NASA JSC TRAJECTORY OPERATIONAL SUPPORT FOR ENTRY OF SPACE STATION MIR

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ABSTRACT

In December 2000, Russian Prime Minister Mikhail Kasyanov signed a decree that announced the Russian plans to safely de-orbit the Mir Space Station. While the Russian government maintained sole responsibility for Mir Space Station de-orbit operations, International assistance was requested to obtain access to additional orbital tracking resources.

The United States government, while maintaining its position as an observer of the Mir de-orbit, agreed to provide orbital tracking data from its Space Surveillance network (SSN) to the degree possible. The National Aeronautics and Space Administration (NASA) was requested and agreed to coordinate this support due to the strong working relationship and communications channels developed between NASA and Russian Trajectory organizations for the International Space Station (ISS) Program.

Additionally, NASA trajectory specialists at Johnson Space Center performed independent orbit decay assessments and re-entry analyses for the Mir de-orbit scenarios.

1. MIR DEORBIT TECHNICAL INTERCHANGE MEETING

A meeting was held in February of 2001 in Houston Texas between Russian and NASA trajectory specialists to review Mir de-orbit scenarios and agree to specific communications and data exchange.

The nominal scenario originally had three braking impulses occurring during a period of 48 hours prior to Mir's final controlled re-entry maneuver. Two of these impulses would be applied two days before de-orbit with a third impulse on the following day. The initial braking maneuvers had a primary goal of establishing the Mir's orbital perigee over the designated impact zone in the South Pacific Ocean. Additionally, it was desired to maintain a perigee altitude above 155 km to protect attitude control authority, which became uncertain below 155 km due to oscillations induced by aerodynamic torques. This plan was later reevaluated by Russian specialists and modified such that two braking impulses and the re-entry maneuver would be performed in a short span of just four orbits.

To facilitate timely data transfer and status reporting, existing file formats and communications channels in use by the ISS program were employed. Specific data to be transferred included orbital tracking data in the form of two line element sets (TLE) and J2000 cartesian state vectors as well as detailed maneuver plans and sequence of events tables.

2. SPACE SURVEILLANCE NETWORKS

Both the Mir Space Station Program and the ISS Program use the term "daily orbit". For normal Station operating altitude ranges, 15 to 16 daily revolutions are experienced with daily orbit 1 defined as the first ascending node pass west of 20° east longitude.

At these altitudes, the Russian tracking network nominally provides orbital tracking during the daily orbit 13 through orbit 4 while the vehicle is in view of ground-based sensors in Russia.

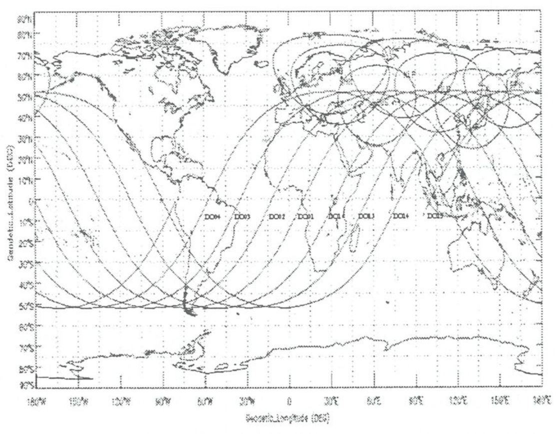

Fig. 1. Russian Ground Sites

The United States SSN nominally provides orbital tracking during the daily orbit range of 5 to 13 for satellites at Station operating altitudes, with limited tracking opportunities on additional orbits.

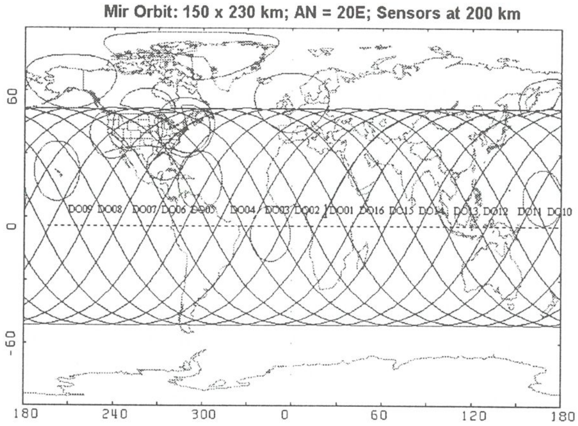

Fig. 2. U.S. Ground Sites

United States tracking data in addition to that provided by European Space Agency (ESA) greatly supplemented Russian tracking data and provided valuable situational awareness of the Mir trajectory.

3. ORBITAL DECAY PREDICITIONS

NASA generated independent orbital decay predictions for Mir to track decision points provided by Russia and to maintain a situational awareness of the Mir trajectory.

The method used by NASA for predicting Mir's orbital decay attempted to bound the decay profile using atmospheric predictions provided by the NASA Marshall Space Flight Center (MSFC). The early and late bounds of the trajectory were modelled using the January 2001 MSFC 5% and 95% percentile atmospheres and fixed ballistic characteristics for each prediction.

The ballistic number (BN) is used to define the ballistic characteristics and is made up of the individual components: mass (M), drag coefficient (Cd), and effective frontal area (A_f).

$$BN = \frac{M}{Cd \cdot A_f} \tag{1}$$

To maintain a best estimate decay profile, the MSFC 50% percentile atmosphere was used. However, the ballistic characteristics were modified for each orbital decay prediction to account for recent changes in solar activity and future short-term atmosphere predictions obtained from the National Oceanic and Atmosphere Administration (NOAA).

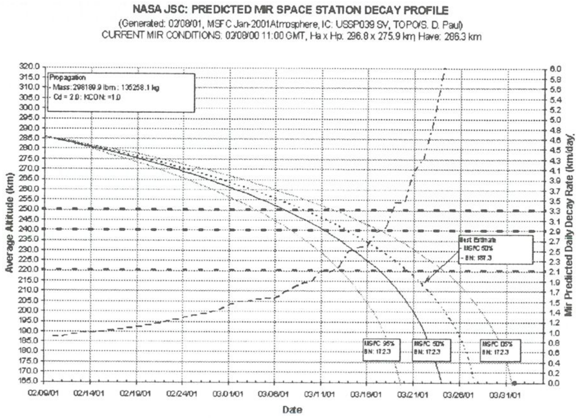

Fig. 3. Mir Space Station Decay Profile

The following table represents a series of orbital decay predictions performed by NASA to gauge the date that Mir would reach 250 km and subsequently the natural decay date in the event that nominal de-orbit operations could not be performed.

Tab. 1. NASA JSC Mir Orbit Decay Predictions

	MSFC 95%		MSFC 50%			MSFC 5%	
Date Generated	250 km Date	Decay Date	BN (kg/m2)	250 km Date	Decay Date	250 km Date	Decay Date
02/08/01	03/04/01	03/20/01	187.3	03/09/01	03/28/01	03/12/01	04/01/01
02/15/01	03/05/01	03/21/01	198.3	03/09/01	03/30/01	03/12/01	03/31/01
02/19/01	03/06/01	03/22/01	200.8	03/12/01	03/31/01	03/12/01	03/31/01
02/26/01	03/08/01	03/23/01	200.8	03/10/01	03/30/01	03/10/01	03/30/01
03/05/01	03/09/01	03/25/01	189.1	03/10/01	03/29/01	03/10/01	03/30/01
03/12/01	N/A	03/26/01	186.4	N/A	03/28/01	N/A	03/29/01
03/17/01	N/A	03/27/01	186.2	N/A	03/28/01	N/A	03/29/01
03/20/01	N/A	03/27/01	190.6	N/A	03/28/01	N/A	03/28/01

** MSFC 95% & 5% Predicitions Used Constant BN = 172.3 kg/m2

4. OBSERVED ORBITAL DECAY AND SOLAR ACTIVITY

The following depicts the observed orbital decay profile and rate of decay for Mir's final months on orbit. Included, in Fig. 4., are the apogee altitude (Ha), perigee altitude (Hp), and the mean altitude (H).

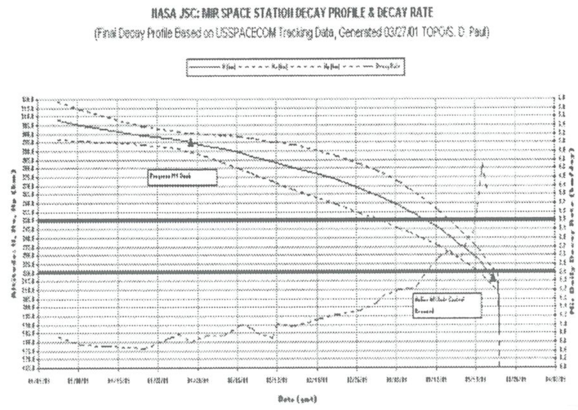

Fig. 4. Observed Mir Decay Profile

The solar activity remained reasonably stable during the final months of Mir's lifetime with only mild fluctuations. The trend, as indicated in Fig. 5., shows lower than expected solar activity with the F10.7 solar flux average being nearer the MSFC 5% than the MSFC 50% predictions.

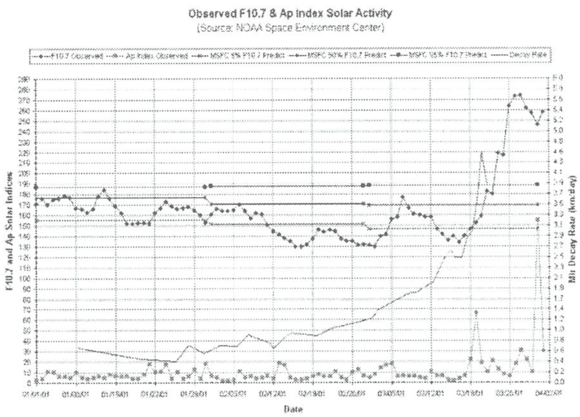

Fig. 5. Observed Solar Activity

On March 19, 2001, a solar storm occurred, as indicated by the spike in the geomagnetic index (Ap), causing a temporary increase in the observed orbital decay rate. Additionally, following Mir's successful de-orbit, a rapid increase in the F10.7 solar flux and an another significant geomagnetic storm were observed.

5. EVALUATION OF PREDICTED DEORBIT MANEUVERS

The final dynamic operations for Mir began on March-23, 2001 with the initiation of two braking impulses designed to lower and establish the Mir orbital perigee over the designated impact region in the South Pacific Ocean.

The first braking impulse of 9.28 m/s occurred on daily orbit 15 and the second braking impulse of 10.40 m/s occurred on daily orbit 16. Both maneuvers were reported to have occurred nominally by Moscow Mission Control (MCC-M) to Houston Mission Control (MCC-H). This was subsequently confirmed based upon comparisons of United States tracking data and post maneuver predictions provided by MCC-M as indicated in Tab. 2. Comparison results represent the predicted state minus the observed state.

Tab. 2. Post De-orbit Maneuver Comparison

	Comparison Time (GMT)	Down Track (km)	Semi-Major Axis (km)	Apogee Altitude (km)	Perigee Altitude (km)	Argument of Perigee (deg)
Maneuver 1	03/23/01 00:53:32.6	37.227	-0.453	-1.146	0.108	3.050
Maneuver 2	03/23/01 02:24:28.2	37.340	0.312	-1.531	2.137	0.329
Maneuver 3	N/A	N/A	N/A	N/A	N/A	N/A

* Comparison of 03/22/01 Russian provided post maneuver predictions to USSPACECOM post maneuver tracking data.

The final de-orbit impulse, nominally planned to be 23.5 m/s, was performed on daily orbit 2 as Mir passed within view of the Russian ground sites. MCC-M reported that the actual final magnitude was estimated to be on the order of 28.5 m/s due to additional propellant that was allowed to burn to depletion.

United States tracking data following the final de-orbit maneuver was not available to perform a comparison although assets at the Kwajelein site briefly saw Mir as it passed by low on the horizon. This final pass was reported to have begun at 5:40:11 GMT and ended at 05:40:35 GMT with no data being recorded.

6. CONCLUSION

March 23, 2001 marked the end of an impressive 15-year era in space with the successful controlled de-orbit of the Russian Space Station Mir.

The United States role as an observer to the Mir de-orbit was extended as agreements were reached to provide Russia with Mir tracking data from the U.S. SSN. Existing working relationships, communications channels, and data exchange formats between MCC-M and MCC-H, developed for the ISS program, were used to provide the required coordination and operational support.

Independent assessments performed by NASA were used to maintain an overall situational awareness of the Mir trajectory and as a learning experience by observing the final days of the largest man-made object to re-enter Earth's atmosphere.