Space Flight Technology, German Space Operations Center (GSOC)
Deutsches Zentrum für Luft- und Raumfahrt (DLR) e.V.

Texus-39
Orion GPS Tracking System

Flight Report

O. Montenbruck, M. Markgraf

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Texus-39 Orion GPS Tracking System – Flight Report

Prepared by :

O. Montenbruck, DLR/GSOC
Project Manager

M. Markgraf, DLR/GSOC
Lead Engineer

Approved by:

Th. Rupp, DLR/GSOC
Head Space Flight Technology

G. Schmitt, Kayser-Threde

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Scope

Within a joint project of DLR and Kayser-Threde, an Orion GPS receiver was flown onboard the Texus-39 mission as part of the payload service module. This document provides a summary and evaluation of the GPS tracking data collected by the Orion GPS receiver, including a comparison with Ashtech G12 measurements recorded during the same flight.

1 Introduction

1.1 Mission Overview

The Texus-39 rocket was launched from ESRANGE, Kiruna, on May 8, 2001 (9:55 UTC). The payload segment weighed a total of 362 kg and comprised five biological and material sciences experiments in four distinct experiment units [1]:

- TEM 01-5: “Investigation of Marangoni Migration in Monotectic Al-Si Systems by Electrical Conductivity Measurements (4 Furnaces)”, H. Neumann (TU Chemnitz)
- TEM 06-21: “Second Messenger Concentration in Gravitactic Ciliates”, Dr. Hemmersbach (DLR Köln)
- TEM 06-16: “Microgravity Retardation to Vesicle Transport in Plants during Endocytosis and Exocytosis”, G. Scherer (University of Hannover) and A. Quader (University of Hamburg)
- TEM 03-4: ARTEMIS (Aerogel Furnace), L. Ratke (DLR Köln)

A dual stage Skylark 7 motor (Goldfinch II & Raven XI) carried the payload to an altitude of almost 250 km and allowed for a zero-g time of six minutes.

1.2 Sequence of Events

Key events of the Texus-39 mission are summarized in Table 1.1, which is based on reference data given in [1] and [2]. All times refer to Tuesday, 8 May 2001 (day of year 128, GPS week 1113).

Table 1.1 Texus-39 main events given in time since launch, UTC time, and GPS time

Event	h [km]	t [s]	UTC	GPS sec
Lift-off	0.3	0.0	9:55:00.0	208513.0
G12 GPS tracking lost		0.4	9:55:00.4	208513.4
Orion GPS tracking lost		2.7	9:55:02.7	208515.7
Burnout 1st stage		4.2	9:55:04.2	208517.2
Booster separation		5.5	9:55:05.5	208518.5
Ignition 2nd stage		6.2	9:55:06.2	208519.2
Orion GPS tracking re-acquired	~2.0	6.6	9:55:06.6	208519.6
Burnout 2nd stage	50.3	46.4	9:55:46.4	208559.4
ORSA tip release	66.9	55.2	9:55:55.2	208568.2
Yo-Yo despin completed	71.3	57.5	9:55:00.4	208570.5
Motor separation/RCS activation	73.9	59.0	9:55:59.0	208572.0
Start of zero-g	96.6	72.0	9:56:12.0	208585.0
G12 GPS tracking re-acquired	119.9	86.4	9:56:26.4	208599.4
Apogee	248.7	254.1	9:59:14.1	208767.1
End of zero-g	105.2	431.0	10:02:11.0	208944.0
Can removal	40.9	467.0	10:02:47.0	208980.0
Loss of GPS tracking	38.0	468.6	10:02:48.6	208981.6
Max. re-entry (18 g)	~30.0	480.0	10:03:00.0	208993.0
Heatshield release	~5.0	569.0	10:04:29.0	209082.0
Main parachute release		588.0	10:04:48.0	209101.0
Loss of signal by DLR TM		655.0	10:05:55.0	209168.0

1.3 Orion GPS Receiver and Antenna System

The Orion GPS receiver is a 12 channel L1 C/A code receiver, which has been modified by DLR/GSOC to support high-dynamics space applications. It has previously been flown on the TestMaxus-4 and Maxus-4 missions. During the various flight phases the receiver was subsequently connected to a tip, can and parachute antenna. For a detailed description of the receiver and the antenna system the reader is referred to [3] and [4].

2 Flight Data

2.1 Tracking Status and Signal Acquisition

The Orion receiver tracked the position and velocity of the Texus-39 payload from launch to reentry with the exception of a brief gap following the lift-off. 3D navigation was lost for a total of four seconds (t=2.7 s to 6.6 s), even though one to three satellites were continuously tracked throughout this interval. No signal interrupts were recognized when the tip was separated and tracking was performed via the can antenna. Prior to hard reentry, GPS tracking was terminated at t=468.6 s, when the can and the antenna were removed by aerodynamic load. Other than expected, tracking could not, however, be regained after full deployment of the main parachute, when a third antenna mounted in the four-leg bridle achieved full sky visibility. Apparently, the antenna cable shielding had been injured during fabrication of the parachute system and did not provide a sufficient signal level for GPS tracking.

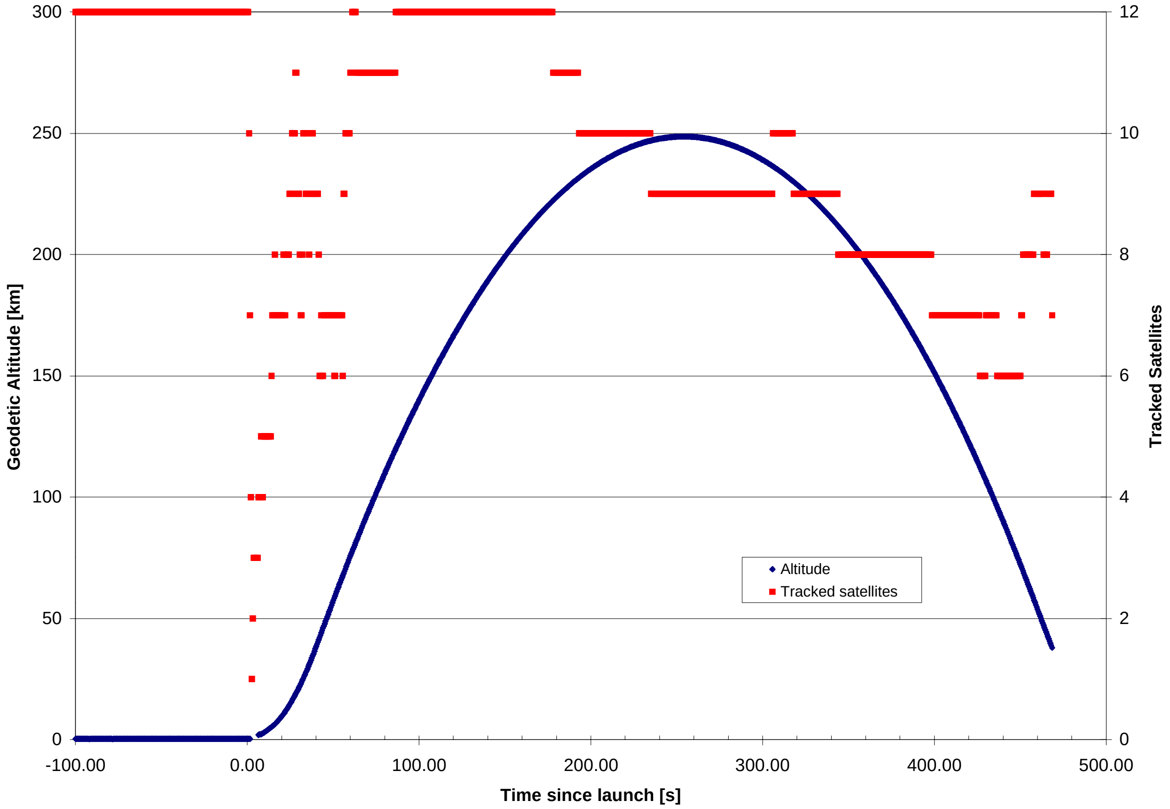

Fig. 2.1 Number of tracked satellites and altitude of the Texus-39 payload as a function of the mission elapsed time

Throughout the free flight phase the Orion receiver tracked between 6 and 12 satellites, yielding typical PDOP values of 1.3-2.7. The steady decrease in the number of tracked satellites correlates with pronounced changes in the signal-to-noise (SNR) ratios (Fig. 2.2), which indicates a slow but notable change in the antenna boresight direction during the parabolic flight. Drops of up to 10 dB may be observed and tracking of the northernmost satellites PRN #8 and #27 is lost even prior to apogee. Table 2.1 summarizes the GPS visibility conditions for the Texus-39 flight considering the elevation limit of –15° that was configured in the Orion GPS receiver. A total of twelve different GPS satellites were visible during the flight with elevation angles between +10° and +70°. Given the good GPS coverage of the Kiruna site, an elevation mask of +5° is suggested for future flights.

Table 2.1 GPS satellite visibility and tracking status during the Texus-39 campaign (elevation threshold –15°)

	Lift-off		Status
PRN	**Az**	**El**	
3	263.8	52.1	partly tracked (t<317 s)
6	119.6	3.9	tracked
8	353.1	17.6	partly tracked (t<192 s)
10	28.6	9.4	partly tracked (t<234 s)
15	145.0	70.3	partly tracked (t<398 s)
17	97.3	59.3	partly tracked (t<426 s)
18	149.1	34.2	tracked
21	178.0	9.7	tracked
22	211.7	34.3	tracked
23	139.7	40.7	tracked
26	68.2	21.0	tracked
27	328.2	22.5	partly tracked (t<177 s)
28	294.7	40.5	-
31	285.8	17.4	-

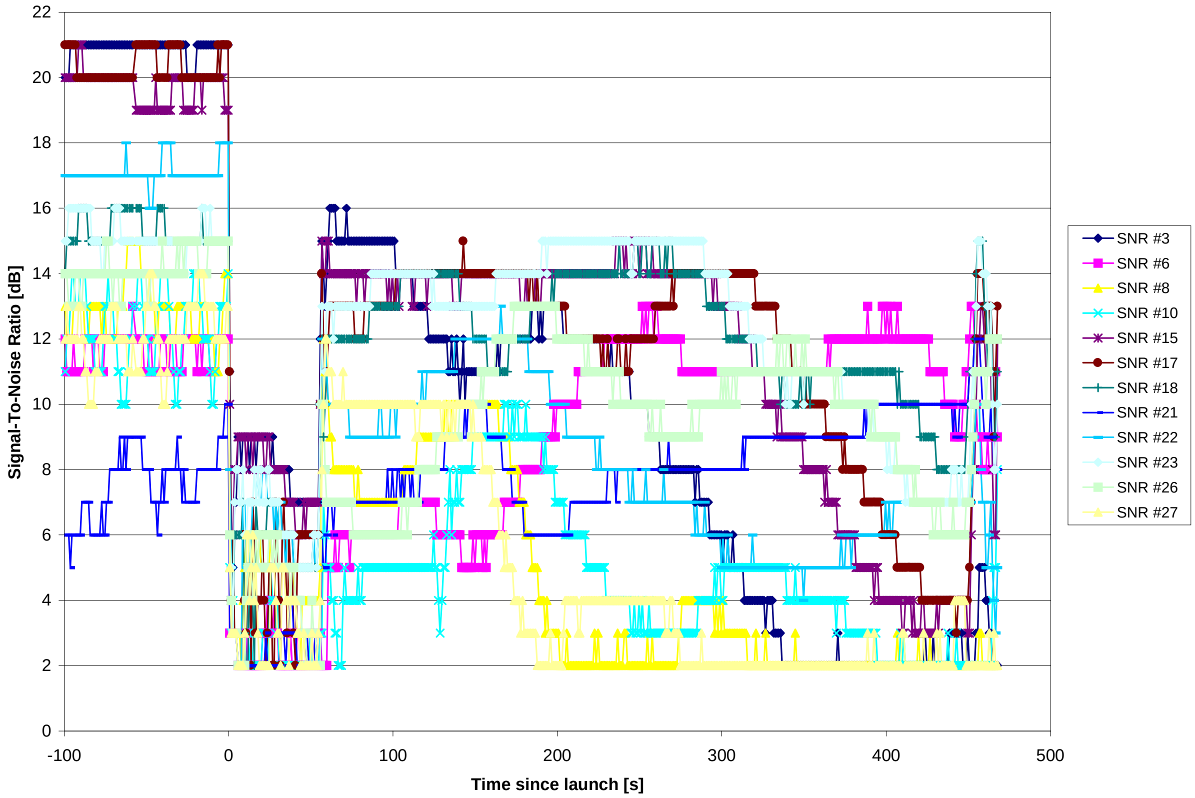

Fig. 2.2 Signal-to-noise ratio of GPS satellites tracked during the Texus-39 mission

2.2 Tracking Accuracy

The accuracy of the GPS Orion navigation solution was assessed by comparison with the Ashtech G12 HDMA data. To this end, the spherical coordinates given in the G12 POS message were converted to Cartesian WGS84 coordinates and interpolated for the uneven time stamps of the Orion navigation solution. A second order polynomial was applied to interpolate position values, while a linear approximation was used for the velocity values. In both cases, approximate accelerations were obtained from the Ashtech velocity data by a symmetric difference quotient. The resulting interpolation errors are essentially negligible with respect to the Orion data noise. To compensate for a known timing problem in the XF02 release of the G12 firmware (cf. [4]), an offset of 0.25 s was applied in the G12 velocity data prior to the interpolation and comparison with the Orion measurements

Table 2.2 Mean tracking errors and standard deviations of the Orion navigation solution as compared to the G12 reference data

Phase		**x [m]**	**y [m]**	**z [m]**	**vx [m/s]**	**vy [m/s]**	**vz [m/s]**
Free Flight (86s<t<460s)	Mean	-3.5	1.9	-13.3	-0.1	-0.1	0.1
	σ	2.4	3.2	6.2	0.6	0.8	0.6

As illustrated in Table 2.2, the Orion and G12 navigation solutions agree to roughly 20 m and 1 m/s during the free flight phase. Prior to t=86 s no reference data are available for comparison due to tracking problems of the G12 receiver.

A detailed view of the position and velocity errors of the Orion receiver (as referred to the Ashtech G12 solution) is given in Figs. 2.3 and 2.4. Overall, the observed differences between the Orion and G12 navigation solution are within expectations and readily understood by differences in the set of tracked satellites as well as the modeling of atmospheric path delays. In addition, no filtering or carrier phase smoothing is applied in the Orion navigation solution, which results in a higher noise level.

A notable increase of the velocity errors may be observed from t=458 s onwards, which is most likely related to the start of the rapid deceleration during the atmospheric re-entry.

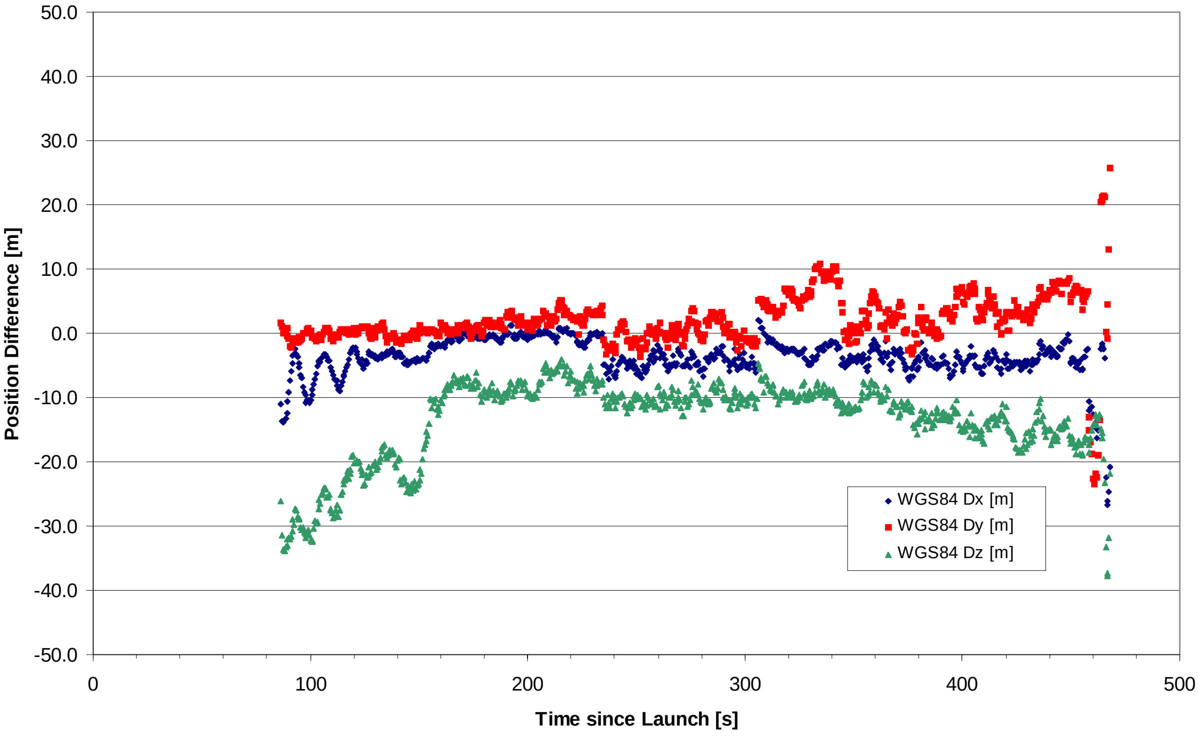

Fig 2.3 Mean offsets and standard deviations of the Orion position solution as compared to the G12 reference data

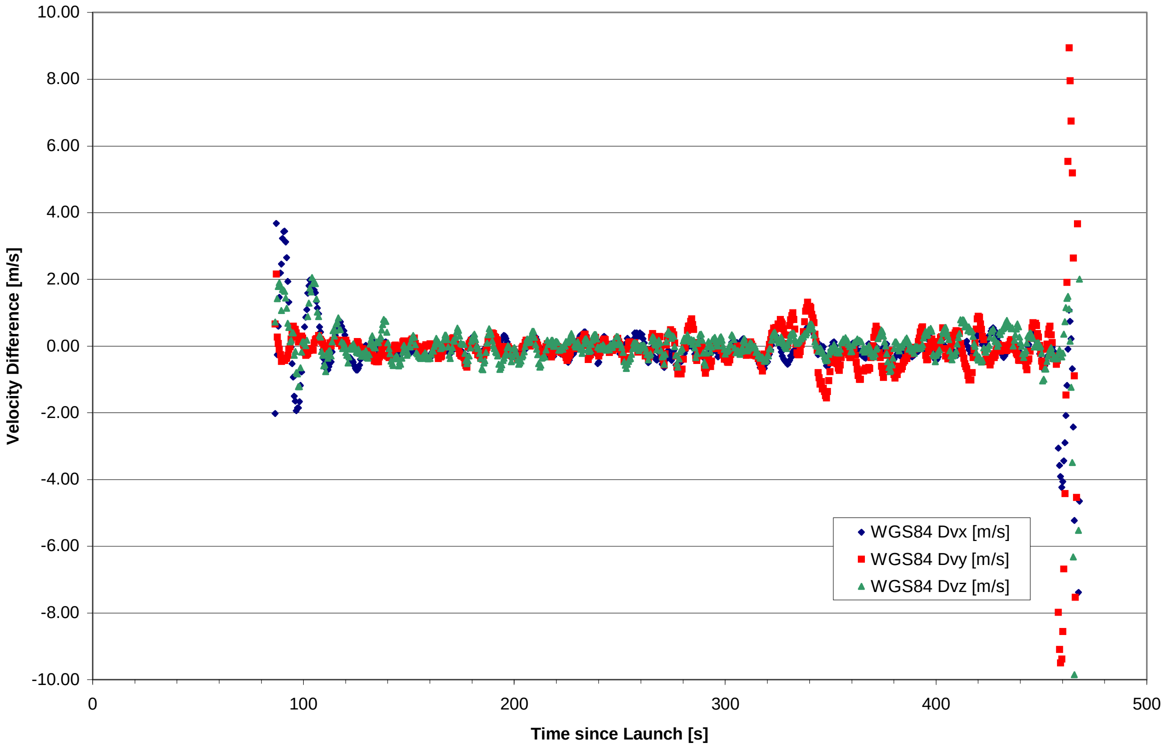

Fig 2.4 Mean offsets and standard deviations of the Orion velocity solution as compared to the corrected G12 reference data

2.3 Boost Phase

For further analysis of the tracking behavior under high dynamics, the boost phase of the Texus-39 mission is discussed in more detail. Due the lack of navigation data from the G12 receiver, no direct reference is available for a valuation of the Orion performance. Instead, a comparison is made with the nominal flight parameters and the internal consistency of position and velocity information is assessed.

As shown in Fig. 2.5, the rocket achieved a peak climb rate of about 1940 m/s around 43 s after lift off. The Orion velocity measurements exhibit a scatter of 50-150 m/s throughout the boost phase and are continuously affected by errors for at least 30 s after the boost end. For comparison, the vertical velocity has also been computed from second order differences of the geodetic altitude over one second time intervals. The achieved results are of similar quality as the Doppler derived velocity data, which indicates a noise of typically 100 m in the position solution. This is in fair accord with the results obtained on an Improved Orion rocket during the TestMaxus-4 campaign [5], where r.m.s. errors of 100-150 m and peak errors of 350 m where attained during the boost phase.

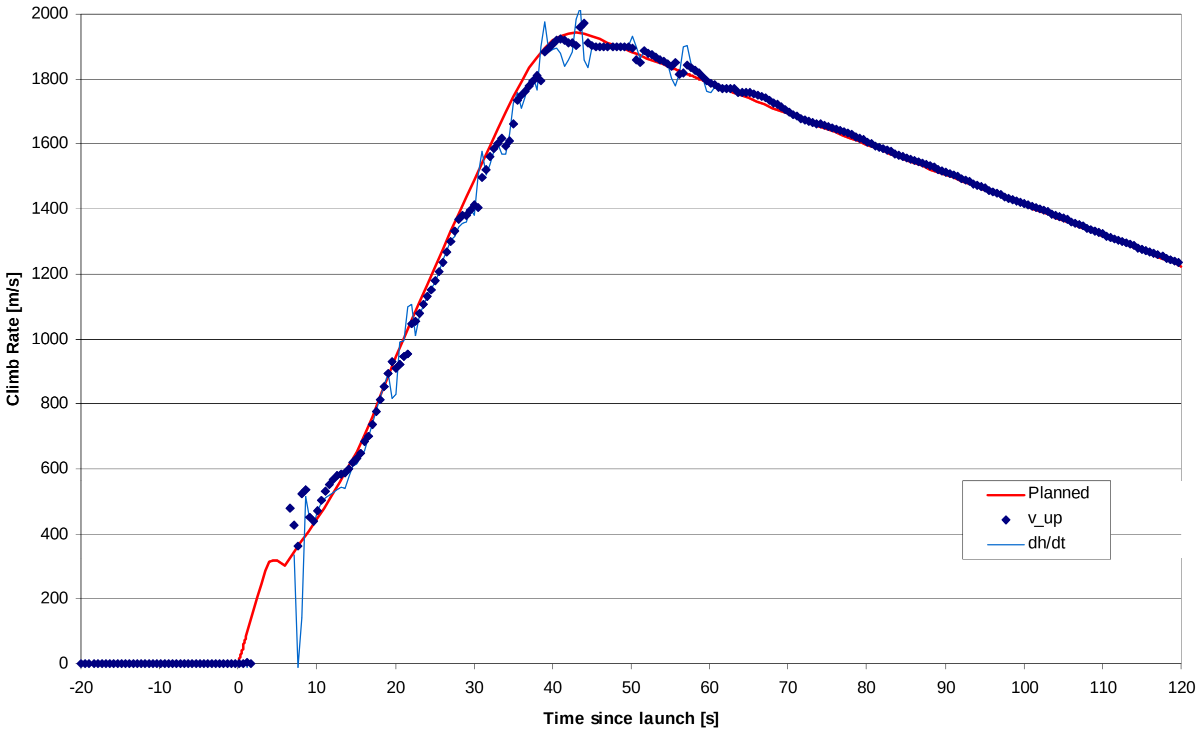

Fig 2.5 Velocity profile during the first 120 seconds of the Texus-39 flight. The Orion velocity solution is indicated by individual markers, while the differentiated positions are depicted by a solid line. For reference, the nominal velocity profile computed in the pre-mission analysis is shown by a bold red line.

As in previous missions ([4], [5]) the inferior tracking quality during the boost phase is well explained by a lacking robustness of the employed quartz oscillator against mechanical loads. More specifically, tracking problems are triggered by phases of high yerk, i.e. rapid changes in the total acceleration. Following this, the oscillator is found to recover within a relaxation time of 20-30 s before the normal performance is re-achieved. This is further illustrated by Figs. 2.6 and 2.7, which show the vertical acceleration (as obtained by differencing the velocity measurements) and the oscillator error during the time of interest.

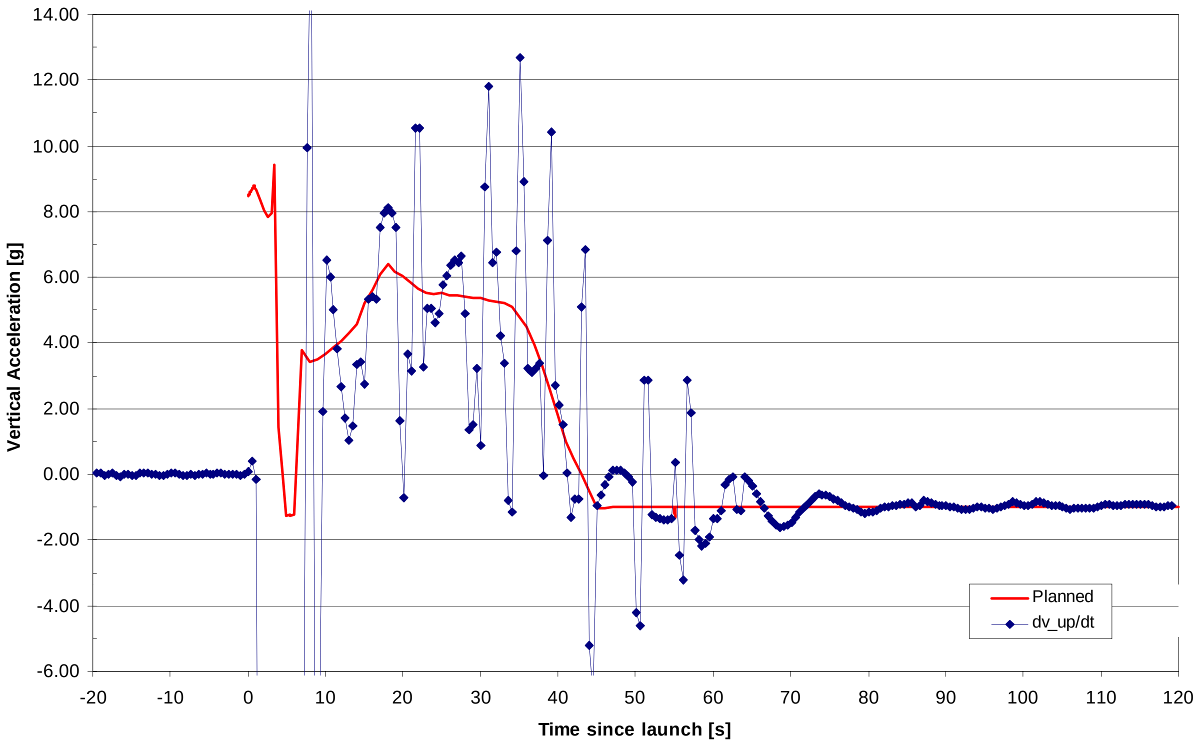

Fig 2.6 Vertical acceleration during the Texus-39 boost phase. Accelerations have been derived from measured velocities using symmetric difference quotients. For comparison the planned thrust profile is shown as a bold red line.

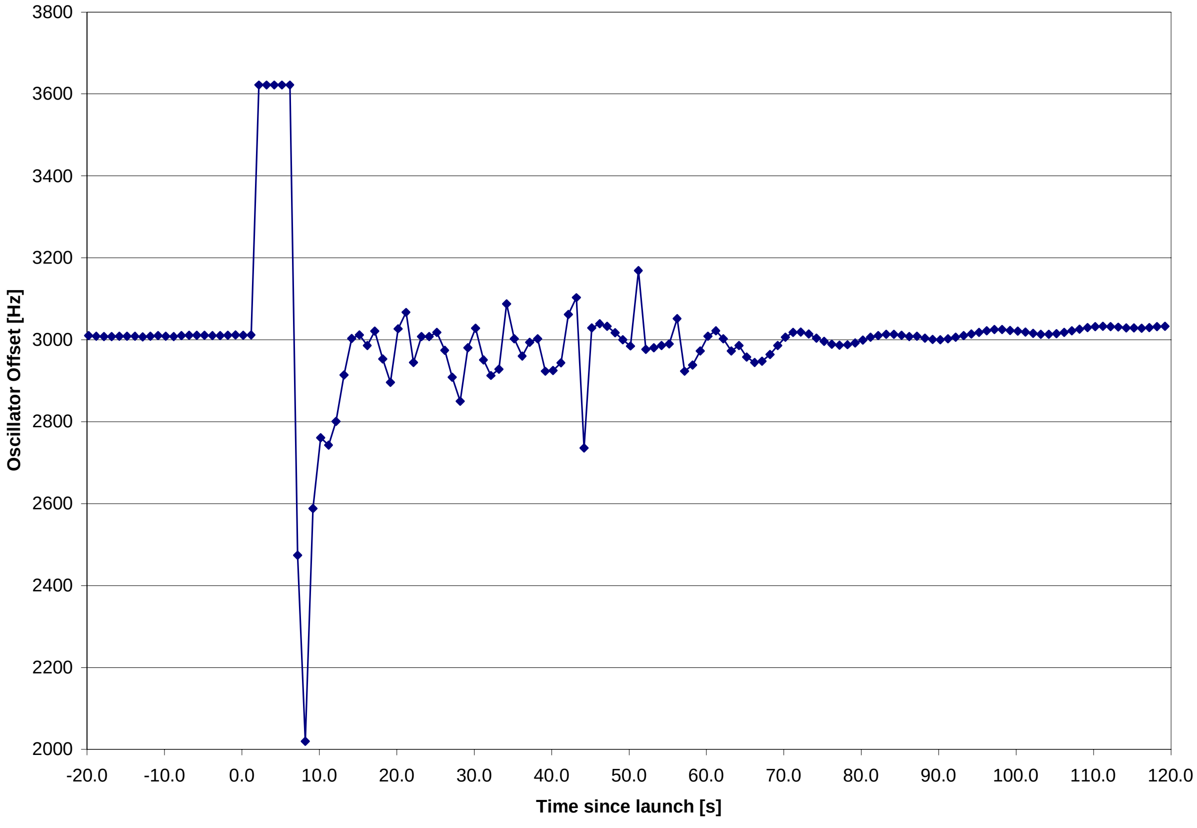

Fig 2.7 Oscillator error during the Texus-39 boost phase.

Summary and Conclusions

Within a joint project of DLR and Kayser-Threde, an Orion GPS receiver was flown onboard the Texus-39 mission as part of the payload service module. The receiver employs a Doppler aiding concept to support the high signal dynamics encountered in sounding rocket applications. During the Texus-39 mission the Orion GPS receiver shared a common tip, can, and parachute antenna system with the Ashtech G12 HDMA receiver, which was used for operational real-time tracking and IIP prediction.

The Orion receiver performed fully satisfactory during the parabolic free flight phase and provided position and velocity measurements in good accord (20 m, 1 m/s) with those of the G12 receiver. During the boost phase, the Orion receiver suffered from the known yerk sensitivity of the employed oscillator. Even though the navigation solution was notably degraded for roughly 70 s, tracking was only lost for four seconds prior to the ignition of the second stage. In contrast to this, the unaided G12 receiver failed to re-acquire 3D navigation completely for about 86 s, after it lost tracking at lift-off.

Concerning future flights of the Orion receiver, the use of alternate oscillators shall be investigated to improve the tracking reliability under high dynamics. In view of the good coverage of the Kiruna launch site by GPS satellites one may, furthermore, refrain from permitting the Orion receiver to track satellites below the mathematical horizon. Other than during the present flight, an elevation mask of about 5° is recommended for future missions. This is expected to improve the overall tracking accuracy during the parabolic free flight due to the incorporation of a larger number of good quality GPS signals.

References

[1] Jung W.; *Texus-39 Campaign Handbook*; 20 April 2001, DLR Moraba, Oberpfaffenhofen (2001)

[2] Engler W.; *Quicklook Texus-39*; Kayser-Threde, Esrange 8.5.01 (2001).

[3] Markgraf M., *Texus-39 GPS Experiment – Interface Control Document*; TEX39-DLR-ICD-0001; Version 1.0, 24 Jan. 2001; DLR Oberpfaffenhofen (2001).

[4] Montenbruck O., Markgraf M.; *Maxus-4 Orion GPS Tracking System – Flight Report*; MAX-4-DLR-RP-0001; 5 July 2001; DLR Oberpfaffenhofen (2001).

[5] Markgraf M. Montenbruck O.; *Orion GPS Post-flight Data Analysis Report - TestMaxus-4 Campaign*;TMX4-DLR-RP-0001; 28 June 2001; DLR Oberpfaffenhofen (2001).

Annex

A.1 Trajectory Polynomials

The following command sentences define the trajectory polynomials used for the representation of the nominal Texus-39 trajectory inside the Orion GPS receiver software:

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ˆLT18˜
ˆF51 0    +0.000 +2245617.4    +0.9654 +12.581569  +866998.7    +0.6260  +4.494843 +5886991.4    +2.8218 +38.26476167˜
ˆF51 1    +4.000 +2245821.9   +99.4286  -1.714286  +867072.9   +35.1714  -0.285714 +5887613.7  +303.6571  -3.42857162˜
ˆF51 2    +6.000 +2246016.1   +89.6023  +5.536131  +867142.5   +32.2145  +1.869464 +5888215.3  +275.7082 +18.5128217B˜
ˆF51 3   +16.000 +2247463.2  +212.0908  +7.786118  +867650.7   +73.8822  +2.569893 +5892819.5  +683.2381 +26.71105477˜
ˆF51 4   +30.000 +2251949.3  +432.0573  +6.097902  +869185.2  +146.2392  +1.916084 +5907592.5 +1439.9319 +21.6177167C˜
ˆF51 5   +40.000 +2256926.6  +553.3651  -1.614528  +870897.7  +181.5211  -0.637879 +5924229.1 +1877.5757  -4.30377860˜
ˆF51 6  +250.000 +2301939.0  -118.1477  -1.611014  +880982.7   -83.8796  -0.574352 +6128710.9   +87.4209  -4.3084116D˜
ˆF51 7  +465.000 +2202033.8  -819.4526  +4.758658  +836434.3  -331.4652  +2.022727 +5948218.1 -1787.6991  +9.60822571˜
ˆF51 8  +473.000 +2195798.9  -737.6964 +22.767857  +833918.2  -296.5119  +9.202381 +5934567.2 -1621.9643 +49.3690487A˜
ˆF51 9  +480.000 +2191730.9  -372.7112 +12.744755  +832285.5  -149.1364  +5.136364 +5925589.9  -827.6098 +27.7482526F˜
ˆF5110  +490.000 +2189257.0    +0.0000  +0.000000  +831299.0    +0.0000  +0.000000 +5920042.0    +0.0000  +0.0000007C˜
ˆET11˜
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