IN-18
158539
P. 34

NASA Technical Memorandum 107731

# Space Station Freedom Assembly and Operation at a 51.6 Degree Inclination Orbit


Patrick A. Troutman
Laura M. Brewer
Michael L. Heck
Renjith R. Kumar


January 1993


(NASA-TM-107731) SPACE STATION FREEDOM ASSEMBLY AND OPERATION AT A 51.6 DEGREE INCLINATION ORBIT (NASA) 34 p

N93-25174

Unclas

G3/18 0158539



NASA

National Aeronautics and Space Administration

**Langley Research Center**
Hampton, Virginia 23681-0001

## Introduction

This study examines the implications of assembling and operating Space Station Freedom at a 51.6 degree inclination orbit utilizing an enhanced lift Space Shuttle. Freedom assembly is currently baselined at a 220 nautical mile high, 28.8 degree inclination orbit. Some of the reasons for increasing the orbital inclination are 1) Increased ground coverage for Earth observations, 2) Greater accessibility from Russian and other international launch sites and 3) Increased number of Assured Crew Return Vehicle (ACRV) landing sites. Previous studies have looked at assembling Freedom at a higher inclination using both medium and heavy lift expendable launch vehicles (such as Shuttle-C and Energia). This study assumes that the shuttle is used exclusively for delivering the station to orbit and that it can gain additional payload capability from design changes such as a lighter external tank that somewhat offsets the performance decrease that occurs when the shuttle is launched to a 51.6 degree inclination orbit.

*Freedom Assembly at a 51.6 Degree Inclination Orbit*

# Outline

- Objective
- Ground Rules
- Assembly Sequence
- High Inclination Operation Impacts
- Summary

## Objectives

The objective of this study is to develop an assembly sequence for Freedom at an orbital inclination of 51.6 degrees using a shuttle with enhanced performance. The impacts of the higher inclination on Freedom operations are also examined.

*Freedom Assembly at a 51.6 Degree Inclination Orbit*

# Objective

**Enable Space Station Freedom to be assembled and operated at an orbital inclination of 51.6 degrees utilizing a shuttle with enhanced performance.**

## Ground Rules

The first ground rule sets the shuttle performance to a 220 nautical mile altitude at a 51.6 degree inclination to 33,000 pounds. This is a performance increase of about 8000 pounds over the baseline shuttle that could be achieved by design changes such as a new aluminum-lithium external tank. Utilization of Advanced Solid Rocket Motors (ASRMs) can add another 8000 pounds of payload capability to the desired orbit for a total of 41,000 pounds. ASRMs are not available till March of 1999. The First Element Launch (FEL) is currently scheduled for March of 1996 thus the first three years of Freedom assembly cannot utilize ASRMs. When re-manifesting the assembly sequence, changes to baseline Freedom elements were minimized in order to minimize growth in hardware costs and schedule slippages.

*Freedom Assembly at a 51.6 Degree Inclination Orbit*

# Ground Rules

- Enhanced shuttle can deliver 33,000 lbms to a 220 nautical mile 51.6 degree inclination orbit

- March 1996 First Element Launch

- ASRM available March 1999

- Minimize changes to Freedom hardware design and schedule

NASA

FREEDOM

# Assembly Sequence

LaRC SSFO

## Baseline Space Station Freedom Assembly Manifest (220 nmi, 28.8$^{o}$ )

The baseline Freedom assembly manifest requires 18 flights to reach a Permanently Manned Capability (PMC) plus one additional flight for the centrifuge accommodation node. Man Tended Capability (MTC) is achieved in June of 1997. PMC is achieved in June of the year 2000. Four ASRM flights are used during the later phase of the assembly sequence.

## Baseline Shuttle to 220 Nmi, 28.8°

# Space Station Freedom Assembly Sequence

| Flight | Date | Mission | Milestones | Assembly Elements |
|---|---|---|---|---|
| 1 | 3/96 | MB–1 | FEL | ITS–S4, ITS–S3, Stbd Inbd Solar Arrays (2), MT, UBM |
| 2 | 4/96 | MB–2 | | ITS–S2, Propulsion Modules (2) |
| 3 | 8/96 | MB–3 | | ITS–S1, Stbd TCS,TDRSS Antenna, SSRMS |
| 4 | 12/96 | MB–4 | | ITS–M1, Ceta Devices (2), MT Batteries, GCA (2) |
| 5 | 3/97 | MB–5 | | Node 2, PMA–A, Cupola |
| 6 | 6/97 | MB–6 | MTC | U.S. Lab Module, Payload racks (3000#) |
| 7 | 9/97 | MB–6A | | Airlock, EMUs, MBS, SPDM/MMD |
| 8 | 12/97 | MB–7 | | MPLM (MWS, 3000# payload racks), ULC, PMA–B (on ULC) |
| 9 | 3/98 | MB–8 | | ITS–P1, Port TCS |
| 10 | 6/98 | MB–9 | | ITS–P2, Propulsion Modules (2) |
| 11 | 9/98 | MB–10 | | ITS–P4, ITS–P3, Port Inbd Solar Arrays (2) |
| 12 | 12/98 | MB–11 | | Node 1, ITS–S5 |
| 13 | 3/99 | MB–12* | | JEM Module (ASRMs) |
| 14 | 6/99 | MB–13* | | ESA Module (ASRMs) |
| 15 | 9/99 | MB–14 | | ITS–S6, Stbd Otbd Solar Arrays (2) |
| 16 | 12/99 | MB–15* | | JEM Exposed Facility, JEM ELM PS, JEM ELM ES (ASRMs) |
| 17 | 3/00 | MB–16* | | U.S. Hab Module (ASRMs) |
| 18 | 6/00 | MB–17 | PMC | ACRV Capability |
| 19 | 9/00 | MB–18 | | Centrifuge Accommodation Node |

*ASRMs

LaRC SSFO

baseline with dates

**Freedom Assembly to a 220 Nautical Mile Altitude, 51.6 degree Inclination Orbit Using an Enhanced Shuttle**

The high inclination Freedom assembly manifest requires 19 flights to reach a Permanently Manned Capability (PMC) plus one additional flight for the centrifuge accommodation node. Man Tended Capability (MTC) is achieved in September of 1997; a three month delay compared to the baseline sequence. PMC is achieved in September of the year 2000; a three month delay compared to the baseline sequence. Five ASRM flights are used during the later phase of the assembly sequence. The increased number of assembly flights and the use of more ASRMs are required since the enhanced shuttle has almost 5000 pounds less of payload to orbit capability to a 51.6 degree inclination orbit as compared to the baseline shuttle payload capability to a 28.8 degree inclination orbit. Some off loading and rescheduling of Freedom assembly elements was also required. Assembly sequence weights were based on the October 1992 release of the *Space Station Freedom Resource Margin Summary*. It was assumed that the Shuttle side of the pressurized mating assembly reduced the payload to orbit capability by 1600 pounds.

## Enhanced Shuttle to 220 Nmi at 51.6°

# Space Station Freedom Assembly Sequence

| Flight | Date | Mission | Milestones | Assembly Elements |
|---|---|---|---|---|
| 1 | 3/96 | MB–1 | FEL | ITS–S4, ITS–S3, Stbd Inbd Solar Arrays (2), |
| 2 | 4/96 | MB–2 | | ITS–S2, MT, UBM, Propulsion Module (1) |
| 3 | 8/96 | MB–2A | | Propulsion Module (1), SSRMS,Ceta Devices (2), MT Batteries |
| 4 | 12/96 | MB–3 | | ITS–S1, Stbd TCS,TDRSS Antenna |
| 5 | 3/97 | MB–4 | | ITS–M1, GCA (2) |
| 6 | 6/97 | MB–5 | | Node 2, PMA–A, |
| 7 | 9/97 | MB–6 | MTC | U.S. Lab Module, Payload racks (3000#) |
| 8 | 12/97 | MB–6A | | Airlock, EMUs, Cupola, PMA–B (on ULC) |
| 9 | 3/98 | MB–7 | | MPLM (MWS, 3000# payload racks), MBS, SPDM/MMD |
| 10 | 6/98 | MB–8 | | ITS–P1, Port TCS |
| 11 | 9/98 | MB–9 | | ITS–P2, Propulsion Modules (2) |
| 12 | 12/98 | MB–11 | | Node 1, ITS–S5 |
| 13 | 3/99 | MB–10* | | ITS–P4, ITS–P3, Port Inbd Solar Arrays (2) (ASRMs) |
| 14 | 6/99 | MB–12* | | JEM Module (ASRMs) |
| 15 | 9/99 | MB–13* | | ESA Module (ASRMs) |
| 16 | 12/99 | MB–14 | | ITS–S6, Stbd Otbd Solar Arrays (2) |
| 17 | 3/00 | MB–15* | | JEM Exposed Facility, JEM ELM PS, (ASRMs) |
| 18 | 6/00 | MB–16* | | U.S. Hab Module (ASRMs) |
| 19 | 9/00 | MB–17 | PMC | ACRV Capability |
| 20 | 12/00 | MB–18 | | Centrifuge Accommodation Node, JEM ELM ES |

*ASRMs

**Mission Build (MB) One to a 220 Nautical Mile Altitude, 51.6 degree Inclination Orbit**

The first assembly flight differs from the baseline MB1 in that the Mobile Transporter (MT) and the Unpressurized Berthing Mechanism have been deferred to the next assembly flight. This was required to offset the decrease in performance that the enhanced shuttle provides to 51.6 as opposed to the baseline 28.5 degree inclination orbit performance. The ExtraVehicular Activity (EVA) operations on this flight are limited to those tasks that could be accommodated while the Freedom elements were in the shuttle cargo bay. The EVA tasks performed are the deployment of the Propulsion Module Attach Assemblies (PMAAs) and preparation of the upper starboard solar array. Some modifications to the Freedom cargo elements may be required to enable access to the PMAAs. A grapple fixture may need to be relocated on the S3 segment. EVA estimates are based on baseline EVA timelines provided in SSJ 10590 *Integrated Operations Scenarios*.

NASA FREEDOM

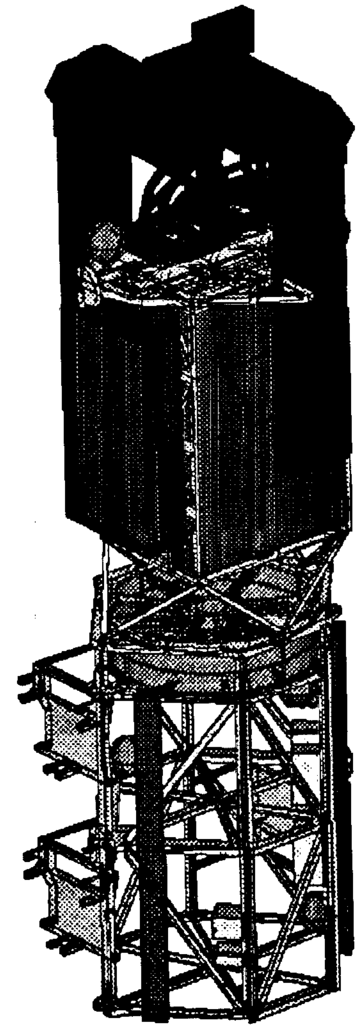
*Freedom Assembly at a 51.6 Degree Inclination Orbit*

# MB1

| EVA performed in the cargo bay : | Task Time (Hrs:min) |
|---|---|
| Deploy lower starboard inboard Propulsion Module Attach Assembly (PMAA). Upper starboard EPS equipment preparation. | 3:00 |
| Deploy lower outboard PMAA. | 1:13 |
| Deploy upper starboard & inboard PMAAs. | 1:49 |
| Total | 6:02 |

After the EVA is performed, the S3/S4 element is lifted out of the cargo bay by the orbiter arm and released .

Some modifications may be required to enable access to the PMAAs and a grapple fixture may need to be relocated on the S3 segment.



LaRC SSFO

## Mission Build Two to a 220 Nautical Mile Altitude, 51.6 degree Inclination Orbit

The second assembly flight differs from the baseline MB2 in that the Mobile Transporter (MT) and the Unpressurized Berthing Mechanism (UBM) are brought up along with the S2 segment and only one Propulsion Module (PM). The MT is attached to the bottom of the S2 segment prior to shuttle integration. This may require strengthening of the MT rail on the S2 segment. The shuttle RMS removes the S2 segment from the cargo bay and places it on top of the UBM. The RMS then captures the MB1 S3/S4 segment and berths it to the S2 segment. This will require active latches on the S2 segment. EVA is then used to remove/reposition the keel pins and the drag link, remove alpha joint restraints, prepare communication and tracking equipment and prepare the lower starboard solar array. The shuttle RMS then attaches the single PM. With the exception of the addition of the second PM, all EVA assembly tasks necessary to obtain "baseline" Stage 2 functionality are accomplished.

*Freedom Assembly at a 51.6 Degree Inclination Orbit*

# MB2

| Assembly Task : | Task Time (Hrs:min) |
|---|---|
| S2 assembly preparation | 3:02 |
| Remove S3 keel pin/drag link | 1:13 |
| Reposition S4 keel pin | 0:30 |
| SARJ launch restraint removal | 1:06 |
| EVA 1 Total | 5:51 |
| C&T Preparation | 0:52 |
| Lower starboard EPS equipment preparation | 2:17 |
| EVA 2 Total | 3:09 |

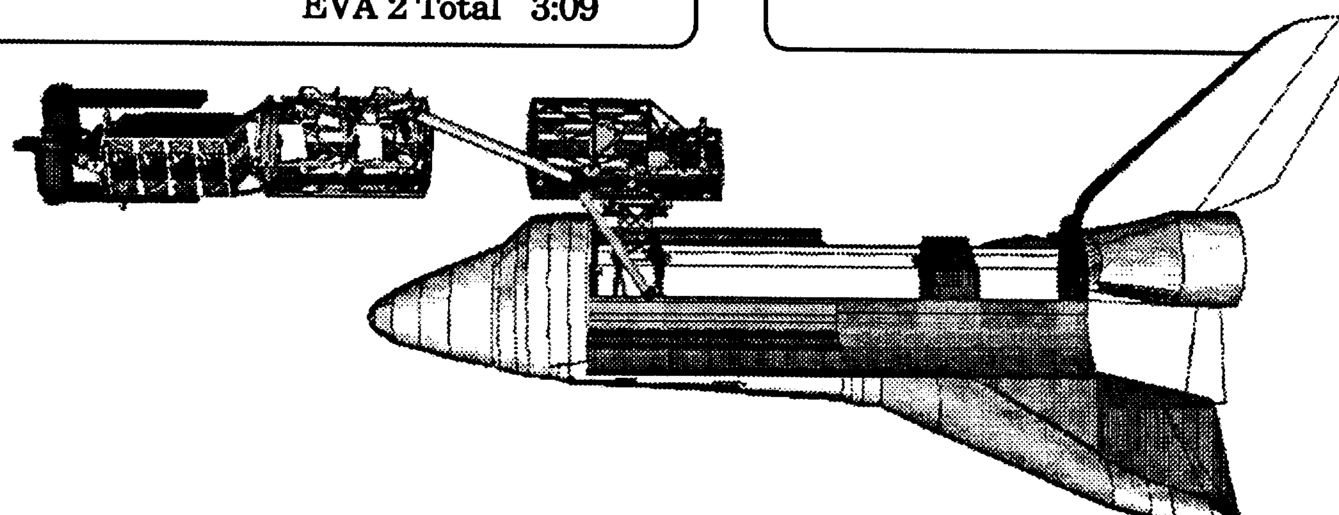
The S2 segment is launched with the Mobile Transporter (MT) attached. The MT rail may require strengthening.

The RMS places the S2 segment on the Unpresurized Berthing Mechanism.

The RMS captures S3/S4 and berths it to the S2 segment. This will require the active latches to be on S2.

EVA tasks are performed.

Single Propulsion Module (PM) is attached with the RMS.



## MB2 Reboost

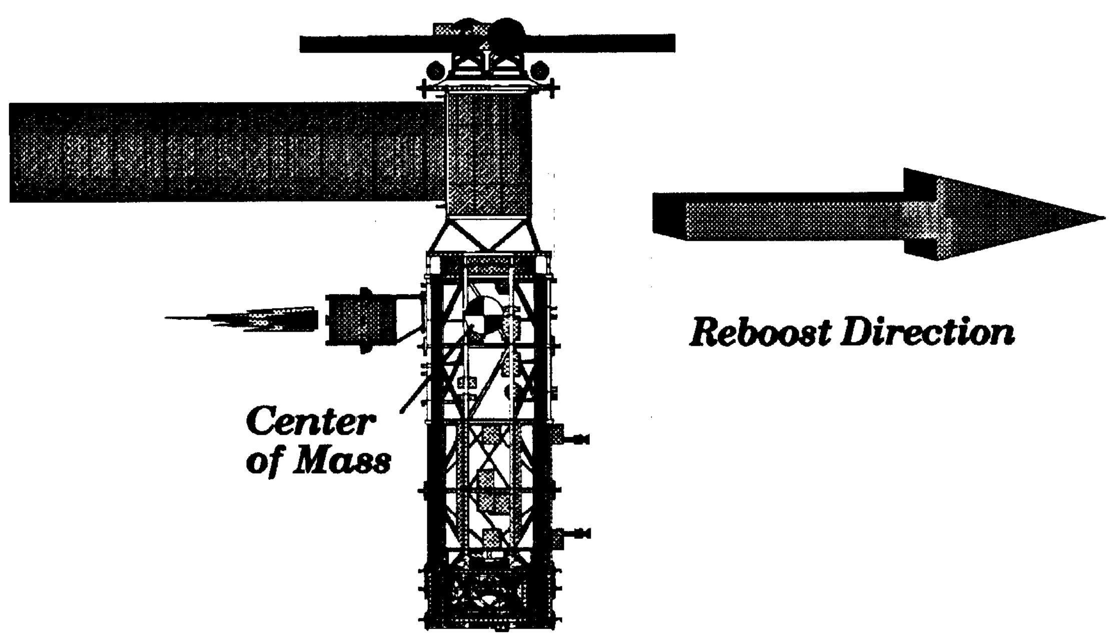
Payload to orbit limitations on the second mission build flight allow only one propulsion module to be brought to the station. Requirements dictate that this stage is to be fully active with reboost capability and attitude control. The baseline assembly sequence meets these requirements by having two propulsion modules in place. Fortunately, the center of mass of the station at this time is directly inline with a propulsion module attach site enabling reboost in the Local Vertical Local Horizontal (LVLH) flight mode with one propulsion module. Attitude control will be required during reboost and at all other times thus necessitating additional thrusters located on the PM or on extension arms attached to the PM. These extra thrusters along with changes to the Reaction Control System (RCS) software may be required.

*Freedom Assembly at a 51.6 Degree Inclination Orbit*

# MB2 Reboost

**Reboost is possible after MB2 but changes to the Reaction Control System (RCS) software may be required.**

**Additional thrusters will be required on the propulsion module to ensure adequate control during reboost.**



## Assembly Sequence Comparison

An additional flight, MB2-A, was required for Freedom assembly at an orbital inclination of 51.6 degrees. This mission delivers the second propulsion module and cargo carrier containing the Space Station Remote Manipulator System (SSRMS), the Mobile Transporter (MT) batteries and Crew Equipment Translation Aide (CETA) devices. The carrier is stowed on the S2 segment until the elements can be utilized. This mission has an excess of available EVA and payload margin. The remaining missions are very similar to the baseline with respect to manifest and mission operations. Some smaller elements have been shifted to different flights and weight margins are smaller for some of the high inclination manifest as compared to the baseline assembly sequence.

# Assembly Sequence Comparison

| Flight | Baseline Shuttle to 28.8° (1) | | Enhanced Shuttle to 51.6° | |
|---|---|---|---|---|
| | Date | Margin (lbs) | Date | Margin (lbs) |
| MB–1 | 3/96 | –1700 | 3/96 | –2200 |
| MB–2 | 4/96 | 1300 | 4/96 | 300 |
| MB–2A | | | 8/96 | 6800 |
| MB–3 | 8/96 | 1100 | 12/96 | 0 |
| MB–4 | 12/96 | 3000 | 3/97 | 500 |
| MB–5 | 3/97 | 1600 | 6/97 | 400 |
| *MB–6* | 6/97 | 1400 | 9/97 | –700 |
| MB–6A | 9/97 | 1700 | 12/97 | 2400 |
| MB–7 | 12/97 | 11000 | 3/98 | 300 |
| *MB–8* | 3/98 | 4800 | 6/98 | 0 |
| *MB–9* | 6/98 | 3600 | 9/98 | 1200 |
| *MB–10* | 9/98 | –1100 | 12/98 | 2400(2) |
| *MB–11* | 12/98 | 7200 | 3/99 | 2100*(2) |
| *MB–12* | 3/99 | 1900* | 6/99 | 0* |
| *MB–13* | 6/99 | 1600* | 9/99 | 0* |
| *MB–14* | 9/99 | 6900 | 12/99 | 2100 |
| MB–15 | 12/99 | 1100* | 3/00 | 2600* |
| *MB–16* | 3/00 | 1400* | 6/00 | –1800* |
| *MB–17* | 6/00 | TBD | 9/00 | TBD |

Note: (1) Assumes 37,800 lbms Shuttle payload lift capability to 220 Nmi, 28.8° inclination
(2) MB–11 hardware brought up on MB–10 (and MB–10 on MB–11) in order to utilize ASRMs
* ASRM Flight
*MB Flights in italics indicates that the same space station hardware is manifested in both scenaios*

## Assembly Sequence Summary

The baseline assembly sequence requires six shuttle flights to reach MTC which is achieved in June of 1997. PMC is achieved in June of 2000 after 18 shuttle flights. Four of these assembly flights utilize ASRMs.

The 51.6 degree orbit inclination assembly sequence requires seven enhanced shuttle flights to reach MTC which is achieved in September of 1997. PMC is achieved in September of 2000 after a total of 19 enhanced shuttle flights. Five of these assembly flights utilize ASRMs. Four of the ASRM flights were nearly identical to corresponding flights in the baseline assembly sequence. An additional ASRM flight was required to bring up the port power system (MB10). This new ASRM flight resulted in the reversal of the order of flights MB10 and MB11 so that the use of the ASRMs would not occur before March of 1999.

The reduction in lift capability of the enhanced shuttle to 51.6 degrees as compared to the baseline shuttle to 28.8 degrees results in a reduced amount of initial user module outfitting. An additional outfitting flight could be added near the end of the assembly sequence to enhance utilization. Freedom's logistics and maintenance flights will also require a reduction in utilization outfitting in order to meet re supply requirements.

# Assembly Sequence Summary

- **Baseline Assembly Sequence to 28.8°**
  - Requires 6 STS flights to reach MTC (6/97) and 18 flights to reach PMC (6/00)
  - Utilizes 4 ASRM flights

- **Enhanced STS Assembly Sequence to 51.6°**
  - Adds one STS flight to the baseline assembly sequence
    - 7 flights to MTC (9/97), 19 flights to PMC (9/00)
  - Utilizes 5 ASRM flights
  - In general, pressurized modules cannot be outfitted as fully as baseline
  - Moved MB–10 (port PVs) to after MB–11 (node 1) in order to utilize ASRMs for the port PV units

- **Preliminary estimates indicate that logistics and maintenance can be accommodated at a 51.6° inclination, however, this results in a reduction in capability for utilization.**

NASA FREEDOM

# High Inclination Operation Impacts

LaRC SSFO

## Operational Impacts

Operational Impacts on Freedom due to a higher orbital inclination discussed in this report include thermal, attitude control and power. Other operational impacts on Freedom are currently being studied by the Marshall Space Flight Center. Preliminary studies indicate there are worse orbital debris and radiation environments at higher inclinations. The launch window for each shuttle assembly flight is reduced to near five minutes due to rendezvous requirements. Greater fluctuations in the atmospheric density may have an impact on orbital decay.

# Thermal Issues Associated with High Inclination Orbit

**Thermal environment:**

Larger Solar angles relative to the spacecraft orbit plane will be experienced during summer season
-the highest solar angles are such that the spacecraft does not enter the Earth's shadow

A wider range of shadow times will result in more extreme temperature ranges
Yearly average solar heating time will lengthen, raising the average solar heating

Albedo factor increases at higher latitudes (but solar reflectance angle decreases)

A wider range of albedo heating may be experienced
Average albedo heating may also increase

Earth thermal radiation decreases at higher latitudes

Combined orbital heating might reduce
Difference in heating on Earth facing and sun facing sides of spacecraft might increase

**Subsystems Issues:**

Articulation of TCS main radiators will need to reflect wider range of solar angles
Longer solar heating times dictate redesign of thermal control for exterior components
Additional heat loads that the TCS must accommodate should be assessed
Truss structure may exhibit more severe thermal distortions

Effects of shorter shadow times on battery design need to be assessed
Effects on EPS thermal radiator is probably not significant

Design of sun sensitive equipment (eg. star trackers) might need re-examination

## Flight Control Characteristics - 52 Degree Vs 28.5 Degree Inclination

An analysis was performed to determine the impact of the high inclination orbit on the flight control characteristics of Freedom. Flight control characteristics examined include Torque Equilibrium Attitude (TEA), Steady state attitude and attitude rate oscillations over an orbit, angular momentum control requirements, and solar array beta axis excursions per orbit.

Assumptions include a 220 nautical mile altitude, a September 30, 1999 two sigma launch date atmosphere, and full sun-tracking solar arrays. A nominal local vertical - local horizontal attitude was assumed. The Control Moment Gyro (CMG) control algorithm simulated was the attitude emphasis mode of the PDR (Preliminary Design Review) control law. All results are based on steady state conditions.

For comparison, the flight characteristics for the nominal 28.5 degree orbit are listed in the leftmost column. Two 52 degree inclination results are presented. The center column corresponds to solar conditions at equinox where the solar beta angle equals zero. Note that the solar array beta joint excursions do not exceed +/- three degrees per orbit. The right column contains results corresponding to winter solstice, whereby the solar beta angle = 52 degrees. Here, the solar array beta joints vary by +/- 75 degrees per orbit.

As can be seen, the TEA does not change much due to the high inclination. Attitude and attitude rate oscillations, as well as CMG control requirements actually decrease for the maximum solar beta case. In summary, there were no flight controllability issues identified for the high inclination orbit simulated.

# Flight Control Characteristics
# 52 Deg vs 28.5 Deg Inclination

- **Assumptions :**
  - 220 Nm
  - 9/30/99 launch date
  - 2 sigma atmosphere
  - PDR CMG control (attitude emphasis)
  - Full sun–tracking solar PV arrays
  - LVLH attitude
  - all results "steady state"

| Inclination | | 28.5 deg ($B_S = 0$) | 52 deg ($B_S = 0$) | 52 deg ($B_S = 52$) |
|---|---|---|---|---|
| – TEA (deg) | yaw | –2.5 | –2.6 | +0.7 |
| | pitch | –13.0 | –13.1 | –12.4 |
| | roll | +0.7 | +0.7 | +0.8 |
| – Attitude oscillations | | $\pm$ 0.4 deg/orbit | $\pm$ 0.4 deg/orbit | $\pm$ 0.1 deg/orbit |
| – Attitude rate oscillations | | $\pm$0.0005 deg/sec | $\pm$0.0005 deg/sec | $\pm$0.0001 deg/sec |
| – Angular momentum req'ts | | 1.2 CMGs | 1.1 CMGs | 0.5 CMGs |
| – Beta axis motion | | 0 $\pm$ 3 deg | 0 $\pm$ 3 deg | 75 $\pm$ 1 deg |

- **NO FLIGHT CONTROLLABILITY ISSUES IDENTIFIED FOR ALTERNATE ORBIT INCLINATIONS**

## Impact of High Inclination Orbits on Freedom Power

High inclination orbits affect power availability in two (offsetting) ways. Power is increased due to the fact that the station is in sunlight more of the time (i.e., it is occulted by the Earth's shadow less often than at low inclination orbits). On the other hand, power is decreased due to more frequent intra-array shadowing. This decrease is either direct, due to an inadequate separation between the solar arrays, or direct, due to beta axis constraints to avoid intra-array shadowing and associated thermal gradients across the solar arrays. For this analysis, the baseline solar array dimensions were assumed: the arrays are 11.68 meters in width, and the starboard pair are separated from each other by 14.99 meters. The port arrays do not shadow the starboard arrays, and vice-versa. A local vertical - local horizontal attitude and a 220 nautical mile altitude were assumed.

In terms of overall power impacts, the total annual accumulated power over one year was nearly identical for the 28.5 degree and 51.6 degree inclination orbits. In other words, the net gain due to increased sun time was offset by the net loss due to intra-array shadowing.

Somewhat surprisingly, the results showed an up to 7% short duration power loss due to shadowing even for the nominal 28.5 degree inclination orbit. This power loss increases to 14% if the inboard starboard array is oriented to prevent shadowing and the accompanying thermal gradients.

The shadowing problem is much worse for the high inclination orbit. Power losses of up to 22% occur when intra-array shadowing is allowed. The inboard starboard array must be completely feathered with respect to the outboard starboard array if shadowing is not allowed. This last case results in 33% power losses for up to four one week periods per year. Calculations show that the separation between the starboard arrays would have to be increased from 14.99 meters to over 45 meters in order to prevent intra-array shadowing at a 51.6 degree orbital inclination. In summary, the high inclination orbit studied results in significant and multiple short term (6 days) power reductions every year.

# Impact of High Inclination Orbits on *Freedom* Power

## (PMC)

- **High inclination orbits affect power availability in two ways :**
  - Power *increases* due to reduced Earth occultation time
  - Power *decreases* due to increased intra–array shadowing

- **Study Assumptions**
  - 220 Nm altitude } (power relatively insensitive to these parameters)
  - LVLH attitude }
  - PV arrays 11.68 m wide; starboard arrays separated by 14.99 m.

- **Results**
  - Assuming one PV pair is allowed to be shadowed :
    - There is a *maximum* power loss of 7% at 28.5 deg inclination
    - There is a *maximum* power loss of 22% at 51.6 deg inclination
  - Assuming one PV pair is oriented to avoid shadowing (thus avoiding thermal gradients) :
    - There is a *maximum* power loss of 14% at 28.5 deg inclination } see Figure
    - There is a *maximum* power loss of 33% at 51.6 deg inclination }
  - The total annual accumulated power over a year is nearly identical for 28.5 and 51.6 deg inclination orbits.
  - The starboard arrays would need to be separated by 45 meters to avoid intra–array shadowing at 51.6 deg inclination (19 m at 28.5 deg!)

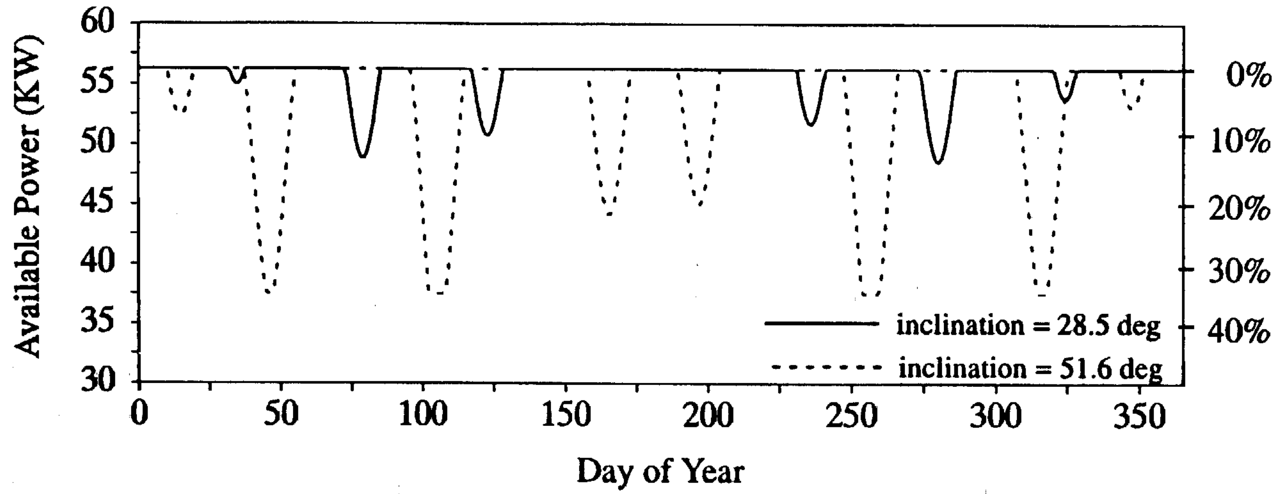
## PMC Power Loss to Avoid Intra-array Shadowing

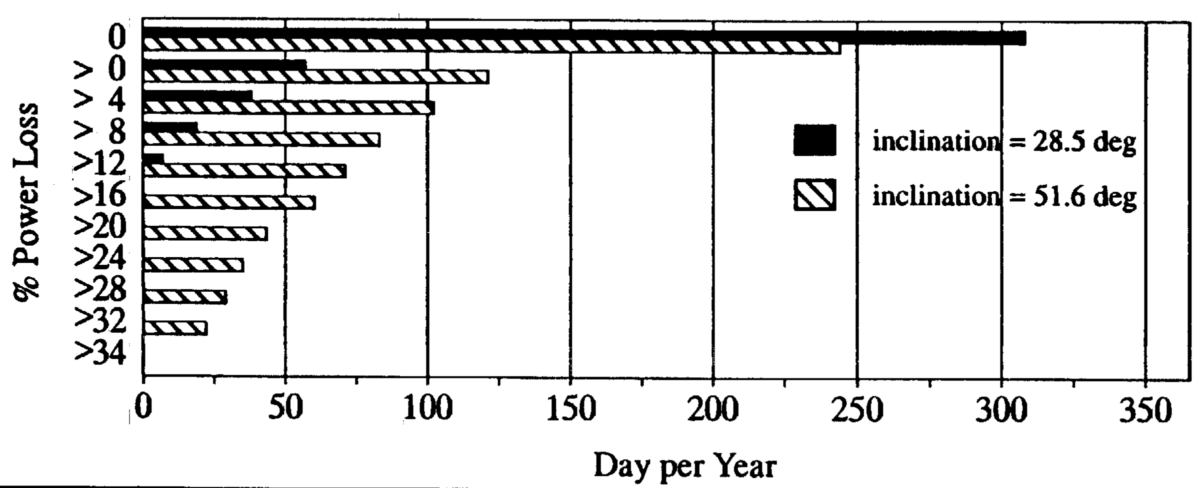
The top graph depicts the power availability on the left (and percent power loss on the right) vertical axis versus day of year on the horizontal axis. The solid line represents the power availability for a 28.5 degree orbit. Note the occasional dips of up to 8 kW (14%). The dashed line represents the power availability for the 51.6 degree inclined orbit simulated. The power reductions are much more pronounced. On at least four occasions, there is a 33% (18.75 kW) power reduction for up to six continuous days.

The second graph illustrates the number of days per year that the various power losses occur for both of the inclinations studied. For example, the 28.5 degree orbit has over 300 days per year where no shadowing occurs, in contrast to the 51.6 degree orbit, which has only 240 shadow free days. No power reductions greater than 16% exist for the 28.5 degree orbit, while the 51.6 degree orbit has over 50 days with power reductions in excess of 16%, and 24 days with power losses of 33%.

NASA — FREEDOM

# PMC Power Loss to Avoid Intra – Array Shadowing




Note : 1/3 reduction in power for up to 6 consecutive days 4 times a year at 51.6 deg. inclination

LaRC SSFO

## Summary

It has been shown that Freedom assembly using an enhanced Space Shuttle at an orbital inclination of 51.6 degrees is possible assuming that some relatively minor design and operational changes are implemented. Design changes include accommodating the unpressurized berthing adapter and mobile transporter on the second assembly flight instead of the first, making all PMAAs EVA accessible while in the shuttle cargo bay, developing a carrier for the SSRMS, MT batteries and CETA carts, and modifying the first propulsion module and any associated software to provide reboost and attitude control capability on the second assembly flight. Operational changes include restructuring EVA timelines on the first three assembly flights, grappling and berthing the first assembly flight with the S2 segment while the S2 segment is attached to the unpressurized docking adapter, and an additional flight which delays MTC and PMC by at least three months. The overall reduction in flight weight margins (especially on the later assembly flights) also makes the assembly sequence much more sensitive to Freedom element weight increases. Off loading of user racks in the pressurized modules in combination with any weight increases may dictate that an additional outfitting flight be added to the assembly sequence.

The most significant operational impact identified is the 22% to 33% power loss that will occur four times a year if the station operates at an inclination of 51.6 degrees. Other changes in operational environment (such as thermal or orbital debris) due to the higher inclination will require further study and possibly some Freedom element modifications. Although none of the impacts identified with respect to assembly or PMC operations would require drastic or difficult Freedom design changes, the cost and schedule risk required to accommodate the sum of all changes may preclude Freedom assembly and operations at an orbital inclination of 51.6 degrees.

*Freedom Assembly at a 51.6 Degree Inclination Orbit*

# Summary

- Assembly at a 51.6 degree inclination is possible with some minor design & operational changes. A three month delay in MTC & PMC is required.

- A 22% to 33% power loss will occur four times a year at six day durations due to shadowing constraints.

# REPORT DOCUMENTATION PAGE

*Form Approved*
*OMB No. 0704-0188*



**1. AGENCY USE ONLY** *(Leave blank)*

**2. REPORT DATE**
January 1993

**3. REPORT TYPE AND DATES COVERED**
Technical Memorandum

**4. TITLE AND SUBTITLE**
Space Station Freedom Assembly and Operations at a 51.6 Degree Inclination Orbit

**5. FUNDING NUMBERS**
476-14-15-01

**6. AUTHOR(S)** Patrick A. Troutman, Laura M. Brewer, Michael L. Heck, and Renjith R. Kumar

**7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)**
NASA Langley Research Center
Hampton, Virginia 23681-0001

**8. PERFORMING ORGANIZATION REPORT NUMBER**

**9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES)**
National Aeronautics and Space Administration
Washington, DC 20546

**10. SPONSORING / MONITORING AGENCY REPORT NUMBER**
NASA TM-107731

**11. SUPPLEMENTARY NOTES** P. A. Troutman, NASA Langley Research Center, Hampton, VA 23681
Laura M. Brewer, Michael L. Heck, and Renjith R. Kumar, Analytical Mechanics Associates, Inc., 17 Research Drive, Hampton, VA 23666

**12a. DISTRIBUTION / AVAILABILITY STATEMENT**
Unclassified - Unlimited

Subject Category 18

**12b. DISTRIBUTION CODE**

**13. ABSTRACT** *(Maximum 200 words)* This study examines the implications of assembling and operating Space Station Freedom at a 51.6 degree inclination orbit utilizing an enhanced lift Space Shuttle. Freedom assembly is currently baselined at a 220 nautical mile high, 28.5 degree inclination orbit. Some of the reasons for increasing the orbital inclination are 1) increased ground coverage for Earth observations, 2) greater accessibility from Russian and other international launch sites, and, 3) increased number of Assured Crew Return Vehicle (ACRV) landing sites. Previous studies have looked at assembling Freedom at a higher inclination using both medium and heavy lift expendable launch vehicles (such as Shuttle-C and Energia). The study assumes that the shuttle is used exclusively for delivering the station to orbit and that it can gain additional payload capability from design changes such as a lighter external tank that somewhat offsets the performance decrease that occurs when the shuttle is launched to a 51.6 degree inclination orbit.

**14. SUBJECT TERMS**
Space Station Freedom, Assembly, High Inclination

**15. NUMBER OF PAGES**
36

**16. PRICE CODE**
A03

| 17. SECURITY CLASSIFICATION OF REPORT | 18. SECURITY CLASSIFICATION OF THIS PAGE | 19. SECURITY CLASSIFICATION OF ABSTRACT | 20. LIMITATION OF ABSTRACT |
|---|---|---|---|
| Unclassified | Unclassified | Unclassified | Unlimited |