You said you're spending money on isolation systems. What are you isolating from what? Where are you spending your money?

Berka: What we're trying to do is work this problem from understanding what the size of the payloads are, and, given a base acceleration that we predict through our flex body models, what is the attenuation you can get force transmissibility across that interface? Now we're looking at it from a passive standpoint, we've got studies at Yale University on a passive system of just springs and masses and dampers...

Garriott: Excuse me. Are you isolating whole modules from the rest of the structure?

Berka: Oh no. We're isolating a mass, it's of suitcase size. You can vary the mass parametrically. We're not isolating modules, we're isolating some device.

Garriott: An experiment in a module from the rest of the module?

Berka: Exactly.

Garriott: Electromagnetic, mechanical, or what?

Berka: We've got studies going on in electromechanical, in strictly passive systems, and recently we've been working on an air jet system that actually flies, there's two ways of doing this, but one of them is similar to an MMU, only with an air jet, floated in a module. It seems very similar to the thing you're talking about. Fly that thing in formation with respect to the module. Those are the kinds of things that we're doing in the isolation area.

Ken Demel, Johnson Space Center: One comment on the flying things inside the module. There's limited aisle volume in a module, and we're trying to maximize the amount of payload capability for the user and his apparatus. Right now it looks like we're getting to the 60 to 65 percent of 44 double racks for user equipment. Now when we start floating things in the aisle, we probably preclude access to a large number of those user racks and operating them like you'd like to. I suspect that free-floating things in the aisleway are going to be very special cases. You may be shutting down the operations of 25 other guys while you do this.

Berka: Yeah, and I'm not trying to advocate that, but I want to say that I think we'd be remiss without looking at that. But it just points again to the critical volume problems that we're running into in the modules, because everybody's trying to get in there.

Demel: I want to make a point that custom integration people have been looking at those kinds of questions and tried to balance, make sure we have a balanced program. The other thing on the solar inertial rotating vectors, turns a lot of material processing things from a stable configuration thermally to a de-stable configuration thermally. When you do that, go to the unstabilizing situation, the g requirements go down by an order of magnitude. That is going to really affect how we scale up research activity to get the development data for commercial production, and if we don't look at commercial activities as the goal I think this support for research is going to have a real problem.

Berka: Yes. And I appreciate that kind of feedback. I'd like to know more about that stability thing and its effect, but, as I said, the idea of LVLH and solar inertial has such an impact on the other aspects, if there's any flexibility there on the user side, we want to hear about it.

Alex Lechoczky, Marshall Space Flight Center: I'm going to speak up here. I come from the user side here. Basically, your argument of averaging out acceleration over a period of several hours to zero, and defining the microgravity requirement in that terms, you should not do that. Let's just look at acceleration, what the definition is. You take the second derivative of position as x equals 0, and these arguments about averaging out acceleration, if you chose your frame of reference correctly, I can sit right here on the ground and I can define for you a frame of reference where if I average it over time, I am in my zero-g. So I am really bothered about the loop you're going around and trying to come up with an explanation how you get rid of requirement by using arguments of averaging accelerations over days or whatever it is. So it turns out if you do a solidification experiment, you don't average out. Because while you are in one half of the cycle, you have grown a segment of material. Then you come back, where the g's in the opposite direction, well you're not going to remelt that material. So whatever you froze in there is in there. So most solidification experiments don't have averaging effects. So any argument you use vis a vis averaging just doesn't work in most of the crystal growth experiments.

Berka: Bob, would you like to comment on that?

Bob Naumann, Marshall Space Flight Center: I follow up on what Alex is talking about. The times that we are safe to average over are response times of the fluid itself. That's on the order of seconds, not thousands of seconds, which is what Alex is talking about. And I guess the thing that worries me is basically same thing Alex is saying here. The only place that you can locate an experiment, where one would have a reasonably well-defined g vector, and I guess I said yesterday, that the steady-state acceleration is what really gets you. The only thing worse than the steady-state acceleration would be a slowly varying periodic acceleration which varies over an orbital period or some fraction thereof. And so the problem is that when I went through the calculations yesterday, I showed a Δt as a typical thing of say 10 degrees. Well that would be the radial gradient that you would have in crystal growth. But the horizontal gradients are more like a hundred or several hundred degrees. So the 10^{-6} g's we were talking about assumes that you were lined up with the growth axis. But if you go perpendicular with that, then the requirements drop by at least an order of magnitude or two orders of magnitude. And then what's worse is, it will go unstable and the whole thing turns over on you. So you've really got a mess. You really cannot grow crystals in an environment where the g-vector is walking around. So the only place that you can grow a crystal in solar inertial would be on that line perpendicular to the orbital plane through the center of mass. Now you've got a problem with the fact that well yes, the gravity gradient is constant, but now the velocity vector walks around. So I'm now having to continually horizontal control, which is going to drive convection also. So I guess, for the crystal growth community, I think what Alex and I are both saying is that we really don't like the solar inertial at all.

Berka: Well, Bob, the thing that comes to mind is that, regardless of the gravity conditions, what you're really going to end up with is not a static single thing pushing in one direction anyway. That's going to be one component of many things. We've already talked about the aero resultants and things like that. You're going to get something that's going to vary anyway. And so I feel like you're going to have to start dealing with that problem regardless of the flight mode. The other thing is, when we talk about the frequency and the time thing, and then for crew motion I understand your point. But, I've got to deal with things that are changing in acceleration and direction anyway because of aero and other disturbances that are going to exist. The gravity gradient condition is a very very low frequency and it's of less value by 50% or more, depending on where you are in the thing. So the value is less. If a thing thinks that that's just a quasi static, it's almost like a quasi static response to whatever experiment location you have. It's like a quasi static response. It's lower. I know we can't solve that here, but I just want to get that out to you that this is the kind of thing that we're having to think about. Get back to me about it. If it creates a problem we want to know.

Byron Lichtenberg, Payload Systems, Inc: I'd like to add some comments from the user community. It seems like you're going to push the solar inertial mode when you said you get half of your materials science respondents saying that in fact they either preferred LVLH first. Nobody said that for solar inertial. If the engineers do prefer that, that's understandable, but the engineers aren't the user community. Besides micro-gravity sides you have Earth observations people who look like they're always looking at the ground. You have astronomy, solar physics, a variety of solar astronomy people that want to look out. And there are a whole bunch of different communities here, and I urge you to go very carefully in trying to push some sort of a solar inertial mode, because a whole spectrum of people that don't want that.

Berka: First of all, the poll that we've taken, I'm sorry I don't have that data with me. Over half of the respondents said they had no preference between the two.

Lichtenberg: I don't think they understand what it means.

Berka: I admit, it's probably not a fair question, but there were some solar inertial preferential respondents to that. The other thing is about the Earth pointing community, we've certainly had to deal with those people, too. A configuration meeting just week before last that answered that they had a very limited Earth viewing requirement at 28½ degrees. With most user viewers preferring the polar platform.

About all you can see from there (28° orbit), is water and tropical rain. These are the kinds of things that if we were going to go LVLH it's fine I'm not trying to push that from the standpoint of that's the way we should go, but I want to make sure that people understand from our side that it does complicate the station in terms of what we need to do to analyze, what it's going to cost us to put that system in orbit. We want to make sure we're getting something back from that.

Lichtenberg: Make sure the station is, as you said in the beginning, going up there to support users.

Berka: There are a lot of users that are not, like servicing and things like that, that we didn't talk about at all. We can talk about this later. Bob?

Naumann: I just wanted to say one other thing. One of the ways of driving the cost up the wall is those acres of solar cells we have to have up there. Our good friends over at SDI area have an SP-100 reactor, which can put out somewhere between 100 kW and a megawatt.

Berka: You've found the solution to both of our problems. We can go nuclear and forget all this.