

Efficient Flight Inspection Without Reference Station

Dr. Mirko Stanisak

System Engineer
Aerodata AG
Braunschweig, Germany
Phone: +49 531 2359-304
E-mail: mirko.stanisak@aerodata.de



Frank Musmann

Project Manager
Aerodata AG
Braunschweig, Germany
Phone: +49 531 2359-341
E-mail: frank.musmann@aerodata.de



Claus Wilkens

Project Manager
Aerodata AG
Braunschweig, Germany
Phone: +49 531 2359-140
E-mail: claus.wilkens@aerodata.de



ABSTRACT

Current flight inspection operations often include the need to set up a GNSS reference receiver (including a telemetry system) at a specific airport location, which is required for high-accuracy reference positioning. Thus, flight inspection missions are often planned to include intermediate landings before and after the measurement flights for a calibration at an aerodrome. By reducing the number of intermediate landings, the overall efficiency of a flight inspection operator could be considerably improved.

Nowadays, various technical principles can be used to achieve the required positioning accuracies without the need for setting up a dedicated GNSS reference receiver, even for CAT II/III ILS inspections. Each has its own advantages and disadvantages. This paper will detail principles like continuously operating reference stations (CORS) installed permanently at aerodromes, precise point positioning (PPP) via L-Band data, commercially available GNSS reference data via Internet, or hybrid inertial-optical navigation algorithms, among others.

Such efficiency optimizations always depend on various specific local factors and are not applicable uniformly for all flight inspection organizations. This paper will discuss possible challenges, including organizational planning, local operational constraints, national approvals, and equipment already installed on the flight inspection aircraft.

INTRODUCTION

Reliable flight inspection results do not only require precise measurements, but also a reference position to which the measurements are related to. As truth data, the obtained position needs to be highly accurate and reliable. Based on older requirements for angular positioning errors, ICAO DOC 8071 [1] was modified to incorporate maximum acceptable positioning errors for absolute truth positioning in flight inspections [2], with different acceptable limits depending on the operational categories of the ground navigation aid. The resulting minimum positioning accuracies (for absolute measurements) as detailed in Table 1 must be met to guarantee sufficient overall measurement performance in flight inspection.

Table 1: Minimum Positioning Accuracies and Corresponding Constraint Points for Absolute Measurements of ILS Ground Installations (based on [1])

Category	CAT-I	CAT-II	CAT-III
Cross Track	2.17 m @ Point C	0.61 m @ Point T	0.33 m @ Point D
Vertical	0.27 m @ Point C	0.083 m @ Point T	0.083 m @ Point T

Along with the numeric values, this table also defines the corresponding most constraining point, i.e. one point at an approach where the highest accuracy is required. While the lateral accuracies are primarily important for localizer measurements, the vertical accuracies are more important for the glide slope measurements.

These requirements are more stringent for higher operational categories of ground navigation aids, as higher categories can be used operationally with lower visibilities. For instance, for inspecting ILS Cat. III installations, the vertical accuracy of the reference position over the threshold must be better than 8.3 cm.

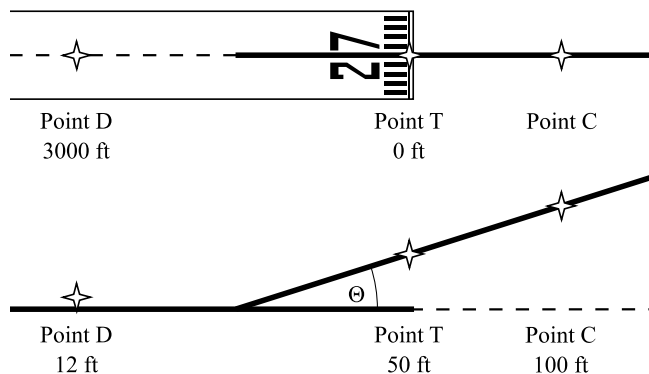


Figure 1: Significant Points of an ILS Installation. (top: lateral view, bottom: vertical view)

The measurements taken with different antennas on different positions on the airframe must be transferred to a common reference point, i.e. compensating the lever arms using the aircraft's attitude. The reference position and the measurements must be synchronized carefully to prevent errors due to diverging time bases.

Over the last few decades, global navigation satellite systems (GNSS) like GPS and Galileo have been used predominantly for reference positioning. Despite not being able to provide sufficient standalone positioning accuracy, GNSS positioning and timing are the basis of most reference positioning techniques but must be augmented by independent systems.

For flight inspections of a ground based navigation aid at an airport, modern automatic flight inspection systems use a GNSS ground station at a precisely surveyed position at the airport. The raw measurements of this GNSS ground station are then uplinked (e.g. via a telemetry system) to the aircraft. With GNSS measurements from the ground and from the airborne GNSS antenna, a highly accurate position solution can be calculated. This position computation uses the code and phase measurements to remove common influences and to resolve the phase ambiguities. This way, techniques like PDGNSS or RTK can achieve sufficient accuracy to meet the requirements given in DOC 8071.

Many operators set up this combined GNSS and telemetry unit (usually called reference station in this context) using the flight inspection aircraft. Typically, the operator ferries the aircraft from its homebase to the airport at which a ground navigation aid is to be inspected. After landing, the reference station is set up at the surveyed position for continuous GNSS data. Afterwards, the flight inspection aircraft starts to conduct its mission, measuring the signal-in-space broadcast by the respective ground navigation aid. The broadcasted GNSS data is used for continuously obtaining the aircraft's high-accuracy reference position. After having completed the measurements, the flight inspection aircraft lands at the airport again to collect the reference station.

If not used for other purposes (e.g. refueling or immigration/customs), the two landings required for this kind of operation reduce the operational efficiency. This paper will thus address the key questions of how these intermediate landings can be reduced, how the aircraft's reference positioning can be determined without setting up a reference station, and how the overall efficiency of flight inspection operations can be optimized.

POSITIONING WITHOUT REFERENCE STATION

Eliminating the need to set up a mobile ground station at an airport has the potential to increase operational efficiency significantly, if the operational requirements can be met without it. Several technologies will be discussed in this section, which have the potential to achieve the required accuracy even without setting up a reference station.

All of these options rely on specific equipment, therefore not all of them are applicable for all flight inspection service providers alike. In addition, the respective operational benefits are highly subjective for each flight inspection service provider and their organization and requirements.

In lieu of the accuracy requirements, it is necessary to distinguish between absolute and relative positioning techniques. The reason behind this is that the resulting reference position must relate to the same coordinates as the surveyed positions of the ground navigation aid, especially regarding the time of surveying.

Absolute positioning technologies are related to an absolute position in a global coordinate system, e.g. WGS84. Even though fixed on the Earth's surface, WGS84 coordinates change over time due to effects like plate tectonic etc. To meet the accuracy requirements, it must be ensured that all relevant points are surveyed and updated periodically to limit potential offsets.

Relative positioning technologies relate to a local fix, e.g. to a surveyed point at an airport. As long as this point was surveyed at the same time as the other relevant coordinates, potential coordinate drifts can be neglected as they are covered by all points drifting identically over time.

Mobile GNSS reference stations set up at local surveyed points at an airport are used in a relative manner by any differential GNSS processing. Subsequently, all coordinates related to the navigation aid (which are stored in the reference database) just need to be surveyed at the same time as the surveyed point for highest overall accuracy.

Continuously Operating Reference Stations (CORS)

The first possibility is to have dedicated reference stations installed permanently at the airports. Like their transportable counterparts, stationary reference stations include a GNSS antenna, a GNSS receiver, a telemetry modem and a telemetry antenna, often integrated into a single enclosure. They are installed permanently at all relevant airports and operate continuously.

Of course, as they must continuously withstand adverse environmental conditions, they need to be housed and installed accordingly, ensuring protection against lightning, rain, wind, etc. This makes ground installations rather expensive, especially when required for numerous airports.

Sometimes, they can be activated via the telemetry system to allow multiple neighboring stationary reference stations on the same telemetry frequency.

An advantage is that the surveyed site coordinates are programmed into the ground station, without the need to select the respective coordinates from within the AFIS software, so that no confusion about the reference coordinates used is to be expected. Due to the relative positioning, the resulting accuracy remains constant even with older surveying data, as long as all coordinates use the same reference datum.

Commercial CORS Data via NTRIP

Continuously operating GNSS reference stations (CORS) are not only used in flight inspections, but also in various industries for positioning (e.g. for surveying or civil engineering).

For interoperability, all major GNSS receivers nowadays support outputting GNSS raw measurements using a device

independent output format, called RTCM v3 [3]. RTCM v3 formats the GNSS data from multiple GNSS constellations and signals in a very compact matter, so that it can be transferred via different physical ways efficiently. It even defines different accuracy classes to further optimize data rate for specific operational service goals.

This allows the use data from different GNSS receiver types transparently for positioning, a feature which is used to integrate heterogenous GNSS reference stations into so called GNSS networks.

Such GNSS networks are operated by commercial companies or land surveying offices and serve as central repositories for (live) GNSS data. For instance, Figure 2 shows the reference stations being operated by the German land surveying offices, SAPOS. Comparable dense CORS networks exist for numerous other countries around the globe.

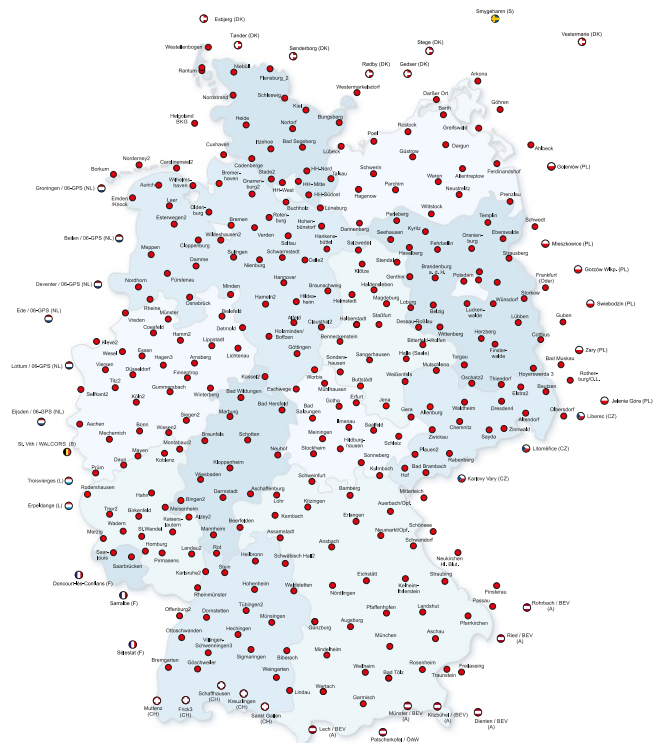


Figure 2: Example for a Nationwide GNSS CORS Network: SAPOS (Germany) [4]

The live raw GNSS measurements of every CORS station in such networks (usually in RTCM v3 format) can be accessed via Internet. This technique, called NTRIP (Networked Transport of RTCM via Internet Protocol) [5], is commonly used to provide data from every GNSS CORS station in a network to users in real time via Internet. Access to the GNSS raw data is handled via user credentials and can potentially include a fee (at least for some commercial networks).

One interesting thing with big GNSS networks is the possibility to generate corrections for the user's position, interpolated from several stations in the vicinity. This way, some networks provide GNSS data for virtual base stations, especially if there is no station directly nearby, for an improved overall positioning performance.

Flight inspection systems with internet connectivity (ref. [6]) can benefit from these capabilities and receive the GNSS reference station data via Internet instead of via a dedicated telemetry system. Even for multiple GNSS constellations and signals, the resulting data rates are below 5 kB/s, which can be handled by almost all internet connectivity technologies.

Typically, professional CORS installations are surveyed regularly to compensate for the tectonic drift and other effects, changing the reference station coordinates with each update. This absolute positioning can lead to degraded accuracies unless all reference coordinates are updated periodically, too.

Precise Point Positioning (PPP)

Both previous GNSS-based options use phase-differential GNSS principles to resolve the carrier-phase ambiguities for sub-decimeter accuracy. Differential GNSS assumes that most of the errors affecting GNSS are identical for the user and the reference receiver and is thus limited to small baselines.

Instead of transmitting GNSS data from a reference receiver on the ground to the aircraft and using this data to eliminate most influence factors, precise point positioning (PPP) tries to model all influences separately and to only send model parameters to the users. For this, a tight network of CORS is required and used to estimate parameters for the models. This way, PPP in principle also enables resolving the integer phase ambiguities to achieve sufficient reference positioning accuracy for flight inspections.

PPP services are offered by different providers and via different ways. Examples for PPP service providers include Terrastar (commercial service offered by Hexagon) or the Galileo High-Accuracy Service (HAL, offered globally as part of the European Galileo system). The data containing the model parameters can be received in different ways.

On the one hand, PPP corrections are broadcast via satellites. Terrastar for instance provides its data via an L-Band data link and geostationary satellites. The Galileo HAS is provided as part of Galileo's E6-B signal by all Galileo satellites. Due to the broadcast of the PPP data on L-Band frequencies, no additional antennas or receivers are required in many situations. On the other hand, the corrections can also be received via Internet (if available) using the NTRIP protocol. PPP solutions are processed on the GNSS receiver itself and are available globally.

Due to its global scale, PPP services must be considered an absolute means of positioning, requiring periodic surveying of all local coordinates used to ensure sufficient overall performance.

Hybrid Inertial-Optical Positioning

Another way to operate without a GNSS reference station is to hybridize the data from a high-performance inertial reference system (IRS) with an optical threshold detection system. The free-running IRS (an example of a high performance inertial reference system is shown in Figure 3) provides continuous, but drifting positions over a measurement run. The free-inertial solution itself does not meet the required performance due to its drift without external updates.



Figure 3: Example of High-Performance Inertial Reference System (image courtesy of iMAR GmbH)

For meeting the accuracy requirements, the IRS must be combined with complimentary sensors, which provide external truth positions for an integrated solution. One example (as shown in Figure 4) is the combination of an optical line scan camera with a laser range meter.

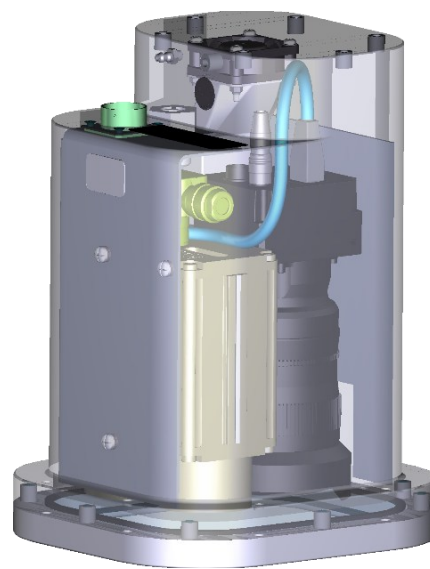


Figure 4: Example for Module Integrating Line Scan Camera and Laser Range Meter

This module is installed downward-looking within the fuselage and can capture both runway thresholds during an overflight. It compensates for the aircraft's attitude and height first and presents the resulting images (along with an automatic detected threshold position) to the FIS operator in the AFIS software. The operator uses this graphical user interface for cross-checking and adjusting the threshold positions.

With this and the heights above the thresholds (as measured by the laser range meter), the flight inspection system has two independent absolute update positions. Once confirmed by the user, all data from that measurement run is reprocessed to correct the inertial reference data to best fit the two external updates. This way, the resulting positional accuracy for the whole measurement run is sufficient to meet all flight inspection requirements.

With the integration of an IRS and the optical system, the dependency on GNSS positioning can be minimized – or used complementary with a GNSS anti-jam system [7].

EFFICIENCY GAIN

The effective gain in efficiency by omitting technical intermediate landings depends on a plethora of different factors, as each flight inspection service provider follows their own operational procedures. Each intermediate stop directly results in additional expenses, e.g. due to landing fees, engine and airframe cycles, additional fuel costs, and additional crew duty time.

Of course, not all intermediate landings can be omitted, but in general their reduction might make investments in new flight inspection technologies feasible and sensible.

In addition to the technical opportunities, various individual operational, technical and legal constraints must be considered here, too. The decision for or against different technologies must be taken very consciously as they need to be aligned closely with the actual or planned operation as well as with the technical equipment already present.

For this reason, the different technologies discussed in this paper should be considered as potential enablers only, which could lead to more efficient flight inspection operations, provided they align with numerous other factors.

CONCLUSIONS

Typical flight inspection operations nowadays often include planned intermediate landings for setting up a local GNSS ground reference station (which includes a GNSS receiver and a telemetry system) at a surveyed position at the airport. After taking off for the mission, this GNSS data is received by the flight inspection aircraft and used for its high-

precision reference positioning. By reducing the number of intermediate stops, the operational efficiency of flight inspection operations can be increased.

Different technical alternatives exist, which can provide similar levels of accuracy without the need to set up a local ground station. Despite requiring approvals by national regulators, these techniques allow flight inspections to meet all relevant requirements without the need for intermediate landings.

Of course, the possible efficiency gain due to this depends on the respective operational procedures and numerous additional factors.

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