Annex C – MB-339CD DGPS IN-FLIGHT INVESTIGATION

C.1 FLIGHT TEST PLANNING

Specific flight profiles were defined in order to allow a comparative evaluation of the TANS and ASHTECH XII receivers on the MB-339CD aircraft. Particularly, the following manoeuvres, representative of the real dynamics conditions that can be encountered during most flight tasks, were performed:

- Turns with constant bank angles;
- Dives followed by a pull up to 4 g's along the four cardinal directions; and
- High dynamic manoeuvres as tonneau and stick-jerks.

The first type of manoeuvre was performed in order to evaluate the antenna masking effect. The second is a typical weapon-aiming manoeuvre, while the third type of manoeuvre was performed in order to obtain a rough estimation of the DGPS positioning accuracy. The last type of manoeuvre was performed in order to test the receivers in a high dynamic environment.

It must be underlined that a determination of the accuracies provided by two systems was not considered essential in this phase of the program and therefore it was not carried out in the MB-339CD test campaign. This was done for two good reasons.

- The availability of a copious literature concerning previous evaluations conducted of DGPS systems, confirmed the high accuracies declared by TRIMBLE and ASHTECH for the two systems under test. This was particularly true for straight-and-level flight conditions and low dynamic manoeuvres; and
- The difficulty of measuring the system accuracy during execution of flight trials. In order to prove that a DGPS system meet its accuracy requirements, an independent reference system is needed with an accuracy of at least 8 (preferably 10) times better. Moreover, the verification should be carried out over the full flight envelope. Systems that could be possibly used were cinetheodolites or laser trackers, with accuracies in the order of 0.2 – 0.5 metre RMS. However, neither cinetheodolites nor laser tracker facilities were available in this phase of the program.

C.2 FLIGHT DATA ANALYSIS

As expected, during straight-and-level flight both receivers under test performed satisfactorily, with no significant data losses recorded. However, during execution of dynamic manoeuvres both systems frequently lost lock to the satellites. Analysing the dynamics of the aircraft it was understood that this phenomenon could be due to shielding of the GPS antenna by the aircraft body (wings, fuselage and tails). Data analysis also showed that during dynamic manoeuvres both systems experienced a very significant increase of the PDOP factor. However, some remarkable differences were noted between the two receivers in terms of reacquisition time after data losses.

C.2.1 GPS Data Losses and Reacquisition

The INS data (recorder by the FTI) relative to variations of significant flight parameters in a period of a few minutes (heading, altitude, pitch, bank, etc.) are shown in Figure C-1. Identification of the aircraft parameters, together with the various scales, is given in Table C-1.

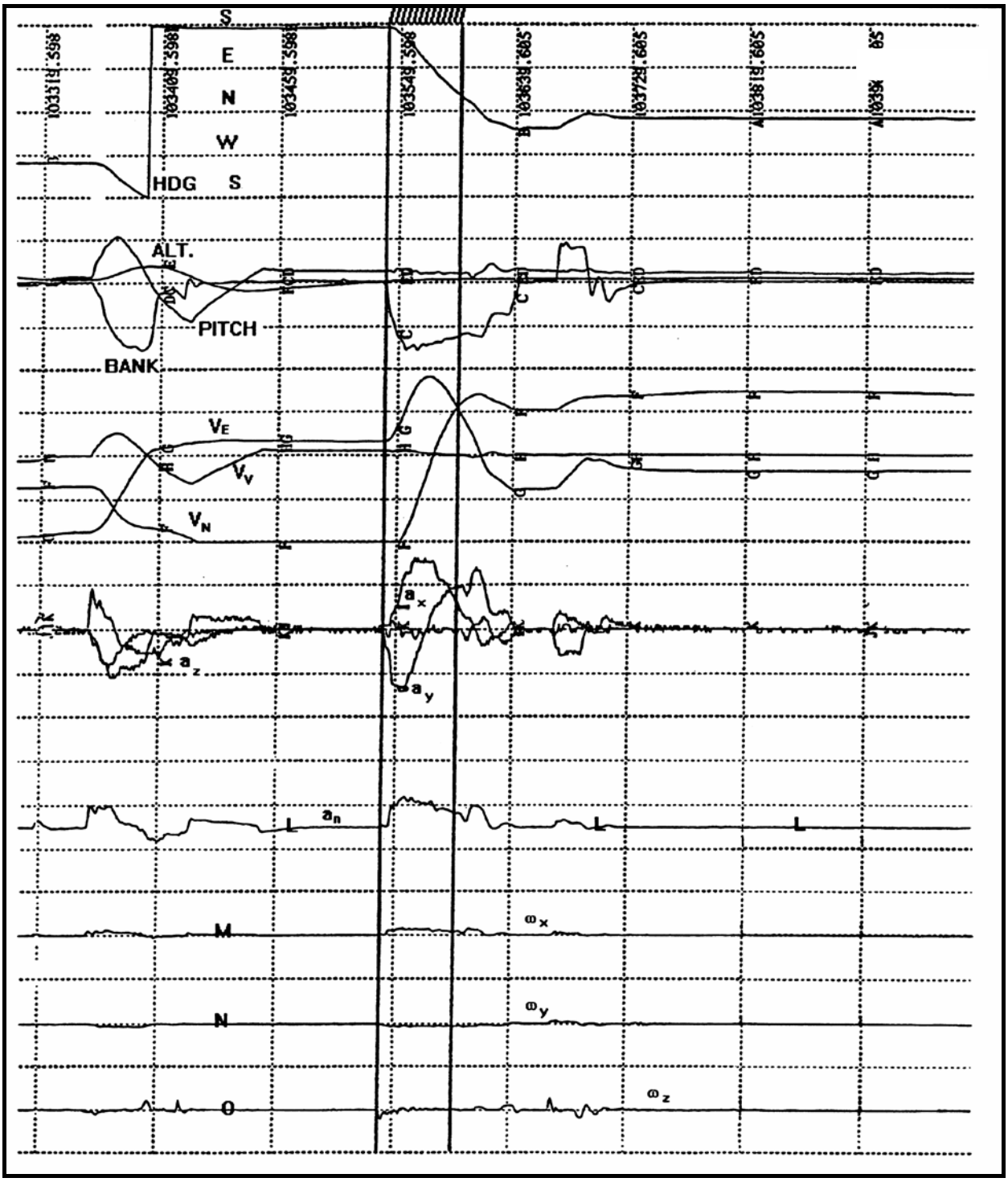

Figure C-1: INS Data Recorded by the FTI.

Table C-1: INS Data Identification

• B = Magnetic Heading (–180° ÷ 180°);	• I = Along X Acceleration (–80 ÷ 80 ft/s^2);
• C = Roll Angle (–90 ÷ 90°);	• J = Along Y Acceleration (–80 ÷ 80 ft/s^2);
• D = Pitch Angle (–40 ÷ 40°);	• K = Along Z Acceleration (–80 ÷ 80 ft/s^2);
• E = Barometric Altitude (0 ÷ 40000 ft);	• L = Normal Acceleration (–2 ÷ 6 g);
• F =NORTH Velocity (–800 ÷ 800 ft/s);	• M = Angular Vel. about X (–40 ÷ 40 °/s);
• G = EST Velocity (–800 ÷ 800 ft/s);	• N = Angular Vel. about Y (–40 ÷ 40 °/s);
• H =Vertical Velocity (–800÷800 ft/s);	• O = Angular Vel. about Z (–100 ÷ 100 °/s).

Particularly, the manoeuvre presented in Figure C-1 is a left turn (about 60° bank angle) corresponding to a GPS signal loss (for both TANS and the ASHTECH receiver). The Signal-to-Noise Ratios (SNR) measured for the satellites are shown in Figure C-2. It is evident that the signal intensity did not decrease gradually. This confirms that the signal loss, in this case, was due to interposition of an obstacle between the satellites and the antenna and not to receiver tracking problems.

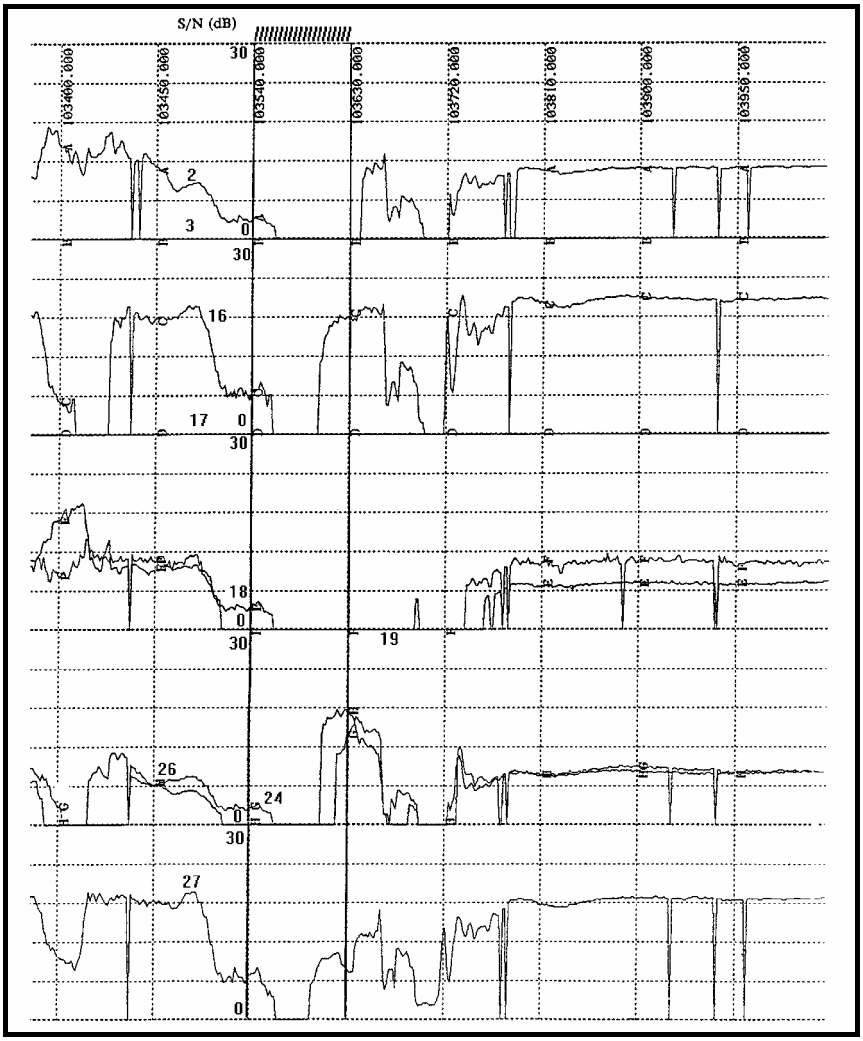

Figure C-2: SNR of the GPS Satellites.

The relative positions of the aircraft and satellites during the manoeuvre are shown in Figure C-3. It can be noticed that the aircraft body masked many of the satellites during the turn (starting from an initial heading of 180°). Signal reacquisition took place when the aircraft progressively reduced the bank angle and the heading variation rate.

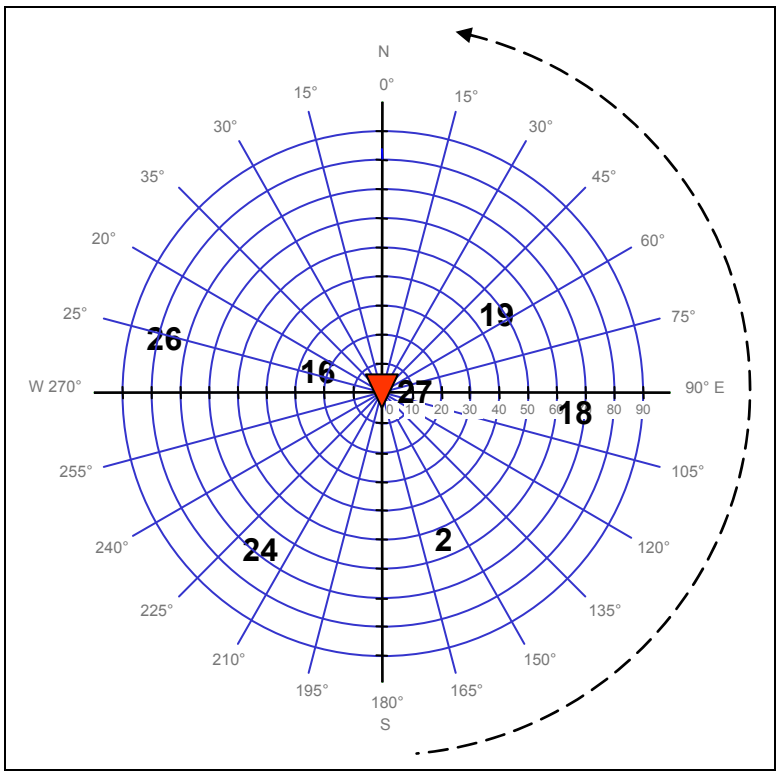

Figure C-3: Relative Geometry of the Aircraft and Satellites.

Similar considerations can be done looking at the Figures C-4, C-5 and C-6 relative to a left turn with –45° bank angle. However, in this case, a difference was noticed between the two receivers. As the position of the aircraft longitudinal axes during the turn got closer to satellite 2 (in the horizontal plane) the TANS receiver experienced a loss of track to all satellites, while the satellites 19 and 27 were still tracked by the ASHTECH receiver. This was due to the internal processing of the receiver. In fact, the ASHTECH receiver was able to maintain track to the satellites in view (19 and 27) even when their SNRs were very low (i.e., below 5 dB), while in the same conditions TANS lost track to all satellites. This significantly reduced the time required by the ASHTECH receiver for a new position fix as soon as four satellites were available again. Other trials, performed with similar conditions, confirmed that with the ASHTECH receiver shorter periods were needed to compute a new positioning solution after loss of satellite signals.

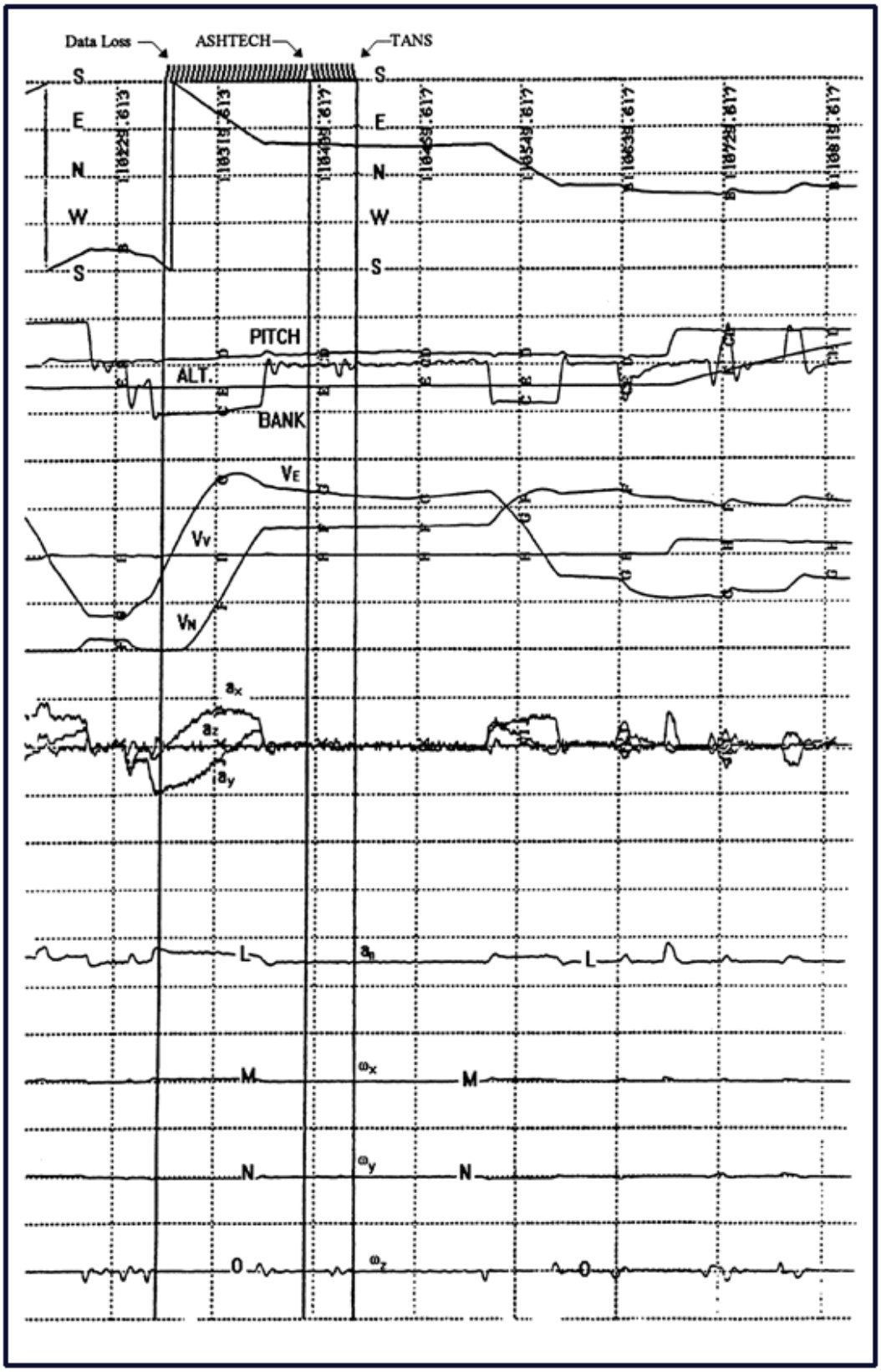

Figure C-4: ASHTECH and TANS Data Loss Periods (Manoeuvres).

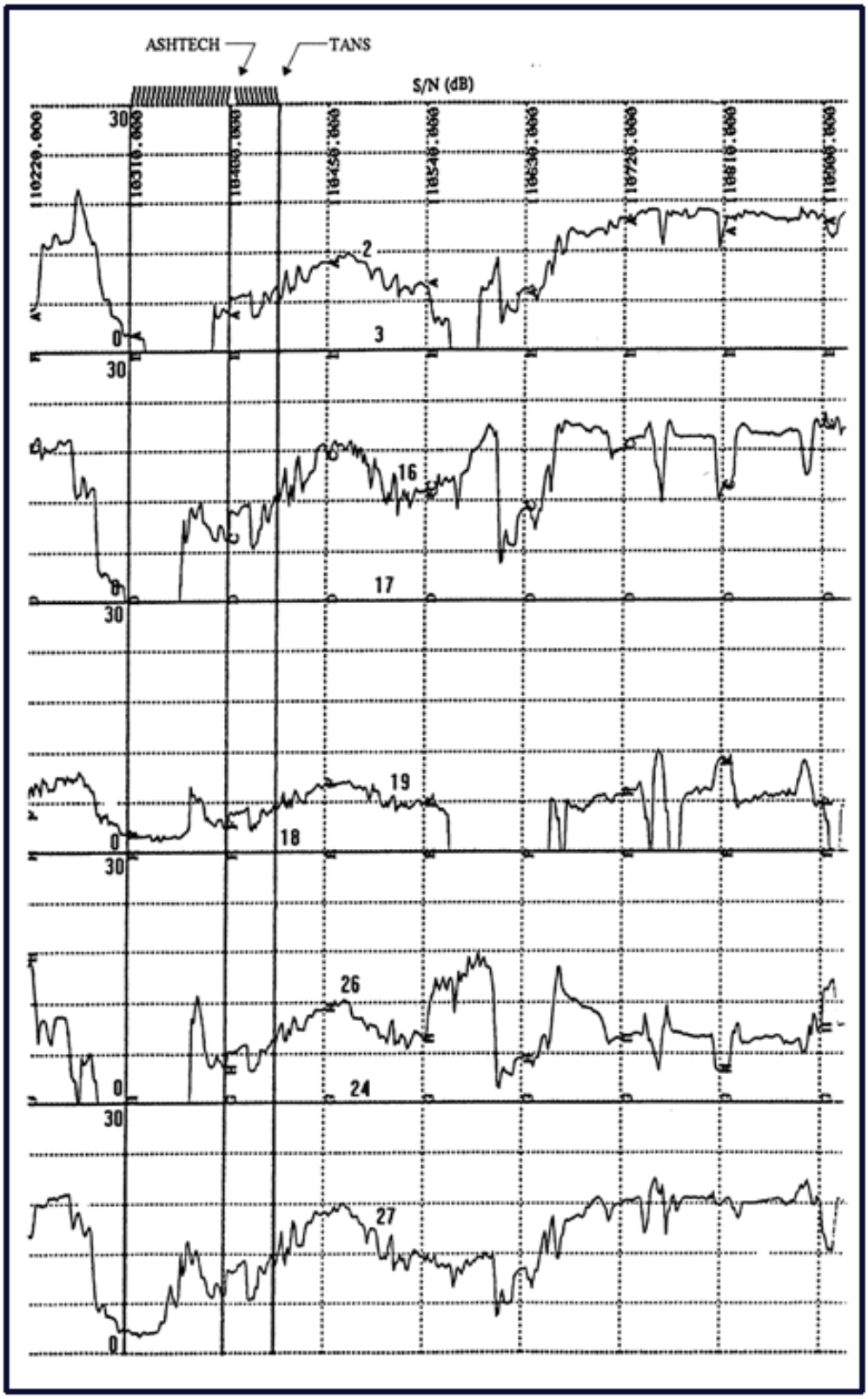

Figure C-5: ASHTECH and TANS Data Loss Periods (SNRs).

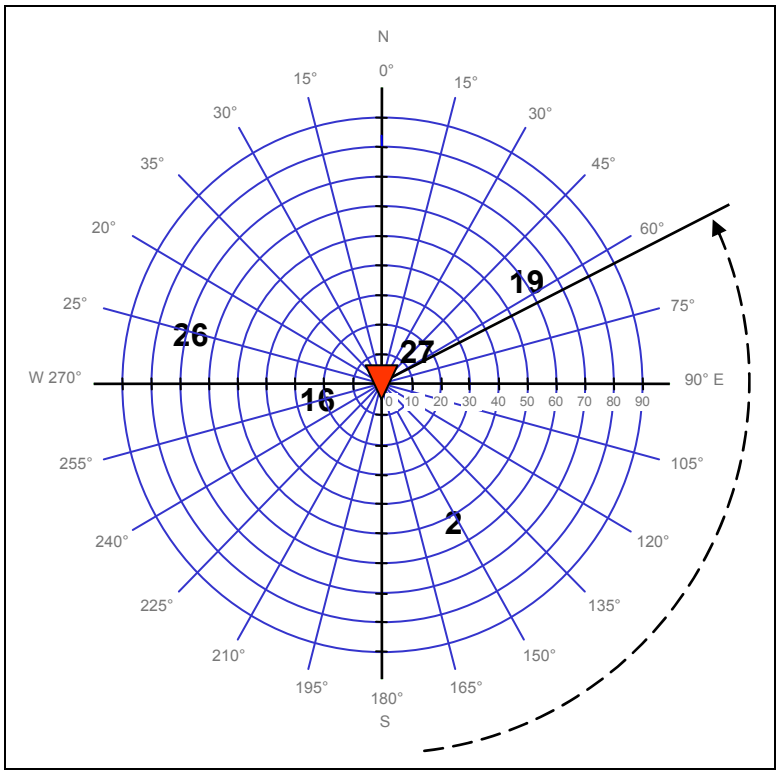

Figure C-6: Aircraft-Satellites Relative Geometry During Data Loss.

Figures C-7, C-8 and C-9 confirm that both the increase of PDOP (due to degradation of satellite-receiver geometry) and the progressive reduction of the SNRs during dynamic manoeuvres were responsible, together with masking of the GPS antenna, for the satellite signal losses in the TANS receiver. In this case, the TANS navigation data were lost with a small variation of the aircraft-receiver relative geometry, loss occurred with a small variation of the aircraft-receiver relative geometry, and no satellites were lost due to masking. The ASHTECH receiver, in the same conditions, did not experience any signal loss.

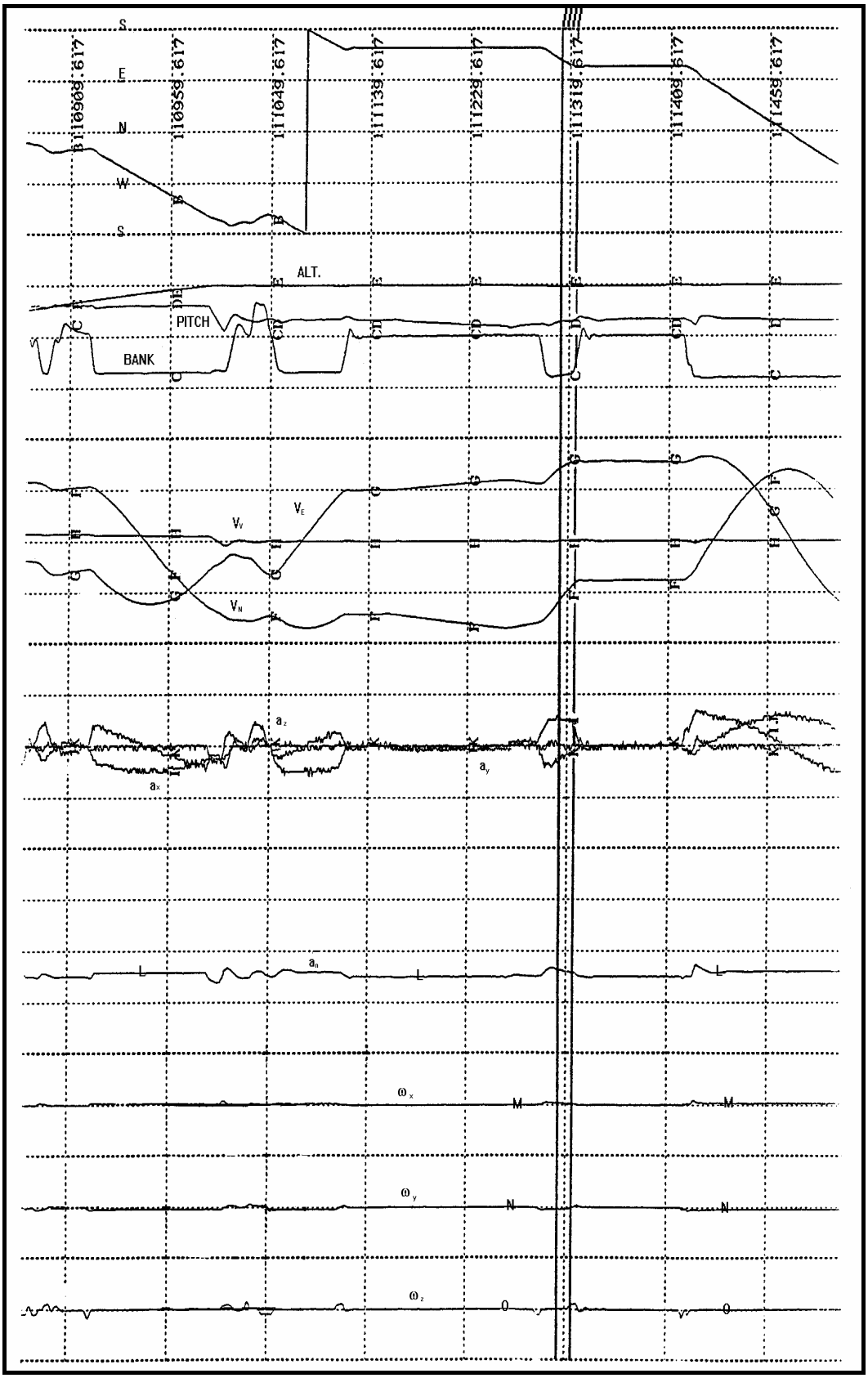

Figure C-7: TANS Data Loss Periods (Manoeuvres).

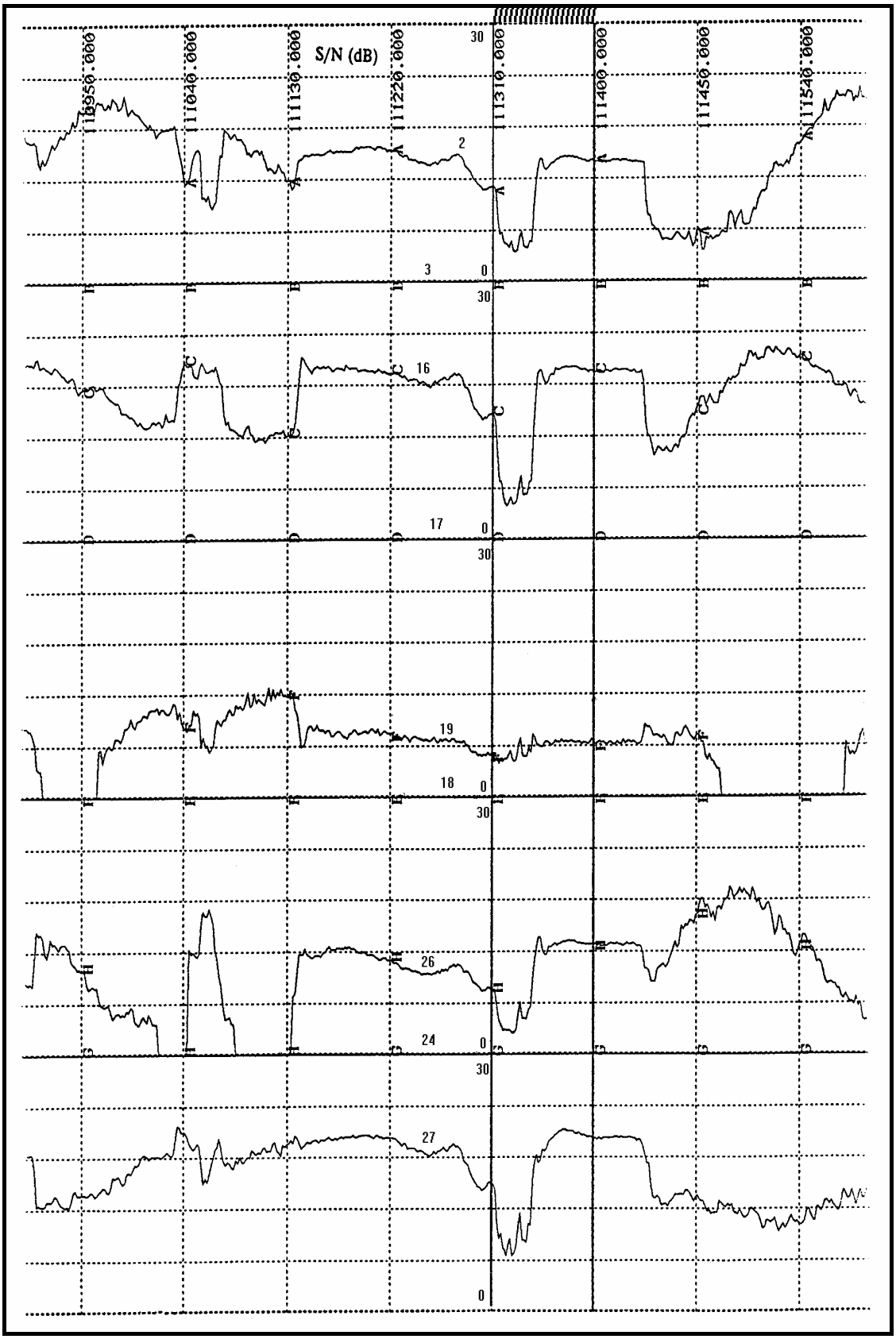

Figure C-8: TANS Data Loss Periods (SNRs).

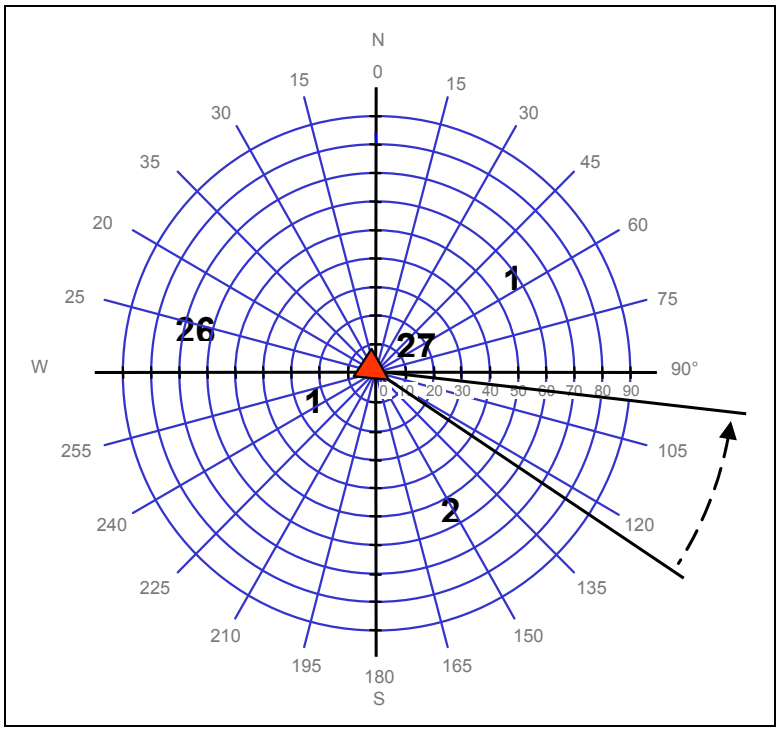

Figure C-9: Aircraft-Satellites Relative Geometry During TANS Data Loss.

Similar manoeuvres, performed in other directions, did not cause any problem to the receivers. An example is shown in the Figures C-10 and C-11 relative to a right turn at 40° bank, where some changes of satellite configuration occurred, but not signal losses.

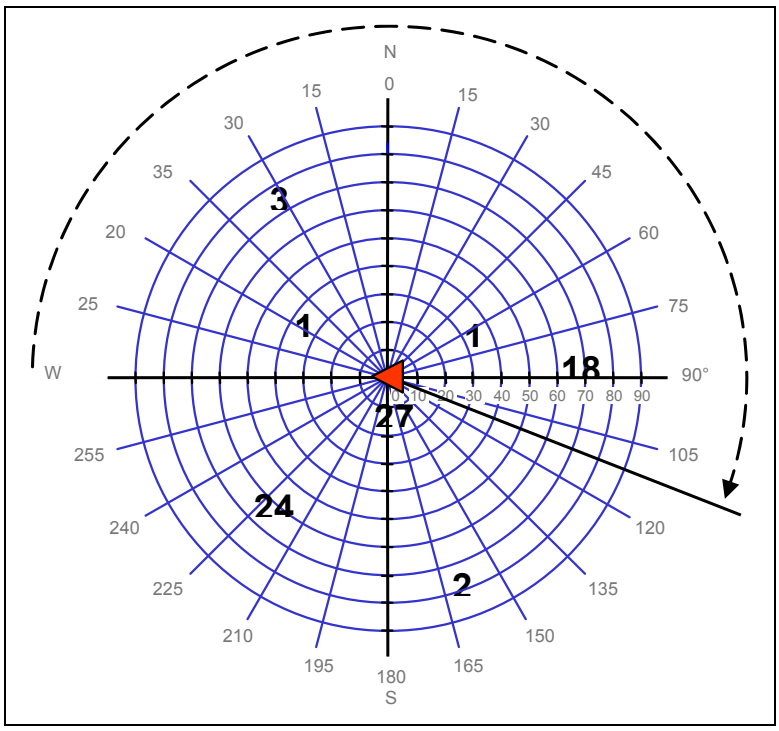

Figure C-10: Aircraft-Satellites Relative Geometry (No Data Losses).

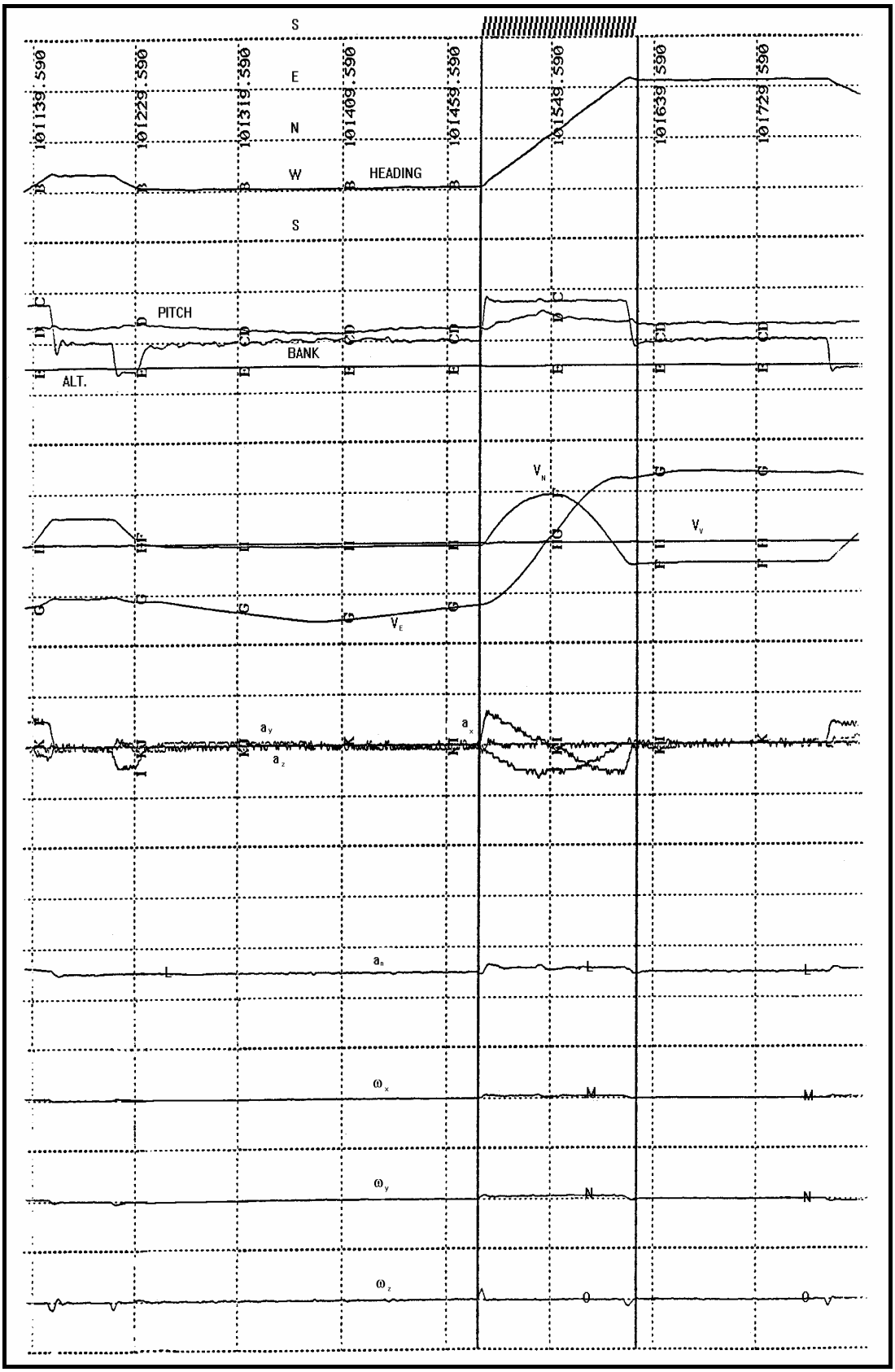

Figure C-11: Manoeuvres Without GPS Data Losses.

C.2.2 TANS 2-Dimensional Fix

The ASHTECH XII receiver could only provide a 3-dimensional (3-D) position fix (ϕ, λ and h) when a minimum of four satellites were tracked. On the other hand, the TANS receiver could provide a position fix even with only three satellites being tracked. In this case, the altitude could be alternatively provided by another airborne sensor (e.g., a radar or a barometric altimeter) or the system could use the last available altitude data to provide a 2-dimensional (2-D) position fix (ϕ, λ). The preferred option had to be selected on the ground using a PC and, for the MB-339CD flight test campaign, the second option was chosen (see paragraph 6.4.3, Chapter 6).

During the trials, it was observed that with only three satellites being tracked by the TANS receiver, the accuracy of the 2-dimensional position data decreased considerably, even when the altitude of the aircraft was kept constant. Particularly, during the trials, the availability of only 3 satellites determined a significant error in the latitude computation, while the longitude data was almost unaffected. This is shown in Figure C-12 where a short leg of a flight trial is represented (the full horizontal track is shown in Figure C-13).

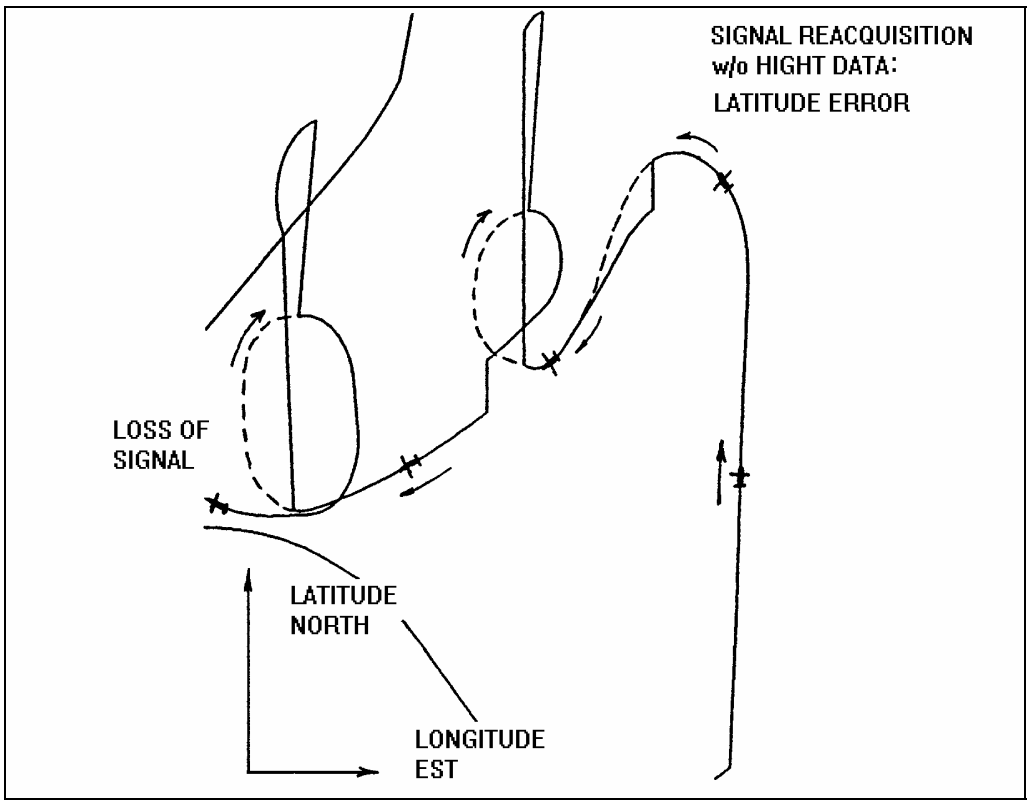

Figure C-12: Latitude Error (TANS – 3 Satellites).

During execution of one left and two right turns at constant altitude, shielding of the GPS antenna occurred, so that only three satellites were tracked. In these situations, the TANS receiver continued to give 2-dimensional position data (using the last available altitude), but the TANS latitude data showed a remarkable error compared with the INS latitude data.

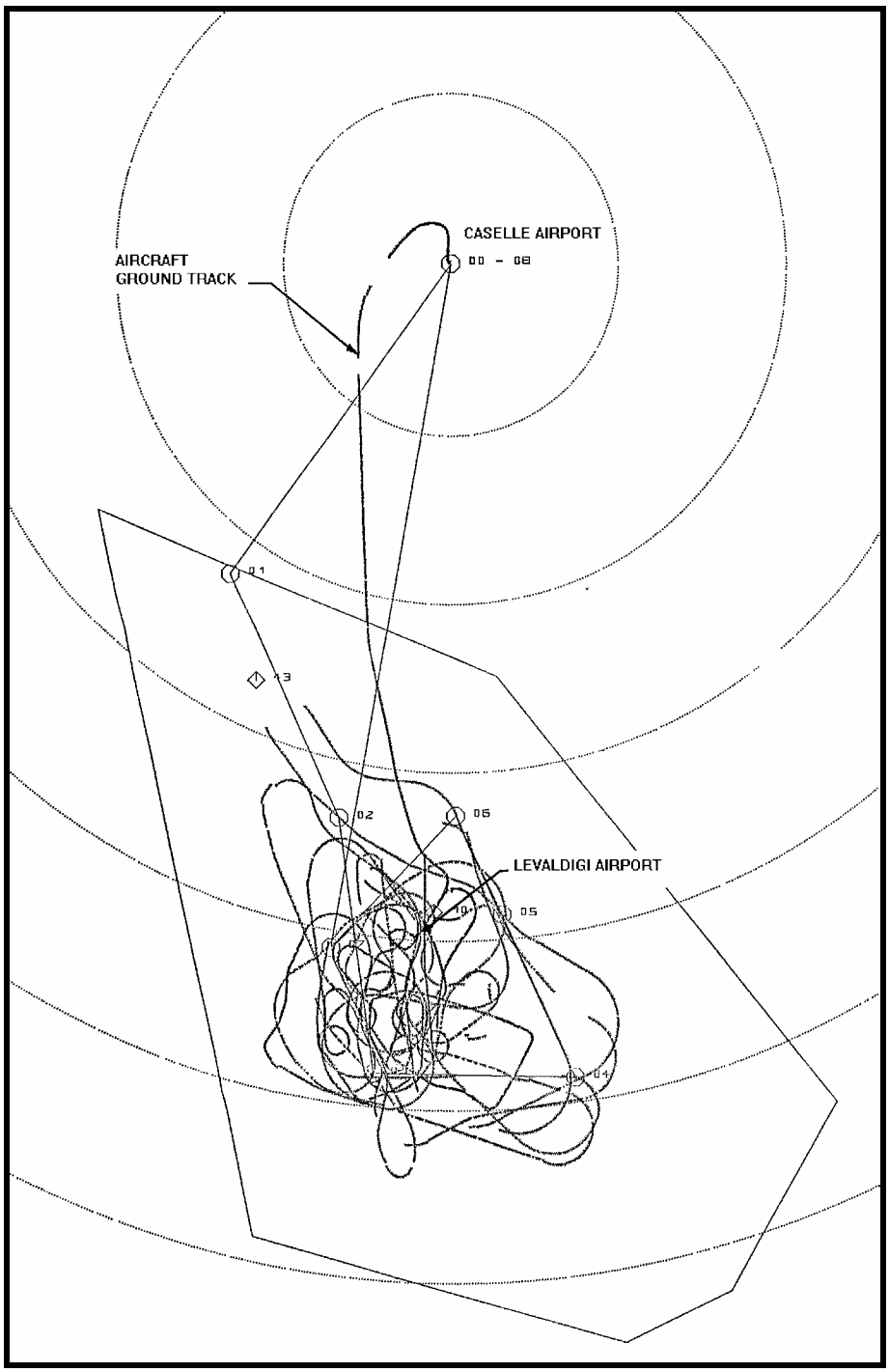

Figure C-13: Complete Ground Track (TANS – 3 Satellites).

C.2.3 Manoeuvres Investigation

Figure C-14 shows that a change of satellite configuration, even with low dynamics aircraft manoeuvres, may determine significant accuracy degradation. Particularly, the loss of one satellite (from five to four satellites tracked), determined a considerable increase of the PDOP.

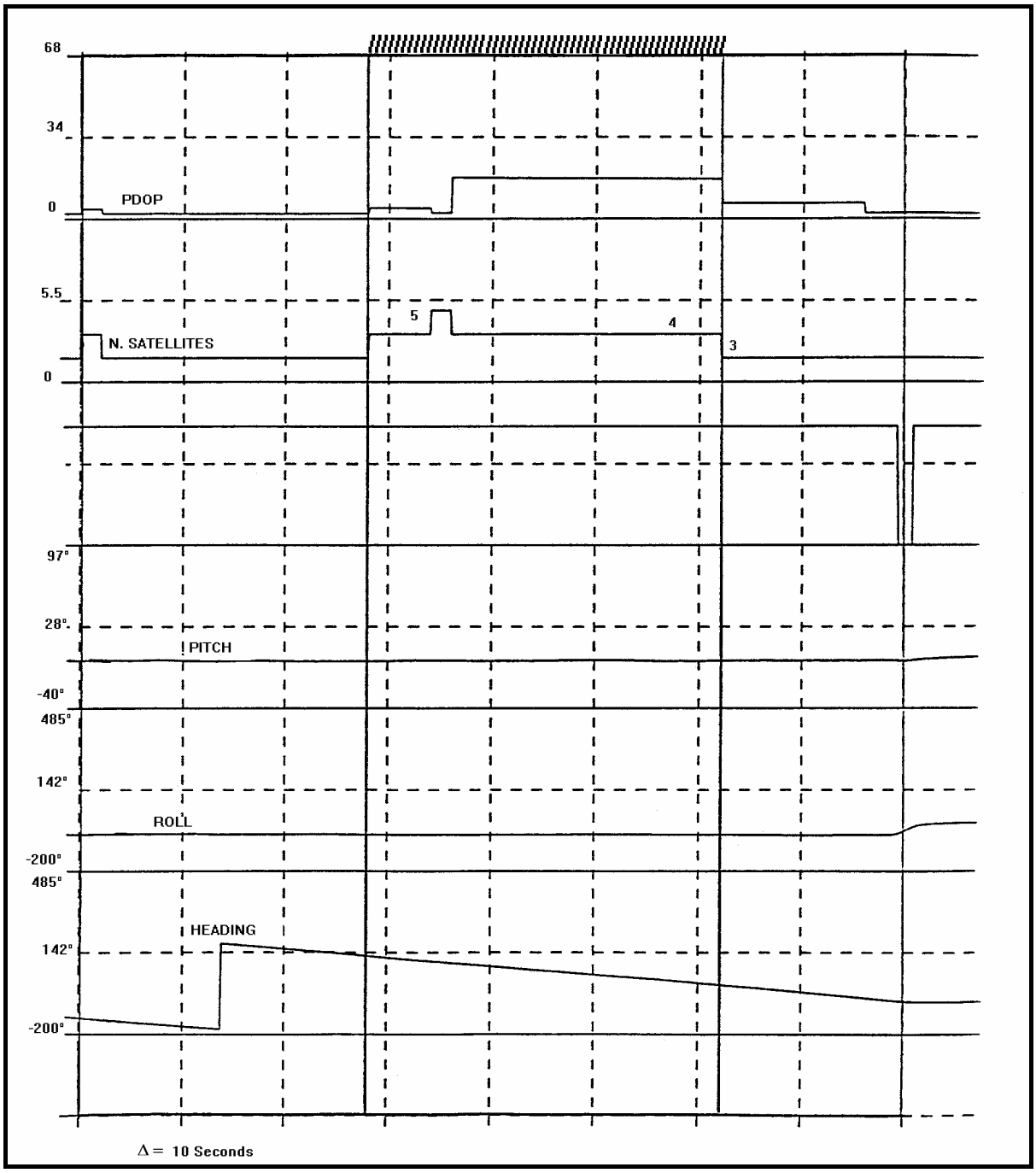

Figure C-14: PDOP Increase with Loss of 1 Satellite.

We therefore started to investigate if the problem could be significantly amplified by medium/high dynamics aircraft manoeuvres typical of high performance aircraft flight test. The flight parameters relative to a stick-jerk manoeuvre are shown in Figure C-14. During this manoeuvre the stick is repetitively pulled and pushed in order to obtain high jerks. This can be a very critical manoeuvre for the GPS receivers (especially for the code correlation circuits). The jerk limits were not specified for the ASHTECH receiver, while for TANS a jerk limit of 2 g/s (20 m/s^3) was quoted. During the manoeuvre shown in Figure C-15, a jerk of about 2.8 g/s was obtained, but no data loss occurred in any of the two receivers.

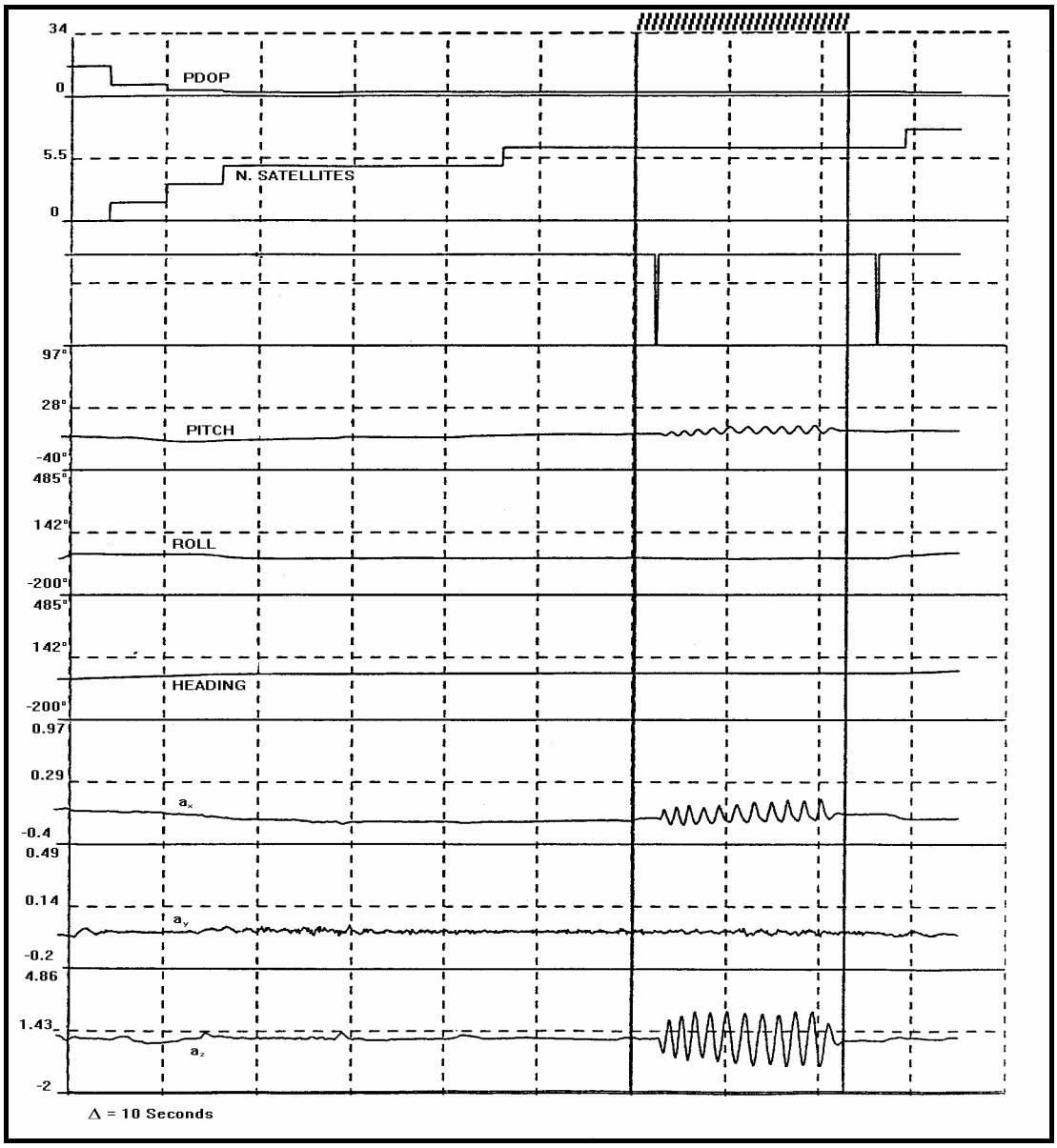

Figure C-15: Stick-Jerk Manoeuvre.

The data shown in Figure C-16 were recorded during three pull-up manoeuvres at 4 g's (typical in weapon-delivery trials). While during execution of the manoeuvres lock on to the satellites was kept (between four and three satellites tracked), at the end of each manoeuvre total signal losses occurred. The three manoeuvres were always preceded by straight-and-level flight (about 30 seconds) to allow optimal satellite tracking. Again, the reacquisition time after total signal losses was significantly longer for the TANS receiver than for the ASHTECH XII receiver.

Further tests were also performed with rapid-rolling horizontal manoeuvres (tonneau). In these cases, the lock to the satellites was efficiently maintained by both receivers, as long as the duration of the manoeuvres did not exceed a time about 5 seconds, which is considered adequate for the majority of flight tasks including rapid-rolling manoeuvres requirements. In general, the performances of the receivers during medium/high dynamics manoeuvres without turns were significantly better than the performances during turns with high bank angles (antenna masking).

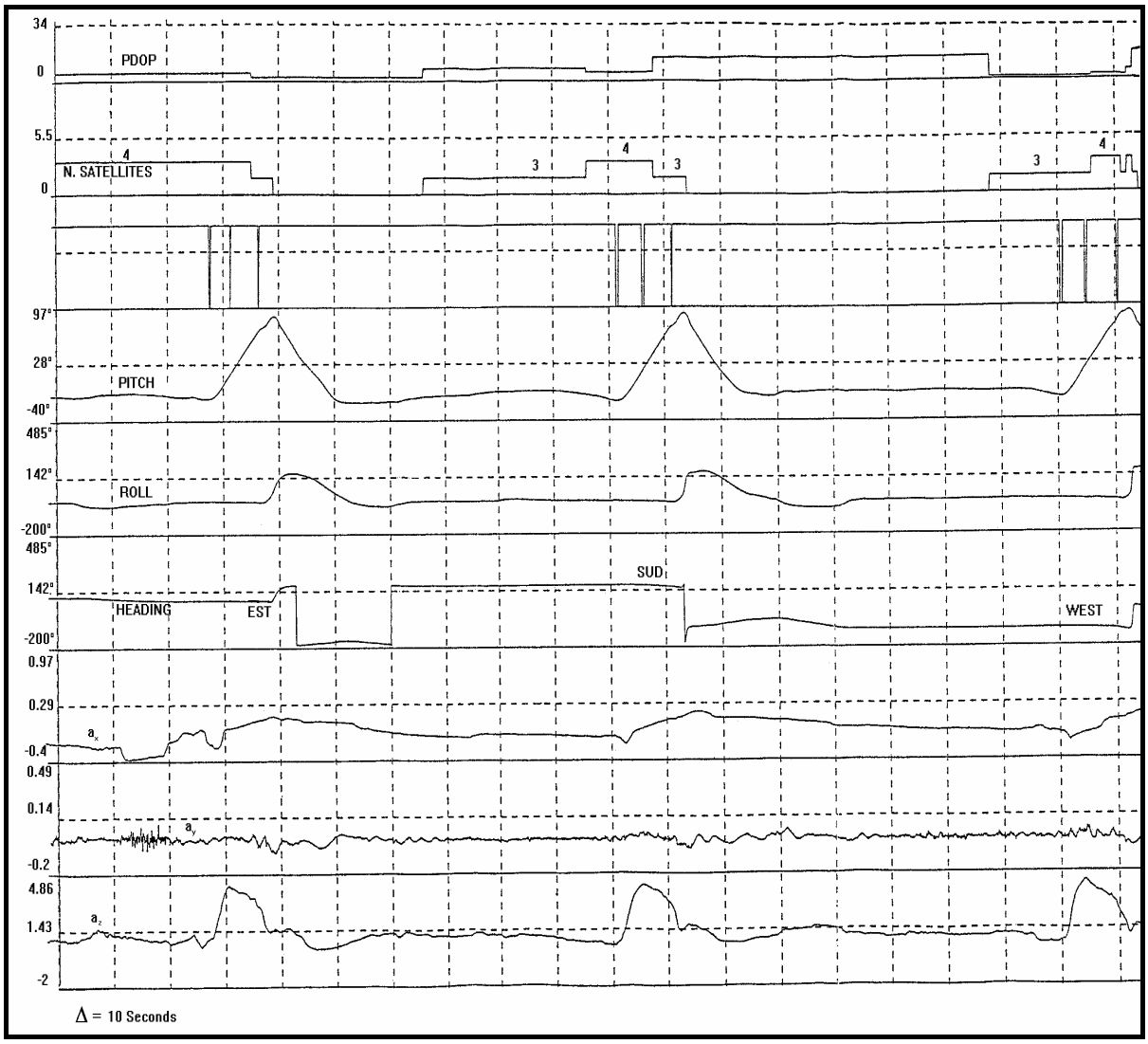

Figure C-16: Pull-up Manoeuvres (4 g's).

C.2.4 DGPS Data Quality

In order to approximately evaluate the accuracy provided by the systems under test, some low level (400 – 500 ft AGL) overshoots were executed over defined ground sites. Two of them were located at the Levaldigi Airport (edges of runway 03 and 21), distant about 50 nautical miles from Caselle Airport. Data from the on-board ASHTECH receiver were processed post-flight with differential corrections from the DGPS-RS receiver located at Caselle Airport. When the differentially corrected coordinates approached the runway edge coordinates (Figure C-17) a comparison was made between the DGPS altitude data and the altitude given by barometric altimeter (B/A) and the radar altimeter (R/A). Since the coordinates of the runway were expressed in the Italian Reference System (International Ellipsoid – Roma Monte Mario) they were transformed into WGS-84 (GPS datum). Altitude from the barometric instrument (height over MSL) was corrected with R/A data, also using the known MSL altitude of the runway. This was appropriate at low altitudes (400 – 500 ft AGL) since the quoted errors of the two instruments were: ± 3% for the R/A and ± 50 ft for the B/A. Figure C-18 shows the results of the comparison.

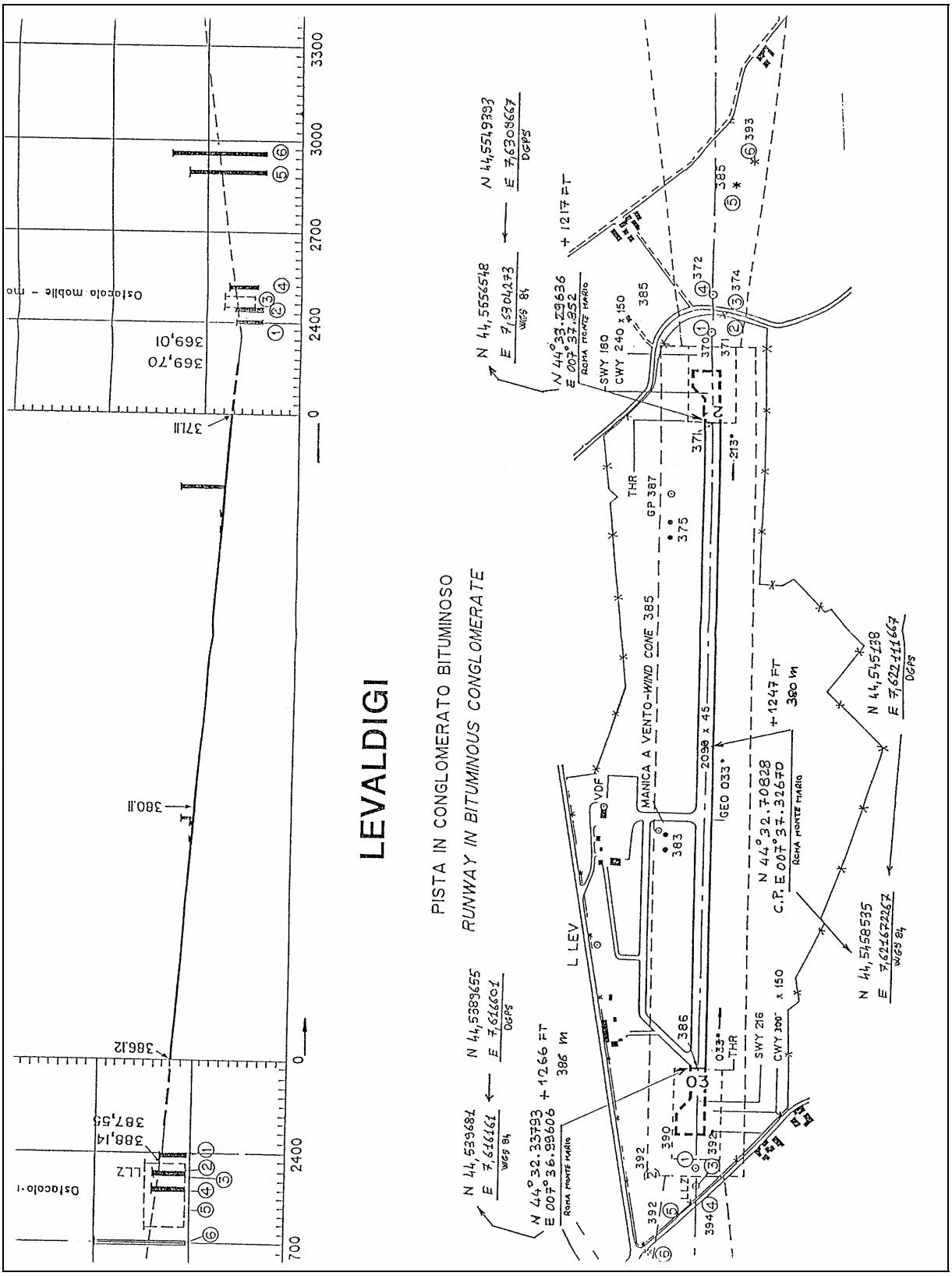

Figure C-17: Levaldigi Airport.

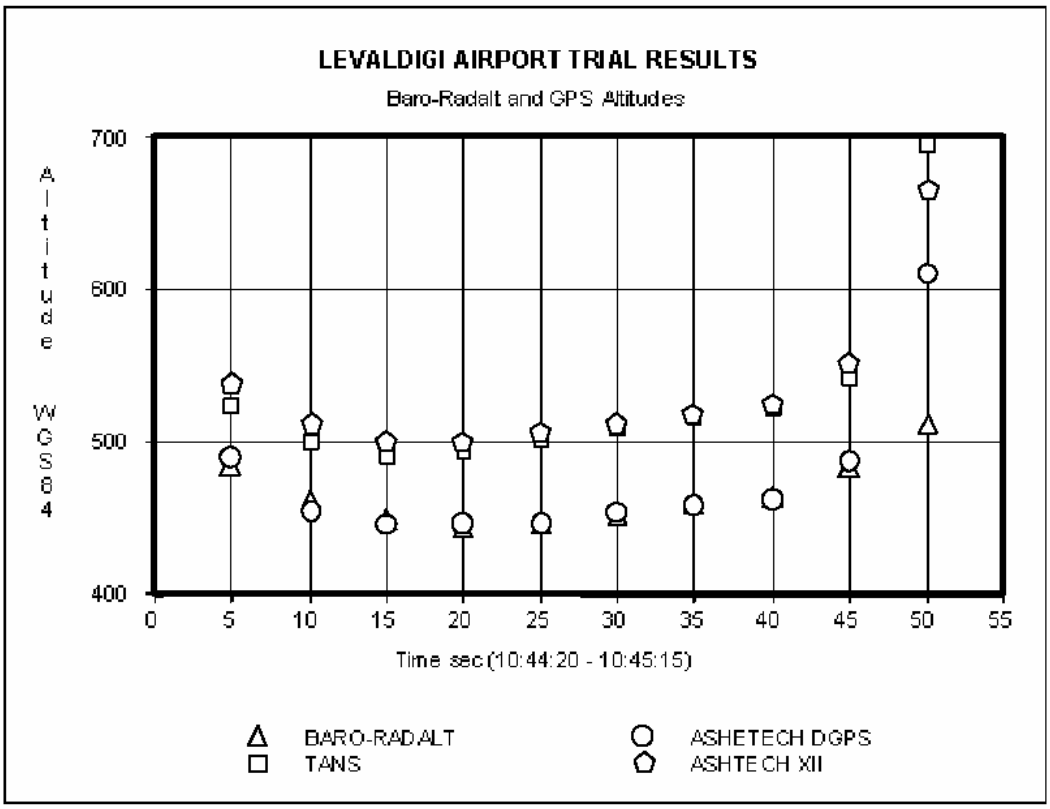

Figure C-18: Comparison of GPS and Altimeter Data.

C.3 DISCUSSION OF RESULTS

Analysing the data collected during the first DGPS flight test campaign conducted on the MB-339CD, it was concluded that the ASHTECH receiver was better suited than the TRIMBLE receiver for flight test applications. Particularly, the ASHTECH tracking and reacquisition strategy significantly reduced the time required for new position fixes after total GPS signal losses. Therefore, the ASHTECH XII data continuity during medium to high dynamics manoeuvres was significantly better than TANS. On average, the GPS data loss occurred in 25% of the total flight time for the ASHTECH receiver and in 35% of the time for the TANS. These results were obtained with similar settings of the threshold parameters for position computation.

The TANS receiver was able to provide a positioning solution even with only three satellites tracked, but in this case the accuracy degradation of the horizontal coordinates (especially the latitude) was significant.

The results of the data quality assessment carried out by comparing DGPS (ASHTECH) and barometric-radar altitude data were encouraging, but further investigation was required in order to evaluate the accuracy provided by the system.