

RELIABILITY PERFORMANCE IN GPS RECEIVERS AND THE NATURE OF THEIR FAILURES: PLANNING TO LIVE WITH REALISTIC FAILURE RATES IN SATELLITE NAVIGATION SYSTEM RECEIVERS.

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ABSTRACT

The National Air Traffic Services (NATS) in London require data on the performance likely to be achieved by the navigation system on board aircraft flying in UK airspace. To that end the performance of three different GPS receiver types (all designed for aviation use) has been examined. This paper details the result of that work. The achieved Mean Time Between Failures (referred to here as “Outages”) MTBO is presented along with the nature of some of the failures that have been encountered. The paper concludes with the operational implication of the findings.

BIOGRAPHIES

Sarah Sharkey obtained her PhD from Liverpool University. She joined National Air Traffic Services Ltd in 1993 and has worked on a number of ATM system projects. More recently she has managed research in both Surveillance and Navigation areas, including GNSS projects. She is an Associate Member of the IEE.

Rolf Johannessen obtained his PhD from London University. A period developing instrument landing systems for aircraft was followed by several years developing computer systems. In 1969 he joined the research laboratory which is now known as Nortel in Harlow where for many years he was manager of the navigation department. In 1994 he left to form his own company, Lambourne Navigation Limited, where as Director he now undertakes consultancy work in Communication, Navigation and Surveillance. Rolf is a Fellow of IEE, a Fellow of RIN and a Member of the ION.

1 INTRODUCTION

The achievement of good safety is crucial for aviation: every system which the UK approves for aviation has to undergo a formal scrutiny which leads to the preparation of a “safety case”. This is a system of documentation which demonstrates that the system is safe to use. A good insight into the failure modes is a pre-requisite. This allows the safety case to document the steps taken to ensure that the effect of such failures is controlled in a manner that adequately safeguards the aircraft. As part of the process of gaining insight into failure modes in GPS NATS has undertaken two projects which are described in this paper. The first project examined the reliability data derived from a GPS receiver fitted in a revenue-earning Boeing 747-400. This project ran during the period April 1994 to December 1995, when it was closed pending the availability of better GPS equipment. The second project involved the data collection from 4 GPS receivers located at a London airport with data collected from late 1995 up to the present time. Important lessons can be learned from both these projects.

2 THE FLYING LABORATORY

The growing interest in using GPS for navigation of aircraft made it necessary for NATS, in common with other administrations, to start gathering data on the performance of GPS receivers that were intended for aviation use. As part of the Automatic Dependent Surveillance (ADS) programme undertaken by NATS, it became possible to gain access to the output data from a GPS receiver installed on board one of the British Airways B747-400 aircraft. This was very attractive for two reasons:

- (a) the aircraft followed tracks and manoeuvred in a manner typical of civil aviation; it was not restrained in operating range or region as is common with research aircraft,
- (b) the aircraft flew at all times during night and day and was not therefore constrained by the hours of work employed by typical laboratories.

The data from the GPS receiver's output terminals was sent to the aircraft's satellite communications terminal, from there it was transmitted via an INMARSAT communications satellite to the Ground Earth Station at Goonhilly and passed to the Air Traffic Management Development Centre (ATMDC) at Bournemouth airport in South England. ATMDC extracted the relevant data which was passed to Lambourne Navigation Limited (LNL) for analysis.

3 THE NORMAL DATA AVAILABLE

ATMDC are able to request the aircraft to transmit different data groups; one such combination of "good" data is illustrated by Figure 1 containing a sample transmission at approximate time 1848 UTC. The downlink message comprises first the data from the aircraft flight management system, and then the data from the aircraft GPS receiver, which is not connected to the FMS. The aircraft is at FL310 and south of equator. A small difference will be observed between FMS and GPS positions: this is quite normal since the FMS [position] is derived from an inertial system which drifts with time. GPS on the other hand has no such long term drift, and is generally more accurate.

A study of GPS receiver performance can be accomplished by considering several aspects:

- (a) examination of the difference between the FMS and GPS positions,
- (b) examination of the change in GPS position with time, knowing that the aircraft position changes with time in a fairly confined manner (it cannot for instance move 100 miles in one minute),
- (c) examination of the "sanity" of the GPS position (in some cases for instance the GPS receiver claimed to be at north latitude 180 degrees).

For the purpose of this analysis it was concluded that there was a "GPS outage" if the data stream as received at LNL had any of the following symptoms:

- (i) GPS integrity flag was set "invalid",
- (ii) GPS latitude $>+90$ degrees or <-90 degrees,
- (iii) GPS longitude $>+179$ degrees or <-179 degrees,
- (iv) GPS altitude $<-2,000$ feet or $> 50,000$ feet,
- (v) GPS height rate >250 feet/minute when the baro height showed the aircraft to be in level flight,
- (vi) the GPS 2-D position differed from the FMS position by >5 n miles.

4 DATA VOLUME

It will be apparent from this that the data base is substantial and is collected from aviation trajectories that are representative of the way GPS is expected to be used in earnest. The authors are not aware of any comparable comprehensive examination of GPS data from revenue operating flights, though reference has been made earlier [1] to some of the first results from this project.

5 RESULTS OF THE ANALYSIS

The total number of ADS downlinked messages examined from a GPS point of view amounted to 34,419. These came from 150 flight legs, the first on 6th April 1994, and the last on 13th December 1995. The data was derived from 819.7 flight hours though in many cases the flights were longer. The 819.7 represents the time during which GPS data was available.

The flights were of a wide variety, including long flights like London to Mexico City which are about 12 hours, and short flights like Sao Paulo to Rio which are about one hour. The data includes samples from flights between the UK and the US West Coast (eg Los Angeles), the US East Coast (eg Boston), South America as far south as Buenos Aires, South Africa as far south as Cape Town and Bangkok in Asia (though during this last study the coverage of the INMRSAT satellite limited data collection to the western part of the flight). In many cases recording started soon after the aircraft was airborne and continued until shortly before landing, though the majority of the data are taken from cruising altitudes. Some of the flights took place during daylight hours while others were during the night. The downlinked messages were divided into three different groups:

- (a) messages which had the GPS integrity flag set “INVALID”,
- (b) messages which had the GPS integrity flag set “VALID” but where there was found to be an outage defined by (ii) to (vi) at section 3 above,
- (c) messages which had the integrity flag set “VALID” and where no outage could be observed, ie the data was “good”.

Based on this division the results were:

Group	No of messages	% of total
(a) “Invalid” type outages	759	2.21
(b) “Valid” type outages	487	1.41
(c) “Valid” and good	33173	96.38
Total	34419	100.00

In all cases the erroneous messages came as a continuous block. In most cases the fault cleared itself in flight without the flight crew taking any action, but in a few cases the fault persisted until the aircraft landed, or until data recording ended. The total number of such outage blocks found in this analysis was 28. The total outage time was 2260 minutes, giving a mean outage time of 81 minutes per outage, during which the aircraft would have moved over 600 miles (assuming a mean ground speed of 450 knots).

For part of this project the only flights that were analysed in detail from the GPS point of view were those known to have a GPS problem. However, in order to get the order of magnitude of Mean Time Between Outages (MTBO), there was a substantial period during which all flights containing GPS data were analysed whether there was a failure or not. That analysis showed 15 outage blocks with a MTBO of 54.6 flying hours.

6 DISCUSSION OF MALFUNCTIONS

There is not, and is unlikely ever to be, uncontroversial evidence that the cases cited as “outages” are due to failures in the avionics or in the signals-in-space. What is certain is that an Air Traffic Management system cannot be based on position reports in which more than 3% of the messages hold a useless GPS position report. In that sense it does not matter much whether the origin of the failures lies in the GPS signals-in-space, the receiver or in the communication system that brings the data to the ATC unit. In order to see some of the implications, however, it is valuable to examine some of the characteristics of these failures.

One example is an extract of part of the data stream associated with the outage that took place 30th April 1994 while the aircraft was operating a flight from Nairobi to London. That data stream contained the information given at Figure 2.

At 2305 UTC the GPS data was good. At 2306 it was invalid and continued to be so until 2315 UTC (indicated by the line of asterisks). At 2316 and 2317 it claimed to be valid but was clearly in error with an altitude below sea level and latitude and longitude seriously wrong, as can be seen by comparing GPS and FMS positions.

The following summarises some of the findings concerning all the 28 outages.

- (a) At no time was the GPS receiver repaired. The problems seen are therefore either an intermittency in the receiver hardware, or a software problem.
- (b) In 18 of the 28 failure cases the outage commenced during the time period between 2200 UTC and 2400 UTC Saturday night. This is 1.2% of the week for 64% of the cases. This is clearly not a random failure but shows some systematic problem likely to be linked to inadequately debugged software. It will be appreciated that in GPS the time is defined in terms of week number, and seconds into that week measured from midnight Saturday/Sunday. Thus candidate explanations include problems with the resetting of the GPS receiver's “Z-counter”, or problems with mismatch between the week number in the Almanac and Ephemeris data fields. The nine most recent failures took effect

Saturday 06.05.95 at 2256 UTC
Saturday 13.05.95 at 2304 UTC
Saturday 03.06.95 at 2302 UTC
Sunday 04.06.95 at 0352 UTC
Saturday 17.06.95 at 2305 UTC
Saturday 12.08.95 at 2304 UTC
Saturday 14.10.95 at 2243 UTC
Saturday 25.11.95 at 2305 UTC
Sunday 26.11.95 at 1236 UTC

- (c) During the period considered the almanac generally had a Time of Applicability (ToA) of 32768 seconds. This is the time reference used in the almanac portion of the data stream coming from the satellites, and is defined as the number of seconds from midnight Saturday/Sunday in the week in question, 32768 seconds corresponds, therefore, to about 0906 UTC on Sunday morning. However, at least 5 of the cases arose during a week with a different ToA. This is considered too small a sample to say whether this link is significant or not.
- (d) The possibility of a link with interference was explored in many cases. For instance, the geographic region in which the outage commenced was explored for ATC communications frequencies that might have a sub-harmonic of the GPS L1 frequency. The locations where the GPS data were first found to be bad in the above 9 cases were 32N 07E, 41N 10W, 33N 07E, 43N 05E, 50N 100W, 06N 08E, 45N 07E, 25N 94W and 61N 27W. These clearly represent a good spread of locations. Out of the 28 cases where a failure arose, some repeated the location, like the first and third above.
- (e) The satellite communications link also enables the captain to talk with ATMDC. Since there was a possibility that the problem could have been caused by these calls, the time of incident was compared to the time of those voice transmissions, a time taken from an itemised invoice from the telecommunication company. No correlation could be found to link the cases, though it may have been a factor in some of the cases.
- (f) It is not known whether any of the outages were linked to a circuit breaker being operated on the aircraft, though the symptoms of the failures suggest the probability of this being the cause is very small.

7 PROJECT SWITCH OF EMPHASIS

When this project started this GPS receiver was the only one installed on a revenue-earning aircraft which was also accessible to NATS. It was however not a TSO-approved receiver. Such enhanced receivers have gradually been becoming available and during 1995 the attention of NATS began to switch to a better receiver. It has not yet been possible to install such a receiver on the aircraft fitted with ADS, though the most beneficial way of doing so is being actively considered. Meanwhile the portion of the GPS analysis associated with this older receiver was concluded at the end of 1995.

However, during 1995 4 TSO-approved GPS receivers were procured and installed in a fixed location at London's Stansted airport where they were arranged to log their output regularly to computers for subsequent analysis.

8 STANSTED SYSTEM DESCRIPTION

The four receivers comprise two receivers from each of 2 different manufacturers. As it matters not from the project point of view who those manufacturers are, they are referred to as receivers 1A, 1B, 2A and 2B, with A and B in each case being as identical as possible. Each of the receivers is connected to its own antenna and all antennas are mounted on a common ground plane which is well above the buildings nearby. There is therefore no significant low elevation obstruction for any of the antennas. The multipath environment is good compared to what might be expected in most locations on a busy airport or on an aircraft.

The receivers are fed from two 13.5 volt supplies and each receiver is connected to its own PC. There was no altitude input to the receivers. Figure 3 illustrates the general arrangement.

The equipment is installed in an air-conditioned building.

9 THE DATA AVAILABLE

A short sample of “good” data from one of the receivers is at Figure 4.

This data was recorded on the 20th August 1996 for a short period from 1328 UTC. The interval between successive samples stored is nominally 15 seconds, though the receivers produce data more frequently than that. The time of day is followed by the latitude and longitude of the receiver, the altitude and the number of satellites being tracked.

The data is studied to identify “outages” which, in this case, are defined as being periods where more than 2 records either

- (a) contained no 2-D position, or
- (b) contained an output position which differed from true position by more than 1 km. These outages are defined differently from those examined for the aircraft for two reasons. First, the precise position of the Stansted receivers is known. Second, a preliminary examination of the Stansted data had suggested that an absence of position output had featured and therefore needed further examination. It was therefore decided that focusing on the absence of 2-D position, along with the precision when the position was present, constituted the aspects it would be most cost-effective to examine.

10 DATA VOLUME

After a shake-down period the system commenced recording for analysis purposes on 22nd August 1995. The data reported in this paper covers results up to 21st August 1996. During the intervening period there have been a few short periods when the equipment was off due to modifications of the equipment room, and due to a failure in one GPS antenna and one computer used for logging. Apart from these cases the recording has been virtually continuous.

During the period analysed the equipment recorded for a period of 31,604.1 equipment running hours and provided 7,584,984 records of latitude and longitude. It represents, therefore, a considerable volume of data which enables a reliable estimate of long term performance. The start of this experiment was announced to RIN at the Interference Workshop in October 1995 [2].

11 RESULTS OF THE ANALYSIS

During the same period there were 20 outages which lead to a Mean Time Between Outages (MTBO) of 1,580.2 hours. The outages were spread fairly evenly between the receivers; there were 7, 4, 5 and 4 outages for each of receivers 1A, 1B, 2A and 2B respectively. The one faulty antenna referred to above is not included in this since it is not clear whether that antenna was in fact faulty from the start.

12 DISCUSSION OF MALFUNCTIONS

The site is un-manned so that no-one watches either the receivers or the environment as the malfunctions arise. It is not, therefore, and will never be, absolutely certain that the “outages” that appear in the recorded data stream are due to a malfunction in the receiver. An uncertainty arises because there has been a number of violent thunderstorms in the Stansted area leading to severe mains transients. In some cases the receivers failed to operate at a time when such transients or mains failures occurred. Where this is known to have been the cause, those outages have not been included. However, it may be that some of the 20 referred to are also linked to such a transient and are therefore not strictly a receiver failure. It is a question, therefore, of analysing the data, looking at the symptoms, comparing the receivers with each other and examining abnormalities in signals-in-space as noticed through the NANU system. An example of the kind of detective work is the last 5 outages that were experienced by receiver 1A. These took place on 5 days after each other as follows:

- 17.08.96 at 0122 UTC for 10 samples
- 18.08.96 at 0118 UTC for 14 samples
- 19.08.96 at 0114 UTC for 15 samples
- 20.08.96 at 0110 UTC for 13 samples

21.08.96 at 0106 UTC for 3 samples

It will be observed that the “outage” arose approximately 4 minutes earlier each day. As this is the amount by which the satellites advance their orbit each day it is a very strong indicator that this failure is systematic. On the 16th and the 22nd August there was no problem. A link to the probable cause was found in NANU 141 which states that PRN01 was unusable. This NANU is shown in full in Figure 5.

PRN01 was visible to the site on these occasions with an elevation angle of around 42 degrees. An unusual behaviour of that satellite could therefore affect the receiver. However, the NANU suggests there was a problem in the morning of 17, 18, 19, 20, 21 and 22nd August. Receiver 1A failed on the first 5 days but not the last. Receiver 1B did not fail at all. Just why the receivers reacted differently is not known. It may be linked to the nature of the satellite malfunction, combined with the two receivers holding different almanacs. Unfortunately the NANUs do not as a rule give details of the nature of the problem. It would certainly be helpful if there was information about the kind of malfunction, such additional information was requested in [3]. The goal of this work is, however, not to identify the specific place in the receiver where the problem is located, rather, it is to establish how often a TSO approved receiver might be expected to misbehave.

It was noted above that these receivers in their current configuration are not provided with an altitude input. If they had been so provided then 4 satellites might have been sufficient to estimate position. However, the fact remains that one of the two receivers was only able to track 4 satellites when the other tracked 6; clearly, therefore, there was a malfunction.

A particular objective of this project is to establish the probability that two identical receivers simultaneously encounter a problem such that redundancy in a dual installation is lost. Such a situation arose on 18 October 1995 in the period between 1600 UTC and 1700 UTC. During this period receivers 2A and 2B displayed considerable abnormalities. Receiver 2A had 5 outages while receiver 2B had 4 outages. In each case the receivers recovered without manual intervention. According to NANUs 223 and 224 both PRNs 26 and 12 were causing problems at this time. Nevertheless receivers 1A and 1B were operating normally. This case on 18 October was the only occasion when two receivers were simultaneously displaying an outage.

13 DISCUSSION OF SOME OF THE RESULTS AND OPERATIONAL IMPLICATIONS

A receiver installed on an aircraft which experiences vibration and large thermal variations might be expected to yield a performance which is less favourable than that of a receiver which is located on the ground in an air-conditioned room. However, the environmental conditions on the B747 are unlikely to differ substantially from that for which the receiver was designed. A comparison between the one airborne and the 4 located on the ground is therefore not unreasonable. A considerable improvement in reliability performance is observed with the receivers located at the airport. Nevertheless a MTBO of 1,580 hours is extremely poor. Even if a few of the outages were in fact caused by environmental problems such as power transients or lightning strikes close by, rather than by bad receiver design, this would still leave a performance considerably worse than that expected from other modern electronics.

It may be argued that data derived from non-TSO approved equipment (i.e. data recorded from the Boeing 747) should be disregarded when it comes to designing for airspace safety. The counter argument must be that if any avionics manufacturer has in place an effective quality control system. then he is unlikely to allow out through his factory gates any system with a MTBO of 54.6 hours, as was the failure rate found for the aircraft receiver reported in section 5 of this paper. This suggests that the programme has shown up an undue haste in implementing GPS in civil aviation.

The presence of systematic errors that are triggered by unusual, but in-specification, signals-in-space events is important since these malfunctions have the potential to affect multiple receivers simultaneously. In particular, the Saturday/Sunday problem encountered by the first of the receivers discussed was of such a nature that multiple identical receivers would be highly likely to fail simultaneously. This would mean that the failure protection achievable through redundancy would offer no protection at all. This would be extremely serious in a busy volume of airspace. The seriousness is further increased in an environment where surveillance is effected through a GPS-dependent surveillance system.

It should be noted, however, that only some of the Stansted project outages have simultaneously affected two receivers. It is crucially important to establish the probability of this event and work is ongoing to do so.

Once adequate data has been gathered on the probability of simultaneous failure in GPS receivers a decision will need to be made on whether that probability is low enough. If it proves difficult to get the probability down to an acceptable level, candidate solutions are to achieve the necessary redundancy by using dissimilar receivers, or by using GPS receivers coupled with inertial platforms.

14 CONCLUSIONS

There is no doubt that GPS will have a significant role in civil aviation. However, there remains a need to ensure that the systems have been properly debugged before they find their way into aircraft. The projects discussed in this paper have illustrated clearly that there are far too many failures in the GPS receivers examined. A considerable reduction in such failures will need to be achieved before GPS can be considered a reliable Sole Means system.

ACKNOWLEDGMENTS

The projects reported here have involved the cooperation of many individuals. The flying receiver is installed on board a British Airways aircraft and the data files relevant to GPS have been extracted from the much greater ADS data base by the R&D group at ATMDC led by Chris Townend. The receivers at Stansted airport were installed by Nortel under the guidance of Paul Crampton. Many colleagues within NATS have also been involved in making this project a success: these include John Coulson, Mike Asbury, David Wright and Paul Nisner.

ACRONYMS

ADS	Automatic Dependent Surveillance
ATC	Air Traffic Control
ATMDC	Air Traffic Management Development Centre
FL	Flight Level
FMS	Flight Management System
IEE	Institute of Electrical Engineers
ION	Institute of Navigation
LNL	Lambourne Navigation Limited
MTBO	Mean Time Between Outages
NANU	Notice Advisory to Navstar Users
NATS	National Air Traffic Services Ltd
PRN	Pseudo Random Noise
RIN	Royal Institute of Navigation
TSO	Technical Standards Order
UTC	Universal Time Coordinated

REFERENCES

- [1] Asbury MJA and Johannessen R; Single Points of Failure in complex aviation systems of Communication, Navigation and Surveillance. RIN, 8-10 November 1994.
- [2] Johannessen R; Stansted Receiver Trials. GPS Interference - Is it a problem?, Workshop Notes following the meeting held in London 12-13 October 1995.
- [3] Civil GPS Service Interface Committee 27th Meeting held at Falls Church, VA, 19-21 March 1996. Summary Report.

ADS Basic Group
 18:48:43.18
 Lat: S 29-19.14459' Long: E 013-58.87825'
 Alt: +031000 ft
 Nav: 2+ Accuracy: <1.00 nm TCAS: NONE
 Updated At: 46:24.500

ADS GPS Position Group
 18:48:43.18
 Lat: S 29-18.87680' Long: E 013-58.48686'
 Updated At: 46:24.500
 GPS Alt: +032488 ft GPS: VALID
 Barometric Corrected Alt: +031000 ft

Figure 1
 Sample data from the ADS data link.
 Normal circumstances.

200896 132800 N 5153.376 E 00013.948 91.2 07
 200896 132815 N 5153.372 E 00013.946 85.7 07
 200896 132829 N 5153.370 E 00013.943 82.7 07
 200896 132845 N 5153.370 E 00013.945 78.8 08
 200896 132900 N 5153.370 E 00013.943 76.3 08
 200896 132915 N 5153.368 E 00013.941 79.2 08

Figure 4
 Sample of normal data from one
 of the Stansted receivers.

NOTICE ADVISORY TO NAVSTAR USERS
 (NANU) 141-96234
 SUBJ: PRN01 UNUSABLE
 REF: NANU 134-96229 (DTG 161712 AUG 96)
 1. CONDITION: GPS SATELLITE PRN01 (SVN32)
 WAS UNUSABLE ON JDAY 229 (16 AUG 96)
 BEGINNING 1655 ZULU UNTIL JDAY 235 (22
 AUG 96) AT 1620 ZULU.
 2. POC: NAVIGATION ANALYST AT
 COMMERCIAL (719) 567-6378 OR DSN 560-6378.

Figure 5
 NANU 141/1996

Figure 2
 Extract from data stream 30.04.1994.
 Nairobi to London Flight.

ADS Basic Group
 23:05:14.57
 Lat: N 09-36.57623' Long: E 033-51.55060'
 Alt: +035000 ft
 Nav: 2+ Accuracy: <1.00 nm TCAS: NONE
 Updated At: 02:24.875

ADS GPS Position Group
 23:05:14.57
 Lat: N 09-36.20544' long: E 033-50.89142'
 Updated At: 02:24.875
 GPS Alt: +040928 ft GPS: VALID
 Barometric Corrected Alt: +035000 ft

ADS Basic Group
 23:06:17.13
 Lat: N 09-44.89838' long: E 033-49.27437'
 Alt: +034996 ft
 Nav: 2+ Accuracy: <1.00 nm TCAS: NONE
 Updated At: 03:24.875

ADS Position Group
 23:06:17.13
 Lat: S 180-00.00000' Long: W 180-00.00000'
 Updated At: 03:24.875
 GPS Alt: -131072 ft GPS: INVALID
 Barometric Corrected Alt: +034996 ft

ADS Basic Group
 23:15:13.81
 Lat: N 10-58.97369' Long: E 033-28.89130'
 Alt: +035004 ft
 Nav: 2+ Accuracy: <1.00 nm TCAS: NONE
 Updated At: 12:23.500

ADS GPS Position Group
 23:15:13.81
 Lat: S 180-00.00000' Long: W 180-00.00000'
 Updated At: 00:00.000
 GPS Alt: -131072 ft GPS: INVALID
 Barometric Corrected Alt: +035004 ft

ADS Basic Group
 23:16:17.30
 Lat: N 11-07.33704' Long: E 033-26.57387'
 Alt: +034996 ft
 Nav: 2+ Accuracy: <1.00 nm TCAS: NONE
 Updated At: 13:22.875

ADS GPS Position Group
 23:16:17.30
 Lat: N 04-57.81532' Long: E 024-22.53433'
 Updated At: 13:22.875
 GPS Alt: -131072 ft GPS: VALID Barometric
 Corrected Alt: +035000 ft

ADS Basic Group
 23:17:13.82
 Lat: N 11-15.70038' Long: E 033-24.26674'
 Alt: +035008 ft
 Nav: 2+ Accuracy: <1.00 nm TCAS: NONE
 Updated At: 14:22.875

ADS GPS Position Group
 23:17:13.82
 Lat: N 05-08.55789' Long: E 024-24.19258'
 Updated At: 14:22.875
 GPS Alt: -131072 ft GPS: VALID
 Barometric Corrected Alt: +035004 ft

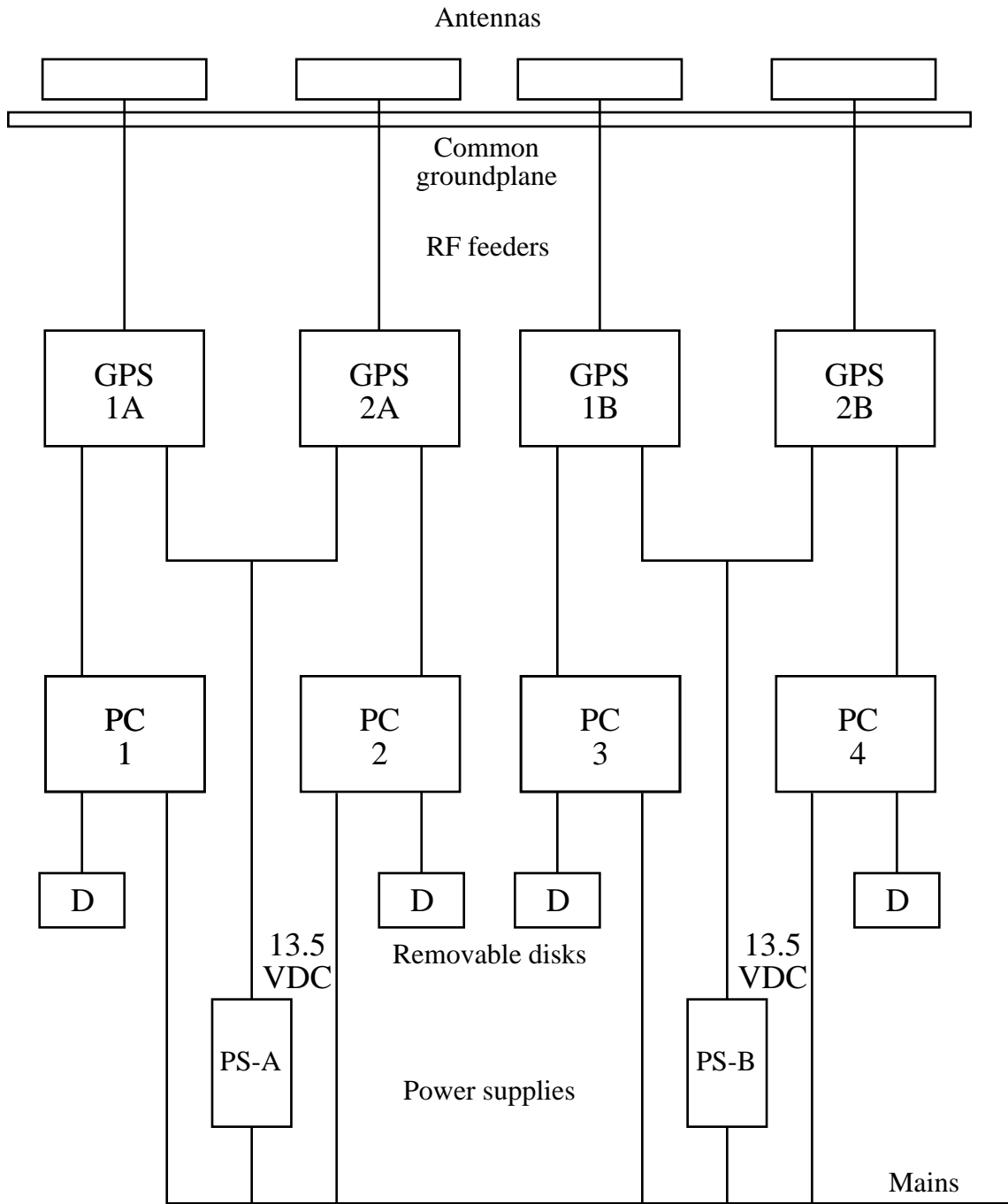


Figure 3
Equipment arrangement at Stansted