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JOINT JSC/GSFC TWO-TDRS NAVIGATION CERTIFICATION RESULTS FOR STS-29, STS-30, AND STS-32*

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ABSTRACT

This paper describes the procedures used and the results obtained in the joint Johnson Space Center (JSC)/Goddard Space Flight Center (GSFC) navigation certification of the two-TDRS S-band tracking configuration for support of low- to medium-inclination (28.5 to 62 degrees) Shuttle missions (STS-29 and STS-30) and Shuttle rendezvous missions (STS-32). The objective of this certification effort was to certify the two-TDRS configuration for nominal STS on-orbit navigation support, thereby making it possible to significantly reduce the ground tracking support requirements for routine STS on-orbit navigation.

JSC had the primary responsibility for certification of the two-TDRS configuration for STS support, and GSFC supported the effort by performing Ground Network (GN) and Space Network (SN) tracking data evaluation, parallel orbit solutions, and solution comparisons.

In the certification process, two types of orbit determination solutions were generated by JSC and by GSFC for each tracking arc evaluated, one type using TDRS-East and TDRS-West tracking data combined with ground tracking data (the reference solutions) and one type using only TDRS-East and TDRS-West tracking data. The two types of solutions were then compared to determine the maximum position differences over the solution arcs and whether these differences satisfied the navigation certification criteria. The certification criteria were a function of the type of Shuttle activity in the tracking arc, i.e., quiet, moderate, or active. Quiet periods included no attitude maneuvers or ventings, moderate periods included one or two maneuvers or ventings, and active periods included more than two maneuvers or ventings.

This paper presents the results of the individual JSC and GSFC certification analyses for the STS-29, STS-30, and STS-32 missions and the joint JSC/GSFC conclusions regarding certification of the two-TDRS S-band configuration for STS support.

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1.0 INTRODUCTION

1.1 BACKGROUND

NASA is transitioning navigation support for Shuttle missions and for unmanned spacecraft from a primarily ground-based system (the Ground Network (GN)), utilizing Ground Spacecraft Tracking and Data Network (GSTDN) S-band tracking stations and Department of Defense (DOD) C-band tracking stations, to a primarily space-based system (the Space Network (SN)), utilizing the Tracking and Data Relay Satellite (TDRS) System (TDRSS). Currently, TDRSS consists of three geosynchronous satellites: TDRS-East, located at 41 degrees west longitude; TDRS-Spare, located at 171 degrees west longitude; and TDRS-West, located at 174 degrees west longitude.

The task of certifying the TDRSS for navigation support for the Space Transportation System (STS) was assigned to the TDRSS Orbit Determination and Navigation Working Group (TODNWG), a group composed of engineers from the Johnson Space Center (JSC) Navigation Section and from the Goddard Space Flight Center (GSFC) Flight Dynamics Facility (FDF). This group first met in 1982 to develop the STS/TDRSS Navigation Certification Plan (Reference 1). The first step in the certification of TDRSS for STS support was a joint JSC/GSFC single-TDRS certification effort, which took place between August 1983, the start of TDRSS tracking services, and the end of the STS-41G mission in October 1984. This effort was successful in certifying the augmented single-TDRS network (TDRS-East plus ground stations outside the TDRS-East coverage) as an adequate navigation system for noncritical Shuttle flight periods (see Reference 2).

The second step in the certification process was a joint JSC/GSFC two-TDRS certification effort with the objective of certifying the TDRS-East/TDRS-West configuration (without ground station augmentation) for nominal on-orbit navigation support of STS flights. A successful certification effort would mean that ground tracking support for routine STS on-orbit navigation could be significantly reduced or eliminated. Some ground-based tracking would still be necessary to support critical and high-activity periods.

This certification effort consisted of two phases: (1) certification of the two-TDRS configuration for navigation support of low- to medium-inclination (28.5 to 62 degrees) missions that do not include a rendezvous and (2) certification of the two-TDRS configuration for navigation support of low- to medium-inclination rendezvous missions. The STS certification missions were STS-29 and STS-30 (nonrendezvous missions) and STS-32 (a rendezvous mission). This paper documents the certification results obtained for these three missions at JSC and GSFC. A more detailed report of the certification results will be published at a later date (Reference 3).

JSC had the primary responsibility for certification of the two-TDRS network for STS support. GSFC supported this effort by performing tracking data evaluation for the GN and SN tracking data and by performing parallel orbit solutions and solution comparisons.

1.2 ORGANIZATION OF PAPER

Section 2 describes the JSC and GSFC certification criteria and procedures used in this study, and Section 3 presents the certification results. Conclusions are given in Section 4.

2.0 CERTIFICATION CRITERIA AND PROCEDURES

This section presents the two-TDRS navigation certification criteria and describes the procedures used in the orbit determination process and in the comparison of orbit solutions at both JSC and GSFC. It also defines the spacecraft (Shuttle and TDRS) characteristics and force modeling parameters used in the orbit solutions.

2.1 TWO-TDRS NAVIGATION CERTIFICATION CRITERIA

The criteria for evaluating the navigation certification results for the two-TDRS effort are documented in Reference 4. For each tracking data arc evaluated, orbit determination solutions were obtained using TDRS-East and TDRS-West tracking data combined with ground tracking data (the reference solution) and using only the TDRS-East and TDRS-West tracking data. These solutions were then compared to determine the maximum position differences between the reference and two-TDRS solutions over the tracking data arc. These maximum differences could not exceed the certification criteria shown in Table 1. Quiet periods included no attitude maneuvers or ventings within the tracking arc; moderate periods included only one or two attitude maneuvers or ventings; and active periods included more than two attitude maneuvers or ventings and the 6-hour period just prior to deorbit ignition. TDRSS tracking of the Shuttle was rated satisfactory when 70 percent or more of the Doppler data were usable during scheduled support periods.

Table 1. Acceptance Criteria for STS Navigation Certification

EPHEMERIS COMPARISONS	MAXIMUM TOTAL POSITION DIFFERENCES (METERS)				
	STS ACTIVITY LEVEL				
	QUIET	MODERATE	ACTIVE	POSTINSERTION	RENDEZVOUS
TWO-TDRS-ONLY BTB VERSUS REFERENCE BET	320	420	570	420	700
TWO-TDRS-ONLY BET VERSUS REFERENCE BET	280	420	640	420	750

NOTES:

1. EPHEMERIS COMPARISONS SHALL SATISFY THE ABOVE CRITERIA IN 90 PERCENT OF THE CASES FOR EACH ACTIVITY LEVEL.
2. BTB = BATCH-TO-BATCH
   BET = BEST ESTIMATED TRAJECTORY

2.2 JSC CERTIFICATION PROCEDURES

The JSC two-TDRS certification procedures that were common to all three missions are described in Sections 2.2.1 and 2.2.2. The mission-specific procedures are described in Section 2.2.3. The reference and two-TDRS-only solutions generated by JSC used the spacecraft characteristics and force modeling parameters given in Table 2.

TDRS-East and TDRS-West ephemerides were updated every 6 hours using accurate GSFC-supplied vectors. The tracking data sampling rate was every 40 seconds for TDRSS S-band measurements, every 10 seconds for GN S-band measurements, and every 6 seconds for GN C-band measurements. Data weights (sigmas) used in the solutions were (1) 0.10 hertz for TDRS S-band Doppler measurements; (2) 18.3 meters, 0.0344 degree, and 0.60 hertz for GN S-band two-way range, angles, and Doppler measurements, respectively; and (3) 18.3 meters and 0.0229 degree for GN C-band two-way range and angle measurements, respectively.

2.2.1 Batch-to-Batch (BTB) Processing

JSC Ground Navigation normally processes data in a batch-to-batch (BTB) mode, where data batches are processed sequentially after the end of each tracking pass. A weighted least-squares differential correction of the spacecraft orbital estimate is performed according to the following equation:

$$\Delta x_i = [A^T W A + (k^n \Gamma)^{-1}]^{-1} [A^T W \Delta y + (k^n \Gamma)^{-1} \Delta x_{i-1}] \qquad (1)$$

where

Δx = current and last corrections to the a priori position and velocity state vector estimate for each iteration

Δy = vector of residuals (observations minus the expected values)

A = matrix containing the partial derivatives of the data observations with respect to the Cartesian position and velocity components

W = diagonal matrix of observation data weights ($1/\sigma^2$)

Γ^{-1} = covariance from the last BTB solution, propagated to the time of the current batch

k^n = covariance multiplier

The multiplier k^n is applied to the a priori covariance to control the amount by which previous history constrains the current solution. The number of times the k value is applied, n, is controlled by the JSC navigator during processing. The multiplier can be applied to the entire covariance matrix (an (XYZ) $k\Gamma$). The in-plane or out-of-plane elements of the covariance can be selectively downweighted through a transformation of the covariance from Cartesian to UVW (radial, along-track, and cross-track) coordinates (a (UVW) $k\Gamma$). An in-plane (UV) $k\Gamma$ allows the current data to change the in-plane elements of the state vector while constraining out-of-plane changes. A (W) $k\Gamma$ affects only the out-of-plane covariance elements. A (UV) $k\Gamma$ followed by a (W) $k\Gamma$ is completely equivalent to an (XYZ) $k\Gamma$. TDRS BTB processing often employs in-plane covariance downweighting in an attempt to compensate for the weakness of Doppler-only TDRS data in orbital plane determination following trajectory perturbations.

2.2.2 Best-Estimated-Trajectory (BET) Processing

The mathematical basis of best-estimated-trajectory (BET) differential correction processing is essentially the same as for BTB processing, although in practice there are several differences between the two modes. Rather than processing a single pass of tracking data from one station, BET processing considers data arcs that contain measurement information from several tracking passes. The solved-for state vector can include up to three vents, whose start and stop times are specified by the JSC navigator. These solved-for vents are often used to account for unmodeled thrusting due to attitude and translational maneuvers. BET processing does not normally use an a priori covariance, because this would unrealistically constrain the solved-for position, velocity, and vent force solutions. Angle measurements are usually excluded from BET processing.

The two-TDRS-only BET processing was performed over the same data arcs used in the reference BET. Quiet periods were certified during STS-29 and therefore were not included in the STS-30 and STS-32 processing. Each data arc began and ended with TDRSS data so that the reference and two-TDRS-only BETs would be directly comparable. Adjacent arcs included one or two common batches to minimize discontinuities between successive trajectories. The start and stop times for each BET arc were defined as the points of minimum trajectory difference within the overlap portions of the surrounding arcs. Solution residuals were minimized by solving for the Shuttle state vector and for vents that were placed to match actual trajectory perturbations as closely as possible. Vents were not solved for in the overlap regions. Solution quality was judged on the basis of residuals beyond the data arc, as computed from the propagated solution vector, solution statistics, and the reasonableness of solved-for parameters.

2.2.3 Mission-Specific Procedures

The JSC two-TDRS certification procedures that were mission specific are discussed below for STS-29, STS-30, and STS-32.

2.2.3.1 STS-29 PROCEDURES

JSC Ground Navigation maintained two realtime BTB sequences (chains) throughout the entire mission. The reference BTB chain was initialized on the revolution 2 C-band ground pass from Kwajalein. The two-TDRS-only BTB chain was initialized with a BET solution over the first two post-OMS-2 TDRSS passes (OMS is the Orbital Maneuvering System). A Shuttle body-axis correction vent was modeled during the on-orbit timeframe to account for unmodeled translation effects of attitude control thrusting. Both the reference and two-TDRS BET solutions included this vent, meaning that any solved-for vent force was in addition to the already modeled forces. A reference BET and a two-TDRS-only BET were generated for 23 data arcs spanning the entire mission.

2.2.3.2 STS-30 PROCEDURES

JSC Ground Navigation maintained two realtime BTB chains throughout the entire mission. The reference BTB chain was initialized on the revolution 2 C-band ground pass from Kaena Point, Hawaii. The two-TDRS BTB chain was initialized on a BET solution over the first two on-orbit TDRS passes. Constant Shuttle body-axis correction vents were modeled. Both the reference and two-TDRS BET solutions included these modeled vents, meaning that any solved-for vent force was in addition to the already modeled forces. The STS-30 reference BET consisted of 19 data arcs spanning the period between OMS-2 and the deorbit burn.

2.2.3.3 STS-32 PROCEDURES

JSC Ground Navigation maintained the reference BTB chain throughout the entire mission. The two-TDRS BTB chain, which spanned only the rendezvous period, was initialized on a TDRS-East solution from the well-established reference BTB chain. Five reference and three two-TDRS-only BET arcs were processed during the rendezvous certification period. Constant Shuttle body-axis correction vents were modeled. Both the reference and two-TDRS BET solutions included these modeled vents, meaning that any solved-for vent force was in addition to the already modeled forces.

2.3 GSFC/FDF CERTIFICATION PROCEDURES

The GSFC/FDF certification processing and procedures are described below. The GSFC solutions were generated using the spacecraft parameters and force modeling parameters given in Table 3. The TDRS-East and TDRS-West ephemerides used in conjunction with SN tracking data were those generated as part of the normal FDF daily operations.

The tracking data types used in the solutions were (1) TDRSS S-band Doppler measurements, (2) GN S-band range and range-rate measurements, and (3) GN C-band range measurements. The tracking data sampling rate was every fourth observation for the TDRS S-band measurements and every observation for the GN S-band and C-band measurements. The data weights (sigmas) used in the solutions were (1) 0.25 hertz for the TDRSS S-band Doppler measurements; (2) 20 meters and 10 centimeters per second for the GN S-band range and range-rate measurements, respectively; and (3) 20 meters for the GN C-band range measurements.

2.3.1 <u>GSFC FDF Batch Processing</u>

The GSFC FDF uses a differential correction process to estimate the spacecraft orbit and associated parameters. This process uses a Bayesian weighted least-squares estimation algorithm with an a priori covariance matrix. The Cowell equations of motion are integrated with a predictor/corrector algorithm. For low-eccentricity orbits (such as TDRS and Shuttle), GSFC/FDF uses a fixed integration step size, in contrast to JSC, which uses a variable step size. The orbit processing at GSFC/FDF is essentially equivalent to the JSC BET processing.

2.3.2 <u>GSFC FDF Procedures</u>

For each certification tracking data arc, the GSFC/FDF generated a reference solution including both GN and SN tracking data and a two-TDRS solution including only SN tracking data. The orbit solutions for each tracking data arc were initially generated with no attempt to model the thrusting activities within the arc, as the FDF does not have an STS thrust modeling capability comparable to the JSC modeling. For those cases where the maximum position differences exceeded the certification criteria, the solutions were regenerated applying along-track thrust components provided by JSC. Finally, the reference and two-TDRS solutions were compared to determine the maximum position difference between the two solutions for each of the tracking data arcs. Whenever successive tracking data arcs overlapped, overlap comparisons were performed for both the reference solutions and the two-TDRS solutions.

Table 2. Spacecraft Characteristics and Force Modeling Parameters (JSC)

PARAMETERS	STS-29, STS-30, STS-32	TDRS-EAST AND TDRS-WEST
CROSS-SECTIONAL AREA	ATTITUDE-DEPENDENT	N/A
TYPE OF INTEGRATION	ENCKE	ENCKE
INTEGRATION STEPSIZE	52 SECONDS	333 SECONDS
INTEGRATION COORDINATE SYSTEM	MEAN OF 1950.0	MEAN OF 1950.0
GEOPOTENTIAL MODEL	GODDARD EARTH MODEL-10 (GEM-10) 7x7	GEM-10 7X7
ATMOSPHERIC DENSITY MODEL	JACCHIA-LINEBERRY MODEL WITH 90-DAY MEAN SOLAR FLUX (1970-71)	N/A
SOLAR REFLECTIVITY COEFFICIENT (C_R)	NOT USED	NOT USED
DRAG COEFFICIENT (C_D)	2.0	N/A
SOLAR/LUNAR/PLANETARY FILE	JPL DE-19	JPL DE-19
SOLVED-FOR PARAMETERS	STATE (POSITION AND VELOCITY), VENTS, AND MANEUVERS	N/A

Table 3. Spacecraft Characteristics and Force Modeling Parameters (GSFC/FDF)

PARAMETERS	STS-29, STS-30, STS-32	TDRS-EAST AND TDRS-WEST
CROSS-SECTIONAL AREA	120 METERS^2	40 METERS^2
TYPE OF INTEGRATION	FIXED-STEP COWELL	FIXED-STEP COWELL
INTEGRATION STEPSIZE	45 SECONDS	600 SECONDS
INTEGRATION COORDINATE SYSTEM	MEAN OF 1950.0	MEAN OF 1950.0
GEOPOTENTIAL MODEL	GODDARD EARTH MODEL-9 (GEM-9) 7x7	GEM-9 8x8
ATMOSPHERIC DENSITY MODEL	HARRIS-PRIESTER	N/A
SOLAR REFLECTIVITY COEFFICIENT (C_R)	1.5	SOLVED FOR
DRAG COEFFICIENT (C_D)	2.0	N/A
SOLAR/LUNAR/PLANETARY FILE	JPL DE-118	JPL DE-118
SOLVED-FOR PARAMETERS*	STATE (POSITION AND VELOCITY) AND DRAG VARIATION PARAMETER	STATE, C_R

*THRUST MODELING WAS APPLIED FOR SELECTED SOLUTION ARCS.

3.0 CERTIFICATION RESULTS

The JSC and GSFC/FDF certification results for the STS-29, STS-30, and STS-32 missions are described below.

3.1 STS-29

STS-29 was launched into a circular 28.5-degree inclination, 296-kilometer altitude orbit on March 13, 1989. The primary objective of the STS-29 mission was to deploy the third operational Tracking and Data Relay Satellite (TDRS-4). Twenty-three tracking data arcs were used for navigation certification during this mission. The thrusting activity level, the start and stop times, and the number of GN and SN tracking passes for each tracking data arc are given in Table 4.

Table 4. Tracking Arc Definition, Thrusting Activity Level, and Number of Tracking Passes for STS-29

ARC NO.	VENTING ACTIVITY LEVEL	TRACKING INTERVAL				NO. OF TRACKING PASSES			
		START		END		GROUND NETWORK		TDRSS	
		DATE	GMT (HHMMSS)	DATE	GMT (HHMMSS)	S-BAND/ C-BAND	TOTAL	TDRS-E/ TDRS-W	TOTAL
1	ACTIVE	3/13/89	15:53:30	3/13/89	21:10:40	0 / 13	13	3 / 4	7
2	ACTIVE		21:25:20	3/14/89	03:51:10	0 / 4	4	4 / 4	8
3	QUIET	3/14/89	02:25:20		08:48:40	0 / 3	3	3 / 6	9
4	MODERATE		08:01:30		13:21:10	0 / 3	3	3 / 5	8
5	ACTIVE		12:11:30		18:56:40	1 / 11	12	5 / 3	8
6	MODERATE		18:34:00	3/15/89	00:47:30	0 / 3	3	4 / 6	10
7	QUIET	3/15/89	00:17:30		06:11:30	0 / 6	6	4 / 5	9
8	ACTIVE		05:51:30		12:17:10	0 / 3	3	4 / 4	8
9	MODERATE		11:33:10		16:44:20	0 / 4	4	3 / 4	7
10	MODERATE		17:09:00		23:35:10	0 / 1	1	4 / 5	9
11	QUIET		22:03:00	3/16/89	04:23:40	1 / 5	6	4 / 5	9
12	QUIET	3/16/89	02:51:30		09:11:20	1 / 3	4	5 / 5	10
13	ACTIVE		08:27:00		14:03:20	0 / 4	4	3 / 4	7
14	ACTIVE		12:34:20		17:11:20	0 / 3	3	3 / 3	6
15	ACTIVE		15:46:30		21:09:30	0 / 2	2	4 / 3	7
16	ACTIVE		20:40:10	3/17/89	03:38:20	0 / 4	4	6 / 4	10
17	QUIET	3/17/89	02:12:40		08:27:40	0 / 4	4	4 / 4	8
18	ACTIVE		07:59:00		13:15:20	0 / 4	4	4 / 3	7
19	ACTIVE		12:30:00		18:09:20	2 / 11	13	4 / 4	8
20	ACTIVE		17:40:00		23:46:20	0 / 1	1	4 / 5	9
21	QUIET		20:12:20	3/18/89	06:06:50	1 / 5	6	4 / 7	11
22	MODERATE	3/18/89	04:56:30		09:45:10	0 / 3	3	3 / 4	7
23	ACTIVE		08:55:50		13:35:10	0 / 12	12	3 / 3	6

The GSFC tracking data evaluation for STS-29 is documented in Reference 5. A total of 8 S-band and 108 C-band GN on-orbit passes were evaluated. Anomalies were encountered in four of the S-band passes and three of the C-band passes. Approximately 80 percent of the TDRS-East view periods and 84 percent of the TDRS-West view periods had at least 70 percent usable data. With Doppler compensation and GN times deleted, the TDRS-East and TDRS-West data were approximately 95 percent usable.

The JSC and GSFC orbit determination results for STS-29 are presented in Sections 3.1.1 and 3.1.2, respectively.

3.1.1 JSC Orbit Determination Results for STS-29

This section describes the JSC STS-29 two-TDRS BTB and BET certification results.

The maximum position differences between the two-TDRS-only BTB and reference BET solutions (and their radial, cross-track, and along-track components) are shown in Table 5. Three of the two-TDRS-only BTB

Table 5. Maximum Position Differences Between Two-TDRS BTB and Reference BET Solutions for STS-29 (JSC)

ARC NO.	VENTING ACTIVITY LEVEL	MAXIMUM POSITION DIFFERENCE BETWEEN THE TWO-TDRS AND REFERENCE SOLUTIONS (METERS)					NUMBER OF TWO-TDRS SOLUTIONS PASSED/ TOTAL NUMBER	PERCENT PASSED
		RADIAL	CROSS-TRACK	ALONG-TRACK	TOTAL (RSS)	CERTIFICATION CRITERION		
1	ACTIVE	19	-372	-58	377	* 420	7 / 7	100
2	ACTIVE	-72	-324	416	532	570	8 / 8	100
3	QUIET	28	71	-165	182	320	7 / 7	100
4	MODERATE	132	120	-295	345	420	6 / 6	100
5	ACTIVE	-37	7	-276	278	570	7 / 7	100
6	MODERATE	13	148	269	307	420	9 / 9	100
7	QUIET	5	150	-64	164	320	8 / 8	100
8	ACTIVE	-130	188	-169	284	570	6 / 6	100
9	MODERATE	241	-38	103	265	420	7 / 7	100
10	MODERATE	33	377	42	381	420	8 / 8	100
11	QUIET	-1	-160	20	162	320	6 / 6	100
12	QUIET	25	30	-166	170	320	7 / 7	100
13	ACTIVE	-67	-163	304	352	570	5 / 5	100
14	ACTIVE	-20	-139	-80	162	570	3 / 3	100
15	ACTIVE	-115	1102	215	1129	570	3 / 5	60
16	ACTIVE	-17	-141	-11	142	570	9 / 9	100
17	QUIET	-21	-150	83	173	320	6 / 6	100
18	ACTIVE	14	-454	-256	522	570	7 / 7	100
19	ACTIVE	-113	1	-42	121	570	4 / 4	100
20	ACTIVE	369	-522	-375	742	570	5 / 6	83
21	QUIET	-71	-28	-155	173	320	8 / 8	100
22	MODERATE	-67	52	-194	212	420	6 / 6	100
23	ACTIVE	62	-171	40	187	570	6 / 6	100

* ARC 1 WAS A POSTINSERTION ARC

Table 6. Maximum Position Differences Between Two-TDRS BET and Reference BET Solutions for STS-29 (JSC)

ARC NO.	VENTING ACTIVITY LEVEL	MAXIMUM POSITION DIFFERENCE BETWEEN THE TWO-TDRS AND REFERENCE SOLUTIONS (METERS)					PASS/ FAIL
		RADIAL	CROSS-TRACK	ALONG-TRACK	TOTAL (RSS)	CERTIFICATION CRITERION	
1	ACTIVE	-54	217	-102	246	* 420	PASS
2	ACTIVE	-11	-75	-116	139	640	PASS
3	QUIET	-12	-59	27	66	280	PASS
4	MODERATE	6	94	-95	134	420	PASS
5	ACTIVE	25	-90	81	123	640	PASS
6	MODERATE	-23	62	108	127	420	PASS
7	QUIET	-5	-37	-11	39	280	PASS
8	ACTIVE	-7	-44	36	57	640	PASS
9	MODERATE	4	17	-20	26	420	PASS
10	MODERATE	3	28	36	46	420	PASS
11	QUIET	1	68	53	86	280	PASS
12	QUIET	-17	-92	9	94	280	PASS
13	ACTIVE	26	119	-49	132	640	PASS
14	ACTIVE	23	-79	-22	85	640	PASS
15	ACTIVE	-15	162	168	234	640	PASS
16	ACTIVE	-2	67	-6	67	640	PASS
17	QUIET	-7	-14	23	28	280	PASS
18	ACTIVE	4	-30	-9	32	640	PASS
19	ACTIVE	23	-148	-104	182	640	PASS
20	ACTIVE	-36	103	53	121	640	PASS
21	QUIET	8	42	-13	45	280	PASS
22	MODERATE	-5	68	-55	87	420	PASS
23	ACTIVE	33	-371	12	373	640	PASS

* ARC 1 WAS A POSTINSERTION ARC

solutions exceeded the certification criteria out of a total number of 151 solutions, corresponding to a 98-percent pass ratio. Arc 15 produced two failures and arc 20 produced one. The maximum total position difference of 1129 meters occurred during arc 15, primarily due to cross-track position differences.

Another measure of two-TDRS-only BTB solution accuracy is provided by comparisons with the reference BTB chain. Two-TDRS-only BTB differences in inclination and ascending node estimates did not subside until the fifth TDRSS batch after OMS-2. Total position differences were less than 610 meters for the entire postinsertion and deploy timeframe. During the deorbit preparation period, total position differences were below 244 meters.

The STS-29 reference and two-TDRS-only BET consisted of the 23 tracking data arcs described in Table 4. To more accurately model Shuttle trajectory perturbations, JSC Ground Navigation solved for 34 vents in both the reference and two-TDRS-only BET solutions. The first 32 vents had identical start and stop times. Comparable vent forces and associated energy changes were obtained between the reference and two-TDRS-only solutions. The majority of the semimajor axis changes were positive in sign, ranging from 12 meters to 1293 meters. This is normal for Shuttle flights due to translational effects from attitude control and attitude maneuvers.

Minimum trajectory overlap position differences between successive BET solutions were usually less than 360 meters. The two-TDRS-only BET produced comparable position differences relative to the reference BET. Comparisons were performed between the two-TDRS-only and reference BET solutions. Maximum position differences during the 23 data arcs are shown in Table 6. Every two-TDRS-only BET passed the certification criteria. Arc 23 produced the largest total position difference of 373 meters.

3.1.2 GSFC/FDF Orbit Determination Results for STS-29

The GSFC/FDF orbit determination results for STS-29 are presented in Table 7, which gives the maximum position differences between the two-TDRS and reference solutions (with along-track thrust modeling included in the solutions for arcs 1, 4, 5, 8, 13 and 19). The last column of Table 7 indicates whether the two-TDRS solution passed or failed the certification criterion for each arc. All the arcs passed the certification criteria except arc 8. The JSC vent solution for this arc showed that a large radial thrust component was applied, which explains why the application of an along-track thrust component in the FDF solution did not succeed in reducing the maximum position difference for this arc. Maximum overlap position differences between successive two-TDRS solutions ranged from 153 to 2453 meters. In summary, the GSFC/FDF analysis showed that 22 of the 23 arcs satisfied the two-TDRS navigation certification criteria.

3.2 STS-30

STS-30 was launched into a circular 28.85-degree inclination, 230-kilometer altitude orbit on May 4, 1989. The primary objective of the STS-30 mission was to deploy the Magellan interplanetary spacecraft. Nineteen tracking data arcs were used for navigation certification during this mission. The thrusting activity level, the start and stop times, and the number of GN and SN tracking passes for each tracking data arc are given in Table 8.

The GSFC tracking data evaluation results for STS-30 are documented in Reference 6. A total of nine S-band on-orbit passes were evaluated. Anomalies were encountered in four of the S-band passes and four of the C-band passes. Approximately 80 percent of the TDRS-East view periods and 70 percent of the TDRS-West view periods had at least 70 percent usable data. With Doppler compensation and GN times deleted, the TDRS-East data were approximately 90 percent usable and the TDRS-West data were approximately 94 percent usable.

The JSC and GSFC orbit determination results for STS-30 are presented in Sections 3.2.1 and 3.2.2, respectively.

3.2.1 JSC Orbit Determination Results for STS-30

STS-30 was the second of two low-inclination certification flights during which JSC and GSFC assessed the accuracy of two-TDRS orbit determination. This section describes the JSC two-TDRS BTB and BET certification results for each of the 19 data arcs.

Table 7. **Maximum Position Differences Between Two-TDRS and Reference Solutions for STS-29 (With Along-Track Thrust Modeling) (GSFC/FDF)**

ARC NO.	VENTING ACTIVITY LEVEL	MAXIMUM POSITION DIFFERENCE BETWEEN THE TWO-TDRS AND REFERENCE SOLUTIONS (METERS)					PASS/ FAIL
		RADIAL	CROSS-TRACK	ALONG-TRACK	TOTAL (RSS)	CERTIFICATION CRITERION	
1	ACTIVE	21	186	192	268	* 420	PASS
2	ACTIVE	52	47	430	436	640	PASS
3	QUIET	-11	45	-40	61	280	PASS
4	MODERATE	3	-17	-379	380	420	PASS
5	ACTIVE	31	207	318	381	640	PASS
6	MODERATE	0	104	380	394	420	PASS
7	QUIET	3	-60	-8	60	280	PASS
8	ACTIVE	-42	-499	488	699	640	FAIL
9	MODERATE	14	-20	-147	150	420	PASS
10	MODERATE	-1	0	15	15	420	PASS
11	QUIET	16	0	112	113	280	PASS
12	QUIET	15	-211	157	263	280	PASS
13	ACTIVE	-77	-36	342	352	640	PASS
14	ACTIVE	-38	-173	26	179	640	PASS
15	ACTIVE	22	77	117	142	640	PASS
16	ACTIVE	4	115	244	269	640	PASS
17	QUIET	9	-62	-72	96	280	PASS
18	ACTIVE	9	165	188	250	640	PASS
19	ACTIVE	-18	344	-408	534	640	PASS
20	ACTIVE	-7	-26	46	53	640	PASS
21	QUIET	5	-31	27	41	280	PASS
22	MODERATE	-2	-90	-87	125	420	PASS
23	ACTIVE	85	-11	-519	525	640	PASS

* ARC 1 WAS A POSTINSERTION ARC

NOTE: ALONG-TRACK THRUST MODELING WAS APPLIED FOR ARCS 1, 4, 5, 8, 13, AND 19.

Table 8. **Tracking Arc Definition, Thrusting Activity Level, and Number of Tracking Passes for STS-30**

ARC NO.	VENTING ACTIVITY LEVEL	TRACKING INTERVAL				NO. OF TRACKING PASSES			
		START		END		GROUND NETWORK		TDRSS	
		DATE	GMT (HHMMSS)	DATE	GMT (HHMMSS)	S-BAND/ C-BAND	TOTAL	TDRS-E/ TDRS-W	TOTAL
1	ACTIVE	5/4/89	19:45:20	5/5/89	01:01:50	0 / 21	21	3 / 4	7
2	ACTIVE		22:52:00		05:09:00	0 / 7	7	5 / 4	9
3	QUIET	5/5/89	04:49:40		10:59:50	0 / 4	4	4 / 4	8
4	ACTIVE		10:09:10		16:00:00	0 / 4	4	3 / 4	7
5	MODERATE		15:56:10		20:19:40	0 / 4	4	4 / 3	7
6	ACTIVE		19:08:00	5/6/89	01:32:50	0 / 7	7	4 / 6	10
7	ACTIVE	5/6/89	00:00:50		05:21:40	1 / 1	2	4 / 3	7
8	QUIET		04:49:40		11:13:10	0 / 4	4	4 / 4	8
9	QUIET		09:42:10		14:15:50	0 / 1	1	4 / 3	7
10	ACTIVE		12:56:50		18:16:30	0 / 3	3	4 / 3	7
11	ACTIVE		17:44:30		23:49:00	0 / 6	6	5 / 5	10
12	ACTIVE		22:24:50	5/7/89	04:47:50	1 / 4	5	5 / 5	10
13	QUIET	5/7/89	04:12:10		11:26:20	0 / 5	5	4 / 5	9
14	ACTIVE		10:35:00		16:53:00	0 / 4	4	5 / 5	10
15	ACTIVE		15:57:20		22:26:00	0 / 7	7	6 / 5	11
16	ACTIVE		20:56:50	5/8/89	03:35:20	0 / 3	3	5 / 5	10
17	QUIET	5/8/89	03:06:00		10:01:30	1 / 5	5	5 / 3	8
18	ACTIVE		09:10:50		14:55:00	0 / 3	3	3 / 5	8
19	ACTIVE		12:28:50		18:40:10	0 / 12	12	7 / 6	13

The maximum position differences between the two-TDRS-only BTB and reference BET solutions are shown in Table 9. These results satisfied the certification criteria 92 percent of the time. In many cases, however, the reference and two-TDRS-only ascending node estimates differed by about 0.005 degree. This caused large out-of-plane position differences, with the result that several arcs failed the TDRS BTB acceptance criteria. In addition, the two-TDRS BTB processing required several revolutions to recover from ascending node errors induced by the separation maneuver on revolution 5 and by several other orbit perturbations during the flight. The ascending node errors are not a general characteristic of two-TDRS postmaneuver processing, however. For example, the post-OMS-2 plane was fixed within three TDRS passes. Analysis of the failed two-TDRS-only realtime BTB processing revealed that the errors were probably due to over use of the (UV) kΓ, which so constrained the BTB solutions that actual plane changes were not allowed.

Two-TDRS-only BTB processing met the postinsertion acceptance criterion with the exception of the first two solutions, which had significant (−0.012-degree) ascending node errors. The two-TDRS-only BTB chain was initialized on a one-orbit BET solution over the first two on-orbit TDRSS passes, which should not have changed the plane appreciably. The first TDRS-West pass outside of the initialization data arc corrected most of the plane error, and the two-TDRS-only BTB processing met the acceptance criteria throughout the rest of postinsertion. The large initial ascending node error highlights the weakness of TDRSS Doppler-only data in determining the orientation of the orbit plane.

Two-TDRS-only BTB processing during the predeorbit phase compared favorably with the reference BET. Position differences were for the most part less than 300 meters and were at all times under the 570-meter certification criterion for active periods. None of the ascending node errors seen in earlier processing were evident during the deorbit preparation period.

The STS-30 reference BET consisted of the 19 data arcs described above, within which JSC Ground Navigation solved for vent forces to more accurately model trajectory perturbations. All two-TDRS-only BET arcs met the acceptance criteria, as shown in Table 10. The maximum position difference between the reference and two-TDRS-only BET solutions, seen in arc 12, was 536 meters. Minimum overlap position difference comparisons between successive BET solutions were normally less than 300 meters. Arcs 4, 5, 12, and 14 initially failed the acceptance criteria but passed after postmission reprocessing. It is interesting to note that every failure was due to inclination and ascending node errors and the associated cross-track position error.

The majority of orbital energy changes during the flight were positive. Solved-for vents accounted for semi-major axis changes ranging from 20 to 293 meters. The arc 2 solution also solved for the large OMS separation maneuver following deployment of the Magellan spacecraft.

3.2.2 GSFC/FDF Orbit Determination Results for STS-30

The GSFC/FDF orbit determination results for STS-30 are presented in Table 11, which gives the maximum position differences between the two-TDRS and reference solutions (with along-track thrust modeling included in the solutions for arcs 2 and 15). The deployment of the Magellan spacecraft during arc 2 was also modeled. The last column of Table 11 shows that all the arcs passed the certification criteria. Except for arc 2, the maximum overlap position differences between successive two-TDRS solutions ranged from 100 to 1560 meters. In summary, the GSFC/FDF analysis showed that all 19 of the 19 valid arcs satisfied the navigation certification criteria.

3.3 STS-32

STS-32 was launched into a circular 28.5-degree inclination, 352-kilometer altitude orbit on January 9, 1990. The major objective of this mission was to retrieve the Long-Duration Exposure Facility (LDEF) spacecraft and return it to Earth. As the certification efforts for STS-29 and STS-30 had already certified the two-TDRS configuration for nominal STS support, the certification effort for STS-32 was focused on the period around the rendezvous activities. Consequently, there were only five tracking data arcs used for navigation certification during this mission. The thrusting activity level, the start and stop times, and the number of GN and SN tracking passes for each tracking data arc are given in Table 12.

The GSFC tracking data evaluation is documented in Reference 6. A total of 167 C-band GN on-orbit passes were evaluated. Anomalies were encountered in two of the C-band passes. Approximately 72 percent of the

Table 9. **Maximum Position Differences Between Two-TDRS BTB and Reference BET Solutions for STS-30 (JSC)**

ARC NO.	VENTING ACTIVITY LEVEL	MAXIMUM POSITION DIFFERENCE BETWEEN THE TWO-TDRS AND REFERENCE SOLUTIONS (METERS)					NUMBER OF TWO-TDRS SOLUTIONS PASSED/ TOTAL NUMBER	PERCENT PASSED
		RADIAL	CROSS-TRACK	ALONG-TRACK	TOTAL (RSS)	CERTIFICA-TION CRITERION		
1	ACTIVE	116	-488	-38	503	* 420	5 / 7	71
2	ACTIVE	-87	605	-253	662	570	7 / 8	88
3	QUIET	41	136	-148	205	320	8 / 8	100
4	ACTIVE	-61	54	217	232	570	7 / 7	100
5	MODERATE	-19	14	-403	404	420	4 / 4	100
6	ACTIVE	10	378	386	540	570	8 / 8	100
7	ACTIVE	-8	433	381	577	570	6 / 7	86
8	QUIET	33	203	126	242	320	8 / 8	100
9	QUIET	-56	-158	130	213	320	3 / 3	100
10	ACTIVE	-37	-651	-11	653	570	6 / 7	86
11	ACTIVE	-98	181	-234	311	570	8 / 8	100
12	ACTIVE	135	-187	505	555	570	6 / 6	100
13	QUIET	-4	136	203	245	320	9 / 9	100
14	ACTIVE	81	-226	399	466	570	7 / 7	100
15	ACTIVE	-44	79	-342	354	570	8 / 8	100
16	ACTIVE	-31	206	84	225	570	8 / 8	100
17	QUIET	-8	-34	-212	215	320	8 / 8	100
18	ACTIVE	-4	-429	460	629	570	3 / 4	75
19	ACTIVE	48	28	265	270	570	5 / 5	100

* ARC 1 WAS A POSTINSERTION ARC

Table 10. **Maximum Position Differences Between Two-TDRS BET and Reference BET Solutions for STS-30 (JSC)**

ARC NO.	VENTING ACTIVITY LEVEL	MAXIMUM POSITION DIFFERENCE BETWEEN THE TWO-TDRS AND REFERENCE SOLUTIONS (METERS)					PASS/ FAIL
		RADIAL	CROSS-TRACK	ALONG-TRACK	TOTAL (RSS)	CERTIFICA-TION CRITERION	
1	ACTIVE	-8	96	-83	127	* 420	PASS
2	ACTIVE	-23	172	185	253	640	PASS
3	QUIET						
4	ACTIVE	-30	-141	22	145	640	PASS
5	MODERATE	20	-168	177	245	420	PASS
6	ACTIVE	-33	133	6	137	640	PASS
7	ACTIVE	-38	109	209	239	640	PASS
8	QUIET						
9	QUIET	-10	58	49	77	280	PASS
10	ACTIVE	-8	-95	-208	228	640	PASS
11	ACTIVE	-56	-234	209	319	640	PASS
12	ACTIVE	-88	-202	-489	536	640	PASS
13	QUIET						
14	ACTIVE	-135	62	-418	444	640	PASS
15	ACTIVE	7	-194	-231	302	640	PASS
16	ACTIVE	8	-4	113	114	640	PASS
17	QUIET						
18	ACTIVE	16	-144	165	220	640	PASS
19	ACTIVE	4	-121	112	165	640	PASS

* ARC 1 WAS A POSTINSERTION ARC

NOTE: TWO-TDRS BET COMPARISONS WERE NOT PERFORMED FOR QUIET ARCS 3, 8, 13, AND 17

Table 11. **Maximum Position Differences Between Two-TDRS and Reference Solutions for STS-30 (With Along-Track Thrust Modeling) (GSFC/FDF)**

ARC. NO.	VENTING ACTIVITY LEVEL	MAXIMUM POSITION DIFFERENCE BETWEEN THE TWO-TDRS AND REFERENCE SOLUTIONS (METERS)					PASS/ FAIL
		RADIAL	CROSS-TRACK	ALONG-TRACK	TOTAL	CERTIFICATION CRITERION	
1	ACTIVE	13	147	177	231	* 420	PASS
2	ACTIVE	9	306	370	480	640	PASS
3	QUIET	15	-85	99	132	280	PASS
4	ACTIVE	-21	-299	362	470	640	PASS
5	MODERATE	1	4	87	87	420	PASS
6	ACTIVE	12	114	-36	120	640	PASS
7	ACTIVE	24	279	-421	506	640	PASS
8	QUIET	8	-29	-38	48	280	PASS
9	QUIET	2	80	61	101	280	PASS
10	ACTIVE	29	410	476	629	640	PASS
11	ACTIVE	-40	-423	267	501	640	PASS
12	ACTIVE	15	254	222	338	640	PASS
13	QUIET	-1	-2	34	34	280	PASS
14	ACTIVE	6	-430	420	601	640	PASS
15	ACTIVE	20	172	-398	434	640	PASS
16	ACTIVE	1	126	111	168	640	PASS
17	QUIET	3	-22	58	63	280	PASS
18	ACTIVE	-1	-164	176	240	640	PASS
19	ACTIVE	-102	65	461	476	640	PASS

* ARC 1 WAS A POSTINSERTION ARC

NOTE: ALONG-TRACK THRUST MODELING WAS APPLIED FOR ARCS 2 AND 15.

Table 12. **Tracking Arc Definition, Thrusting Activity Level, and Number of Tracking Passes for STS-32**

ARC NO.	VENTING ACTIVITY LEVEL	TRACKING INTERVAL				NO. OF TRACKING PASSES			
		START		END		GROUND NETWORK		TDRSS	
		DATE	GMT (HHMMSS)	DATE	GMT (HHMMSS)	S-BAND/ C-BAND	TOTAL	TDRS-E/ TDRS-W	TOTAL
1	ACTIVE	1/11/90	12:28:20	1/11/90	18:42:00	0 / 10	10	3 / 4	7
2	QUIET		17:22:50		23:36:30	1 / 4	5	4 / 5	9
3	QUIET		22:10:00	1/12/90	04:25:50	1 / 3	4	4 / 5	9
4	ACTIVE	1/12/90	03:54:00		10:22:00	0 / 4	4	4 / 4	8
5	ACTIVE		09:32:50		15:04:30	0 / 10	10	3 / 5	8

TDRS-East view periods and 81 percent of the TDRS-West view periods had at least 70 percent usable data. With Doppler compensation and GN times deleted, the TDRS-East data were approximately 81 percent usable and the TDRS-West data were approximately 93 percent usable.

The JSC and GSFC orbit determination results for STS-32 are presented in Sections 3.3.1 and 3.3.2, respectively.

3.3.1 JSC Orbit Determination Results

The maximum position difference comparisons between the two-TDRS-only BTB and reference BET solutions are shown in Table 13. One TDRSS BTB solution exceeded the certification criterion out of 25 total solutions, corresponding to a 96-percent pass ratio. Arc 5, which contained three attitude maneuvers, two rendezvous burns, and four midcourse correction maneuvers, produced the sole two-TDRS-only BTB failure; this failure occurred in close proximity to a rendezvous maneuver.

Total position differences between the two-TDRS-only and reference BTB solutions were usually less than 152 meters. Inclination and ascending node differences were acceptable, indicating that the two-TDRS-only BTB processing determined the correct orbital plane.

The STS-32 rendezvous certification period included five reference and three two-TDRS-only BET arcs. Comparable vent forces and associated energy changes were obtained for the two-TDRS-only and reference BET solutions. Semimajor axis changes for the solved-for vents ranged from 62 to 5068 meters. Minimum overlap position differences between successive BET solutions were less than 150 meters.

Maximum position differences between the two-TDRS-only and reference BET solutions for arcs 1, 4, and 5 are shown in Table 14. Each arc satisfied the certification criteria. Arc 1 produced the largest total position difference of 439 meters.

3.3.2 GSFC/FDF Orbit Determination Results

The GSFC/FDF orbit determination results for STS-32 are presented in Table 15, which gives the maximum position differences between the two-TDRS and reference solutions (with along-track thrust modeling included for arcs 1, 4, and 5). The two quiet arcs (arcs 2 and 3) passed the certification criteria, but all three active arcs (arcs 1, 4, and 5) failed the certification criteria. Arc 1 showed the largest maximum position difference, which can be attributed to three large ventings in both the radial and cross-track directions. Arcs 4 and 5 also included large ventings in the radial and cross-track directions. This explains why the application of along-track thrust components in the GSFC solutions did not succeed in significantly reducing the maximum position differences for these arcs. Except for arc 1, the maximum overlap position differences between successive two-TDRS solutions ranged from 99 to 5066 meters. In summary, the GSFC/FDF analysis showed that two of the five arcs satisfied the two-TDRS navigation certification criteria. However, GSFC/FDF was unable to corroborate the JSC results for the three active arcs because of thrust modeling limitations.

4.0 SUMMARY AND CONCLUSIONS

This section presents the JSC and GSFC/FDF conclusions from this certification study and discusses additional considerations.

4.1 CERTIFICATION CONCLUSIONS

During STS-29, STS-30, and STS-32, JSC Ground Navigation certified that the two-TDRS network is an effective tool for Shuttle navigation. Two-TDRS-only BTB processing satisfied the certification requirements for over 90 percent of the solutions obtained during each flight. BET processing met the acceptance criteria for every data arc considered in the three flight certification efforts. The BET state vector and vent solutions were quite similar to those of the reference solutions, and direct comparisons showed that these results were uniform throughout the data arcs.

Table 13. Maximum Position Differences Between Two-TDRS BTB and Reference BET Solutions for STS-32 (JSC)

ARC NO.	VENTING ACTIVITY LEVEL	MAXIMUM POSITION DIFFERENCE BETWEEN THE TWO-TDRS AND REFERENCE SOLUTIONS (METERS)					NUMBER OF TWO-TDRS SOLUTIONS PASSED/ TOTAL NUMBER	PERCENT PASSED
		RADIAL	CROSS-TRACK	ALONG-TRACK	TOTAL (RSS)	CERTIFICATION CRITERION		
1	ACTIVE	-35	-164	-187	251	700	7 / 7	100
2	QUIET	-	-	-	-	N/A	-	-
3	QUIET	-	-	-	-	N/A	-	-
4	ACTIVE	55	88	-34	109	700	9 / 9	100
5	ACTIVE	43	698	359	786	700	8 / 9	89

NOTE: TWO-TDRS-ONLY SOLUTIONS WERE NOT PERFORMED DURING THE QUIET PERIODS.

Table 14. Maximum Position Differences Between Two-TDRS BET and Reference BET Solutions for STS-32 (JSC)

ARC NO.	VENTING ACTIVITY LEVEL	MAXIMUM POSITION DIFFERENCE BETWEEN THE TWO-TDRS AND REFERENCE SOLUTIONS (METERS)					PASS/ FAIL
		RADIAL	CROSS-TRACK	ALONG-TRACK	TOTAL (RSS)	CERTIFICATION CRITERION	
1	ACTIVE	-61	363	239	439	750	PASS
2	QUIET	-	-	-	-	N/A	-
3	QUIET	-	-	-	-	N/A	-
4	ACTIVE	-10	-11	24	28	750	PASS
5	ACTIVE	-146	382	-67	415	750	PASS

NOTE: TWO-TDRS-ONLY SOLUTIONS WERE NOT PERFORMED DURING THE QUIET PERIODS.

Table 15. Maximum Position Differences Between Two-TDRS and Reference Solutions for STS-32 (With Along-Track Thrust Modeling) (GSFC/FDF)

ARC NO.	VENTING ACTIVITY LEVEL	MAXIMUM POSITION DIFFERENCE BETWEEN THE TWO-TDRS AND REFERENCE SOLUTIONS (METERS)					PASS/ FAIL
		RADIAL	CROSS-TRACK	ALONG-TRACK	TOTAL	CERTIFICATION CRITERION	
1	ACTIVE	265	10,232	17,346	20,141	750	FAIL
2	QUIET	1	16	48	50	280	PASS
3	QUIET	20	-51	-32	64	280	PASS
4	ACTIVE	-251	-139	2,333	2,350	750	FAIL
5	ACTIVE	1,267	-1822	5,596	6,020	750	FAIL

The GSFC/FDF orbit determination results for STS-29, STS-30, and STS-32 corroborated the JSC certification results. The GSFC/FDF analysis showed that 43 of the 47 certification arcs passed the certification criteria. GSFC/FDF was unable to corroborate the JSC results for the remaining four certification arcs because of thrust modeling limitations.

The GSFC/FDF tracking data evaluation showed that approximately 80 percent of the TDRS-East and TDRS-West view periods had at least 70 percent usable data. With Doppler compensation and GN times deleted, the TDRS-East data were approximately 91 percent usable and the TDRS-West data were approximately 94 percent usable.

The two-TDRS certification effort has established the ability of TDRSS to detect and correct for unmodeled orbital energy changes. In the JSC BET processing, the presence of TDRSS data results in more precise vent solutions, because of the close proximity of the TDRSS data to the solved-for events. In the JSC BTB mode, the effects on orbital energy from drag mismodeling, translational effects from Shuttle venting and attitude control, attitude maneuvers, and burn mismodeling are picked up faster and more accurately than was the case with the ground-only network. In addition, the increased communications coverage from the two-TDRS network allows more timely and accurate translational maneuver confirmation, which leads to faster recovery of the JSC Ground Navigation state vector solution. Finally, TDRSS data, used in conjunction with C-band ground data, give good early state vector solutions. This capability has been used several times in the recent past to update and significantly improve the onboard state vector in the revolution following OMS-2.

4.2 CONCLUDING REMARKS

The successful two-TDRS certification effort has already resulted in a significant reduction in on-orbit C-band radar support. In some circumstances, however, the processing of TDRSS Doppler data alone has proved to be insufficient. A normal TDRSS tracking pass duration ranges from 35 to 60 minutes. The JSC Ground Navigation software automatically splits TDRSS batches in the event of a modeled translational maneuver or a change in the telemetry bit rate or transmitter frequency. The resulting shorter TDRSS batches often give adequate results during quiet and moderate activity periods, but a short TDRSS batch often does not give a good BTB solution during very active periods, such as a multiburn rendezvous sequence. In addition, two-TDRS-only BTB processing sometimes needs extra time to recover from orbital plane errors induced by unmodeled or poorly modeled translational maneuvers. In a two-TDRS-only environment, the requirement for accuracy may, in some cases, have to be traded off against the need for a timely state vector.

By comparison, a C-band ground pass will give at least a good local solution in under 10 minutes of tracking. As a result, C-band ground tracking is still required for periods having strict state vector accuracy requirements, for periods requiring state vectors soon after an event, such as a deployment, and for postmaneuver processing.

Another consideration for future C-band scheduling is the availability of usable TDRSS tracking data. For example, TDRS stationkeeping maneuvers and Shuttle attitude-related antenna blockages can result in periods of unusable TDRSS tracking data. During the STS-32 mission, two TDRS-West maneuvers resulted in unusable TDRS-West tracking data for two revolutions after the first maneuver and one revolution after the second maneuver. Consequently, the TDRS-East satellite tracking was augmented by ground C-band trackers during those periods.

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