# BOEING COMMERCIAL AIRPLANES

# FLIGHT OPERATIONS TECHNICAL BULLETIN



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**SUBJECT:** Global Positioning System (GPS) Signal Interference

**ATA NO:** 34-00

**APPLIES TO:** 777-200/300 airplanes with AIMS BP14 and later.

**REASON:** To describe the flight deck effects associated with a loss of GPS signal or GPS signal interference. This revision adds GPS signal interference effects on time, date, and datalink including information gained from in-service reports.

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## BACKGROUND INFORMATION

This bulletin provides engineering data to help operators understand the flight deck effects during GPS signal interference and to assess risks and mitigations to a level that is satisfactory to operators and their regulatory authorities.

There have been several occurrences where airplanes were subjected to GPS signal interference by external sources. The sources of interference include portable devices, GPS jammers, and GPS repeaters that are found in hangars, which cause interference in the immediate area. Also wider areas of intentional GPS interference occur in areas with conflicts. During GPS signal interference, systems that are dependent on the GPS are affected, such as the Flight Management Computer (FMC), the Ground Proximity Warning System (GPWS) Look-Ahead Terrain function, and the Automatic Dependent Surveillance (ADS) Air Traffic Services (ATS) function. Airplane systems that are not affected by GPS signal interference such as flight controls, airplane attitude, and heading are not covered in this bulletin.

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GPS receivers use signals from satellites to determine an accurate position. However, if unwanted Radio Frequency (RF) energy is present in the band of the desired signal, that energy can interfere with the receiver's ability to track satellites and produce an autonomous GPS Position\Velocity\Time (PVT) solution.

This bulletin covers the flight deck effects and the effect on airplane systems during GPS interference. Basic GPS jamming has an effect similar to a loss of GPS signal; however more sophisticated GPS signal interference (GPS spoofing or smart-jamming) can cause flight deck effects to vary based on the level of sophistication.

## GPS Jamming (basic)

GPS interference typically causes a loss of measurement data from at least one satellite and degrades the receiver's PVT solution. It normally does not result in an output of misleading data from the GPS receiver. The position simply becomes degraded or unavailable and the systems that use GPS position can be affected. The FMS can revert to using another navigation source such as inertial navigation or radio navigation when radio updating is available and not inhibited. GPWS Look-Ahead Terrain and ADS/ATS can be affected too.

## GPS Smart Jamming or 'Spoofing'

When the interfering signals are similar to the desired GPS signals, the effects can be more severe. Such 'smart jamming' or 'spoofing' can potentially result in misleading data from the receiver. This signal interference is more difficult to produce; however, the means to produce such signals are becoming more accessible and affordable due to advances in electronics capabilities such as Software Defined Radios. Spoofing can result in position outputs that are erroneous to various degrees, from small errors to larger more significant errors. If sufficiently large, such erroneous position outputs can be detected and mitigated when comparing GPS position to the position from an independent navigation aid.

During smart jamming, the flight deck indications of the impacted system can vary depending on the sophistication of the jamming.

## OPERATIONAL INFORMATION

## 1 NAVIGATION GPS SIGNAL AVAILABLE (NORMAL OPERATION)

FMC position update status is shown on the Navigation Display (ND) in Figure 1. “GPS” is normally the FMC position update status.


**Figure 1 – ND with GPS as the FMC Position Update Status**

When radio updating is enabled and available, the FMC position update status changes in the priority order shown in Table 1.

**Table 1 - FMC Position Update Source**

| FMC Position Update Source | POS REF Page 2 | FMC Position Update Status on ND |
|---|---|---|
| GPS valid | GPS | GPS |
| LOC and DME/DME valid; GPS invalid * | LOC-RADIO | LOC–DME–DME |
| LOC and VOR/DME valid; GPS invalid * | LOC-RADIO | LOC–VOR–DME |
| LOC valid; GPS, DME, and VOR invalid * | LOC-INERTIAL | LOC |
| DME valid; GPS invalid | RADIO | DME–DME |
| VOR DME valid; GPS invalid | RADIO | VOR–DME |
| ADIRU valid; GPS, VOR, DME invalid | INERTIAL | INERTIAL |
| GPS valid; ADIRU failed | GPS | GPS |
| GPS invalid, ADIRU failed | blank | map not available |

Note that localizer updating is inhibited if GPS is the navigation update mode.

* The FMC changes to LOC updating when:
- the tuned localizer is associated with the destination runway
- the airplane is less than 6,000 feet above the localizer navaid elevation
- the airplane is less than 20 nm from the localizer navaid for a front course approach or less than 12 nm from the localizer navaid for a back course approach
- the airplane is within 25° sector of the inbound localizer course
- the difference between airplane track and the localizer course is less than 45° intercept angle.

*EFIS Control Panel POS Button*

When the "POS" button on the EFIS control panel is selected, the symbols for the GPS, ADIRU, and radio positions, relative to the FMC position, are shown. See Figure 2.

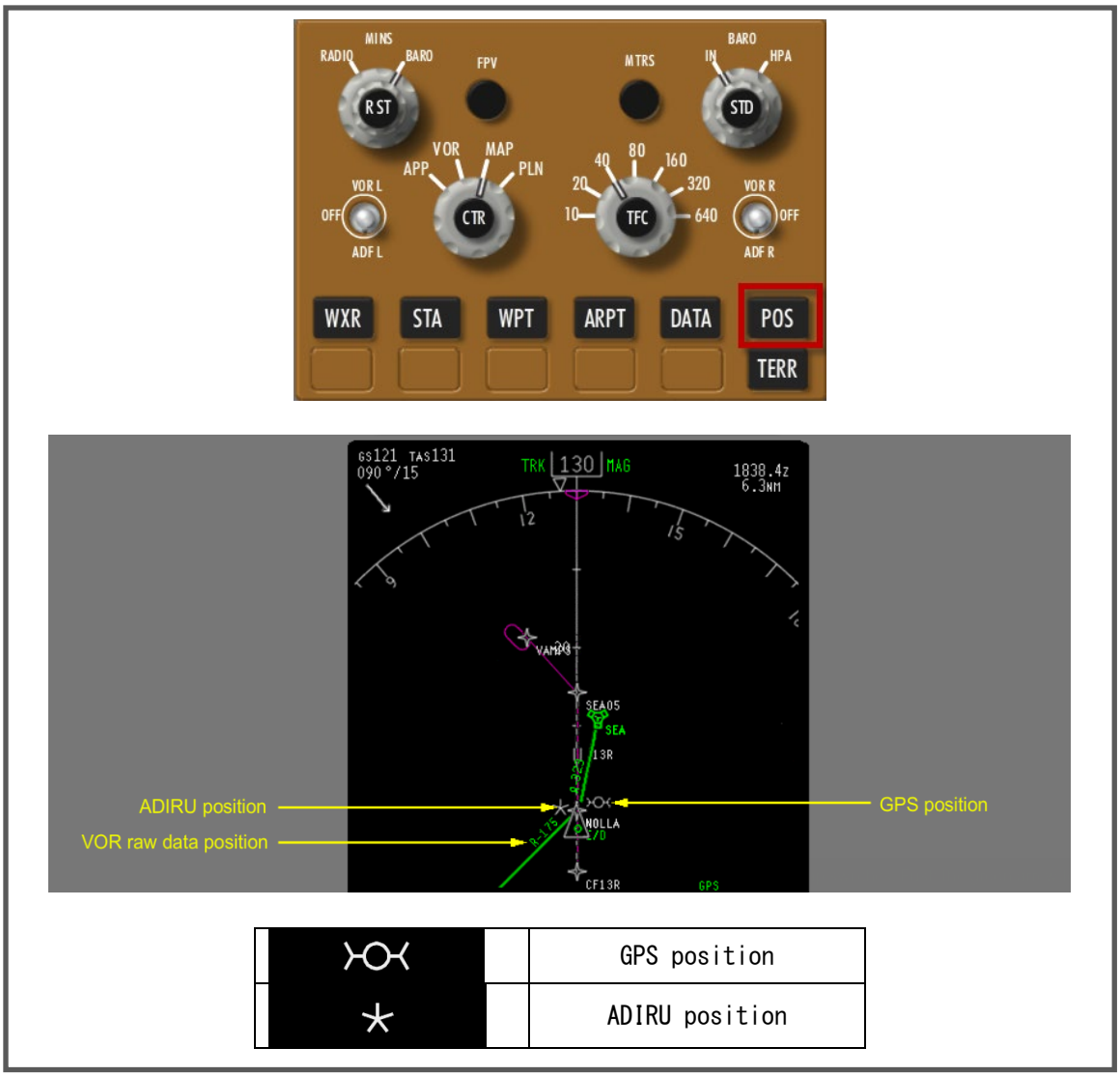


**Figure 2 - GPS and ADIRU Positions on ND**

*Control Display Unit (CDU) POS REF Page 2/3*

POS REF page 2 shows FMC, Inertial, GPS and radio positions. This page allows updating of the FMC-computed position to match either the Inertial, GPS, or radio position. Figure 3 shows both GPS and radio positions available.

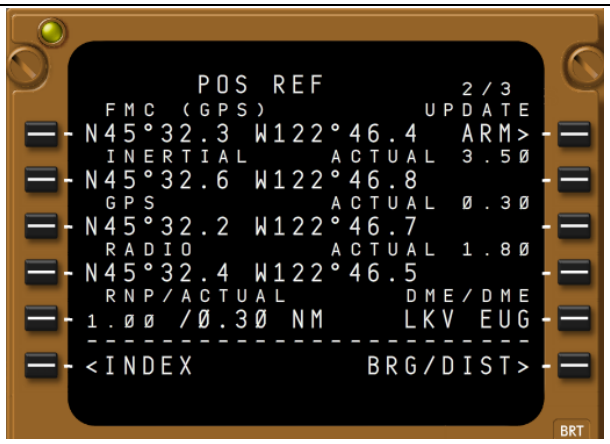


**Figure 3 – GPS, Inertial, and radio Positions on CDU POS REF page 2**

Line 1L shows the FMC position and, in the header line, the primary source of update displays in parentheses above the FMC position (as described in Table 1).

Line 4L shows the radio position. When in range of a navigational radio, this line shows the radio position even when radio updating is inhibited. If radio updating is inhibited, the FMC does not use the shown radio position as an update source until radio updating is enabled.

Line 5R shows the identifier(s) of the navigation station(s) currently being used to compute the radio position regardless of whether radio updating is inhibited or enabled.

*Control Display Unit (CDU) POS REF Page 3 / 3*

GPS L and R BRG / DIST from the FMC computed position should be 0.1 NM or less under normal circumstances. See Figure 4.

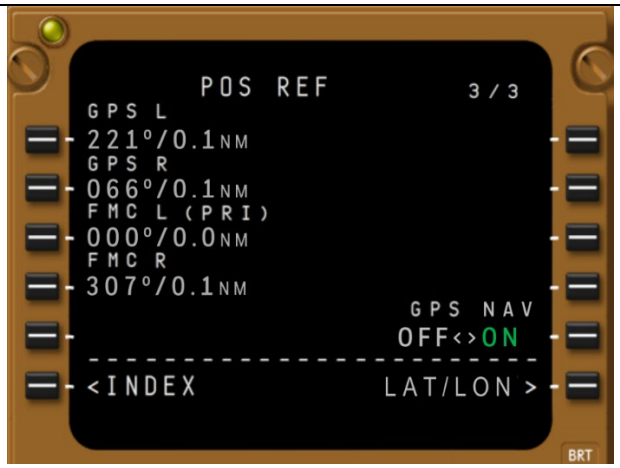


**Figure 4 – GPS Bearing and Distance on CDU POS REF page 3**

*Navaid Inhibit or Enable*

The Navaid Inhibit or Enable Supplementary Procedure in Volume 1 of the Flight Crew Operations Manual (FCOM) provides the steps to inhibit and enable navigation sources. Selecting the RAD NAV INHIBIT to "OFF" enables radio navaids to be used for position determination and navigation.

Figure 5 below shows the REF NAV DATA page. It shows that radio navaids are enabled for position determination and navigation.

Lines 4L, 4R, 5L, 5R on the REF NAV DATA allow individual navaid stations to be inhibited from the navigation computation. If RAD NAV INHIBIT is selected "ON", all four of these lines show "ALL" since all navaids are inhibited. When RAD NAV INHIBIT is selected "OFF" or "VOR", these lines show dashes, and individual navaid identifiers can be entered.

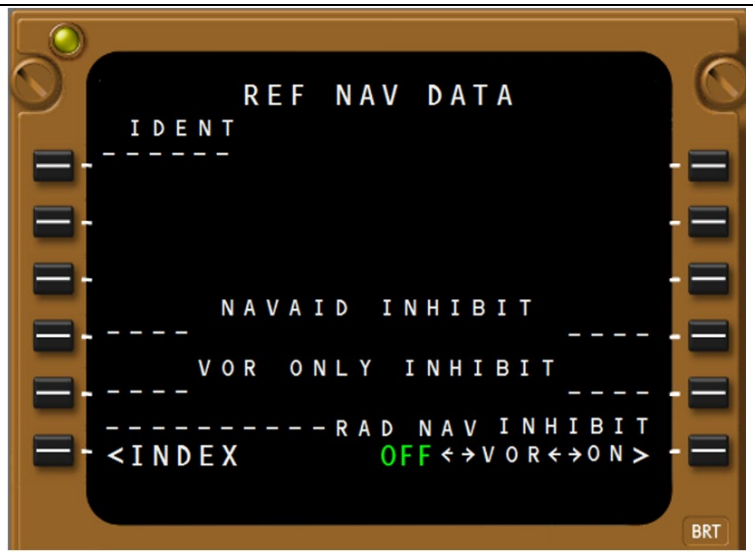


**Figure 5 - CDU NAV OPTIONS Page**

## 2 SYSTEM OVERVIEW

The 777 models are equipped with one fault-tolerant Air Data Inertial Reference Unit (ADIRU) which provides aircraft position initialization. The ADIRU calculates airplane position, acceleration, track, vertical speed, ground speed, true and magnetic heading, wind speed and direction, and attitude data. This data is supplied to the displays, FMS, flight controls, engine controls, and other systems.

777s have two GPS antennas and two GPS receivers to support navigation. The GPS receivers receive satellite inputs and determine the aircraft position, velocity, date and time.

The GPS receivers on Boeing airplanes have receiver autonomous integrity monitoring (RAIM) algorithms to detect and mitigate erroneous GPS signals. These algorithms offer some protection against errors from interference. For example, RAIM detects smart jamming where the receiver tracks both real and fake satellite signals that cause inconsistent measurement data. The RAIM horizontal integrity limit (HIL) must be valid before the GPS output is used by airplane systems.

The GPS receivers provide a 95% horizontal position accuracy, Horizontal Figure of Merit (HFOM), as well as a 99.99999% Horizontal Integrity Limit (HIL). The GPS data from both receivers are transmitted to each Flight Management Computer (FMC). The FMCs use the data as one of several sensor inputs. The FMC uses the onside GPS as the primary and the offside GPS is only used if the onside becomes invalid.

The FMC determines airplane position and velocity using the best sensor data available to compensate for inertial reference errors. The FMC then uses this data to compute the 95% horizontal position accuracy data and Actual Navigation Performance (ANP). Normally, GPS data is the most accurate and the resulting navigation mode is GPS. When GPS data is not valid or when GPS data is not available and radio update is inhibited, the FMC determines position and velocity using only inertial reference data with the most recent corrections. The FMC position update source becomes “INERTIAL”, and the FMC ANP begins to increase based on inertial drift. In this same scenario, if radio updating is available and not inhibited, the FMC uses inertial reference data with radio navaids as the update source. The resulting navigation mode shown on the ND is either DME-DME, VOR-DME, LOC, LOC-DME-DME, or LOC-VOR-DME.

Figure 6 shows the path of the GPS data and its use by the airplane systems.

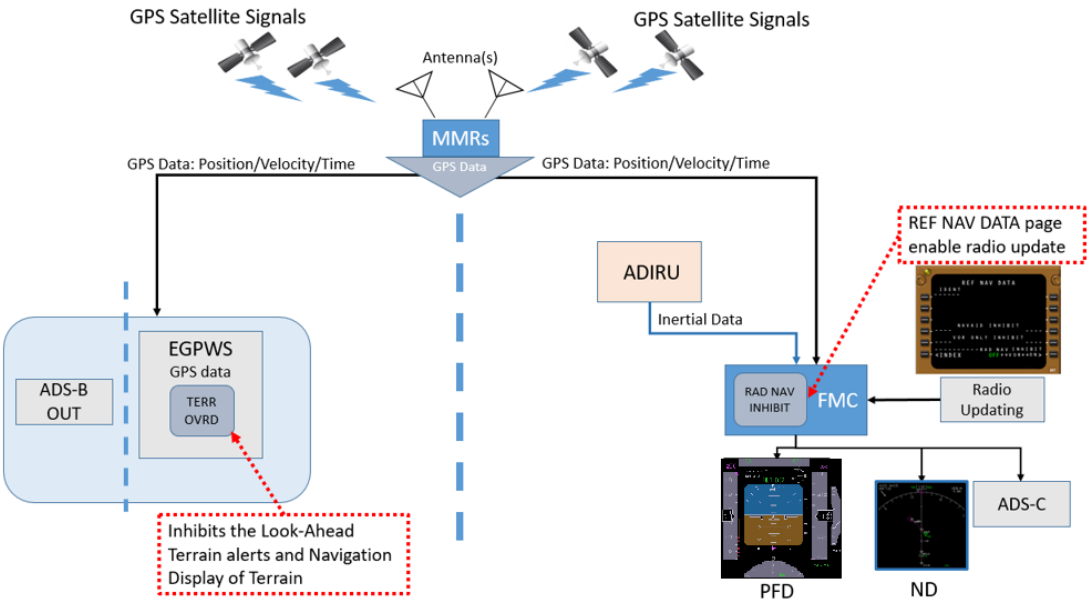


**Figure 6 - Block Diagram of Airplane Systems using GPS**

# 3 FLIGHT DECK INDICATIONS

This section describes flight deck indications for the impacted systems during GPS signal interference events.

## 3.1 Navigation when GPS Update is Not Available or during GPS Signal Interference

When a GPS signal is not available to update the ADIRU position and radio updating is either not available or is inhibited, FMC position update status transitions from GPS to INERTIAL, and the lateral ANP starts to increase.

Selecting RAD NAV INHIBIT "OFF" on the REF NAV DATA page enables radio updating. Details are covered in the Navaid Inhibit or Enable Supplementary Procedure in Volume 1 of the Flight Crew Operations Manual (FCOM). Selecting RAD NAV INHIBIT "OFF" allows conventional navigation aids like DME-DME or VOR-DME to update the FMC position provided they are in range with proper geometry. A change of the update source from inertial to radio updating can cause a slight map shift.

When GPS or radio updating are not available, INERTIAL is displayed as the FMC Position Update Status on the ND. See Figure 7 below.

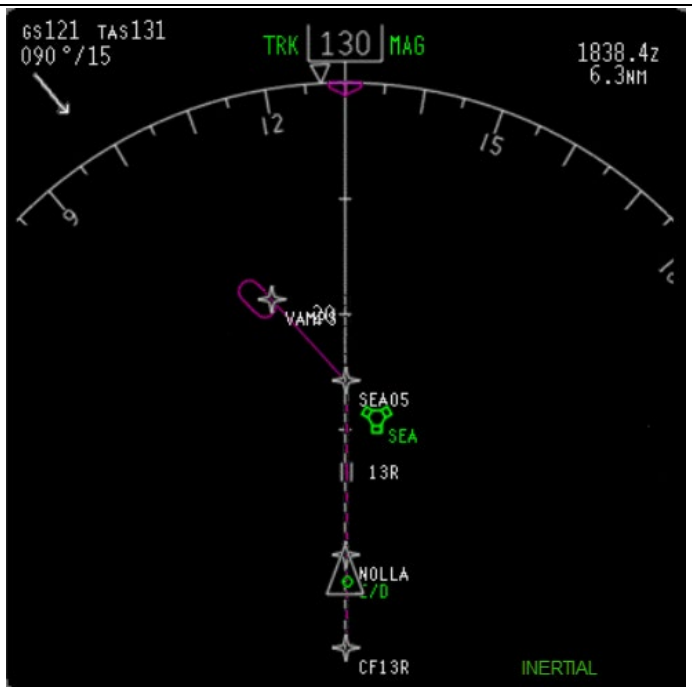


**Figure 7 - Loss of GPS Signal**

Due to inertial drift, the ANP continues to increase as shown in Figure 8 below.


**Figure 8 – No Inertial Position Updating**

For airplanes with Navigation Performance Scales (NPS), the PFD also shows the increasing ANP value. See Figure 9.

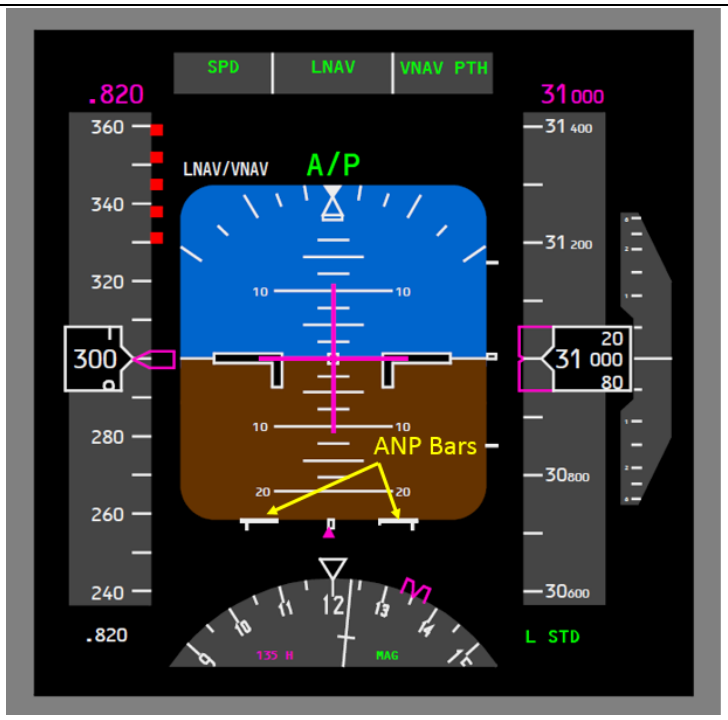


**Figure 9 – NPS Scale with increasing ANP value**

When ANP exceeds RNP, the NAV UNABLE RNP message shows as shown in Figure 10.

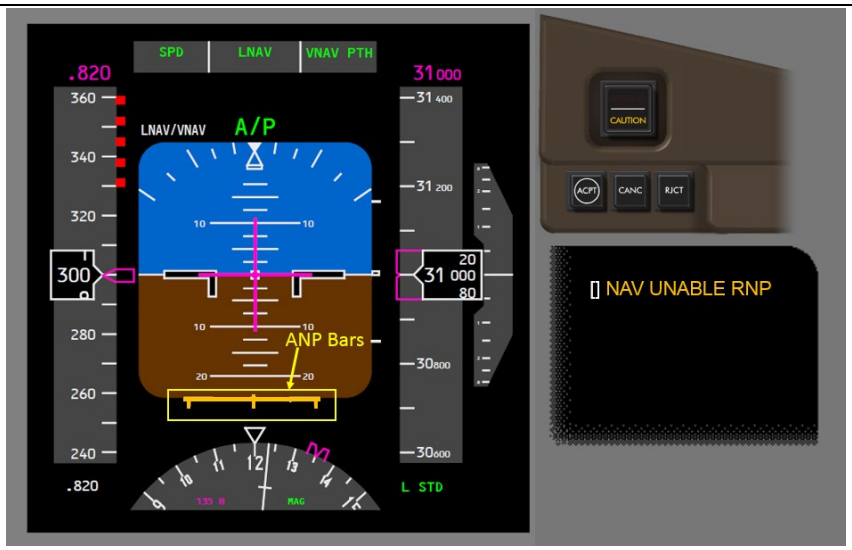


**Figure 10 – NAV UNABLE RNP Caution Message**

During a localizer-based approach, if the GPS signal is not available, the FMC uses the localizer for position updating if all of the conditions described in Table 1 are satisfied.

*CDU POS REF Page 2/3*

GPS position is shown on the POS REF 2/3 page and updates as the airplane moves. During oceanic operations, when a GPS signal is not available and the airplane is out of range of any radio navaid, both the GPS and RADIO position fields are blank. See Figure 11.

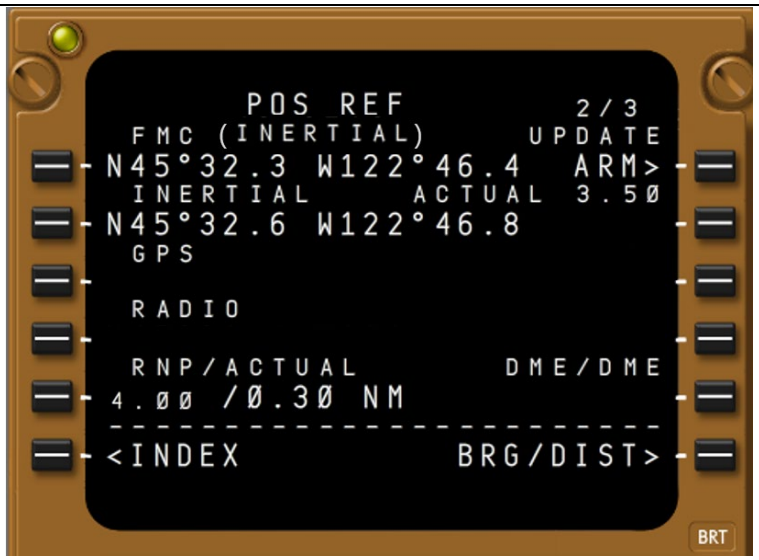


**Figure 11 - Oceanic Out of Radio Range**

When a GPS signal is not available but the airplane is in range of radio navaids, only the GPS position field is blank. If radio updating is inhibited, the FMC uses inertial as the only navigation source as shown in Figure 12 below.

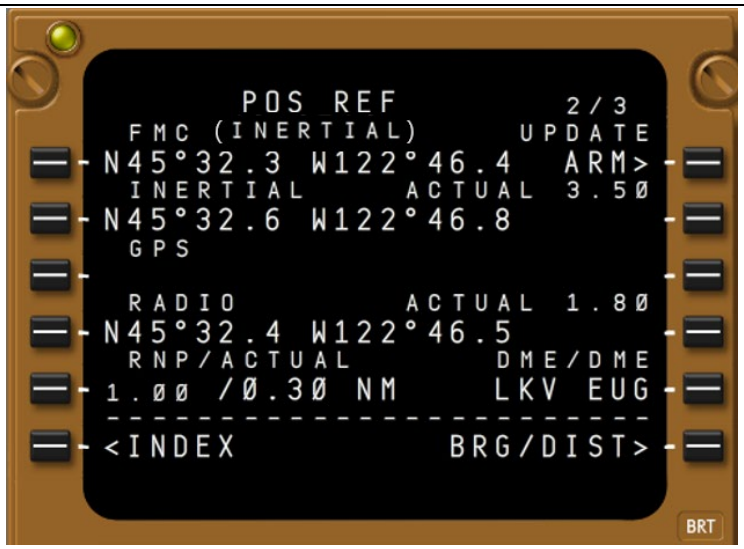


**Figure 12 - Domestic within Radio Range**

When radio updating is enabled, the FMC uses the radio navaids as the navigation source as shown in Figure 13 below.

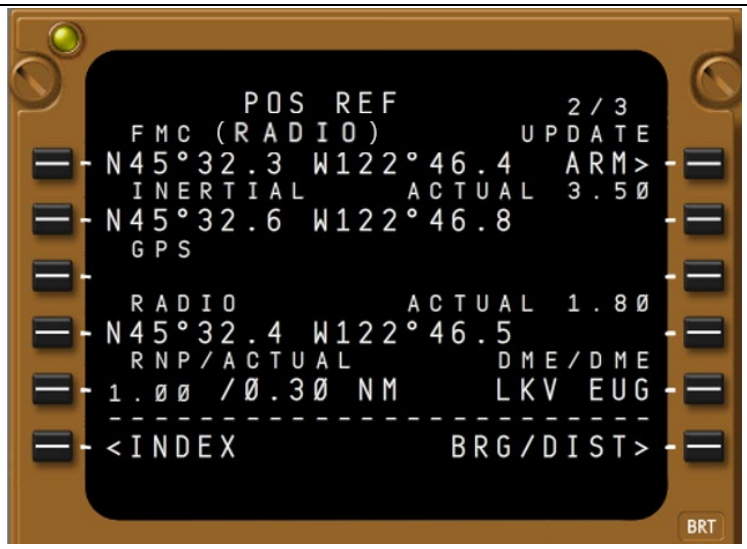


**Figure 13 - FMC Radio Position Update**

Line 5R shows the identifier(s) of the navigation station(s) being used to compute the radio position.

*CDU POS REF Page 3 / 3*

Once exiting the GPS interference area, GPS L and GPS R distance of less than 0.1 NM on the CDU POS REF Page 3 / 3 is an indication of recovery of the GPS receiver.

If one GPS BRG / DIST is blank, then that GPS has not recovered from the interference, and the FMC is using the other GPS sensor. This can indicate GPS interference is still occurring or that lingering effects remain after the airplane has left the GPS interference area.

If one GPS distance is greater than 0.1, this can be an indication that the GPS position is still affected by GPS interference. Although that GPS is not being used by the FMC for position determination, other systems can still use data from that GPS.

Figure 14 below is an example of a blank value for GPS R.

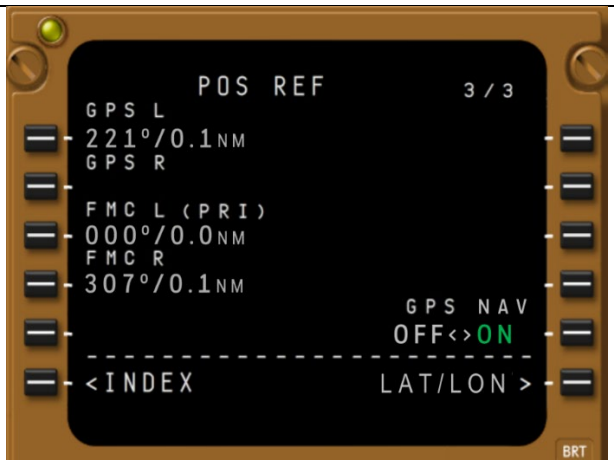


**Figure 14 – GPS R Field Blank**

## 3.2 EICAS Messages and Non Normal Checklists (NNC)

*GPS Receiver Failure*

For AIMS BP17A or later, failure of a GPS receiver, a GPS antenna, or loss of the signal between the antenna and the receiver results in the EICAS advisory message "GPS L" or "GPS R".

The EICAS advisory message "GPS" shows when both GPSs fail.

On airplanes with the GLU-925 Multi-Mode Receiver (MMR), loss of GPS signal or GPS signal jamming for a period in excess of 12 minutes can result in one or more of these EICAS messages: GPS, GPS L, GPS R, RUNWAY SYS, and GND PROX SYS. On airplanes with other MMRs, loss of the GPS signal or signal jamming does not result in any EICAS message because there is no system failure.

When the GPS signal is lost or jammed, the navigation update mode changes to the next available sensor. If the navigation position accuracy is reduced, the ANP increases. When ANP exceeds RNP, the NAV UNABLE RNP message shows. The same non-normal procedures apply whether the messages are caused by GPS signal jamming, loss of GPS signal, or GPS receiver failure. If this occurs on the ground, all EICAS messages should be addressed before take-off.

*Other Non-Normal Checklists NNCs*

It is not possible to develop checklists for all situations. In all situations, the captain must assess the situation and use good judgment to determine the safest course of action.

## 3.3 Ground Proximity Warning System (GPWS) Look-Ahead Terrain

The GPS is the primary source of position data for the GPWS Look-Ahead Terrain function. When the GPS signal is not available, the GPWS Look-Ahead Terrain function uses inertial data as a backup. When the inertial horizontal position uncertainty stays within limits, the terrain continues to be shown on the ND and the look-ahead terrain alerting continues to function. Once the inertial position uncertainty exceeds limits, the terrain is removed from the ND and the "TERR POS" message shows. Ground proximity alerts that occur are valid.

The GPWS Look-Ahead Terrain function cannot detect a small or gradual changes in the GPS position or altitude. If this occurs, depending on the landscape in the terrain database for the GPS position, alerts associated with look-ahead terrain function can occur when alert thresholds are exceeded. There have been several in-service cases where false GPWS look-ahead terrain alerts occurred during GPS smart jamming.

*Ground Proximity Terrain Override (TERR OVRD)*
If TERR OVRD is selected, it inhibits the GPWS look-ahead terrain and obstacle display and the TERR OVRD message shows.

GPWS immediate alerts are based on radio altitude, barometric altitude, ADRS, glideslope deviation, and airplane configuration. These alerts continue to function during GPS jamming and if an alert occurs, it is valid. GPWS alerts occur for the following conditions:

- altitude loss after takeoff or go-around
- excessive descent rate
- excessive terrain closing rate
- unsafe terrain clearance when not in the landing configuration
- excessive deviation below ILS glideslope

These functions also remain valid:

- reactive windshear
- altitude call outs
- bank angle callouts (as installed)

GPWS alerts that do occur are valid. Accomplish the maneuver associated with the alert as described in the FCOM/QRH.

### 3.4 Runway Awareness and Advisory System (RAAS)

On airplanes equipped with RAAS, when the GPS signal is lost, RAAS is unavailable and either “RUNWAY SYS” or “RUNWAY POS” are shown on EICAS. Ground proximity alerts that occur are valid.

### 3.5 Air Traffic Control (ATC) data link

Boeing has received reports in which the time and/or date shown on the flight deck changed due GPS interference. In most events, once the airplane has exited the GPS interference area, the time and/or date shown returns to the correct value. However, in some occasions the time and/or date shown can still be affected by the past GPS interference.

Airplane system time and date is shown on the flight deck clock (as installed) or by selecting the STATUS display for airplanes without a flight deck clock. Operators can set up Airline Modifiable Information (AMI) COMM pages to display the system clock and track changes when time or date unreasonably change.

Air Traffic Control (ATC) data link functions use the airplane time and date and can therefore be impacted by GPS interference.

- The Aeronautical Telecommunication Network (ATN) data link logon reports the time and date. With an incorrect time or date, ATN data link logons can be rejected by the ground system. If the aircraft is already logged on to ATN when the time or date becomes incorrect, any subsequent uplinks show “INVALID UPLINK” due to the difference in time and date between the aircraft and ground system. The ground system can disconnect from the aircraft due to the error in which case the ATN connection will be terminated and indicated in the message “ATC COMM TERMINATED”.

- Future Air Navigation System (FANS) Controller-Pilot Data Link Communication (CPDLC) does not compare date or time between the aircraft and ground systems. Current airplane time is appended to any FANS CPDLC uplinks, but all FANS CPDLC functionality remains the same if time and date are incorrect. However, if a FANS CPDLC Uplink Delay Monitor is established between ATC and the airplane, uplinks appear to be old due to the incorrect airplane time or date. The resulting text “UPLINK DELAY EXCEEDED” is shown on the uplink message header. However, the flight crew can still respond to this message and utilize FANS CPDLC normally.

Once the airplane exits the GPS interference area, the airplane clock should return to normal operations. If the time or date shown on the clock is not correct, the airplane is likely to be in the GPS interference area, but lingering effects can persist affecting the time and date even after exiting the GPS interference area.

### 3.6 Automatic Dependent Surveillance - Broadcast (ADS-B) during GPS signal interference

During GPS interference or when the GPS signal is lost, the transponder ADS-B Out function is inoperative.

- ADS-B OUT L or ADS-B OUT R messages show, as installed. Selecting the opposite transponder causes the other message to show since the GPS signal remains unavailable.
- Loss of ADS-B position reports by ATC. ATC may notify the pilot and request a switch to the other transponder; however this does not restore the ADS-B function. The transponder Mode C remains operational.
- ADS-B Out reporting of incorrect airplane position during a GPS smart jamming event is possible. In this case, ATC can observe a position difference between ADS-B Out position and airplane position on primary and secondary radar.

### 3.7 Automatic Dependent Surveillance - Contract (ADS-C)

ADS-C uses the FMC position to provide position reports to ATC.

### 3.8 EFB

Some EFB applications use GPS data, and GPS interference can affect those applications.

## 4 ADDITIONAL INFORMATION

A full listing of FAA-issued flight prohibition and advisory NOTAMs, and flight prohibition SFARs for areas in which the FAA does not provide air navigation services is posted on the FAA website at:

http://www.faa.gov/air_traffic/publications/us_restrictions

Collins Aerospace GLU-925/GLU-2100 MMR can experience a date shift that persists after exposure to extended GPS interference.

Maintenance tip 777 MT 34-051 provides recommended actions to correct GPS impacts that have resulted from interference on previous flight legs. When the actions are executed on the ground, effects of GPS interference can be corrected.

## 5 SUMMARY

Basic GPS jamming has similar flight deck effects and impacts on the airplane systems as a loss of GPS signal for any reason; however smart jamming or "spoofing" which is more sophisticated can produce various additional flight deck effects.

When a flight crew encounters GPS signal interference, report the event to ATC as soon as practical. Flight crews should be informed of the impact of lost or jammed GPS signal on navigation specifications requiring its use such as RNP-AR approaches. Such navigational procedures can be unusable during these events and alternative procedures can be needed. If an EICAS alert message shows, do the checklist for that message.