Quality Assurance During Flight Inspection

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BIOGRAPHY

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Main subject: Flight Guidance and Control

With Aerodata AG, since 2000
Responsibilities:
- Project management
- Flight inspection system design
- Development of AFIS cockpit flight guidance and autopilot interfaces
- Development of moving map applications for AFIS and cockpit displays
- Development of RNAV/RNP procedure inspection capabilities
- Development of GBAS inspection capabilities
- Certification of flight inspection systems and aircraft modifications
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ABSTRACT

Flight inspection today includes flight calibration as well as flight validation of instrument flight procedures. Flight Inspection is an essential element of quality assurance for the air navigation infrastructure. The aim is to ensure that air navigation based on navigation aids and instrument flight procedures is safe. Flight inspection is the last element in this chain of checking. Any undetected errors might have a significant impact on the safety of users of the navigation aid or instrument flight procedure. Therefore, quality assurance of flight inspection results itself is imperative. Many contributing elements involved in the flight inspection can influence the process. These elements include personnel (pilots and inspectors), equipment (e.g. aircraft and flight inspection equipment) and operation procedures. Means to identify database or equipment issues as well as operational and human problems are required in order to avoid affecting the results.

This paper describes elements that have been implemented to flight inspection in order to ensure a high level of integrity and accuracy of flight calibration output.

INTRODUCTION

Flight Inspection of radio navigation aids and Flight Validation of instrument flight procedures are required as part of quality assurance in order to ensure the use of navigation aids and flight procedures is safe. The results from the flight inspection are communicated from the flight inspector on board an aircraft to the navigation aid technician on ground. According to the measured flight inspection result, the ground technician adjusts the navigation aid until the results show satisfactory performance and compliance with the requirements laid down by the ICAO SARPs. A Navaid technician will typically try to minimize the error of the navigation aid. If the flight inspection results indicate e.g. a localizer alignment error of some µA, normally the localizer is adjusted in order to get close to 0µA error. This is a normal process during flight inspection.

But what would happen, if the flight inspection results are wrong? What if the localizer was perfectly aligned, but the flight inspection system indicated an alignment error that does not exist? Two possible scenarios might be caused by wrong flight inspection results:

1) Out of tolerance conditions of a navigation aid are not detected during flight inspection
2) A perfectly aligned navigation aid is adjusted to out-of tolerance according to the wrong flight inspection results.

Undetected out-of-tolerance conditions of a navigation aid could be very dangerous. The impact to aircraft using such navigation aid could be:

- Collision with obstacles after intercept of a “false ILS course“
- Hard landing due to a course bend at threshold
- Controlled flight into terrain due to incorrect To/From VOR Flag
- Collision with obstacles due to wrong LTP/FTP coordinates
- …many other catastrophic or hazardous scenarios

For that reason, quality assurance for the flight inspection, which is a part of a quality assurance process itself, is imperative.

Flight inspection is a complex process. The results can be effected by many contributing elements. Flight inspection elements consist of involved equipment and involved personnel in combination with operation procedures. Each of these elements might have a direct impact on the results.

Involved Equipment:

Sensors:
An Automatic Flight Inspection System integrates sensors for receiving the signals radiated by the navigation aid under inspection. The receivers connect via RF cables to the antenna mounted on the airframe. Antennas might fail because of external damage or as result of vibration e.g. under icing conditions. Improper bonding between airframe and antenna because of matured sealing in combination with humidity also may lead to wrong results when measuring signal in space power density or modulations and deviations respectively. Such effects are hard to detect since they typically do not appear instantly but fade in instead. Often such effects only have an impact on certain frequencies.

Computer / Software:
Wrong flight inspection results can occur by erronous software algorithms executed on the flight inspection system. Quality assurance during the software development process, including intensive testing might help to reduce errors.

Database:
Different databases are typically stored in a flight inspection system:

- Receiver calibration data. Correction data applied to the receiver output in order to improve the accuracy
- Antenna pattern data: Model for the antenna gain variation depending on azimuth, frequency. These patterns are required for signal in space power density determination.
- Equipment database: Aircraft specific antenna position data (for lever arm transformation) and cable loss data.
- Facility database: Accurate coordinates and nominal geometry of the facility under inspection

Any error in the above data has a direct impact on the flight inspection results. Integrity of these databases is extremely important.

Position Reference Equipment
Differential GNSS is the most typical position reference. Calibration of precision approach aids (like ILS or GBAS) requires the use of DGNSS with carrier phase measurements. The setup of DGNSS ground equipment and the coordinates of the ground reference station directly affect the resulting accuracies. Low GNSS coverage may also lead to low accuracy.

Calibration Equipment
The calibration data for the flight inspection receivers is determined by feeding a reference signal to the flight inspection receiver and comparing the receiver output to the reference input. The receiver calibration data is applied for correction of each receiver output. A single fault in the signal generator during the calibration process can lead to incorrect calibration data for both receivers. A faulty signal generator would affect both NAV receivers in a flight inspection system during calibration. Detection of the resulting effect is very difficult, since both receivers show the same (wrong) data.

Involved Personnel

Human Errors occur whenever human being are involved in a process. The following personnel is typically involved in flight inspection operation:

AFIS Operator:
The AFIS operator controls and monitors the flight inspection system during the flight. Typical errors during system operation can occur because of difficult system operation and non-intuitive graphical user interface (GUI) in combination with high workload and stress.
He further interprets the flight inspection results and communicates them via voice communication to the Navaid technician.

Navaid Ground Technician:
The ground technician adjusts the Navaid according to the measurement results reported via voice by the AFIS operator,. Typical errors occur during voice communication:

- Language problems
- Use of different units (µA versus DDM)

Pilots:
Typically, one pilot is flying the aircraft as precisely as possible on the desired measurement path, while the second pilot communicates with air traffic control (ATC), looks out for obstacles and ensures that the aircraft stays on a safe track.

Non-precise flying has an impact on the flight inspection results and is typical a result of high workload or pilot fatigue when manually flying.

AFIS Maintenance Engineer
The AFIS Maintenance Engineer maintains the AFIS and performs regular calibration or check of the AFIS receivers. By this, he ensures the use of valid AFIS receiver calibration data.

Human Performance

Whenever human beings are involved in the process, the error probability according to **Fehler! Verweisquelle konnte nicht gefunden werden.**is relatively high:

Description	Error Probability	
General rate for errors involving high stress levels	0.3	Stress
Error in a routine operation where care is required	0.01	Normal Conditions
Error in simple routine operation	0.001	

Figure 1 Human Error Probability [1]

The operation of a flight inspection system might be “simple routine operation” or “routine operation where care is required” the resulting error probability is 0.01 or 0.001 per operation. Under “high stress level” the probability increases up to 0.3 per operation.

Human performance is very limited. The error probability increases dramatically with stress level. A high level of automation is required to reduce error probability of human beings. In order to achieve high integrity, it is required to have a low workload. Automatic integrity checks can help the operator during system monitoring.

What does this mean?

- Flight Inspection is a complex! A lot of equipment is involved in this process. Human beings execute many tasks.
- Many things can go wrong! According to Murphy’s Law: “Anything that can go wrong will go wrong”.
- Errors in each involved element can directly lead to incorrect flight inspection results, if not detected.
- Errors in flight inspection results can lead to a Navaid of-of-tolerance conditions, if not detected by other mitigation.

IMPLEMENTED MITIGATIONS IN AFIS

The following mitiagtions have been implemented to the AFIS decribed by this paper in order to achieve high integrity of flight inspection results.

Software:

Special care is required during the software development of the flight inspection software. AFIS software should be developed in accordance with applicable guidance material for the production of software.

The software for the AFIS described by this paper is developed according to RTCA DO178:

- Level C: for reference position algorithms and time synchronization

- Level D: for elements of the graphical user interface

Every software change is classified:

- Change Category I: Change which may affect the measurement results, e.g.:
    - Change of Reference Position calculation
    - Change of measurement - algorithms
- Category II: Change not affecting the measurement results, e.g.:
    - Change of GUI
    - Enhancement of graphic header information

The AFIS Software is developed using a version control system. Every software build is traceable by a unique version number and can be reproduced any time. During a software build a software change report and a configuration status document (CSD) are automatically created.

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Software Change Report

afis_260_fis_smatsa__7_0_3__2017_03_14__16_25

to

afis_260_fis_smatsa__7_0_4__2017_06_01__15_58

Attached (Category I)

AID Nr.	Ref.	Change Description	Affected Module(s)	Chg. Cat.
14975	Other Customer's Request	Avoid artefakts in GP structure tolerance by no longer using data between T and C.	Tolerances	I

Attached (Other Categories than I)

AID Nr.	Ref.	Change Description	Affected Module(s)	Chg. Cat.
10444	Other Customer's Request	Integrated USB oscilloscope into FI software.	Data Acquisition	II
15013	SMATSA Feedback	Fixed wrong QNH unit displayed on PFD. (in Hq instaed of hPa).	EFIS	II

Figure 2 Extract from Software Change Report

The software change report documents in comparison to a previous delivered software version:

- Reference to action item database (AID):
    - Change request description
    - Detailed description of implemented change
    - Link to test protocol
- Brief description of change
- Classification (Category I or II)

The configuration status document (CSD) contains:

- Libraries used
- Compilers used
- Target hardware

Every software change is tested and documented. Customers have a clear picture what has changed in a new software version and can carry out specific testing themselves, if needed.

Incorrect Flight Path:

Non- precise flying can have an impact on the accuracy of the flight inspection results. Typical examples are:

- The aircraft is not stabilized at start point for LLZ partial orbit. The variation of bank angle will lead to incorrect clearance measurement and incorrect signal in space measurements.
- Excessive path deviation during ILS offset approach will lead to incorrect width measurement due to non–linearity.

Two mitigations have been developed to reduce the likelihood of such effects.

Mitigation 1:
An AFIS information display is installed in the cockpit:

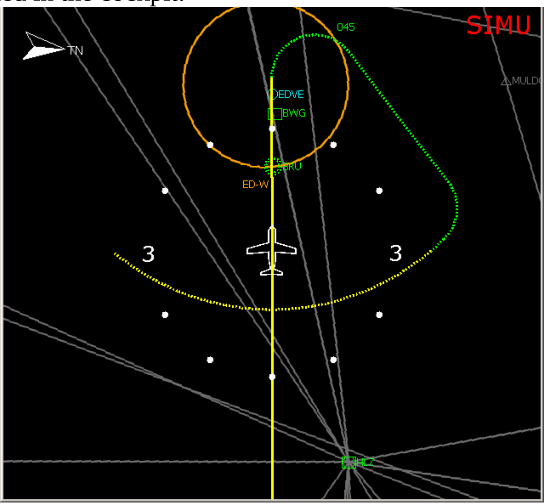

Figure 3 Cockpit Information Display

This cockpit information display shows the position of the aircraft in relation to the desired calibration procedure to the pilots. A displayed green line suggests a smooth path to intercept the next calibration profile. When following the guidance to the next calibration profile, the aircraft will be properly established on the next calibration profile when overflying the starting point for the measurement. The overall situation awareness of the pilots is improved as well as the communication between AFIS operator and pilots.

Mitigation 2:

As second mitigation for incorrect flight path, AFIS flight guidance can be selected for display on the pilot PFD. With this feature ILS offset approaches can be flown with “needles centered”. The autopilot can be coupled to the AFIS guidance, which allows flying all kind of flight inspection profiles using the autopilot:

- Orbit profiles
- Offset approaches
- Instrument flight procedures (during flight validation)

This precise flying ensures reliable results during ILS width measurements and ensures correct signal in space power density measurements. Further, this feature reduces the cockpit workload significantly.

Incorrect AFIS Setup:

A wrong setup of the AFIS can lead to unusable or wrong flight inspection results. A typical mistake is that ILS inspection runs are flown in a non-suitable order or the profile altitude was selected wrong. The error rate increases significantly with the operator workload. Time pressure and uncomfortable temperatures also have a negative impact.

Mitigation 1:

The complete flight inspection mission can be prepared using a portable mission planner. Using this mission planner the mission can be prepared in a stress-free environment (e.g. air-conditioned hotel room or office). The mission setup is then loaded to the AFIS by simple file transfer. Human errors during system setup can be reduced to a minimum by this feature.

Mitigation 2:

Using the integrated simulator training mode the operator can familiarize himself with the system operation and can practice on ground in preparation of the mission. The correct use of "Event" pushbuttons for PAR and PAPI calibration can be practiced prior to flight.
The mission planner also allows the operator to review the flight inspection data from the last time the facility was inspected. On the AFIS "old" flight inspection data can be loaded in the background of the "new" graphics for direct comparison during the flight.

Mitigation 3:
A comfortable, intuitive and easy-to-use Graphical User Interface (GUI) can reduce the workload of the operator. The AFIS GUI described in this paper has been designed according to the latest design guidance for man machine interfaces (MMI) in close cooperation with professional industrial designers. According to customer feedback the operator workload was reduced by the introduction of this new GUI. Operational errors occur less frequently.
The way flight inspection data is displayed has also been re-worked. Graphic windows integrate labels with computed results. The results are displayed so that they refer directly to the position of the graph. Data interpretation has been simplified leading to less errors in data interpretation.

Undetected Equipment Problems:

Abnormal Equipment Status occurs very rarely. For that reason such situation can easily be overseen by the operator. Abnormal equipment status could be e.g.:

- Excessive temperature: the system accuracy could be reduced.
- Receiver calibration data is expired: the equipment is due for calibration or check

Mitigation:
The AFIS described in this paper integrates automatic integrity checks. In case any abnormal situation has been identified, the operator is automatically alerted. Like in a crew alert system (CAS) the alerts are color coded according to their rated severity and impact to the current measurement:

- Warning: RED
- Caution: AMBER
- Information: GREEN or WHITE

The operator can acknowledge certain alerts or mark them to be ignored in the future. Abnormal system status will be easily identified.

Faulty Receiver:
A problem in a flight inspection receiver or its antenna could lead to incorrect results.

Mitigation:
The AFIS integrates a dual set of VOR, GP, LLZ and DME receivers. When both receivers of a type are used for measuring the same facility, the AFIS automatically compares the (calibrated) receiver output. If the output differs too much an automatic Alert "Warning (RED): ILS Receiver Output Differs" is triggered to highlight this situation to the operator.
This automatic check allows easy detection of receiver or cable problems. An on board signal generator (if available) allows to investigate in flight, which receiver is reliable and which one is not.

Antenna Fault:
A faulty antenna would directly lead to incorrect results. Antenna problems can be various; sometimes only one receiving direction or certain frequencies are affected. Sometimes antennas mature due to poor bonding resulting from leaking sealer allowing humidity to enter the gasket.

Mitigation:
The dual receiver constellation in the AFIS and the antenna-switching unit, which allows connecting each receiver individually to each antenna. Antenna problems can be identified easily.

Communication with Ground Technician:
Quite often problems originate in the communication between AFIS operator and navaid technician. Language problems and misunderstanding might lead to wrong navaid adjustments or incorrect navaid settings.

Mitigation:
A data downlink ground station, which is setup at the navaid shelter directly, displays online flight inspection data. The data is received from the flight inspection aircraft via telemetry. The effect of any navaid adjustment becomes directly appearing on the display of the ground station. The data downlink station, once setup works fully automatically and does not need any user input or control. No training is required for navaid technicians for using this equipment.

Wrong Database Coordinates:
The integrity of the facility database is of highest importance. Wrong coorinates will directly lead to incorrect flight inspection results.
Typical errors in flight inspection databases are:
- A wrong point has been used during the survey, e.g. as point for the rover setup
- Typing errors during transfer of the coordinates from the survey equipment to the AFIS
- Errors during format conversion e.g. [dd mm.mmmmmm] into [dd mm ss.ssss]

Mitigation 1:
Manual data entry or handling are avoided. The coordinates are directly imported from the survey equipment into the AFIS database. The survey data is imported via SD-card to the portable mission planner. By this process human errors in the database are reduced dramatically.

Mitigation 2:
Visual verification of the database. Using the Portable Mission Planner the database is typically prepared in an office environment (e.g. hotel room). The database can be visualized in Google Earth. Single reference points as well as facility locations, localizer with front course or entire instrument flight procedures are shown in Google Earth. Typical database errors become immediately visible and can be corrected prior to flight.

Mitigation 3:
The AFIS supports all kinds of formats for coordinate entry. Any format can be entered and the AFIS will automatically convert into the standard format [dd mm ss.ssss].
This feature eliminates conversion errors.

Wrong Calibration Data:
Since AFIS receiver calibration data is applied to the actual measurement, any wrong calibration data has a direct effect to the flight inspection results.

Errors in calibration data can result from a wrong signal generator setup during calibration. Correct signal generator setup requires setting numerous switches correctly. Any wrong switch could lead to wrong reference signals. The likelihood of a wrong setup is very high due to the limited human performance and the number of settings required.

Another scenario is a defective signal generator. If the non-accurate reference signal is used for AFIS calibration, the error of the signal generator is transferred to the AFIS and subsequently to the navaid, if not detected.

Mitigation 1:
Full automatic calibration. During the AFIS calibration process the AFIS software controls the antenna switching unit for automatic connection of the signal generator output to the receiver's input. Further the software remote controls the signal generator during the calibration process. Step by step different reference signals are provided to the receiver and the receiver's response to these signals is measured and recorded by the AFIS. The software considers cable losses and automatically compensates for them. Finally, curve-fitting algorithms determine characteristic curves. The display shows the characteristic curves and the determined correction values numerically and graphically for acceptance by the operator.
This automatic process avoids errors during the calibration process.

Mitigation 2:

Independent receiver check has been implemented. An independent check of the resulting AFIS accuracy after its calibration is performed. The aim of this check is the detection of a possible signal generator error of the signal generator used for calibration.
The receiver check is works similar to the calibration process. Antenna switching unit automatically connects the signal generator to the receiver, the signal generator is tuned by software and the calibrated receiver output (with the calibration data applied) is determined by the software. By this process the overall accuracy of the calibrated AFIS can be checked. The effect of a signal generator fault during calibration becomes will be detected by this check.
This is a very important mitigation, since otherwise such signal generator fault might be transferred to a mis-aligned navaid!

Wrong DGPS Setup:
A wrong DGPS setup would lead to incorrect flight inspection results. The typical errors that occur during DGPS setup are:

- Configuration of DGNSS station with wrong coordinates
- Selection of a wrong reference point (setup over wrong reference marking)

The flight inspection graphics would e.g. show a curved graph for a localizer error:

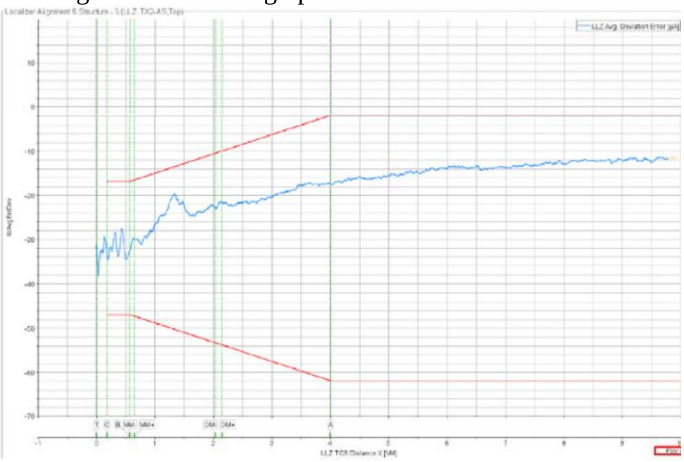

Figure 4 Example:Localizer Error with wrong DGPS setup

Mitigation:
The DGNSS ground reference station of the AFIS described in this paper does not need any programming. First of all this reduces the workload but it also avoids human errors during setup. The DGNSS ground reference station is just transmitting GPS raw data (as seen from the ground station) to the AFIS on board the flight inspection aircraft. On board the operator selects the setup location of the DGNSS ground station from a previously prepared database. According to the operator's selection the DGNSS correction data is calculated by the on-board AFIS. Even without landing, the operator can correct his selection in case of a mistake. The correction of coordinates can even be done after the flight by the capability for reprocessing the flight inspection data with modified DGNSS coordinates.
The scenario of a wrong DGNSS setup/configuration is very unlikely.

CONCLUSION

Many elements are involved in flight inspection. Many things can go wrong.
Errors of the contributing elements can lead to wrong flight inspection results. Wrong flight inspection results can lead to catastrophic or hazardous navaid out-of-tolerance conditions, if not detected. Human beings are limited in their performance; therefore, automation shall be used to the highest extent. Functions for automatic checks are required for reliable detection of abnormal conditions. The various mitigations explained in this paper are highly recommended in order to achieve integrity of flight inspection results.

REFERENCES

[1] Kirwan, Barry, A Guide to Practical Human Reliability Assessment. London: Taylor & Francis Ltd., 1994