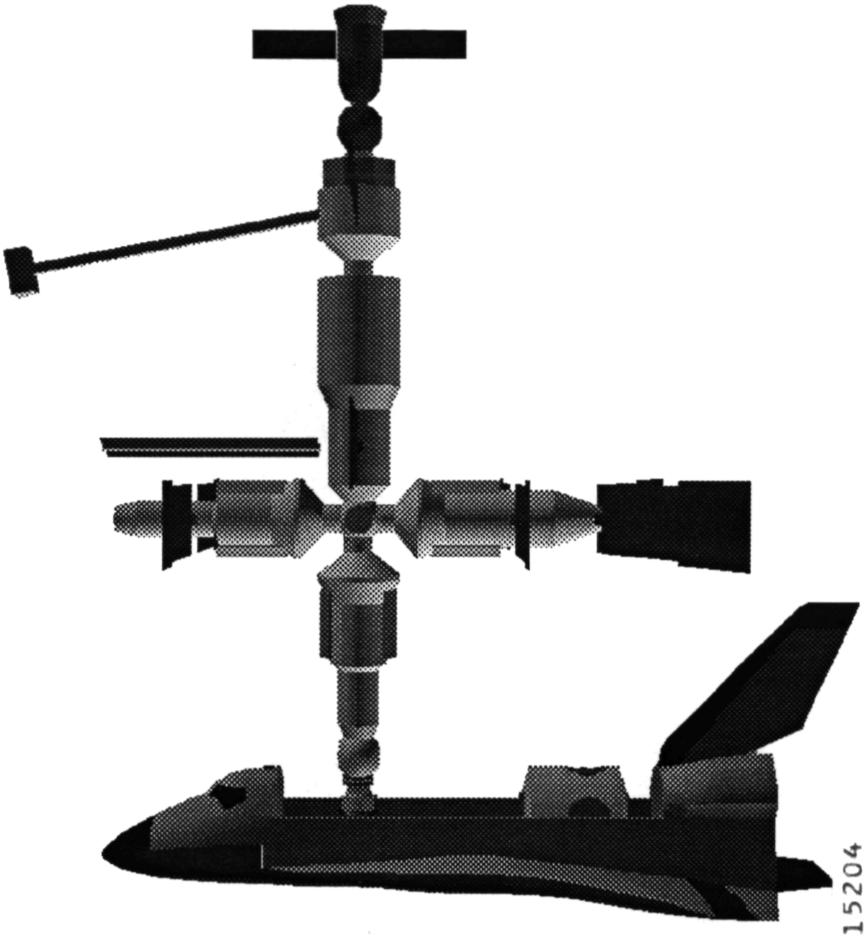

CSDL-R-2699

STS-71 Shuttle/Mir Mission Report

July 31, 1995

Douglas J. Zimpfer

Acknowledgements

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1. Summary

The on-orbit flight control system (FCS) performed nominally during all phases of the STS-71 mission, including approach, mated operations and separation. No dynamic interaction stability concerns were observed. All planned flight tests (RME1301 and DTO 1120) were completed successfully. All new OI-24 software capabilities performed as expected, including the Post Contact Thrusting (PCT) sequence. During periods of inertial attitude hold, the MCC PROP team noted the propellant consumption rates were 70% higher than pre-flight predictions. This was determined to be the result of an actual in-flight negative pitch acceleration 25% lower than that calculated by the on-board software and was not related to the flexible dynamics of the stack. This discrepancy is believed to be a result of modeling error in the aft down-firing VRCS jets, most likely due to the modeling of plume impingement. Additional periods of GO attitude holds were planned and propellant margins remained positive, so no further action was taken to improve propellant consumption during the flight. Analysis of the Shuttle downlisted data indicated the Mir ACS control performance was nominal, although, data indicated performance did not match pre-flight predictions.

Performance of the autopilot during mated operations demonstrates that the Shuttle can control and stabilize large space station sized structures, such as the Mir and planned International Space Station (ISS) assembly stages. Valuable data was obtained on the performance of the vehicle during control of these large structures and will be incorporated into the on-going design and analysis of the assembly operations of the ISS. One lesson learned from this flight is that sufficeint margin should be built into ISS assembly control performance to account for system tolerance and errors, such as the jet modeling discrepancy uncovered during this flight. Further flight tests will be planned for upcoming Phase I Mir flights to minimize the possibility of discovering additional modeling or system problems during ISS assembly.

2. Mission Overview

The on-orbit control system performance during all phases of the STS-71 flight was nominal. Table 1 provides a timeline of the significant control activities during the flight.

On Flight Day (FD) 2, two tests of the flight control system were performed. The first was an in-flight firing of the PCT sequence, which mimicked the firings performed during pre-flight SAIL testing. Data indicated the PCT sequence performed nominally. The second was the uplink and verification of the notch filters and mass property I-loads required to support operations following Soyuz separation. These values were uplinked into CNTL ACCEL 8, which was then selected with the DAP in free drift to verify successful completion of the uplink. No problems were encountered during this process. Also on FD2, a concern was raised over a fax sent to the Russians outlining the effects of Orbiter Docking System (ODS) freeplay on mated stack structural frequencies. Direct discussions between NASA and Russian flight control and loads counterparts indicated there was no concern over the effects of freeplay outlined in the fax and the go ahead was given to proceed with the planned flight operations (CHIT 008).

Table 1 - On-orbit Flight Control Activity Timeline

Event	GMT Time
PCT Test	179/15:03
CNTL ACCEL 8 Uplink	179/15:10
Docking	180/13:00
VRCS Control Initiated	180/13:20
RME Part 1	182/12:34
RME Part 2	182/14:00
Mir ACS H/O	183/10:10
STS H/O	183/14:55
Free Drift DTO1120	184/09:19
DB Collapse	185/10:42
Shuttle Undock	185/11:09

On FD3 the Shuttle successfully docked with the Mir and mated operations began. During the approach, at a range of approximately 270 feet the Mir maneuvered from the inertial attitude to an OSC attitude for docking, and when the Shuttle had reached 50 feet, the gyrodins were manually desaturated to reduce the probability of an automatic desaturation firing during final approach. RSC E data indicates the gyrodine momentum remained low throughout the approach. Nearly at the exact planned time, Atlantis's crew initiated the PCT firing, the ODS indicated capture and the Shuttle and Mir were docked. Fifteeen minutes later following retraction of the docking mechanism and hook closure, daploads A12 and B12 were loaded. Since the docking had nulled the vehicle rates to -0.01, -0.02, 0 deg/sec in roll, pitch and yaw respecitvely and an inertial attitude was planned, rate damping in the INRTL mode was not required. The DAP was moded to

AUTO and the vehicle maneuvered to the IO1.4B inertial attitude. Control performance during the maneuver was nominal and no dynamic response was noted in the DAP rate estimate, indicating the notch filters were succesfully attenuating any structural excitation induced by the verneir thrusters. Several additional inertial maneuvers were performed and the DAP remained in inertial holds for the entire initial day of mated operations.

During the initial period of inertial operations, the MCC PROP team reported that the propellant consumption rates were exceeding the pre-flight predictions by nearly 70%. Simultaneously the MER flight control team observed negative pitch limit cycle rates higher than expected based on pre-flight simulations, i.e., the DAP was commanding jet firings to induce larger negative pitch rate whenever the positive attitude deadband was exceeded. These higher than expected rates were causing the increased propellant consumption. To assess the DAP performance the roll and pitch undesired accelerations were added to the variable downlist (CHIT 22). The undesired acceleration values were consistent with the DAP limit cycle rates, indicating the software was performing nominally. The longer jet firings were traced to large transients in the undesired acceleration due to an actual acceleration 25% lower than the on-board calculated acceleration.

On FD 4, the Russians agreed to increase the amount of time spent in the GO attitudes, if an additional period of GO1.2 orientation was added prior to crew sleep to observe Mir solar array power performance. Indications were the Mir was generating sufficeint power during this period of attitude hold and it was agreed to remain in the attitude during the crew sleep period. Attachment 1 provides a summary of the attitudes maintained during the entirity of mated flight. Since the only adequate solutions to resolve the increase in propellant would require a GMEM of the flight software and the Russians agreed to increase the duration of time spent in the GO (minimum disturbance) attitudes which provided positive propellant margins, it was decided to simply operate with the degraded, albeit acceptable DAP performance. Control performance at the GO attitudes was quite nominal, with few deadband exceedances requiring control firings, indicating that the mass properties had been well predicted in determining the GO attitudes pre-flight. During the crew sleep period, control remained quite stable and insufficeint firings of the forward VRCS jets were required, resulting in low temperatures and a false F5R fail leak indication. To avoid further false leak annunciations the GO1.1 attitude was biased by two degrees in pitch to increase the number of thruster firings and maintain adequate jet temperatures. Also, during the night the circulation pumps were activated and the inboard elevons were driven to the full down positions, +21°, decreasing the -pitch acceleration to 35% lower than the onboard calculations.

The mated PRCS firing structural model verification test, RME 1301, was successfully performed on FD 5. This test commanded a series of open loop PRCS jet firings followed by queiscent periods to observe the structural response. The response was compared to pre-flight predictions based on the finite element model. Part I of the test commanded single pulse firings, while Part II commanded two pulses separated by the Alt mode delay time. Part I firings provided excellent comparison to the expected results, well within the 20% frequency and 6db amplitude uncertainties used in control system design. Part II demonstrated the delay time had been correctly selected to insure that a series of PRCS firings would not resonate the primary bending modes. Given the results observed from the test, CHIT 35 was written to accept contingency use of the Alt PRCS in the event of a VRCS jet failure.

Also, to insure that the forward VRCS jet temperatures would not again fall below leak annunication levels and have false annunication wake the crew, the attitude deadband was reduced. CHIT 36 was transmitted to allow the use of a 3° deadband to increase the likelihood of firings, but to not excessively increase propellant consumption. The lower deadband was still above the 1° value found acceptable for Shuttle separation. Since this deadband still did not assure adequate jet firings, it was used for an orbit prior to crew sleep and all indications were it would maintain adequate forward VRCS jet temperatures. Yet, to insure forward thruster temperatures above the leak values, a DEU equivalent command load was created to reduce the deadband to 1°, to induce firings, and then to increase the deadband back to 3° once the jets had warmed to acceptable levels. Again, this procedure was reviewed by the MER flight control team and it was approved based on reducing the maneuver rate to 0.1°/sec to match the planned deadband collapse of separation. The crew reduced the maneuver rate and a test of the load was performed successfully prior to the sleep period. During the remainder of mated operations the reduced deadband and biased attitude provided sufficeint firings to avoid further false leak annunciations and the DEU equivalent command was not required.

The highlight of FD 6 was the demonstration of the Mir Attitude Control System. The Mir assumed control of the stack at the GO2.1 attitude used during the Shuttle water dump and maneuvered the stack to the GO1.1 attitude and performed a 1.5 hour period of attitude hold on gyrodines. An RCS maneuver was then performed to the IO1.2 attitude and a two hour period of gyrodine inertial hold performed. Mir ACS performance was monitored via Shuttle downlist of the estimated rates and Universal Pointing total errors. All indications were the system performed well. It was noted that the Mir appeared to have approximately 2-3° of inertial platform misalignment, required desaturations during the inertial hold period at rates twice as often as predicted pre-flight and that the gyrodine system bandwidth appeared lower than expected.

Conversations with Yuri Kasnecheev confirmed the indications of the Shuttle downlist. Additionally, Mr. Kasnecheev indicated that the Mir estimate of mass properties implied the flight values were within 3% of the predicted values, but the inertia values used in the gyrodine control loop had not been updated to reflect the mated Shuttle/Mir values.

During the Mir control demonstration the Shuttle elevons were parked at the 7.5° up position at the request of the Mir flight control team (CHIT 37). This provided a third data point on the effects of elevon position on VRCS aft down-firing jet acceleration and self impingement off the elevons. As expected, the acceleration was increased (i.e., plume was decreased) resulting in a flight value only 16% below the onboard calculation. The limit cycle performance improved and propellant consumption was reduced from a first day average of 38 lbs/hr to 27 lbs/hr (it should be noted that post-flight analysis has shown the decreased consumption to be a function of the varying IO attitudes). Since adequate consumables existed, the Aero Surface Assembly (ASA) remained powered up, keeping the elevons at the 7.5° up position for the remainder of the mated operations and until the OPS 8 FCS checkout was performed to support deorbit.

Shuttle control during the waste water dump at the GO2.1 attitude was nominal.

The final flight test of the mated operations phase was performed on FD 7 with the successful completion of DTO1120, Free Drift Test. The test performed at the GO1.1 biased attitude was to demonstrate the stability of the selected attitude. All pre-flight predictions had been performed based on the nominal GO1 attitudes, but a real-time simulation performed based on the flight attitude and rates, without aerodynamic effects of the Mir solar arrays, indicated stable performance. Although, all flight indications were the attitude was stable, the yaw attitude error showed a slight increase over the duration of the test, exceeding pre-flight predictions of 5°, but not the 10° test limit. Roll and pitch also showed larger than expected attitude deviations, but did not indicate a growing attitude instability. A review of the Mir configuration post-test showed an asymmetrical solar array configuration due to the problems encountered pre-flight with the Kvant-1, Kvant-2 and Spektr arrays, implying the planned attitude may not have been a true torque equilibrium (TEA) attitude. Post-flight discussions with the Russians also uncovered that the Soyuz jets had been commanded on during the test as part of a Soyuz checkout for undocking.

Following completion of the free drift test the Shuttle was returned to automatic control. To command sufficeint jet firings to warm the forward thrusters, DAP B was selected with the lower 1° attitude deadband. This was an example of performing the deadband collapse required prior to Soyuz separation on the following day. During this deadband collapse the DAP initiated a maneuver to attitude, overshot the desired attitude and commanded a maneuver cycle. The maneuver was terminated via re-selection of DAP A before the maneuver cycle had completed. A review of the DAP performance during this deadband collapse indicated that the reduced -pitch acceleration was causing performance worse than seen in pre-flight simulations which did not incorporate jet modeling error. Since the maneuver cycle had been terminated via reselection of DAP A, no flight data existed to determine the time that would have been required to fully null the overshoot and determine if convergence would have occurred. To provide confidence in the pre-flight separation analysis, a simulation was performed utilizing the reduced pitch acceleration and verified convergence of the attitude within the time alloted in the separation timeline. To protect for a possible timeline exceedance due to the reduced acceleration, a plan was developed to reselect DAP A if the DAP had not converged on attitude at least 90 seconds prior to going Free Drift to support Soyuz separation. This would terminate any on-going maneuvers and damp residual rates. This was discussed with the Rendezvous and Proximity Operations team and determined to be an acceptable option. This contingency procedure was not required.

During the crew post-sleep period on FD8, an erroroneous command caused the Mir ACS to attempt to activate. The Shuttle was moded to Free Drift, to avoid a possible force fight, but the Mir did not actually issue any control commands because the second logical command to activate the RCS and gyrodine effector systems had not been issued. Once the Mir system was determined to be in free drift (indicator mode), the Shuttle was moded to Manual Inertial and then auto to maneuver to the GO1.1 separation attitude.

A summary of the actual separation timeline is compared to the planned timeline in Table 2. As planned the deadband was collapsed to 1° via selection of DAP B12. A maneuver was initiated to null the attidue errors and a maneuver cycle was observed. The overshoot was nulled and the maneuver terminated within the alloted time. The rate errors were damped to -0.001, -0.023, 0.005 °/sec when the DAP was moded to Free Drift. This moding occured approximately two minutes early. The Soyuz separation was nominal at the planned time of PET-15 minutes (where PET = 0 was Shuttle separation). The CNTL ACCEL was changed to 8 to select the "No Soyuz" mass properties and notch filters. The DAP was moded back to AUTO/B12 approximately 3 mintues after Soyuz separation. The early selection of Free Drift allowed an attitude error of nearly 17° to grow requiring the DAP to maneuver back to attitude, which was accomplished without a problem. The maneuver was completed and the rates damped in the reduced time alloted (due to the late reselection of auto following Soyuz separation) prior to moding to Free Drift to support Shuttle separation. The Shuttle rate errors were only 0.005, 0.005, 0 °/sec at selection of Free Drift, well below the desired 0.02°/sec limit.

Table 2 - Separation Timeline

Event	Planned PET	Flight PET
DAP B12 DB Collapse	-29:00	-28:00
Free Drift (Soyuz Sep)	-21:00	-23.30
Soyuz Separation	-15:00	-15:00
DAP Auto	-12:00	-10:00
Free Drift (Shuttle Sep)	-4:00	-4:30
Shuttle Separation	0:00	0:00

All times are in minutes, where PET = 0 was Shuttle separation.

The effects of the Soyuz and Shuttle separations were evident in the DAP rate estimate. The Soyuz imparted a pitch rate on the stack, while the Shuttle separation resulted in a roll rate and a pitch rate. The roll rate indicates the separation springs did not symmetrically effect the Orbiter. The DAP was correctly moded to A9/B9 with CNTL ACCEL set to 0 (Orbiter Alone mass properties). No DAP problems were reported during the Shuttle separation and fly around.

During the Soyuz redocking the Mir ACS experienced a problem. An errorenous solar array uplink overwrote a segement of computer memory and moded the control system to free drift. The Mir was nearing the completion of the maneuver to the docking attitude and had reduced the maneuver rates to the pre-completion levels. An attempt to restore the computer memory was unsuccessful, and the Soyuz re-docked to the Mir immediately. No problems were observed in docking to the freely rotating station. Due to the Mir rotation, adequate power was maintained on the solar arrays, allowing for a non-damaging de-spin of the gyrodines. The backup computer system was not utilized and the Mir remained in a drift mode until the system was restored on FD9. After control system reselection, RCS control was utilized until all of the gyrodines had been spun up to nominal operating speeds. The adquate power levels allowed the magnetic supension systems on the gyrodines to operate nominally and the spin down and up was performed in a controlled manner to minimize disturbances on the station.

On FD9, a -pitch firing was performed for the Orbiter without the Mir to assess the acceleration of the minus pitch VRCS jets (CHIT 44). The results of this test indicated a close match between the predicted and actual accelerations.

3. Stability & Control Performance

The principal flight control concerns in preparation for the STS-71 mated operations were the Shuttle's ability to control the mated stack, stabilize the mated system structural vibrations and ensure that RCS firings would not exceed loading constraints. Control of the mated stack was based on pre-flight simulation utilizing high fidelity flexible models to insure that the Shuttle control system could maneuver the mated stack and maintain attitude hold within acceptable propellant limits for the planned orientations without exceeding vehicle constratints on RCS performance (on time and pulsing) and loads constraints on Alt PRCS delay times. The stability of the control system was based on insuring that the flexible dynamics of the system would not adversely interact with the control system and was achieved by developing notch filters to attenuate the structural modes effect on the control system feedback loop. Figure 1 provides the "ultra robust" notch filters utilized during all mated operations. These filters were designed to provide robustness to 30% frequency uncertainty and 9 db amplitude uncertainty [1]. Finally, the flight control system was configured when using the PRCS to the Alt mode and a delay was enforced between firings to insure that worse case firings can not violate loads constraints. The planned Alt PRCS delay time was 10.96 seconds.

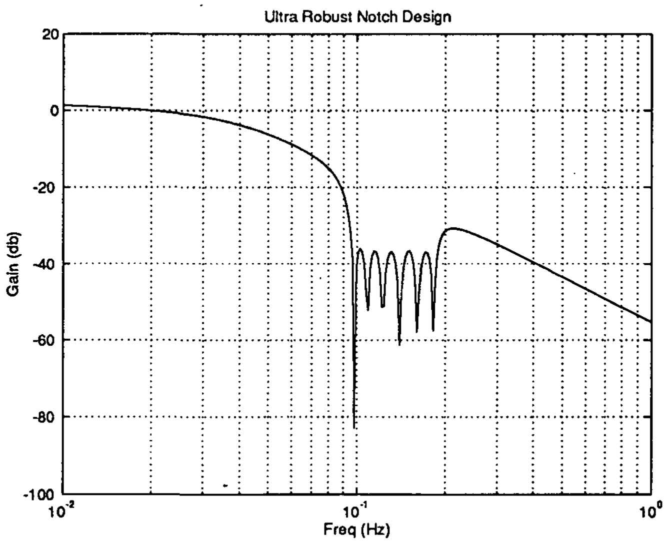

Figure 1 - Ultra Robust Notch Filter Frequency Response

The performance of the VRCS control system during the mated portions of the flight was nominal and no failures occured eliminating any requirement to perform closed-loop Alt PRCS control. The system was able to successfully re-orient the mated stack between various required attitudes and maintian these orientations within the propellant and hardware constraints. No dynamic interaction instabilities were observed and the effects of the vehicle dynamics on performance were negligble. Figure 2 of the estimated rate response from a pitch firing during mated control cleary shows that notch filter design adequately attenuated any flexure during VRCS control. A later section describes that the notch filters also provide adequate attenuation to the dynamic response from the RME 1301 PRCS firings and indicates the pre-flight models accurately represented the flight response.

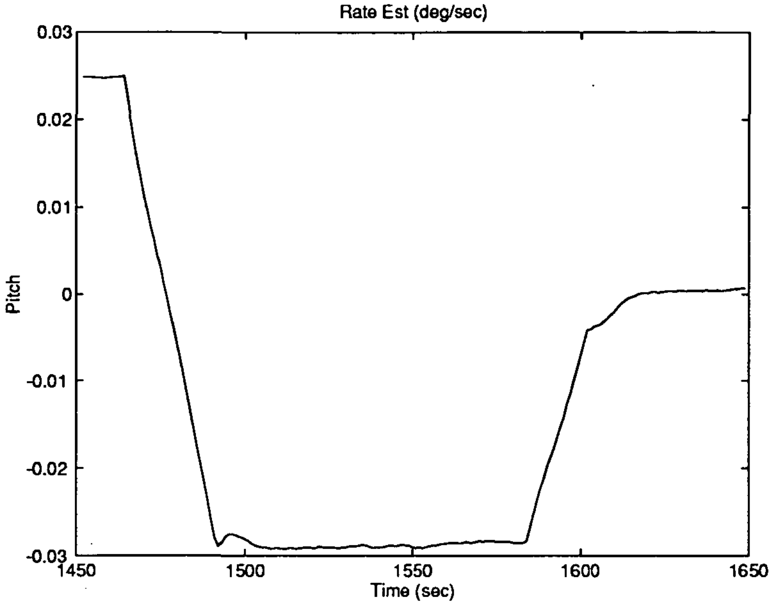

Figure 2 - Pitch Rate Estimate (GMT 180/19:43:35 - 180/19:47:30)

Figure 3 provides the rate estimate response from the initial maneuver to inertial attitude. The control system response was nominal and the autopilot had no difficulty controlling the mated stack. The transient seen near the completion of the maneuver in Figure 3 is due to the group B power down completed during the maneuver. An I/O Reset was performed causing the DAP to re-initialize. Adequate performance was maintained during this reset, but this re-initialization of the DAP during maneuvers should be avoided whenever possible.

As expected periods of VRCS jet pulsing in the control system phase plane shelf were noted during flight. One period of extremely high jet pulsing was observed immediately following the first maneuver to the IO1.4B attitude. This high period of jet pulsing was exacerbated by the inertial attitude held, the reduced acceleration filter gains and the low control accelerations. Low frequency periodic pulsing of L5D and R5D was observed in the pitch axis shelf as the control system offset the orbital disturbance. This was followed by a period of high frequency pulsing of F5R, L5D, R5R and R5D as a roll firing was commanded. When the roll command was terminated the pitch axis was driven off the shelf and the pulsing terminated. Analysis of the RCS firings during a 40 minute period including this pulsing, indicated that no individual jet was commanded for more than 375 firings, and therefore the firing constraint of 1000 pulses / hour was not in jeopardy of being exceeded.

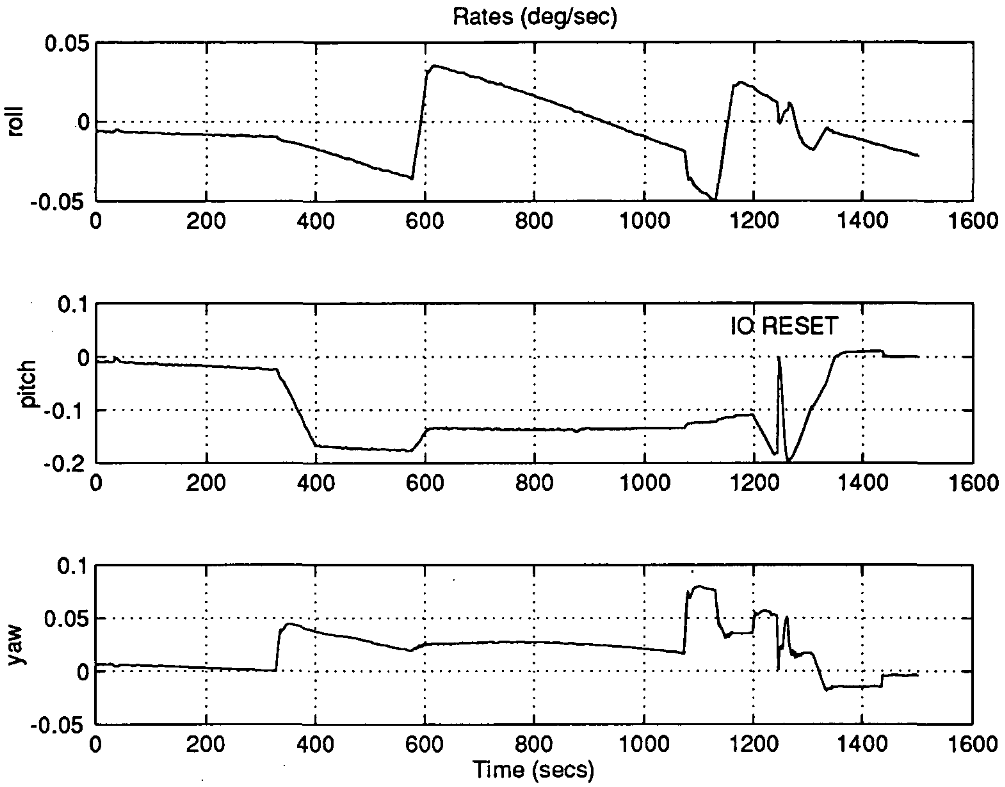

Figure 3 - Estimated Rate during Maneuver to IO1.1A (GMT 180/13:15 - 180/13:40)

Prior to the flight ES/RI [2] had predicted that the pitch frequencies of the mated Shuttle / Mir may be amplitude dependent as a result of freeplay in the Orbiter Docking System attachment to the Orbiter. Pre-flight analysis [3] showed the control design was robust to the non-linearity, but this amplitude dependency was not observed in the flight results and therefore had no effect on the control performance.

During the first periods of inertial attitude hold, higher than expected negative pitch limit cycle rates were observed (see Figure 4) and higher than predicted propellant consumption was reported. This was traced to a modeling error in the aft down firing VRCS jet control authority and is explained in detail elsewhere in this report. The control system demonstrated significant robustness to maintain it's nominal capabilities in the presence of a 25% low acceleration error. This error impacted control performance by increasing propellant consumption, causing longer firings during auto maneuvers and increasing the probability of overshoots during the deadband collapse prior to separation. The increased propellant consumption was caused by transients in the estimation of the disturbance acceleration, while the longer firings and overshoots are caused by the requirement to fire longer to acheive and null rates. There also was an interaction between the notch filters and the acceleration error. The notch filters will tend to induce lag between the rate estimate and the actual vehicle rate (rigid body), while an acceleration error can provide lead (less acceleration than predicted onboard) or lag (more acceleration than predicted onboard). The error seen during the STS-71 flight, resulted in an over prediction of the acceleration and therefore estimate lead, which combined with the lag of the notch filters, resulted in nearly ideal rate estimates. Although this assisted in the general stability and control of the vehicle it had an adverse effect on limit cycle performance as described later.

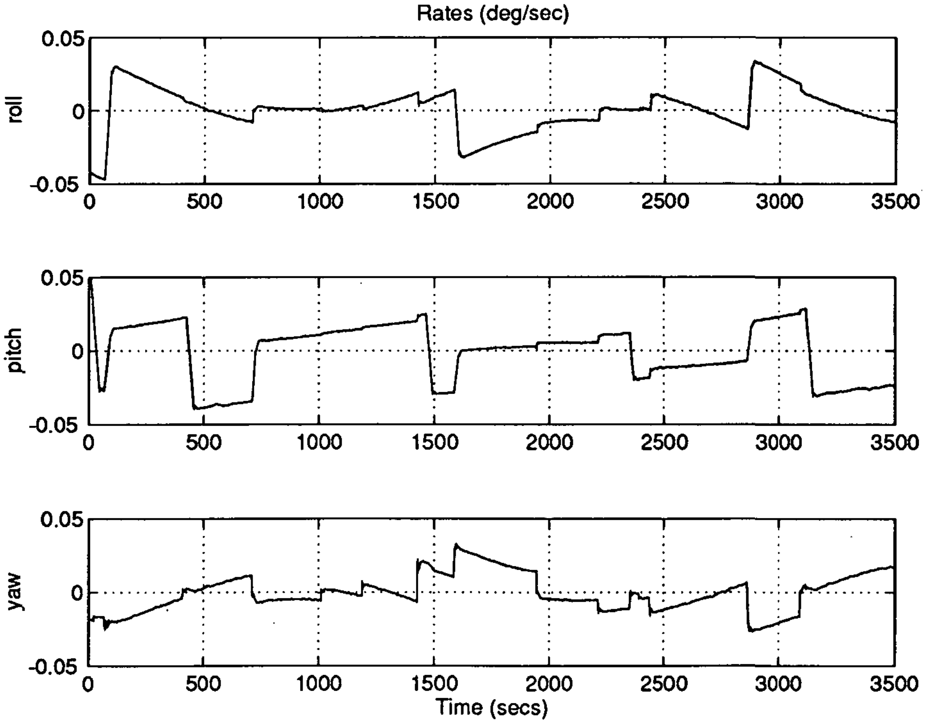

Figure 4 - Limit Cycle Response During IO Hold (GMT 180/19:20 - 20:20)

While maintaining the GO1.2 attitude during the crew sleep period following FD4, F5R was annunicated failed leak. This false annunciation was caused by the stable GO attitude requiring an insufficeint number of jet firings to maintain adequate forward jet temperatures. To avoid this problem, the GO attitudes were biased by two degrees to increase the number of jet firings during

FD5. Observation of the jet tempartures while maintaining GO holds indicatied that a false annunication was again possible during the crew sleep period. To avoid this, the deadband was reduced to 3° (from 5°) to increase the jet firing frequency, while minimizing the impact to propellant consumption. Since this reduction did not insure jet firings, because the deadband (3°) was still larger than the attitude bias (2°), a procedure was developed to allow the ground to command DEU equivalents to reduce the deadbands further. This deadband reduction, to 1°, would insure jet firings. Once the jets had warmed to an acceptable level a second command would be issued to reinstate the 3° attitude deadband. Analysis [4] had been completed pre-flight to support separation which indicated that it was acceptable to reduce the attitude deadbands as low as 1°, if the maneuver rate was reduced to 0.1°/sec. The assumptions and guidelines of this analysis were followed in developing this jet warming deadband collapse. Although the DEU equivalent deadband collapse was not required during sleep periods, a deadband collapse was manually performed subsequent to the completion of the free drift DTO 1120.

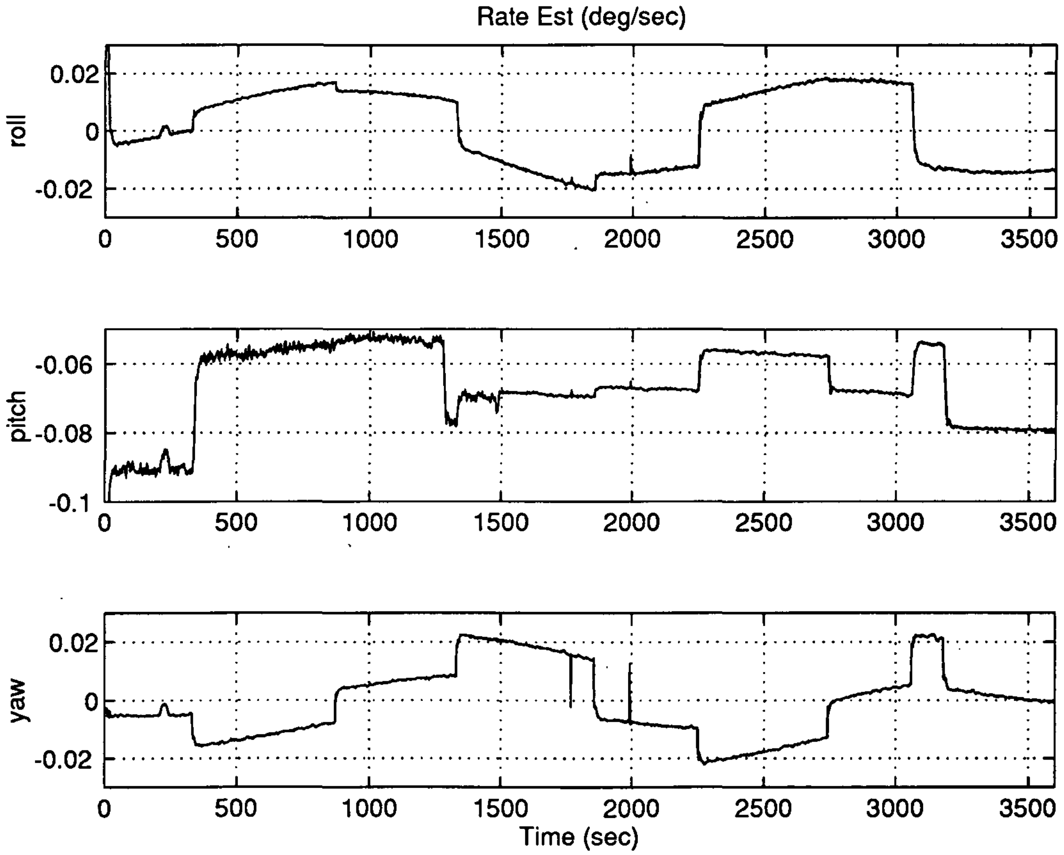

Figure 5 - Limit Cycle Response During GO Hold (GMT 181/13:00 - 181/14:00)

4. Increased Propellant Consumption Summary

During the first periods of inertial attitude hold, higher negative pitch limit cycle rates and increased propellant consumption were observed. Table 3 provides a comparison of propellant consumption to pre-flight predictions for the initial periods of inertial attitude hold. The IO1.1A attitude shows a 70% increase over perflight predictions while most other attitudes remained close. Although pre-flight simulations had not been performed for comparison, significant propellant consumption was also observed at the IO1.1B attitude. Data review also indicated that the DAP negative pitch limit cycle rates were higher than desired and higher then seen in pre-flight simulations. To assess the limit cycle performance, a variable downlist patch was implemented to add the roll and pitch undesired accelerations, which indicated that the autopilot was commanding rates to offset a perceived disturbance as seen in Figure 6. This perceived disturbance was the result of a negative pitch acceleration approximately 25% lower than the acceleration calculated onboard. The flight pitch acceleration was derived from the rate as shown in Figure 7. Similar calculations on the positive pitch response indicated acceleration close to that calculated onboard. Simulations completed with the aft-down firing VRCS acceleration reduced by 25% duplicated the flight performance [5]. Several factors that could contribute to the the errors seen in the negative pitch acceleration, including mass property errors and jet modeling errors were investigated, and several possible solutions to resolve the propellant increase were assessed, including updating to less robust notches, modification of DAP deadbands, and patching (GMEM) the software. Since the Russians agreed to remain at the GO attitude for longer periods of time, which provided improved propellant consumption and increased propellant margins, no effort was made to implement any of the software solutions assessed. Analysis of the derived accelerations and the various causes indicate the principal contributor to the modeling error was inaccurate modeling of the Shuttle plume self impingement. This has been partially validated by off-line analysis completed post-flight [6]. To prevent a recurence of this problem on future Shuttle/Mir flights an investigation of the plume modeling errors will be undertaken and an analysis of enabling the inhibit logic in the DAP acceleration estimator will be completed to support STS-74.

Table 3 - Actual vs. Predicted Propellant Consumption (lbs/hr)

	Flight			Predicted		
Attitude	Tot	Fwd	Aft	Tot	Fwd	Aft
IO1.1	26.3	8.5	17.8	25.4	9.6	15.8
IO1.1A (with -25%)	38.4	10.7	27.7	22.8 39.6	9.0 12.3	13.8 27.3
IO1.2 (with -25%)	25.9	8.3	17.6	26.5 30.6	9.4 10.0	17.1 20.6
GO1.2	3.5	1.4	2.1	6.0	2.7	3.3
GO2.1 (water dump)	13.6	4.5	9.1	17.3	7.1	10.2
IO1.4B	22.7	8.8	13.9	N/A	N/A	N/A
IO1.1B	54.9	18.2	36.7	N/A	N/A	N/A

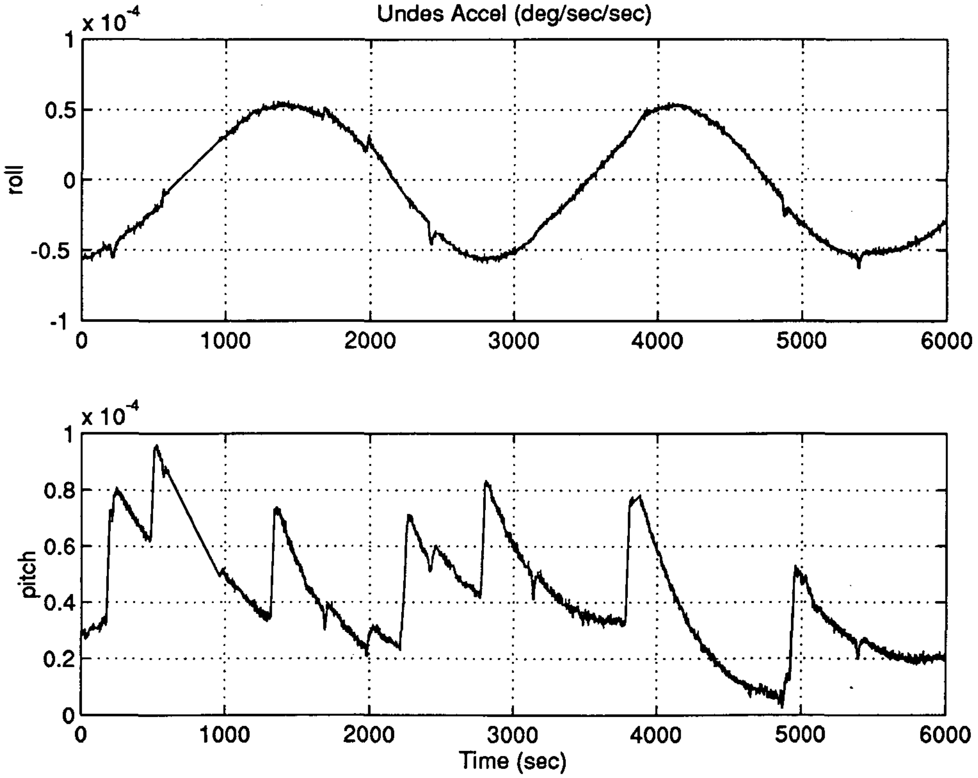

Figure 6 - Undesired Accelerations (GMT 180/21:00 - 180/22:40)

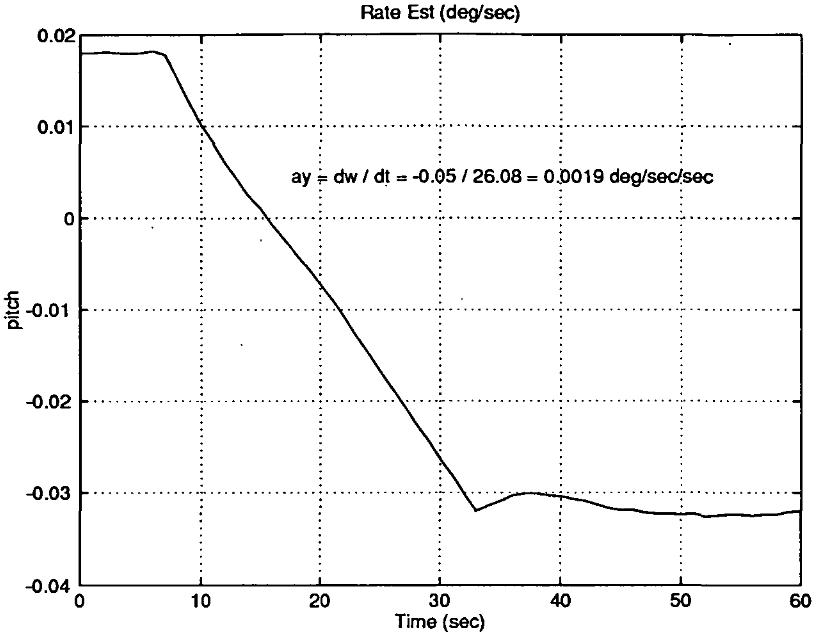

Figure 7 - Negative Pitch Response (GMT 180/17:59 - 180/18:00)

4.1. Control Response to Acceleration Difference

The increased propellant consumption was caused by the acceleration difference adversely impacting the control systems estimate of the disturbance acceleration. To provide the desired one-sided and two-sided limit cycles seen in Figure 8, the DAP estimates the slowly varying accelerations of gravity gradient, aerodynamic, euler coupling and venting disturbances. In the absence of large disturbances the control system will command jet firings resulting in low rate two-side limit cycles, but when disturbances are present the DAP will command efficient one-side limit cycles. The estimate of the undesired disturbance acceleration is the principal component used to determine the S11 swithing curve which determines the limit cycle target rate. The error between the actual negative pitch acceleration and that calculated onboard results in a large transient in the estimate of the disturbance acceleration during the firing, as the DAP perceives a large disturbance causing the vehicle to respond slower than predicted. This transient, which decays once the firing has terminated, drives the target rate down in the phase plane to induce a one-side limit cycle to offset the perceived disturbance, but since a real disturbance is not present, this results in the high rate two-sided limit cycle seen in Figure 7. This highly inefficeint limit cycle results in more frequent firings, wasting aft propellant to command the higher rates and then forward propellant to remove them when the opposite attitude deadband is reached.

A software solution to resolve these limit cycles by inhibiting the acceleration calculation during jet firings was implemented in the OI-23 software, but had been disabled for the STS-71 flight. This inhibit which significantly reduces the acceleration transient in the presence of the jet firing acceleration errors, was disabled to avoid an unstable interaction with the Alt PRCS tail only mode. Pre-flight analysis [7] indicated the roll modes of the mated stack could be sufficeintly excited to corrupt the acceleration filter during periodic Alt PRCS firings, a phemonena noted during feasibility analysis of Shuttle control during Space Station assembly[8].

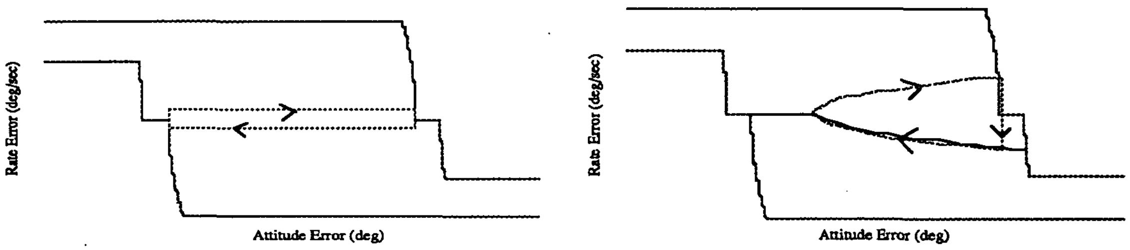

Figure 8 - Ideal DAP Limit Cycles

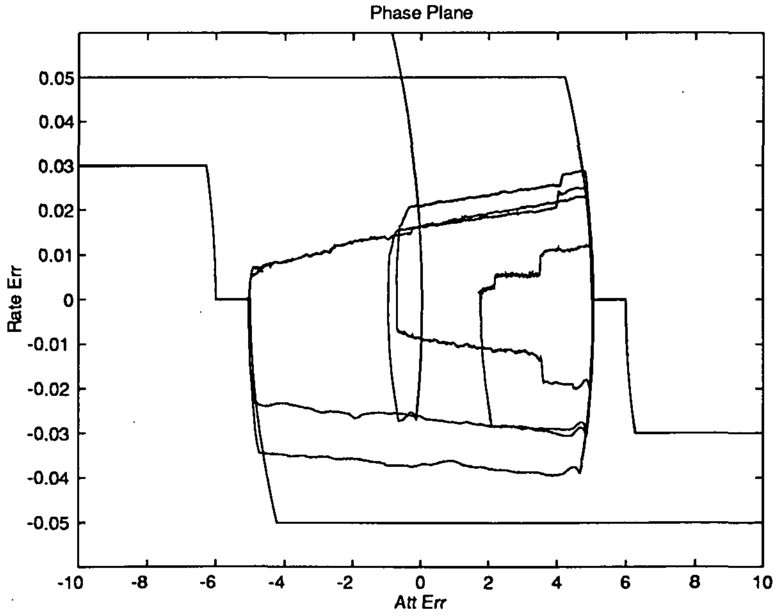

Figure 9 - STS-71 DAP Limit Cycles (GMT 180/19:20 - 180/20:20)

4.2. Analysis of Modeling Errors

Review of the possible modeling errors has indicated the most likely source of the error is Orbiter RCS self impingement. Although, not believed to be principal contributors to the problem, several additional errors sources were investigated, including jet mounting errors, jet thrust errors and mass property errors. During the flight, data was obtained for several jet firings and Orbiter elevon locations (see Table 4).

Table 4 - Pitch Acceleration by Elevon Postion (°/sec^2)

Elevon	I-Load	Actual
+21.6	-0.0026	-0.0017
0.0	-0.0026	-0.0019
-7.5	-0.0026	-0.0022

Jet mounting and thrust errors were eliminated as principal contributors. The MER propulsion group reported that the thrust profiles of the VRCS jets were all nominal. An analysis of the mounting error [9] required to induce the acceleration differences seen indicated this was an unlikely source. If no thrust error was present, it would take 20° mounting error, while for a 15% reduced thrust, a 10° mounting error was still required. These errors were determined to be outside of feasible tolerances.

Mass property errors were eliminated as principal contributors. All indications from the GO attitude holds were that the GO attitudes based on pre-flight predicted mass properties were very near to the minimum gravity gradient attitudes providing confidence in the inertia values. The Russians also reported [10] that based on their estimates, the mass properties were within 3% of the pre-flight predictions. Finally, an analysis to determine the combination of pitch inertia change and X cg shift that could result in a 25% acceleration error in minus pitch and no error in positive pitch was completed [11]. The derived values resulted in a non-physical inertia value, as the required pitch inertia (Iyy) was greater than the sum of roll (Ixx) and yaw (Izz) inertias.

All indications are the principal contributor to the acceleration difference is a modeling error in the self impingement for the aft down-firing VRCS jets. As the elevon was repositioned the jet acceleration also changed, indicating that the plume effects varied as a function of elevon, which is not included in the current model. A long VRCS firing was completed following undocking, which indicated the model provides valid answers for nominal Orbiter configurations. The VRCS jet model has a value of force and torque about a reference point. The torque value is then translated to the actual center of gravity by summing the reference torque and the cross product of the difference between the center of gravity and the reference point and the reference force. Figure 10 provides the relationship between the CG for the Shuttle / Mir stack, the reference point and the Orbiter alone CG. It is obvious there was a much larger offset between the mated CG and the reference point, than for Orbiter alone, which would increase the significance of the reference forces. Rough calculations indicate it only takes a small amount (4-6 lbs) of unmodeled X force to provide the differences seen in flight.

To support the hypothesis that plume impingement was causing the error, EG3 completed an analysis to determine the plume impingement values based on the updated plume model and updated Orbiter geometry. Preliminary results indicate the model should be updated and the values seen in flight fall within shadowing tolerances of the newly calculated data. The results also indicated there is a larger X force than predicted by the previous model. It is currently planned to validate the updated plume model against additional flight data (from STS-74 and possibly STS-76) prior to updating the onboard software Kloads of the jet force and torque.

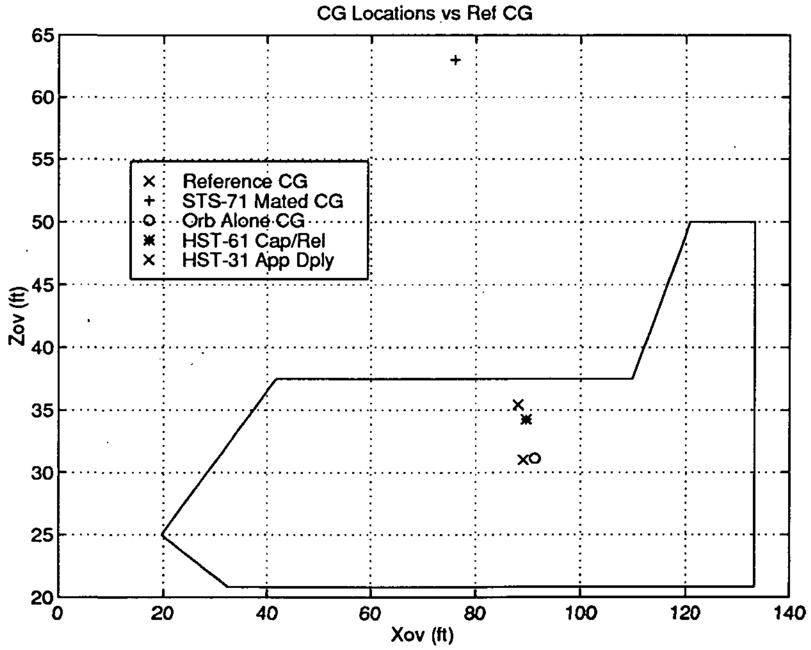

Figure 10 - Center of Gravity Locations

4.3. Analysis of Possible Control System Solutions

Several updates to the control configuration and/or operations were assessed during the flight to mitigate the effects of the decreased pitch acceleration. The only solutions that were determined to provide adequate resolution required patches or uplinks to the software. Given adequate Mir power and Shuttle propellant in the GO attitudes, none of these solutions were implemented. The following provides a brief summary of each option assessed.

Decreasing the rate deadband would have resulted in an indeterminate impact on propellant consumption. It would have reduced the duration of the -pitch firings, but may have caused additional roll and/or yaw firings. Additionally, it would have reduced flight control stability margin.

Decreasing the attitude deadband would have reduced the magnitude of the -pitch firings, but increased limit cycle frequency. More propellant may have been required to control roll and yaw. The deadband could not be decreased for maneuvers, unless the maneuver rate was also decreased. This decrease in maneuver rate would have increased maneuver time.

Uplinking new notch filters would have decreased propellant consumption in general, but would not explicitly minimize the effects of the disturbance transient. It would have decreased the magnitude of the -pitch limit cycle if the notch induced lag were reduced significantly. To achieve a performance improvement stability robustness would been compromised. Although RME data indicated the pre-flight predictions were close, uncertainty remained in the system due to the possible presence of freeplay.

A single variable GMEM could have been used to set the acceleration filter inhibit counter to 31. Reenabling the inhibit logic would significantly reduce the transients seen in the disturbance acceleration by disabling the calculation of the distrubance during jet firings. This would have significantly improved propellant consumption, but may have had an adverse effect on Alt PRCS control if required to offset a VRCS failure. Analysis of this solution for STS-74 have indicated large Alt PRCS transients may have been encountered, and a filter inhibit count of 2 is currently planned for STS-74 to reduce the VRCS transient during the firing and the Alt PRCS transients of periodic firings.

The jet force and moment K-loads could have been updated via GMEM to provide a closer match to flight data. This would have required modifying twelve parameters (Fx, Fy, Fz and Mx, My, MZ for both jets). Additionally, it was unknown what the correct values were and updating to incorrect values may have adversely impacted separation and "Orbiter Alone" operations.

5. RME 1301 - Mated PRCS Firing Test

RME 1301 consisted of a planned series of PRCS jet firings designed to excite the mated Shuttle/Mir structural dynamics to allow near real-time verification of the math model. The test was divided into two parts, each consisting of several 80 ms manual pulses of the rotational PRCS jets with delays between each pulse. Table 5 shows the RME timeline as executed. This section highlights the major results of the experiment. For a description of the RME tools and a complete analysis of control related results, see [12].

Primary Pitch Mode

The first test firing was a negative pitch firing to excite the primary pitch mode. Figure 11 shows detrended pitch attitude, filtered pitch attitude, and back-differenced rate from the first firing.

Graphical analysis of the data in the figure showed that the primary pitch mode frequency is close to that predicted for use in conrtols and load analysis [13]: 0.139 Hz predicted, 0.149 Hz graphically observed.

Table 5 - RME 1301 timeline

Firing Number	Command	Jets Fired	Firing Pattern	GMT of Pulses
Part 1. 1	-Pitch, Low-Z	L3D, R3D	80 ms pulse	182:12:35:32:094
2	+Pitch, Low-Z	F3D, F4D	80 ms pulse	182:12:38:02:494
3	-Yaw, Low-Z	F4R,L1L	80 ms pulse	182:12:40:02:494
4	-Roll, Low-Z	F3L,F3D	80 ms pulse	182:12:43:32:814
Part 2. 1	+Pitch, Low-Z	F3D,F4D	2X80 ms pulses 10.96 s between	182:14:11:19:694 182:14:11:30:734
2	-Pitch, Low-Z	L3D,R3D	2X80 ms pulses 10.96 s between	182:14:13:20:334 182:14:13:31:374
3	+Yaw, Low-Z	F3L, R3R	2X80 ms pulses 10.96 s between	182:14:15:19:854 182:14:15:30:894
4	+Roll, Low-Z	F4R,F4D	2X80 ms pulses 10.96 s between	182:14:16:31:374 182:14:16:42:414

Preflight analysis of the docking mechanism predicted that freeplay in the Orbiter Docking System (ODS) would cause the pitch mode frequency to vary with amplitude. Also, freeplay should have "flattened" the tops of the fitered rate sine waves. Since neither of these effects were present in the IMU derived data, it was concluded that freeplay was not present at the amplitudes observed.

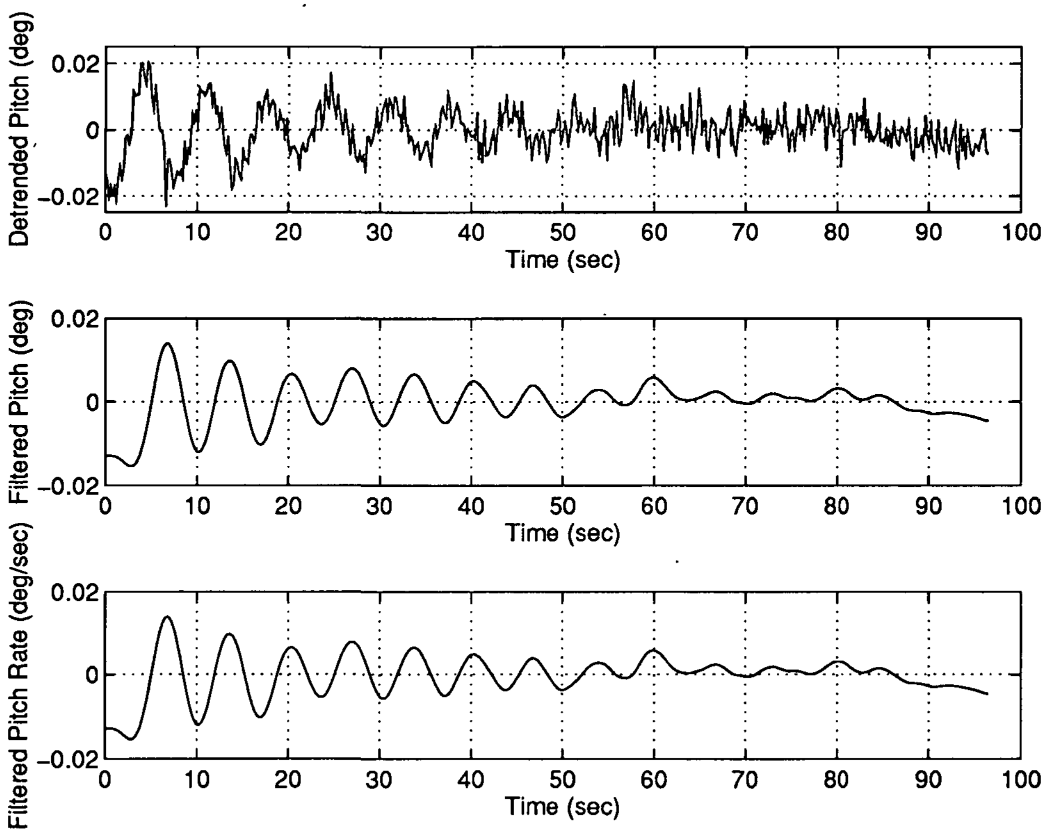

Figure 11 - Results from Part 1, negative pitch firing.

Figure 12 is the power spectral density (PSD) of the unfiltered attitude trace above. This plot was produced by the Frequency Identification Tool (FIT) documented in [14]. The PSD has a peak at 0.155 Hz with a frequency resolution of 0.0135 Hz. The amplitude is 0.0086 degrees, which is approximately the average amplitude of the raw attitude trace of figure 11.

Figure 13 compares the filtered flight response to the -pitch firing with that predicted by the linear model. From the figure, it is clear that primary pitch mode frequency and initial amplitude are very close to those predicted. Damping is shown to be conservative in the model.

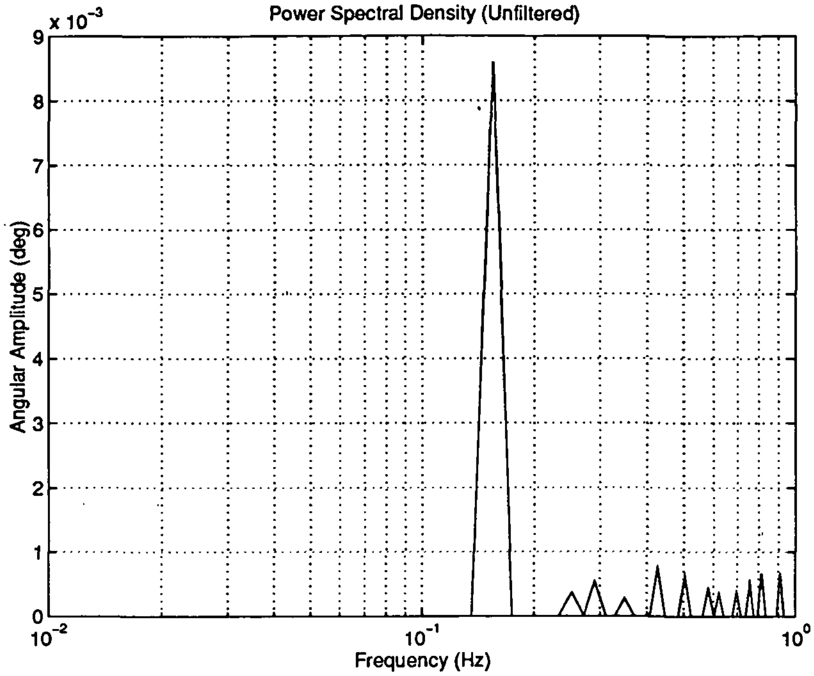

Figure 12 - PSD of detrended pitch attitude.

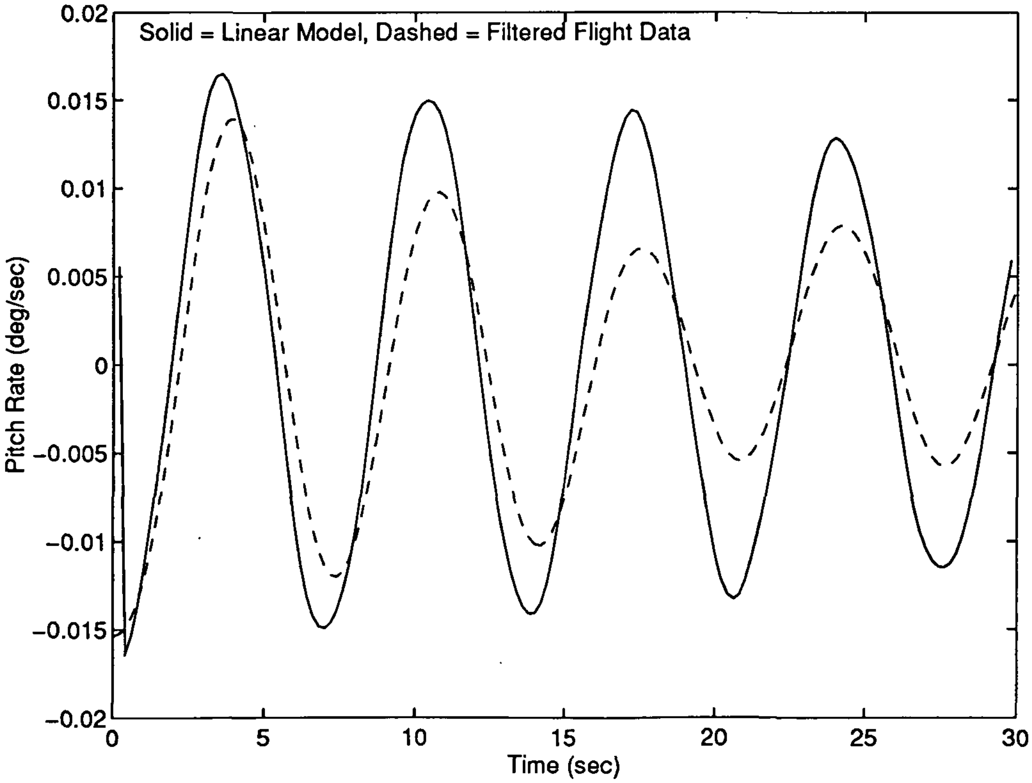

Figure 13 - Pitch rate comparison .

Similar results were derived for the higher frequency roll modes which were shown to be inconsequential to the attitude control system.

Effects of Firings at the Alt Delay Period

One of the primary goals of Part 2 of the test was to show that firings spaced by the planned Alt mode delay time would not resonate the primary modes. Figure 14 shows the flight results from the second set of pitch firings in part 2. Examination of the filtered attitude and rate plots in the figure shows that firing at the Alt mode delay time (10.96 seconds) reduced the amplitude of the response, and thus did not further excite the mode. Firing pairs in other axes appeared to have negligible effects on the other modes.

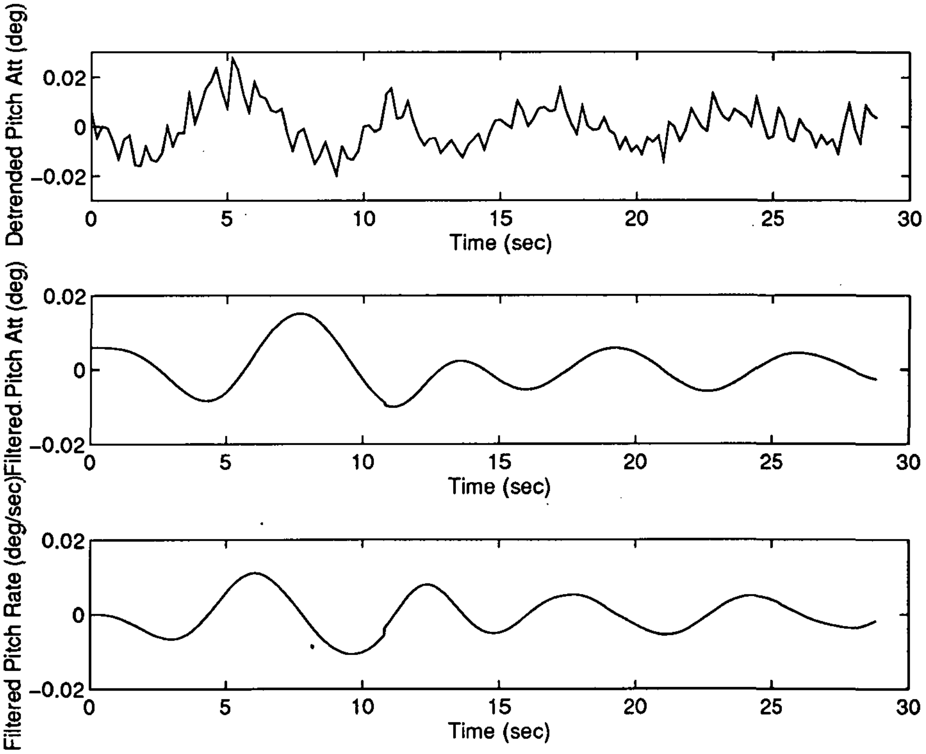

Figure 14 - Effect of negative pitch firings at 10.96 sec interval.

Evaluation of Notch Design Based on Flight Data

Figure 15 shows the I-loaded notch design. These notches were created to be robust to 9 dB amplitude variations and 30% frequency variations in the model. The asterisk on the plot represents the attenuation required to guarantee stability against the observed mode at the observed frequency. The horizontal line adds 6 dB amplitude uncertainty and 20% frequency uncertainty to this mode. These were the nominal uncertainty factors used for baseline designs. The plot indicates that the notch filters were appropriately placed and were sufficiently conservative. Conservatism in the design could have been reduced with a notch redesign/uplink, but this was not required since the improved propellant margins would have been negligible.

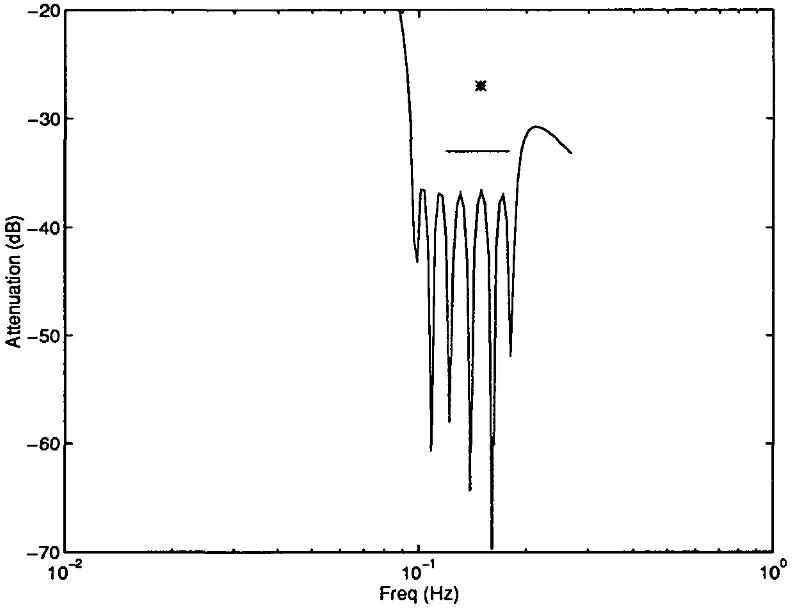

Figure 15 - I-loaded notches with observed mode.

At the observed frequency and amplitude of the primary roll mode, the required attenuation in roll would be well above, and to the right of the filter roll-off in figure 15.

The main conclusions drawn from RME 1301 were:

- The linear model of the mated system was highly accurate. About 8% frequency error and 0.4dB amplitude error were measured for the primary pitch mode.
- The damping used in control and loads analyses was conservative. Loads analysis used 1% damping and control/stability analysis used 0.5%. Observed damping was about 3.6% for the primary pitch mode.
- The expected freeplay in the docking mechanism was not seen in the orbiter flight data.
- The Alt mode delay time (10.96 sec) selected for the mated configuration was appropriate in that it did not resonate any of the primary modes.
- The tools used for real-time system identification worked well.

Based on these results, it was determined that the STS-71 Notch Filter design and Alt mode delay times would provide adequate stability and performance margins in either VRCS or Alt mode.

6. DTO1120 - Free Drift Test

The free drift test, DTO1120, was initiated at 184/09:30:00 GMT. The purpose of this test was to demonstrate the dynamic stability of the mated stack at gravity gradient stable attitudes to determine the feasibility of planning long duration periods of free drift to conserve propellant consumption. The stack orientation must remain stable to insure adequate Mir power generation from the solar arrays, ground communications and Orbiter thermal requirements. Control of the mated stack was transferred to the Mir at the biased GO1.1 attitude. The Mir nulled attitude and rate errors about this attitude, dumped momentum and then moded to drift (indicator mode). The mated stack was then left to drift for approximately 3 orbits. As seen in the plot of the attitude error from the predicted stable attitude, Figure 16, the Shuttle pitch and roll attitudes remained within the five degree error predicted pre-flight, but the yaw axes deviated to near eight degress. All three axes had oscillations centered within a degree of the predicted stable attitude. A review of the rates (Figure 17) showed that several distinct rate changes occured during the test. Although the attitudes did deviate further than predicted pre-flight, they showed a stable nature indicating that it may be possible to utilize free drift to conserve propellant when stable attitudes provide sufficeint station power. This will be further assessed with a longer drift period on STS-74.

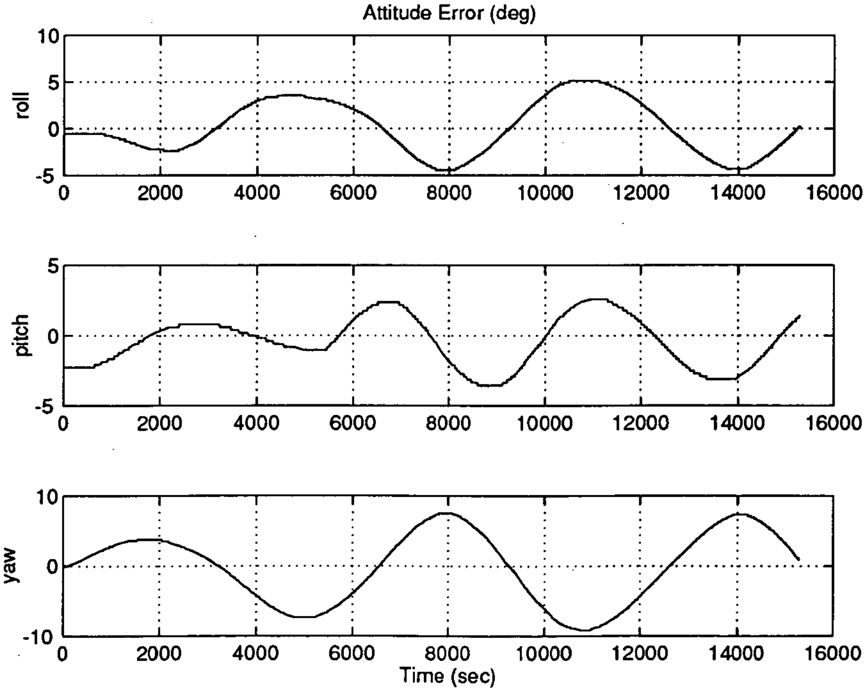

Figure 16 - Shuttle Attitude Deviation Free Drift Test (GMT 184/09:30 184/13:45)

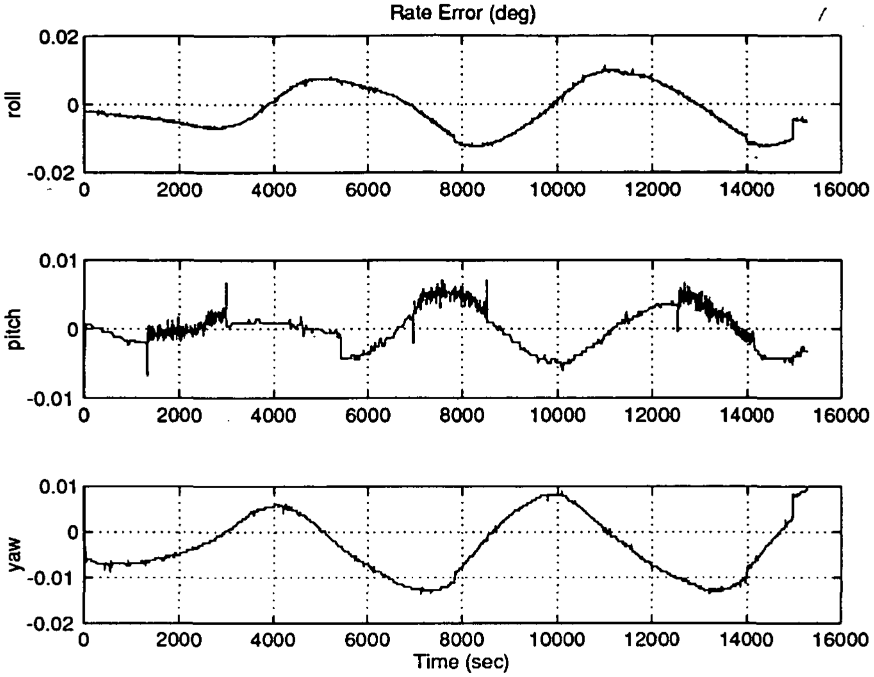

Figure 17 - Shuttle Rate Errors Free Drift Test (GMT 184/09:30 184/13:45)

Post-flight review of the drift test results has resolved some of the issues with the test, but has been unable to duplicate the exact test results to date. A contributor to the larger yaw attitude deviation is the non-symmetrical nature of the Mir solar arrays. Prior to flight several problems were encountered in configuring the solar panels for STS-71. The $+Z_b$ Spectr array was unable to be deployed, the $-Y_b$ Krystall array was not completly retracted and the $-Z_b$ Kvant-2 array motion was restricted to a "feathered for approach" orientation. Each of these contribute additional aerodynamic disturbance in the Shuttle yaw axis. An updated model of the aerodynamics was developed indicating this should have contributed a negligble vehicle torque in yaw of approximately, $0.0109\sin(\omega t)+0.0235$ ft-lb, where ω is orbital rate. The distinct rate change in pitch was traced to an unscheduled check out of the Soyuz during the test resulting in a firing of the Soyuz reaction control system. It appears the the roll/yaw rate change may be related to the effects of sunrise on the solar arrays, or possibly another disturbance occuring at an orbital period. Further analysis will be conducted on STS-74 to determine the feasibility of long periods of drift to conserve propellant during International Space Station operations.

The Russians have also assessed the results of the drift test [15] and have been unable to completely duplicate the results. They did conclude that the Mir ACS had not fully nulled the rates prior to selection of indicator mode, and the time allocated to null the rates will be increased for STS-74 to insure minimal initial transients.

7. Mir ACS Performance

Mir control performance throughout the joint operations was nominal. The Mir maintained the IO2 attitude, until the Shuttle approached a range of approximately 300 ft. At this range, while the Shuttle was station keeping the Mir maneuvered to the OSC-5 docking attitude at GMT 180/10:55, arriving at the attitude at GMT 180/11:12, approximately 50 minutes ahead of schedule. At a range of approximately 50 feet the gyrodines werre manually desaturated from H_{xyz}=-787, 14, 2012 N•m•sec to H_{xyz}=192, 995, 394 N•m•sec to minimize the probability of Shuttle plumes inducing saturation during the final approach. Although, the resultant attitude and rate deviation from desaturation would not have affected piloting for the STS-71 configuration, the manual desaturation demonstrated the capability for STS-74 and subsequent flights. The momentum level at capture, H_{xyz}=715, 502, 170 N•m•sec, was well below saturation value (~5700 N•m•sec RSS).

The Mir control system performance during the mated operations was nominal. The performance was monitored via Shuttle downlist of the rate and attitude errors. At 183/10:13, the Mir maneuvered from the GO2.1 attitude to the GO1.1 attitude utilizing RCS. GO1.1 was held under gyrodine control for approximately 85 minutes. The Mir then performed an RCS maneuver to the IO1.2 attitude and maintained that attitude under gyrodine control for nearly 3 hours. The Mir demonstrated it could maneuver the mated stack utilizing the RCS and maintain both inertial and gravity gradient attitude holds with the gyrodins. Figures 18, 19 and 20 provide the rates during the IO and GO control periods. Note: All of the data is in Shuttle body axes reference, where $X_s=Y_b$, $Y_s=-Z_b$ and $Z_s=-X_b$.

During the inertial hold the gyrodines required desaturation periods at least four times an orbit, as opposed to the RSC-E pre-flight predictions of twice an orbit. Given the availability of only 9 gyrodines for control and the twice orbital rate frequency of the gravity gradient disturbing torque, this could be expected. Additionally, Mir inertial platform misalignments were observed in the Shuttle attitude error data. Given the tight pointing control of the Mir gyrodines, most of the attitude error observed is due to misalignments between the Shuttle and Mir inertial platforms. The Shuttle IMU's were aligned during the flight and were reported to be quite accurate, while it was known that the Mir was relying on the Sun sensors and the magnetometer to provide setting of the navigation basis. During the IO1.2 control period the data (Figure 21) indicated a static misalignment of -0.25, 1.5 and 2.75 degrees in the Shuttle pitch, yaw and roll axes respectively, while during the GO1.1 control period the misalignments were cyclic with orbital rate (Figure 22). A review of the Mir X_b desaturation control in Figure 19, indicated that the Mir gyrodine control system bandwidth and damping were lower than the values derived from the control gains provided to NASA. These gains are scaled by a constant value of inertia in the gyrodine control law to provide the appropriate bandwidth as a funciton of varying inertia. The results from this flight indicate that the inertia values were not updated in the gyrodine control law and the loaded roll inertia was 1/4 of the actual mated Shuttle/Mir roll inertia. The derived bandwidth from the flight data was 0.007 Hz compared to an expected value of 0.014 Hz based on the controller gains provided by RSC-E.

Additional comparisons will be made to validate the NASA model of the Mir control system. These results should be able to provide good comparisons for the checkout of the RCS hold and maneuver capability and the gyrodine hold capability, including the response to automatic desaturation firings.

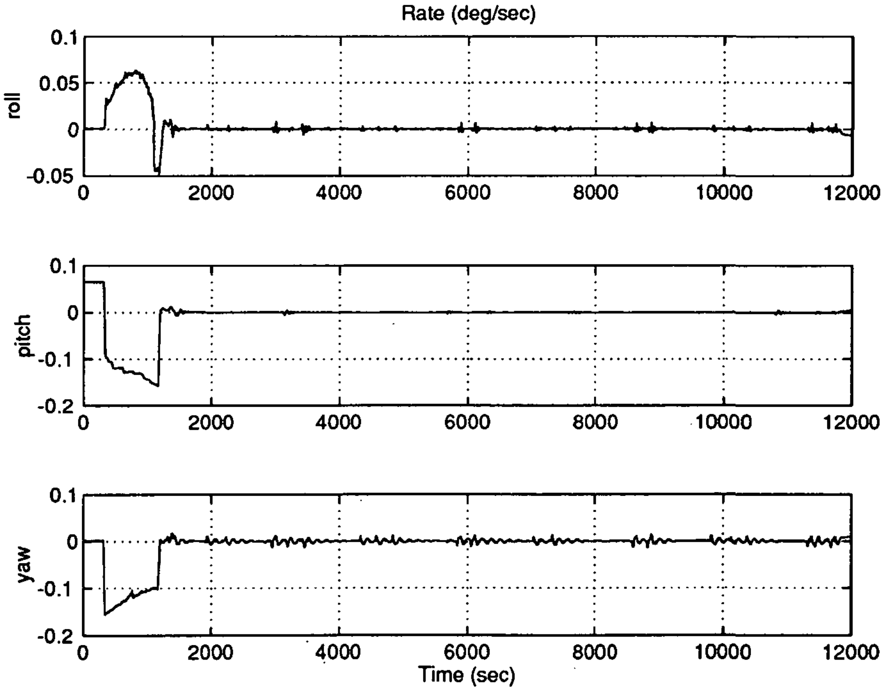

Figure 18 - Inertial Hold Rates (GMT 183/11:40 - 183/15:00)

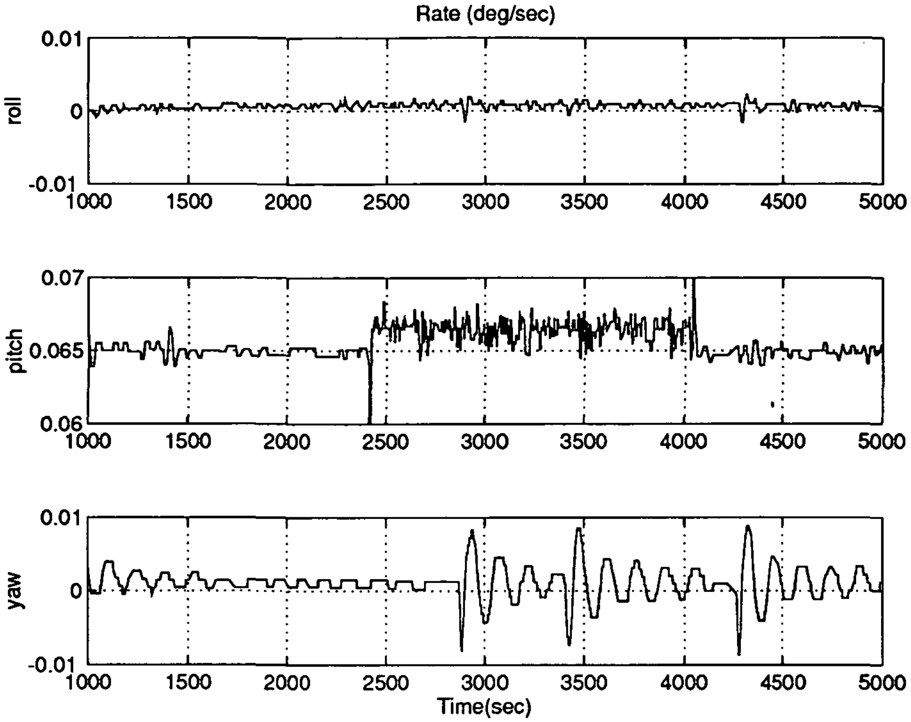

Figure 19 - Gravity Gradient Hold Rates (GMT 183/10:10 - 183/11:40)

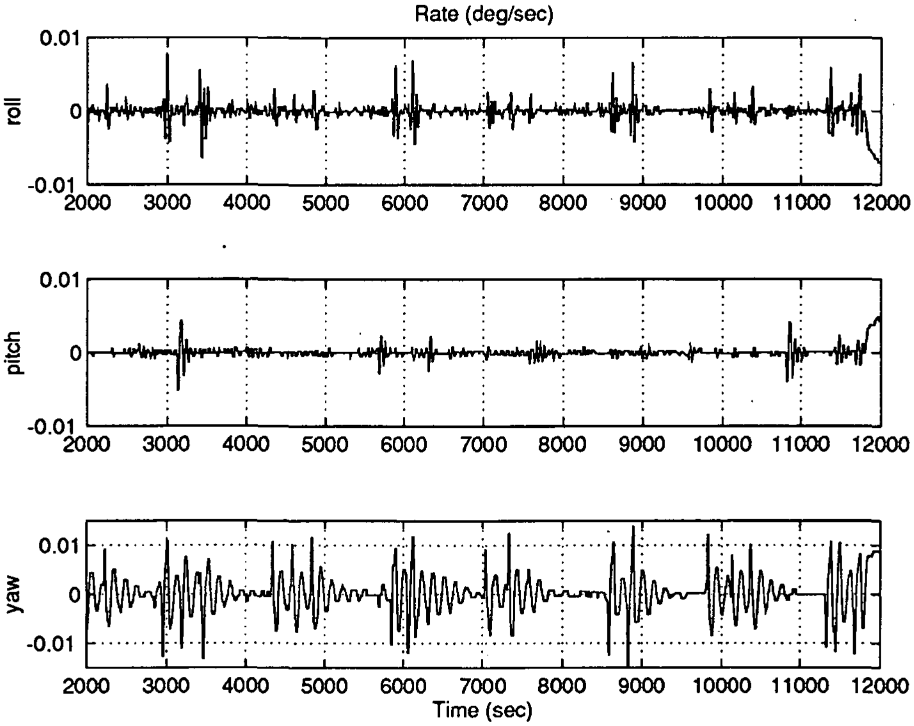

Figure 20 - Desaturations during Inertial Hold (GMT 183/11:40 - 183/15:00)

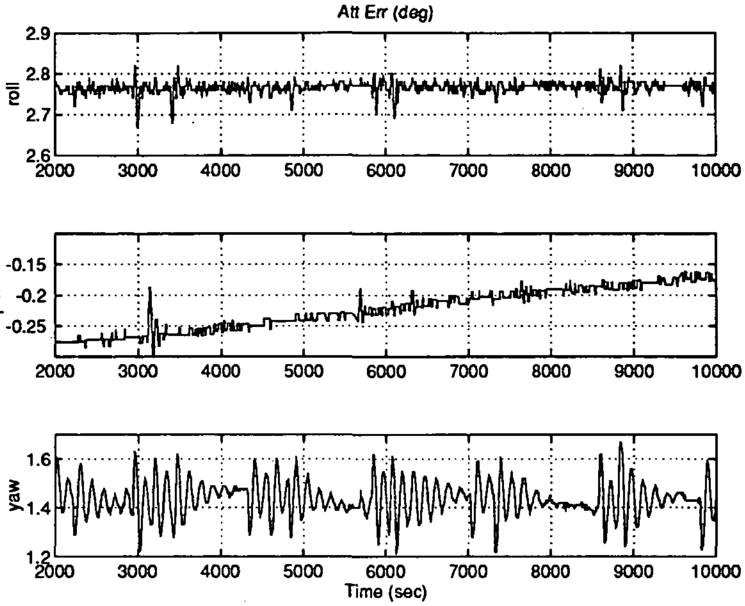

Figure 21 - Inertial Mir Attitude Misalignment (GMT 183/11:40 - 183/15:00)

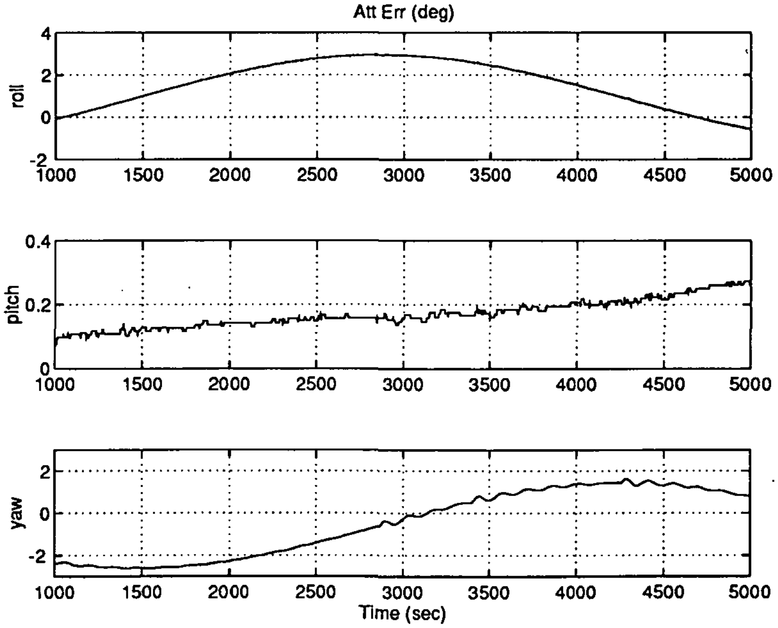

Figure 22 - LVLH Mir Attitude Misalignment (GMT 183/10:10 - 183/11:40)

8. Conclusions & Lessons Learned

The STS-71 Shuttle/Mir flight control joint operations were extremely successful. Both the Shuttle and Mir control systems demonstrated the capability to perform mated stack reorientation and attitude maintenance. The results of the flight indicate that the methods and process used are adequate to perform analysis and flight of the International Space Station. All pre-flight objectives were succesfully completed including:

1.) Demonstrated Shuttle can stabilize and control mated stack.

2.) Demonstrated Mir can stabilize and control mated stack.

3.) Demonstrated Mir manual desaturation capability.

4.) Completed RME1301 to validate structural models for control design and analysis.

5.) Completed DTO1120 to demonstrate ability to maintain the mated stack in a stable gravity gradient attitude to conserve control system propellant.

6.) Demonstrated capability of Shuttle to collapse attitude deadbands for separation.

7.) Successful performance of post contact thrusting software.

The results of the flight also have demonstrated many of the Shuttle capabilities required for control of the early International Space Station assembly flights. Also, lessons were learned that can be applied to future Shuttle/Mir flights.

1.) Substantial structural bending was observed as predicted during the PRCS jet firings.

2.) Notch filters were able to adequately attenuate bending, while maintaining acceptable flight control performance.

3.) Updated modeling is required to account for RCS self impingement.

4.) Mated stack can be maintained in stable orientations, but larger deviations than predicted may be encountered due to unmodeled effects.

5.) Frequency identification tools can adequately identify observable vehicle structural dynamics.

6.) Control system upgrades developed for Space Station Assembly perform as predicted.

7.) Process used for development of flight control system mission specific designs worked well and can be used for the ISS assembly analysis.

8.) Margin should be built into the ISS assembly design to account for unknown modeling errors.

9.) Tests of ISS assembly control designs and operations should be performed on later Shuttle/Mir flights.

10.) During maneuvers avoid operations that cause DAP reinitialization.

Based on these lessons learned some modifications will be made to future mission designs.

1.) An analysis will be completed to assess reenabling the acceleration filter inhibit logic until updated jet force and moment K-loads can be verified and incorporated into the flight software.

2.) Notch filter robustness for STS-76 and subsequent missions will be reduced in amplitude based on the results of RME1301 performed on STS-71 and STS-74.

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10. Attachments

Attachment 1	Attitude Timeline
Attachment 2	Flight CHIT's
Attachment 3	Flight Data Summary

Attachment 1

Attitude Timeline for Mated Operations

Attitude Timeline

MET/GMT	MNVR OPTION	DAP		E/S	REF ATT/REMARKS	EVENT
25 001/17:28:00 MET 180/13:00:19 GMT		A6 INRT ALT	RATE 0.2000 DB AT 5.00 DB RT 0.070	SUN R 284 P 167	INRTL R=258.02 HOLD P= 40.51 Y=290.26	DOCKED
26 001/17:48:00 MET 18:05:10 180/13:20:19 GMT 37:29	INRTL R=244.00 MNVR P=109.00 Y= 80.00	A12 AUTO VERN	RATE 0.1500 DB AT 5.000 DB RT 0.050	SUN R 180 P 33		IO 1.4B POST DOCK HATCH CHECK
27 001/18:39:00 MET 58:03 180/14:11:19 GMT 30:22	INRTL R=127.00 MNVR P=353.00 Y=311.00	A12 AUTO VERN	RATE 0.1500 DB AT 5.000 DB RT 0.050	SUN R 360 P 137		IO 1.1
28 001/20:44:41 MET 45:46 180/16:17:00 GMT 18:05	INRTL R=121.00 MNVR P=345.00 Y=319.00	A12 AUTO VERN	RATE 0.1500 DB AT 5.000 DB RT 0.050	SUN R 0 P 127		IO 1.1A
29 001/23:04:50 MET 06:36 180/18:37:09 GMT 38:55	INRTL R=130.00 MNVR P=347.00 Y=305.00	A12 AUTO VERN	RATE 0.1500 DB AT 5.000 DB RT 0.050	SUN R 360 P 140		IO 1.1B MIR VIP Event
30 001/23:45:02 MET 46:48 180/19:17:21 GMT 19:07	INRTL R=121.00 MNVR P=345.00 Y=319.00	A12 AUTO VERN	RATE 0.1500 DB AT 5.000 DB RT 0.050	SUN R 0 P 127		IO 1.1A
31 002/17:10:00 MET 27:27 181/12:42:19 GMT 59:46	TGT=2 BV=5 P=240.00 Y= 0.00 OM= 0.00	A12 AUTO VERN	RATE 0.1500 DB AT 5.000 DB RT 0.050	EARTH R 180 P 120	LVLH R= 0.00 P= 30.00 Y= 0.00	GO 1.2
32 003/12:00:00 MET 17:37 182/07:32:19 GMT 49:56	INRTL R=136.00 MNVR P= 0.00 Y=304.00	A12 AUTO VERN	RATE 0.1500 DB AT 5.000 DB RT 0.050	SUN R 360 P 147		IO 1.1
33 003/16:00:00 MET 14:48 182/11:32:19 GMT 47:07	TGT=2 BV=5 P=238.00 Y= 0.00 OM=180.00	A12 AUTO VERN	RATE 0.1500 DB AT 5.000 DB RT 0.050	EARTH R 180 P 122	LVLH R=180.00 P=148.00 Y= 0.00	GO 1.1 Biased
34 004/11:30:00 MET 40:00 183/07:02:19 GMT 12:19	TGT=2 BV=5 P=240.00 Y= 0.00 OM=270.00	A12 AUTO VERN	RATE 0.1500 DB AT 5.000 DB RT 0.050	EARTH R 180 P 120	LVLH R= 90.00 P= 90.00 Y=300.00	GO 2.1 Waste Dump
35 004/14:38:00 MET 183/10:10:19 GMT	TGT=2 BV=5 P=240.00 Y= 0.00 OM=270.00	A12 AUTO VERN	RATE 0.1500 DB AT 5.000 DB RT 0.050	EARTH R 180 P 120	LVLH R= 90.00 P= 90.00 Y=300.00	H/O to MIR
36 004/14:40:00 MET 50:00 183/10:12:19 GMT 22:19	TGT=2 BV=5 P=240.00 Y= 0.00 OM=180.00	A12 AUTO VERN	RATE 0.1500 DB AT 5.000 DB RT 0.050	EARTH R 180 P 120	LVLH R=180.00 P=150.00 Y= 0.00	GO 1.1 - MIR

*** ALL ATTITUDES IN MEAN OF 1950 ***
*** PYR EULER SEQUENCE ***

Attitude Timeline

MET/GMT	MNVR OPTION	DAP		E/S	REF ATT/REMARKS	EVENT
37 004/16:13:00 MET 30:03 1[illegible]/11:[illegible]:19 GMT 12:02:22	INRTL R= 54.61 MNVR P=111.03 Y=314.55	A12 AUTO VERN	RATE 0.1500 DB AT 5.000 DB RT 0.050	SUN R 0 P 149		IO 1.2 - MIR
38 004/19:23:00 MET 04 183/14:55:19 GMT 23	INRTL R= 55.00 MNVR P=111.00 Y=315.00	A12 AUTO VERN	RATE 0.1500 DB AT 5.000 DB RT 0.050	SUN R 360 P 149		H/O to SHUTTLE
39 005/02:00:00 MET 13:17 183/21:32:19 GMT 45:36	TGT=2 BV=5 P=238.00 Y= 0.00 OM=180.00	A12 AUTO VERN	RATE 0.1500 DB AT 5.000 DB RT 0.050	EARTH R 180 P 122	LVLH R=180.00 P=148.00 Y= 0.00	GO 1.1 Biased
40 005/13:45:00 MET 184/09:17:19 GMT	TGT=2 BV=5 P=238.00 Y= 0.00 OM=180.00	A12 AUTO VERN	RATE 0.1500 DB AT 5.000 DB RT 0.050	EARTH R 180 P 122	LVLH R=180.00 P=148.00 Y= 0.00	H/O to MIR GO 1.1 Biased
41 005/13:46:41 MET 184/09:19:00 GMT	TGT=2 BV=5 P=238.00 Y= 0.00 OM=180.00	A12 FREE VERN	RATE 0.1500 DB AT 5.000 DB RT 0.050	EARTH R 180 P 122	LVLH R=180.00 P=148.00 Y= 0.00	Free Drift Test
42 005/18:00:00 MET 184/13:32:19 GMT	TGT=2 BV=5 P=238.00 Y= 0.00 OM=180.00	A12 AUTO VERN	RATE 0.1500 DB AT 5.000 DB RT 0.050	EARTH R 180 P 122	LVLH R=180.00 P=148.00 Y= 0.00	GO1.1 Bias SHTL
43 006/02:30:00 MET 45:58 184/22:02:19 GMT 18:17	INRTL R= 57.29 MNVR P=111.77 Y=320.04	A12 AUTO VERN	RATE 0.1500 DB AT 5.000 DB RT 0.050	SUN R 0 P 143		IO 1.2
44 006/11:48:00 MET 51:59 185/07:20:19 GMT 24:18	INRTL R= 93.00 MNVR P=129.00 Y=339.00	A12 AUTO VERN	RATE 0.1500 DB AT 5.000 DB RT 0.050	SUN R 330 P 119		FREE DRIFT
45 006/12:00:00 MET 11:09 185/07:32:19 GMT 43:28	TGT=2 BV=5 P=240.00 Y= 0.00 OM=180.00	A12 AUTO VERN	RATE 0.1500 DB AT 5.000 DB RT 0.050	EARTH R 180 P 120	LVLH R=180.00 P=150.00 Y= 0.00	GO 1.1
46 006/15:23:00 MET 185/10:55:19 GMT						SOYUZ UNDOCK 6/15:23 Ground AOS -30
47 006/15:37:00 MET 185/11:09:19 GMT		A8 INRT VERN	RATE 0.2000 DB AT 1.000 DB RT 0.020	SUN R 352 P 95	INRTL R=106.01 HOLD P= 44.87 Y= 19.27	SHUTTLE UNDOCK 6/15:37

Attachment 2

STS-71 Mission CHIT's

U.S. Gov't

STS-071 ***MISSION ACTION REQUEST (CHIT)*** Launch Date 06/27/95 Vehicle ID OV-104 (15)

GMT TIME **179:16:08:10**	REQUEST ORG **CSR**	RESPONSE ORG **MOD**	CONTROL NUMBER **008**

ACTION REQUESTED BY (TIME): **INFO ONLY**

REQUESTER: **CSR/Draper Labs/D.Zimpfer**

RESPONDER: **RIO/C. Armstrong**

SUBJECT: **EFFECTS OF ODS FREEPLAY**

SPAN OPS	CSR MANAGER	SPAN SYSTEMS	SPAN MANAGER
Paul Maley	Jeffrey G. Williams	Laura Stallard	Tom Kwiatkowski
179:16:18:24	179:16:27:27	179:19:56:04	179:19:55:33

REQUEST 1 Pages in hardcopy file. 0 Graphical Attachments. Page 1

The attached fax has been transmitted to RSC-E. The fax describes the effect of freeplay on stack bending mode frequency. A teleconference was conducted with RSC-E at 8am CDT June 28, 1995, to discuss the effects of this freeplay on Mir control performance and Mir loads. Participants in the telecon included V.Blagov, A.Patsiora, S.Timokov, V.Mezchin/RSC-E, and from NASA G.Lange, J.Dagen, D.Zimpfer and J.Montalbano. At this telecon RSC-E specialists said they had NO ISSUES with the effect of the freeplay on MIR STACK CONTROL CAPABILITY OR MIR LOADS and the Mir could meet planned STS-71 objectives. An official responose will be provided through the RIO.

*** *END OF REQUEST* ***

RESPONSE 0 Pages in hardcopy file. Page 1

Thank you.

*** *END OF RESPONSE* ***

SENT FROM U.S.
ON FRIDAY 6/2

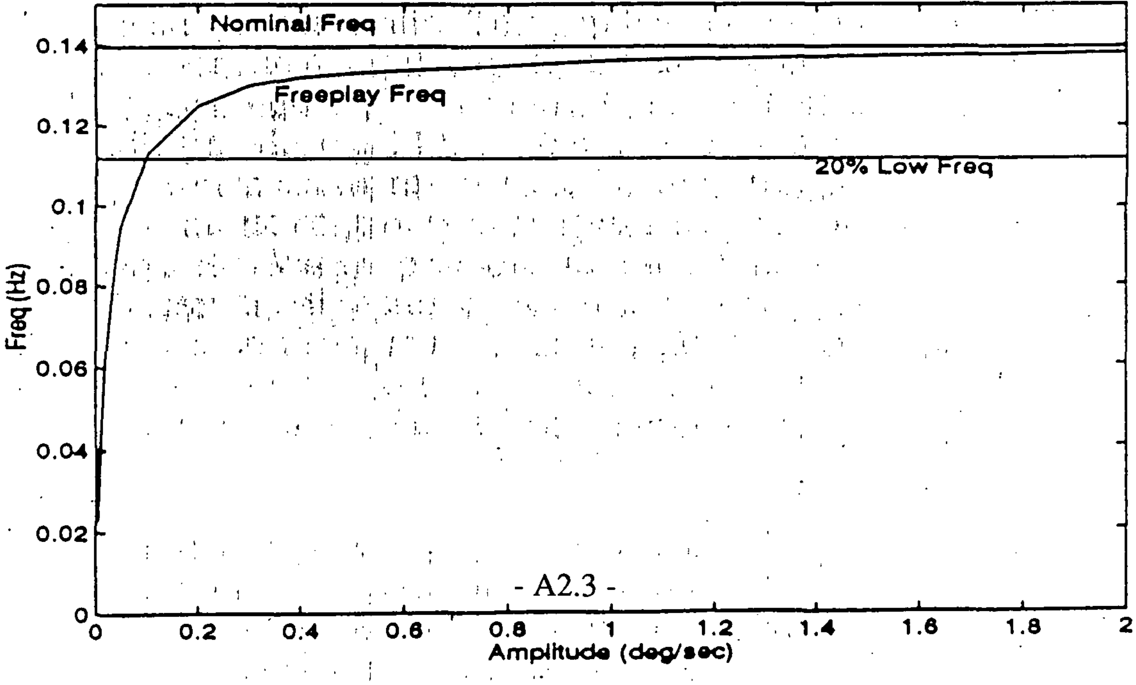
To: Mr. Mezhin
Mr. Kaznacheev

From: Mr. Dagen
Mr. Zimpfer

Subject: Freeplay Effect On The Shuttle Dynamic Loads Model

Recent discussions internal to NASA have identified a structural gap (freeplay) in the interface between the airlock and the Shuttle payload bay side walls. This gap has the effect of changing the mated vehicle natural frequencies dependent on the amplitude of the dynamic oscillations. The most significant effect is on the beam bending mode at 0.14 hertz (Shuttle pitch motion). Attached is a graph which shows the expected natural frequency versus amplitude at the Shuttle control system sensor feedback location in the nose of the Shuttle. We are prepared to discuss this topic with you if it has any effect on Mir control system stability and performance. The previously transmitted maximum loads remain applicable, since the natural frequency will be unchanged at the high amplitude level commensurate with these loads.

Best Regards



U.S. Gov't

STS-071

MISSION ACTION REQUEST (CHIT)

Launch Date 06/27/95
Vehicle ID OV-104 (15)

GMT TIME **180:20:26:31**	REQUEST ORG **MER**	RESPONSE ORG **MOD**	CONTROL NUMBER **022**

ACTION REQUESTED BY (TIME): **180:22:28:00**

REQUESTER: **MER/D. Zimpfer**

RESPONDER: **GNC/S. Schaefer**

SUBJECT: **Downlist DAP Variable**

TEAM LEADER	VE/VG REP	CONTRACT REP	MER MANAGER	SPAN SYSTEMS	SPAN MANAGER
			W. Arceneaux 180:20:45:07	Joseph G. Fanelli 181:03:34:59	Brian K. Todd NASA x47125 181:03:35:14

REQUEST 2 Pages in hardcopy file. 0 Graphical Attachments. Page 1

The MER GNC Console requests that DAP Hal Variable CGCV-Undesired-Accel be included in the variable downlist. Attached is the Hal stat listing of this variable.

****END OF REQUEST ****

RESPONSE 0 Pages in hardcopy file. Page 1

The variable downlist has been updated to include these parameters.

**** END OF RESPONSE ****

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STS-071 *MISSION ACTION REQUEST (CHIT)* Launch Date 06/27/95
Vehicle ID OV-104 (15)

GMT TIME **182:19:40:00**	REQUEST ORG **MER**	RESPONSE ORG **MOD**	CONTROL NUMBER **035**

ACTION REQUESTED BY (TIME): **INFO ONLY**

REQUESTER: **MER/James Dagan**

RESPONDER: **SPAN/B. K. Todd**

SUBJECT: **Mated Vehicle PRCS attitude control using Alt DAP**

TEAM LEADER	VE/VG REP	CONTRACT REP	MER MANAGER	SPAN SYSTEMS	SPAN MANAGER
			W. Arceneaux 182:20:55:49	J.E. Conner 182:21:00:31	Brian K. Todd NASA x47125 182:21:00:35

REQUEST 0 Pages in hardcopy file. 0 Graphical Attachments. Page 1

Shuttle Alt DAP PRCS control is acceptable for use in the mated configuration if vernier jet control is lost.

*** *END OF REQUEST* ***

RESPONSE 0 Pages in hardcopy file. Page 1

Thanks.

*** *END OF RESPONSE* ***

U.S. Gov't
STS-071

MISSION ACTION REQUEST (CHIT)

Launch Date 06/27/95
Vehicle ID OV-104 (15)

GMT TIME **182:21:04:00**	REQUEST ORG **MER**	RESPONSE ORG **MOD**	CONTROL NUMBER **036**

ACTION REQUESTED BY (TIME): **INFO ONLY**

REQUESTER: **MER/CSDL/D. Zimpfer**

RESPONDER: **SPAN/B. K. Todd**

SUBJECT: **VRCS Attitude Deadband Decrease**

TEAM LEADER	VE/VG REP	CONTRACT REP	MER MANAGER	SPAN SYSTEMS	SPAN MANAGER
			W. Arceneaux 182:23:15:05	J.E. Conner 182:23:18:38	Brian K. Todd NASA x47125 182:23:18:44

REQUEST 0 Pages in hardcopy file. 0 Graphical Attachments. Page 1

To increase the probability of commanding forward VRCS jets during crew sleep period to avoid false leak annunciations, the MER concurs that attitude deadband can be decreased from 5 degrees to 3 degrees. Pre-flight analysis indicates that a 3 degree attitude deadband and 0.05 degree/second rate deadband is a stable and controllable DAP configuration. This configuration should NOT be used for attitude maneuvers.

In the event the temperature of the forward VRCS jets do near the leak annunciation level, a further deadband collapse to 1 degree is acceptable. The VRCS maneuver rate must be reduced from 0.15 degree/second (DAP A12) to 0.1 degree/second to meet limits determined during pre-flight analysis for separation deadband collapse.

*** *END OF REQUEST* ***

RESPONSE 0 Pages in hardcopy file. Page 1

Thanks.

*** *END OF RESPONSE* ***

U.S. Gov't

STS-071

MISSION ACTION REQUEST (CHIT)

Launch Date 06/27/95
Vehicle ID OV-104 (15)

GMT TIME **182:23:11:40**	REQUEST ORG **MER**	RESPONSE ORG **MOD**	CONTROL NUMBER **037**

ACTION REQUESTED BY (TIME): **183:12:02:00**

REQUESTER: **MER/R. Friend/MER/RI**

RESPONDER:

SUBJECT: **Elevon Repositioning for Jet Impingement Analysis**

TEAM LEADER	VE/VG REP	CONTRACT REP	MER MANAGER	SPAN SYSTEMS	SPAN MANAGER
			W. Arceneaux 182:23:35:37		

REQUEST 0 Pages in hardcopy file. 0 Graphical Attachments. Page 1

The MER requests that the elevons be driven to or near the full up position to aid in analysis of the minus pitch acceleration delta. It would be optimal to maintain this configuration while holding an IO attitude. As an option, if procedural constraints prevent positioning to full up, the MER requests that the elevons be driven to the -7.5 degree position (ASA zero volts).

****END OF REQUEST ****

RESPONSE 0 Pages in hardcopy file. Page 1

****END OF RESPONSE ****

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OF POOR QUALITY

STS-071 *MISSION ACTION REQUEST (CHIT)* Launch Date 06/27/95
Vehicle ID OV-104 (15)

GMT TIME 183:22:10:00	REQUEST ORG **MER**	RESPONSE ORG **MOD**	CONTROL NUMBER **044**

ACTION REQUESTED BY (TIME): **185:12:00:00**

REQUESTER: **MER/FCS/R. Friend**

RESPONDER: **GNC/S. Spruell**

SUBJECT: **Minus Pitch Acceleration Verification After Undock**

TEAM LEADER	VE/VG REP	CONTRACT REP	MER MANAGER	SPAN SYSTEMS	SPAN MANAGER
			W. Arceneaux 183:22:19:23	Laura Stallard 184:18:12:19	Tom Kwiatkowski 184:18:12:28

REQUEST 0 Pages in hardcopy file. 0 Graphical Attachments. Page 1

The MER requests that an Orbiter minus pitch rotation be performed as soon as possible after separation and flyaway from the Mir. The requested rotation should be performed with the elevons parked at -7.5 degrees and the DAP in FREE mode. Using a Rotation Pulse Size (Item 26 or 46) of 0.2 deg/sec, deflect the RHC in minus pitch. This will provide an L5D/R5D firing approximately 15 seconds in length. Following completion of the pulse, wait 5 seconds before resuming control in AUTO/TAIL (ALT). This avoids expenditure of forward propellant while accomplishing the request.

*** *END OF REQUEST* ***

RESPONSE 1 Pages in hardcopy file. Page 1

The Vernier Pitch Test (L5D/R5D firing) will be scheduled after the Mir flyaround is complete and prior to FCS C/O (elevons move from -7.5 deg during FCS C/O). The procedure is attached. Note that the rotation pulse size was updated to 0.3 deg/sec per subsequent request from MER FCS personnel.

*** *END OF RESPONSE* ***

VERNIER PITCH TEST

1. <u>CONFIG FOR -PITCH FIRING</u>

GNC 20 DAP CONFIG

✓ DAP A1 LOADED

VERN ROT PLS - ITEM 26 + 0.3 EXEC

O14,O15:E ✓cb L DDU (two) - cl

F7 FLT CNTLR PWR - ON

2. <u>-PITCH FIRING</u>

DAP: A/FREE/VERN

RHC: -PITCH (nose down) - one pulse (jets will fire for 20-25 sec)

F7 FLT CNTLR PWR - OFF (22.64sec)

3. <u>CLEANUP</u>

After 60 seconds,

DAP: A/LVLH/VERN

When rates are damped,

DAP: A/AUTO/VERN

O14,O15:E cb L DDU (two) - as reqd

Reconfigure to Flight Plan DAP