Portable Flight Inspection System for Rotorcraft Instrument Flight Procedures Validation

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ABSTRACT

Continuous air traffic growth requires higher flight efficiency in order to optimize available airspace. Area Navigation techniques and satellite-based (GNSS/SBAS) instrument flight procedures (IFP) are currently changing the way to operate in all phases of flight for fixed-wing aircrafts, and soon they will also involve rotorcrafts. The key feature of rotorcraft is the possibility to operate fast and direct point-to-point transports to obtain desired goals in critical missions, like Helicopter Emergency Medical Services (HEMS), while maintaining a positive profit margin. However, since helicopters fly most of the time in Visual Flight Rule (VFR) they can't operate whenever weather conditions become strict, because of fog, clouds, or ice build-up phenomena.

Due to lack in rotorcraft specific routes, nowadays certified Instrument Flight Rules (IFR) helicopters fly the same routes designed for aircraft reducing their benefits and severely increasing their impact on Air Traffic Control. Helicopters IFP, both Point-in-Space (PinS) and Low-Level Routes (LLR), represent a solution since they are exclusively designed for helicopters, but, for the same reason, it's not appropriate perform their flight validation by means of fixed-wing aircraft. On the other hand, the choice to invest in an entire new platform (helicopter) and system (helicopter-customized flight inspection system) is not cost-effective considering the limited market size.

In the light of the above, a flight validation portable system called RIFIS (Repositionable IFP Flight Inspection System), was designed and realized. Such system, capable to be compliant with all regulation requirements, is suitable for being installed in any helicopter provided with certified avionic equipment. Basic idea was to use commercial off the shelf (COTS) components designed for satellites signal monitoring, coupled with a customized software, to fulfill the needs. Despite COTS components the proposed system ensures high level performance in metrics calculation, also providing Navigation System Error (NSE), Flight Technical Error (FTE) and Total System Error (TSE) assessments. This paper illustrates the flight inspection system solution designed for rotary wing aircraft by expounding concepts and choices involved in the project and sharing experiences. Detailed argumentations are reported on pros and cons of most critical technical decisions like antenna positioning, hardware architecture and software solution. Moreover, graphical data overview from a real PinS test procedure validation activity will be illustrated, followed by a proposal of flight validation report compliant with ICAO Doc 9906 vol.5 [1]

INTRODUCTION

Rotorcrafts can quickly connect ground infrastructures inside cities or in their immediate proximity (i.e: helipad, heliport, small airports), and densely populated areas, but they are Visual Meteorological Condition (VMC) dependent. *VMC are the meteorological conditions expressed in terms of visibility, distance from cloud, and ceiling equal to or better than specified minima* (ICAO Annex 2: Rules of the Air), when VMC minima are not fulfilled pilot is required to enter instrument meteorological conditions (IMC). Helicopter flights under VFR in marginal VMC are a major contributor to helicopter accidents. The limited visibility and relatively low speeds contributed to many accidents where loss of control and entering IMC inadvertently was determined to be a root cause. There are undeniable safety benefits in providing helicopter operators with an option to fly some missions under IFR. IFR guarantee operational benefits as it increases the service reliability, but published procedures are only partially compatible with rotorcraft needs. A certain number of significative considerations need to be faced when dealing with rotorcraft operations on fixed-wing IFP procedures:

- Rotorcrafts are routed as aircrafts, rather than to proceed directly to a destination, increasing flight time. This causes difficulties in fuel consumption management, and thus also operative and environmental issues.

- The fuel quantity requirements are higher and, considering the limited helicopter fuel range, sometimes are too high due to the necessity to alternate landing location.

- Flight time can be higher especially if instrument departure and instrument approach are not located next to the helicopter destination. This additional flight time may not be negligible compared to the typically short duration of helicopter flight.

- Operational altitude for fixed-wing procedure may introduce, on en-route phase, icing problem for helicopter, meanwhile on approach phases, a noise impact that could be avoided with customized procedure.

- Rotorcraft applications, as Corporate, Search & Rescue, Emergency Medical Services (HEMS) require absolute flexibility supported by point-to-point IFR access to both congested airport and inaccessible locations.

- Within HEMS activities distance between two hospitals is generally short and it would not be an efficient solution to climb to fly at such IFR levels. Moreover, since helicopters are unpressurised, under certain circumstances HEMS rotorcrafts cannot climb too much without endangering patients health, thus when flying above FL100 or when climbing or descending too quickly patients are put at risk.

- During a HEMS mission, in the event that during en-route phase the weather conditions fall below the cloud base or visibility minima, helicopters which are certified for flights only under VMC shall abandon the flight or return to base. Instead, helicopters equipped and certified for Instrument Meteorological Condition (IMC) operations may abandon the flight or decide to convert in all respects to a flight conducted under IFR, if the flight crew is appropriately qualified.

Specific SBAS-based procedures are designed to provide accurate guidance for rotorcraft flying on specific IFR flight paths. There are two types of IFR helicopter procedure related with specific phase of flight:

- En-route: Low Level Routes (LLR);

- Departure and Approach: Point-in-Space (PinS).

Since the requests for these kinds of procedures are quickly increasing and performing their flight validation with a fixed-wing aircraft is not the best choice, a flight validation portable system called RIFIS (Repositionable IFP Flight Inspection System) was designed and realized to fulfill this need.

SYSTEM ARCHITECTURE

The idea behind RIFIS is that the whole system is fully portable, in order to adapt in as many helicopters platforms as possible, and with a software capable of supporting analysis during pre-flight, in-flight, and post-flight operations phases.

Pre and post-flight operations are achieved using specialized services and software running on a common personal computer hardware. In-flight phase represents, clearly, the most critical stage where data shall be collected, displayed, and eventually analyzed through dedicated hardware components. RIFIS, capable to perform all these tasks, was designed on the basis of the following requirements:

- portability:
  - lightweight, to allow an easy portability.
  - power autonomous, independent from platform power supply.
  - small, to be easily carry and placed on board.
  - equipped with suitable toolbox, to carry on all components in a practical way.

- functionality:
  - real time receiving and recording data.
  - data storage in proper format (suitable for analysis) or including a software specifically configured to convert data in required format.
  - data presentation display to give operator a real time overview of the most significant parameters.
  - graphical user interface allowing a handily management and interaction with RIFIS system and data.

- environmental considerations:
  - wired communication between components, avoiding any wireless communication to prevent any impact towards onboard aviation systems
  - simple and flexible installation.
  - completely offline functioning.

Next figure shows a detailed representation of all elements involved in a flight validation procedure based on RIFIS technology.

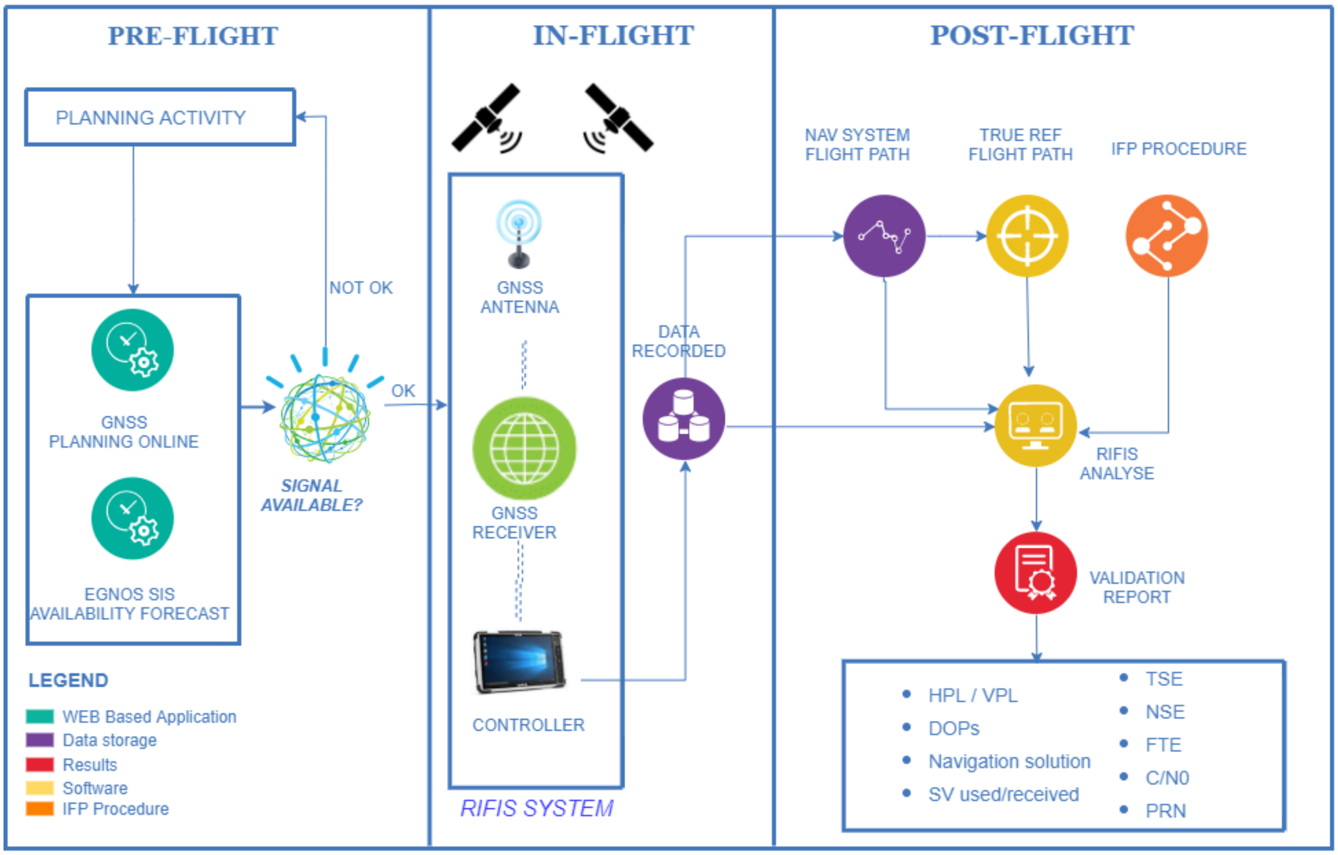

Figure 1. RIFIS Flight Validation flow chart

Workflow Description

Pre-flight stage includes all actions concerning signal availability prediction in scheduled activities time and location. A software with an almanac applicable to the time of the flight test should be used to verify that minimum satellite geometry requirements are met during the whole flight test. Moreover, is necessary to refer to SBAS SIS availability forecast service to know the planning of SBAS outages. If results are positives, activities can be confirmed, therefore it is possible to proceed to next in-flight phase.

In-flight stage is focused on data acquisition and real time visualization. Proposed equipment is an external GNSS/SBAS antenna, a GNSS/SBAS receiver and a tablet as controller and presentation point. GNSS/SBAS receiver and tablet could be placed in the same location, inside the cabin, where the system user will operate. Using described equipment, data are recorded during PinS or LLR procedure flight time. Furthermore, most significant data are displayed on tablet.

Data recorded during flight activities, will be processed in a post flight stage through a customized software which returns measurements results. Finally, the PinS or LLR procedure coming from procedure designer, the so-called desired flight path, together with the actual flight path, will be input to the software to calculate total system error and its sub-components. Whole activities in post-flight stage can be also operated directly in-flight depending on controller hardware and software capabilities.

Design Criteria

As mentioned above chosen solution foresees the purpose of *non-customized* helicopter platform capable to realize flight, equipped with COTS components for signals acquisition, and specialized software, ad hoc developed, to process data and generate report. Therefore, the feasibility study took account of a certain number of degrees of freedom in terms of installation, system features and software specification. In this regard two main aspects need to be explained.

First one is the need to adapt the system to any possible scenario considering best trade-off between signal recording technical methodology completeness, and the invasiveness on the platform itself as well as on pilots. Antenna choice is crucial. Typical helicopter configuration includes two GNSS antenna, whose signal serves avionic system. If possible, and easily accessible, one of those antennas should be chosen to record signal. Employ of helicopter integrated antenna, represent the optimum in terms of measurement methodology correctness because it exactly replicates an IFP user signal-in-space scenario. Sometimes this solution is not possible due to different reasons like helicopter antenna inaccessibility, electrical compatibility issues between helicopter antenna and mobile platform receiver, or unavailability from helicopter owner or pilot, to exclude one GPS antenna from integrated avionic system. In this case is not possible to use helicopter antenna to record signal and another portable one is needed. Such portable antenna must be placed inside cockpit, hooked to windshield, in a position where it keeps as large as possible sky view. With reference to such circumstance, in the following paragraphs an extensive discussion regarding antenna positioning is reported.

The second aspects concern the receiver capabilities. From technical point of view, as usually performed with other flight inspection types, analysis results must be completely independent from the specific receiver employed during the flight inspection. In other words, since the analysis results must be general and valid for any user provided with certified avionic equipment, employed receiver should not introduce any feature able to affect the results. This means that a GNSS/SBAS receiver ensuring all constellations enabled, shall be set to receive only GPS L1/CA and SBAS constellation. Moreover, in order to produce valid metrics calculations, algorithms used to calculate parameters under investigation must be the same implemented on a MOPS certified (RTCA DO-229 [2]) receiver, with a particular focus on horizontal and vertical protection level calculations. Likewise, for the same reason, the receiver can't process and use in a real time reference position fixing corrections, otherwise navigation system flight path under analysis will be "augmented" and not representative for a common IFP user. This means that a post processing stage, is needed to reprocess navigation system flight path and reference position corrections so as to obtain the so called "true reference flight path".

Another feature concerning system design is reference position fixing system employment; RIFIS expects to use a real-time satellite-based position fixing system. Position fixing, providing true references flight path, allows calculation of all navigation performances if used in combination with desired flight path (PinS or LLR procedure flight path from procedures designers) and estimated or navigation system path (receiver processed position): Total System Error (TSE), Flight Technical Error (FTE) and Navigation System Error (NSE) explained in the next figure.

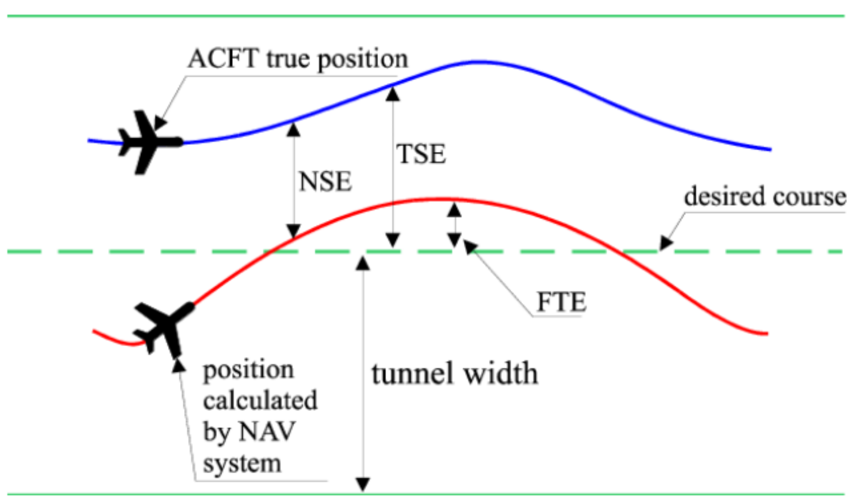

Figure 2. TSE, NSE and FTE Definitions

As is well known position fixing system is based on a specific correction, valid for a certain location in a certain time, calculated from a ground reference station, or a network of them, and then transmitted to receiver through different means of communication (direct radio link, cellular network, satellite communication). Due to excessive operational cost related to place and dismantle an RTK base in each operation site, the rover and base solution would not be worthwhile. There are other ways to transmit corrections to user receiver basically divided into two families: post processing and real time. First one expects to use data downloaded from ground reference network to correct positions in a post processing stage. Real time has the obvious advantage to show corrected position in real time but could have some coverage limitations depending on the way corrections are transmitted. There are two possible real time data correction transmission means: mobile network 4G/5G and satellite link. Mobile network coverage doesn't offer reliable coverage for airborne applications, so the most appropriate solution is satellite link. This kind of service, also called Precise Point Positioning (or PPP) offers worldwide coverage for a receiver in a clear sky view, regardless rover height and motion type (static or dynamic).

Usually, this kind of subscription services are based on a global network of ground GNSS reference stations to calculate the correction data and ensuring the maximum reliability of their augmentation services offering several services which makes it possible to calculate positions with different types of accuracy levels. The correction messages, containing orbital and satellite clock corrections data, are sent to a network of geostationary satellites ensuring a global coverage with an overlap of at least two satellites in each location. Then corrections messages are transmitted from geostationary satellites to the user on a GNSS-like L-Band signal frequency. Therefore, user can receive the correction data directly via the GNSS antenna. GNSS receiver uses correction data, solid earth model and atmospheric model to eliminate the major uncertainties in the point estimation and compute the corrected position. Therefore, even with no RTK correction data at all, PPP works worldwide with centimetre accuracy level real time positioning. The system needs a certain convergence time that can range from 10 minutes to 30 minutes, depending on number of GNSSs systems in use, number of satellites in view and obstruction to the clear sky view, after which it starts to receive real time corrections. After this time usually system can perform the most accurate position until 4 cm (RMS) and 5 cm (95%) of horizontal accuracy, and 6.5 cm (RMS) of vertical accuracy. RIFIS employ a hybrid solution receiving and storing real time satellite corrections to be applied after IFP flight validation is finished. Such solution can operate within the flight and offline, before the following flight activity.

Another crucial feature is the complete power supply autonomy making RIFIS independent from helicopter power supply. In the described architecture the GNSS receiver is powered directly from the tablet (controller) battery that, itself, is hot-swappable with another fully charged battery to guarantee seamlessly operations. Clearly in this scenario the limit will be represented by the number of charged batteries available for swapping operations. Furthermore, it is strongly recommended to use a single cable between GNSS receiver and controller employed not only to provide supply to receiver, but also for any other communication between receiver and tablet as receiver setting command, data recording and so on. Clearly the downside of this choice is a single point of failure represented by this connection but in such system, where autonomous and flexibility are key factors, this solution represents the best choice.

GNSS ANTENNA

As described previously RIFIS antenna is critical for performance parameter evaluations and there are two possible scenarios: helicopter fixed antenna and GNSS mobile antenna.

Helicopter Fixed Antenna

In case of helicopter operator availability to provide helicopter GNSS antenna usage, it is necessary an assessment in close cooperation with helicopters operator CAMO (Continuing Airworthiness Management Organization) and technical department to face up to different topics. Some aspects to deal with, related to outside on-fuselage antenna solution, are:

- electrical compatibility (Low Noise Amplifier supply) between helicopter GNSS antenna and RIFIS GNSS receiver.
- antenna cable wiring from fuselage to RIFIS.
- antenna frequency band range. Certainly, helicopter GNSS antenna operate in L1 C/A band but if it does not operate also in L-band, PPP corrections could not be received. In this case reference trajectory won't be part of post processing analysis.
- helicopter antenna cable connector.
- numbers of helicopter GNSS antennas.
- positioning of helicopter GNSS antennas and receivers.

The followings figures show an example of second GPS antenna installation and its receiver.

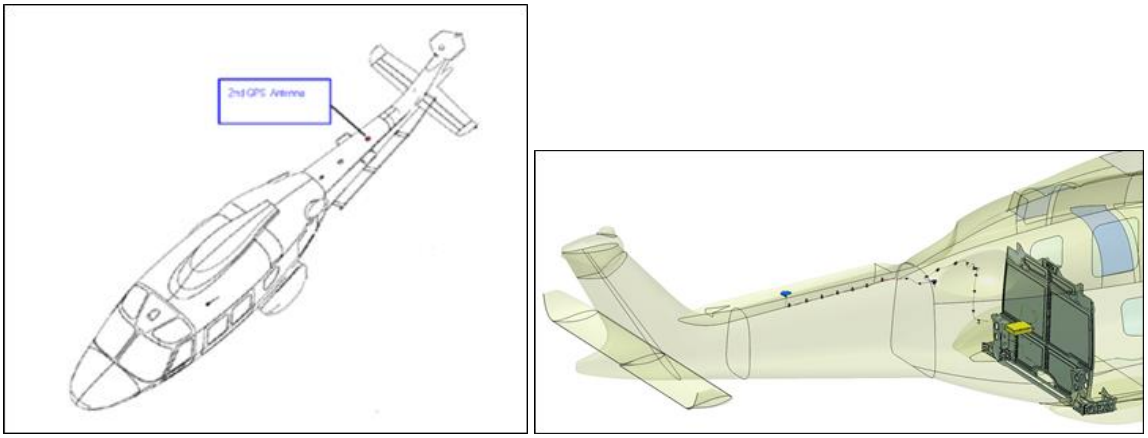

Figure 3. Example of second GPS antenna installation on AW169 helicopter

In summery this choice offers the huge benefit to have the optimum signal-in-space reception exactly as user perspective but it is strong dependent from helicopter antenna position accessibility on fuselage and PPP L-band correction is not guaranteed.

Moreover, in case of helicopter antenna employ, should be evaluated which type of usage can be performed:

- exclusive: this implies helicopter GNSS antenna disconnection from its helicopter GNSS receiver. This could impact helicopter Flight Management System because of GNSS antenna exclusion. Such solution could be walkable only if more than one GNSS antenna is available on helicopter and the fact that Flight Validation shall be performed under VMC conditions could mitigate the exclusion of secondary GNSS helicopter antenna usually employed as back up.
- shared: a 1x2 GNSS antenna splitter will split signal just after the GNSS antenna to send signal to both GNSS helicopter receiver and RIFIS. The downside of this solution is that both users will work with a3dB attenuated signal and, even if this could not be impact, it should be considered in analysis.

Mobile Antenna

The alternative solution, an indoor antenna installation, eliminate some barriers but introduces new precautions to be considered. Usually helicopters have a wide windshield, especially in the upper area, making it the best position for a horizontal antenna positioning. This installation reduces as much as possible impact on pilot view maintaining a large sky view. The fact that, although large, the sky view is not the optimal one represents the only limit of this methodology. Such installation necessarily includes a strong sucker fixing system to prevent any tumble.

In case of RIFIS mobile antenna usage, RIFIS components will be placed on board as proposed for platform showed in next figures.

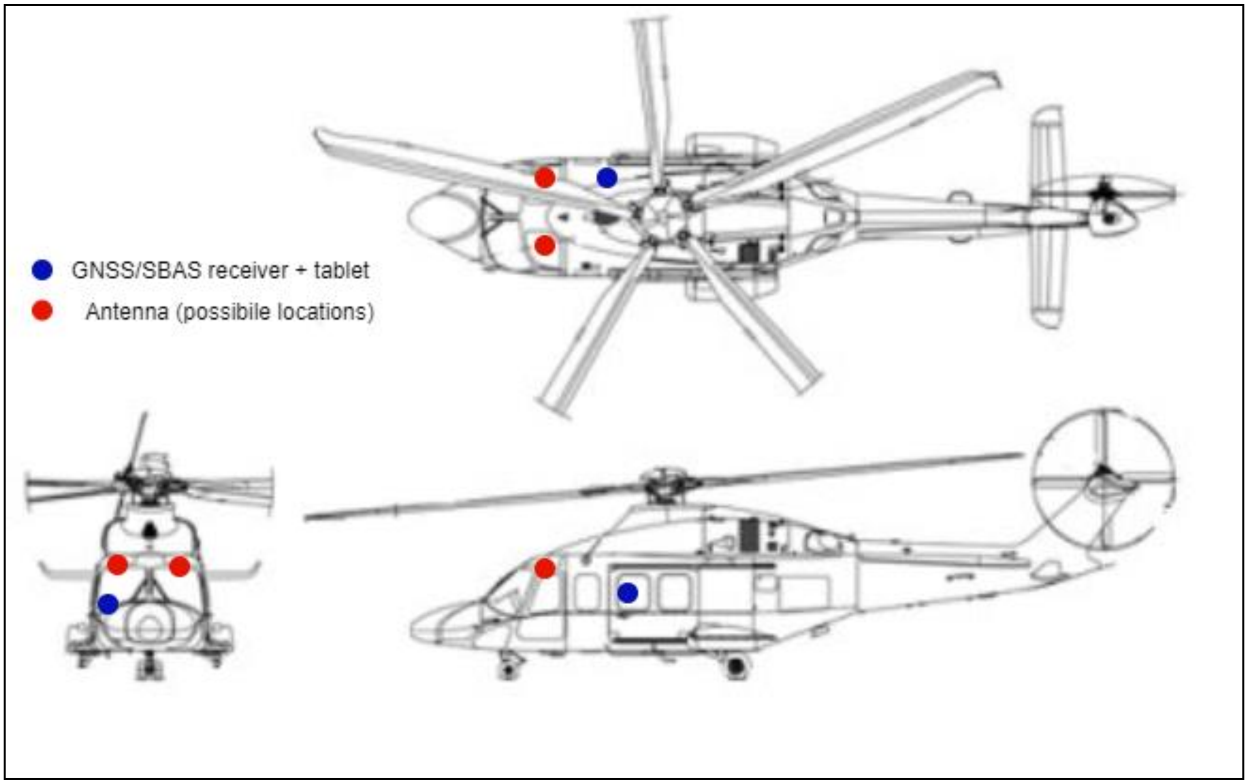

Figure 4. Example of mobile antenna location

It should be noted that, except for the antenna, which is hooked up to windshield by means of sucker fixing system, GNSS receiver and tablet components can be freely moved, being understood that considering wiring manoeuvring area depends on available space inside the helicopter cabin.

This methodology is completely helicopter independent and guarantee correct reception of PPP L-Band corrections with a conservative signal-in-space reception as back side.

RIFIS PROTOTYPE IMPLEMENTATION

This section includes a short description of possible implementations of RIFS prototype with attention to software graphic user interface and report production tools.

Hardware

As showed in the following images a customized rack, joining together GNSS receiver and its controller, was built to provide user with complete control system. An easy system transportation is ensured by dedicated rugged suitcase hosting rack and all accessories, like GNSS antenna, spare batteries, spare cables, antenna windshield hook system and so on..

Figure 5. RIFIS prototype

Software

Customized software was built to display real time data during flight validation mission activity. Most important parameters, and relative thresholds value related to type of operations, are showed in a real time plotter together with navigation system flight path and desired flight path. This data overview allows for a real time qualitative evaluation showed on an interactive map. Colour labelled indicators return feedback on PPP correction PVT SBAS availability other than two important alerts on RFI or Spoofing detected phenomena as showed in the following figures.

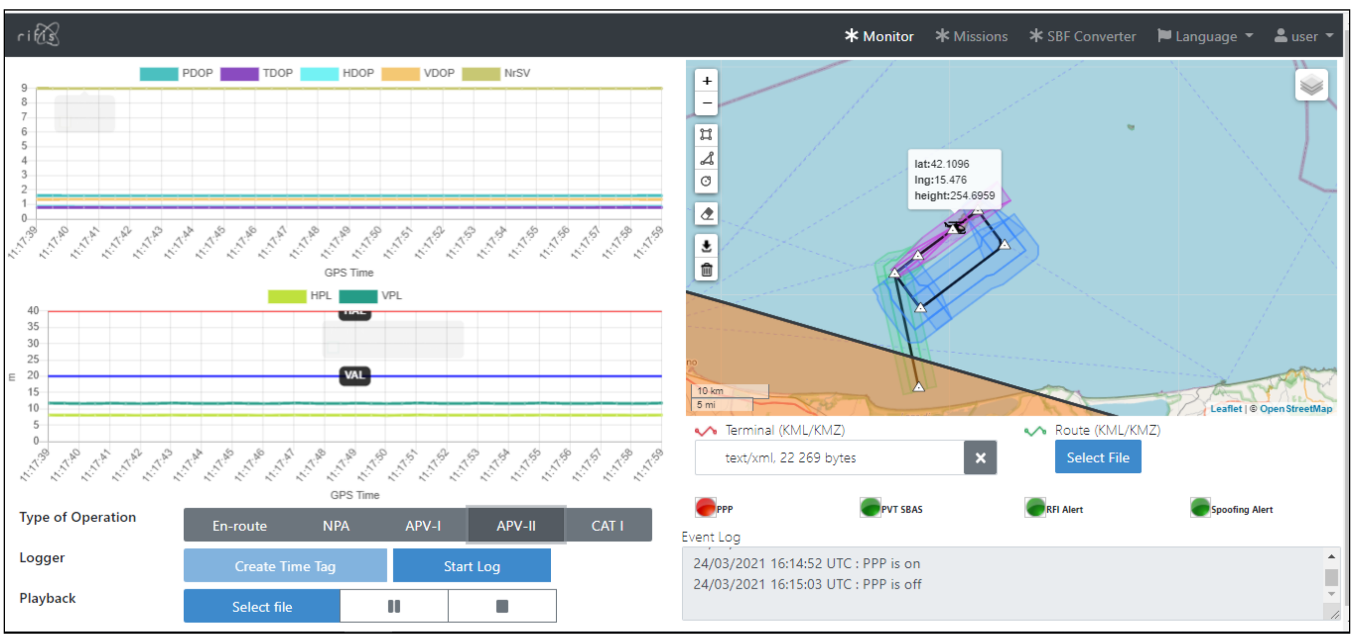

Figure 6. RIFIS GUI

Report

After data recording is concluded, a quick process and a customized report are automatically generated and immediately available to user in electronic format. Report is fully compliant with DOC 9906 vol.5 specifications. It shows all relevant metrics in both graphs and tables views divided per IFP leg allowing an in-depth analysis. A dedicated section contains a zoom in the final approach segment. Next figures show some extracts from Flight Validation Data Report.

enav
Flight Inspection and Validation

rifis

Flight Validation Data Report

Mission # **20220302_3**

IFP Name	ALIT50
IFP Type	APPROACH
Navigation Specification	RNP_APCH
Type of Minima	LPV
Airport/Location	LIKO

Figure 7. Extract from report - cover page

Segment		HDOP Min	HDOP Avg	HDOP Max	VDOP Min	VDOP Avg	VDOP Max	PDOP Min	PDOP Avg	PDOP Max	Number of Satellites Min	Number of Satellites Avg	Number of Satellites Max
WP BF009 IAF	WP BF011 IF	0.79	0.81	0.91	1.19	1.22	1.42	1.43	1.46	1.69	11	11	12
WP BF011 IF													
WP BF012 FAF													
WP BF013 MAPT													
WP BF014													
WP BF116													
WP BF117	B												

Segment		HPL [m] Min	HPL [m] Avg	HPL [m] Max	VPL [m] Min	VPL [m] Avg	VPL [m] Max
WP BF009 IAF	WP BF011 IF	10.56	11.32	14.89	13.30	14.16	19.25
WP BF01							
WP BF01							
WP BF013							
WP BF0							
WP BF1							
WP BF1							

Segment		H-NSE [m] Min	H-NSE [m] Avg	H-NSE [m] Max	V-NSE [m] Min	V-NSE [m] Avg	V-NSE [m] Max	H-FTE [m] Min	H-FTE [m] Avg	H-FTE [m] Max	H-TSE [m] Min	H-TSE [m] Avg	H-TSE [m] Max
WP BF009 IAF	WP BF011 IF	0.06	0.25	0.43	0.00	0.19	0.72	27.87	43.66	598.02	29.85	1873.90	3159.25
WP BF011 IF													
WP BF012 FAF													
WP BF013 MAPT													
WP BF014													
WP BF116													
WP BF117													

Segment		Altitude MSL [m] Min	Altitude MSL [m] Avg	Altitude MSL [m] Max	GS [kt] Min	GS [kt] Avg	GS [kt] Max	Climb Rate [ft/min] Min	Climb Rate [ft/min] Avg	Climb Rate [ft/min] Max	Climb gradient [%] Min	Climb gradient [%] Avg	Climb gradient [%] Max	Climb gradient [°] Avg
WP BF009 IAF	WP BF011 IF	738.46	1002.89	1390.40	97.31	99.28	102.60	-833.44	-436.09	71.73	-8.38	-4.35	0.71	-2.49
WP BF011 IF														
WP BF012 FAF														
WP BF013 MAPT														
WP BF014														
WP BF116														
WP BF117														

Segment		VFTE [m] Min	VFTE [m] Avg	VFTE [m] Max	3D-TSE Min	3D-TSE Avg	3D-TSE Max	3D-NSE Min	3D-NSE Avg	3D-NSE Max	3D-FTE Min	3D-FTE Avg	3D-FTE Max	VTSE [m] min	VTSE [m] avg	VTSE [m] max
WP BF009 IAF	WP BF011 IF	-54.98	61.44	154.57	30.69	96.31	606.04	0.09	0.34	0.76	30.69	96.31	606.04	0.73	289.73	521.99
WP BF011 IF																
WP BF012 FAF																
	MAPT															

FAS descent profile	
Actual Descent Angle [°]	**Course Deviation Error [m]**
-3.65	3.59

Figure 7. Extract from report – tables

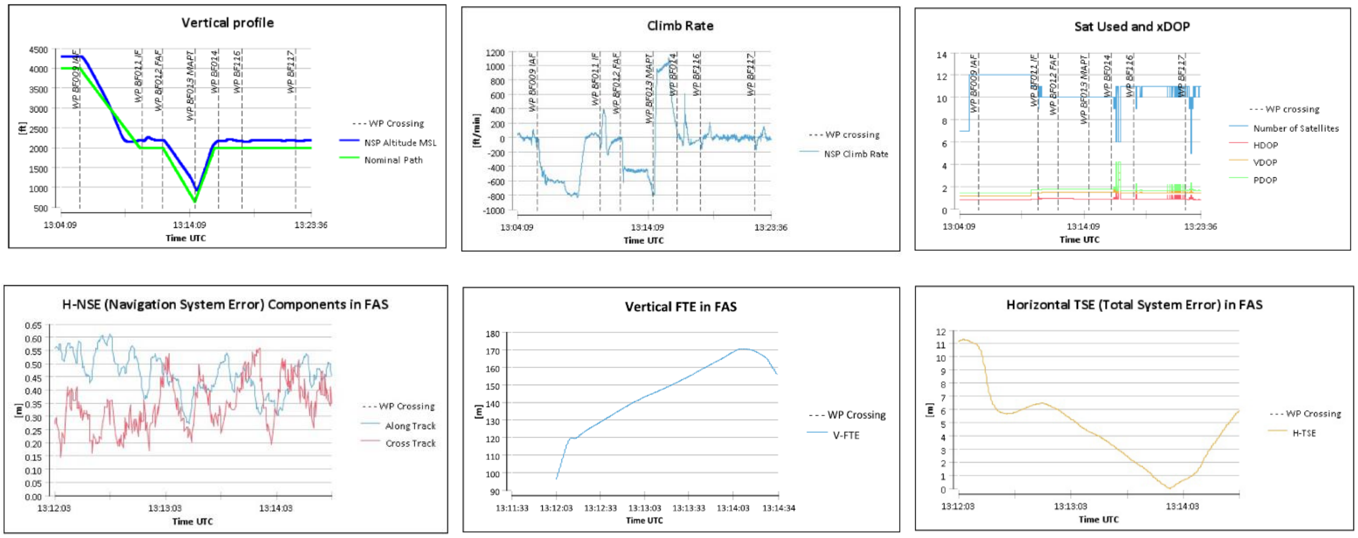

Figure 8. Extract from report – graphs

CONCLUSIONS

The developed system, named RIFIS, was proved to be a flight validation portable system whose distinctive features are adaptability and accuracy. Being specifically designed to operate over *non-customized* avionic platform while ensuring high level performance in metrics calculation and compliance with regulation requirements, it was tested and successfully applied in rotorcraft routes validation field.

In such application context RIFIS turned out to be a strategic service as instrument fit and able to validate Helicopters IFP allowing IFR helicopters to fly under IMC along rotorcraft specific routes, rather than aircrafts ones. RIFIS prototype involves a portable antenna to be placed inside cockpit, GNSS/SBAS receiver, algorithms implemented are the same of a MOPS certified (RTCA DO-229) receiver, and postprocessing software returns flight validation reports compliant with ICAO Doc 9906 vol.5. System can perform the most accurate position until 4 cm (RMS) and 5 cm (95%) of horizontal accuracy, and 6.5 cm (RMS) of vertical accuracy enabling Total System Error, Flight Technical Error and Navigation System Error calculations. Factors and metrics mentioned above make RIFIS compliance with all regulation requirements.

FUTURE WORK

In the next future project foreseen to apply this methodology with other type of flight validation platform like fixed wing aircraft and UAV.

ACKNOWLEDGMENTS

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REFERENCES

[1] ICAO Doc. 9906 vol 5 “Validation Of Instrument Flight Procedure”.

[2] RTCA DO-229 “Minimum Operational Performance Standards for Global Positioning System/Wide Area Augmentation System Airborne Equipment”.