Monitoring of internal and external conditions during a flight test to ensure an efficient Validation procedure

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Abstract: We propose in this paper a monitoring system recording both internal detailed signals of an equipment as well as external conditions, either environmental or relative to the trajectory of the vehicle carrying said equipment. With this system, the analysis of the flight tests are more efficient and allows in particular to determine whether a priori abnormal results are due to the equipment under validation or to external phenomenons. Specific flight tests results with this monitoring system have been carried out to validate a radio-altimeter under an helicopter. They proved able to discriminate cases where the radio-altimeter was not functioning properly from cases where height reference was erroneous due to pitch/roll of the platform, or due to reflection on the helicopter structure.

Keywords: Test data acquisition and recording, radio-altimeter, sensors, flight tests

1. Introduction

The radio-altimeter [1][2] is an instrument that measures the distance of an aircraft to the ground or water surface. It is traditionally an autonomous navigation aid in the approach and critical landing phases.

Various aircrafts, such as plane, fighters, helicopters, UAVs, … use radio-altimeters to provide the platform with accurate measurements of the minimal distance to the terrain (ground or sea). The height information provided by the radio-altimeter can help in aircraft functions like critical plane landing phases, helicopter stationnary flight, Ground Proximity Warning Systems (GPWS), … This information is obtained similarly to radar operations, by measuring the delay τ_i between a transmitted wave and the received wave obtained by reflection on the environment, taking into account the fact that electromagnetic waves propagate through the air at a constant speed c (speed of the light). τ_i can be expressed as follows,

$$\tau_i = \frac{2\,H}{c} \qquad [1]$$

where H is the minimum distance to the terrain.

The radio-altimeters we develop are using FMCW (Frequency Modulated - Continuous Wave), that is to say that the transmitted wave is linearly modulated in frequency by a sawtooth. A beat signal is then obtained by mixing the transmitted waves $F(t)$ and received waves $F(t-\tau_i)$, as illustrated in Figure 1. Measuring the beat frequency allows to determine τ_i, hence to obtain H.

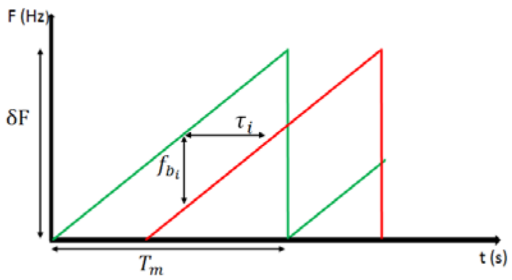

Figure 1 – FMCW radio-altimeter principle.

As any radio mean, its performance depends on the propagation channel, and on the possible reflections due to its environment. As one cannot perfectly model real channels, most industrials rely on a two steps validation procedure for their equipment validation, combining tests done with reference scenarios and flight tests representative of the real operational conditions. This validation procedure is further described in Section 2, as well as used monitoring tools. Section 3 presents tests results from a live test on a helicopter, and the learnings obtained thanks to the monitoring tools, and finally, conclusions are drawn in Section 4.

2. Monitoring tool principle

2.1 Validation procedure of the radio-altimeter

As stated in the introductionn our validation procedure for radio-altimeters relies on a two step approach, illustrated in Figure 2:

- the first step consists in laboratory tests held in a controlled environment, using delay lines as propagation channel and test benches for commanding the whole test platform. Mastering the settings allows to be able to replay the same conditions and hence validate non-regression both for hardware and software parts.
- the second step complements the first one by introducing first real transmission and reception antennas, and second a propagation channel representative of the operationnal one (real conditions tests are made through flight tests, above a variety of grounds : sea, forests, mountains, ...).

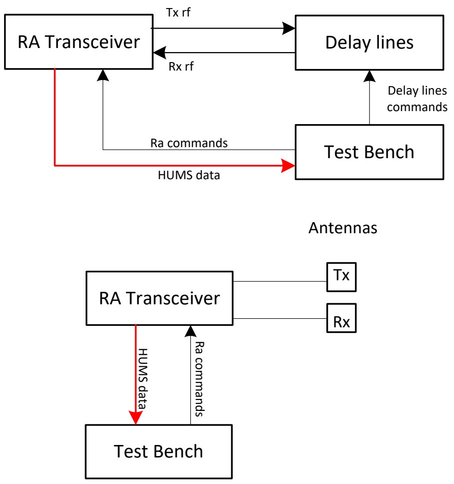

Figure 2 – Validation process: step 1 (top) and step 2 (bottom)

2.2 External sensors for environment capture

As the number of possible flight tests are generally limited, they are heavily monitored, in ordre to both ensure a full analysis of the flight, and eventually to record flight conditions to replay them later. As a consequence, a set of various sensors is used to record the plateform conditions, to help in the radio-altimeter performance validation. As illustrated in Figure 3, the monitoring tools typically includes an IMU (Inertial Measurement Unit), a GPS receiver, ..., whose roles are defined hereafter.

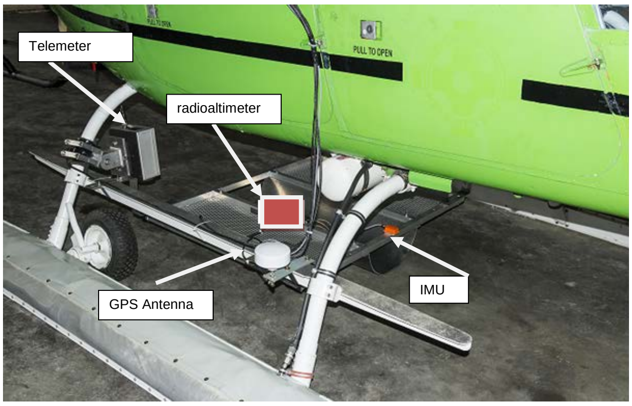

Figure 3 – Flight test external set up.

2.2.1. The Inertial Measurement Unit

The IMU is a device which measures the attitude of the carrier: it returns gives indications on the position along three axes : the roll axis, the pitch axis and the yaw axis, as illustrated by Figure 4.

This carrier information is used to determine if any errors or problems encountered during the flight are caused from the tested system or the test condition

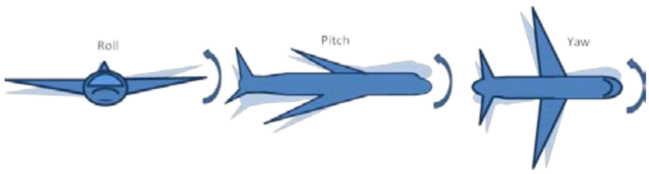

Figure 4 – Platform evolutions : roll, pitch, yaw.

2.2.2. The laser telemeter

The laser telemeter is a device that measures a distance from itself to an object (or ground). It is very directive and has limited measurement capabilities in some conditions such as high heights, flight above very specular grounds like sea. Furthermore, since it is very directive, the distance measure are sensitive to the carrier attitudes, hence the need to determine it with the IMU.

The laser telemeter information remains nevertheless necessary to compare the radio-altimeter distance measurement with a different (neutral) technology.

2.2.3. The GPS receiver

The GPS receiver is used for two purposes. On the first hand, it gives the positions of the carrier during the test time. That information is quite important because we need it to check during the analysis the nature of the ground overflown, the terrain characteristics.

On the second hand, the GPS informations are necessary for synchronization of all recorded data by feeding a IRIG-B device.

2.3 External sensors for environment capture

As any equipment used in a larger system, a radio-altimeter has a functionnal link used to connect it to the Controller Unit of the carrier that command and received the radio-altimeter sensor information measurements. In our case, this functional link payload contains in particular the measured height information, the validity of the that measurement, and a result of a Global Built-in test self performed by the radio-altimeter. That link is generally minimalist in terms of data contents and output frequency, may not be enough to perform a proper performance analysis of the system. Furthermore, it is important in safety equipements such as radio-altimeters to prevent any risk of perturbation of the operational role due to any extra operation such Health and/or Usage monitoring. As a consequence, without being intrusive for the functionnal component of the system (being a sink to the radio-altimeter outputs) to ensure that it cannot perturbate the radio-altimeter behaviour, we have introduced a proprietary link (IFM link) that outputs HUMS (Health & Usage Monitoring System) data coming from the DSP and the FPGA components of the device, to have access to more logs, as illustrated in Figure 5. That link allows to record internal data and operation modes, combining both HUMS information (e.g. internal temperature) and equipment internal processing data (e.g. spectrum of the received signal).

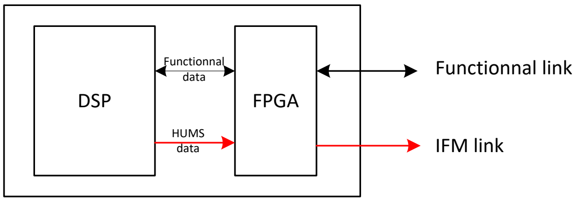

Figure 5 – Position of the internal monitoring link.

Obviously, the IFM link is also handy in the first validation step, to ensure for instance that the environmental conditions are compliant with specifications: typically, it will easily prove that the temperature conditions specified (*e.g.* min-max temperature) are respected. Being also an high speed connection link, it allows to output much more information than the functional link, with typically the height output in the functional link, the height at different places in the processing chain, the system temperature at different spots inside the equipment, details on the built-in tests performed, the associated raw demodulated received signal for each measurement, or other processing data.

3. Results from a real flight test

Flights have been realized the 17 and 18 june 2015 with a radio-altimeter monitored with the internal and external tools presented in Section 2. Figure 3 illustrates the external set-up on a Bell 206 helicopter, with the telemeter used as reference for height validation. The weather conditions were good (17: sunny and cloudy the 18) and the ground was dry. Trajectory followed is presented in Figure 6 (close to Royan city in France).

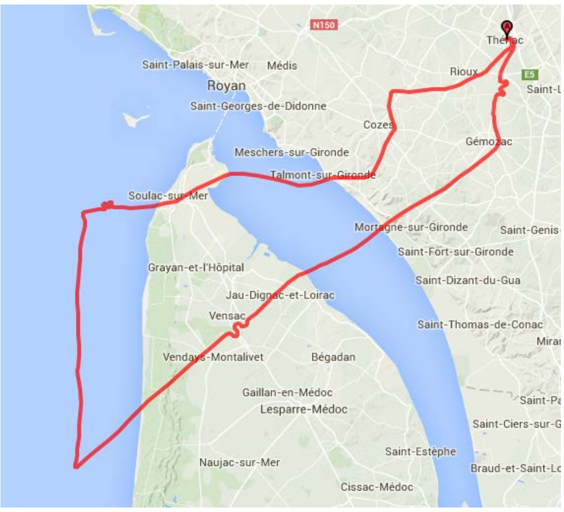

Figure 6 – Flight test trajectory.

Various analysis are possible to interpret the flight tests, but we will focus hereafter on two cases illustrating the monitoring mechanism.

3.1 Correcting the effect of pitch and roll on the height measurement from the telemeter

The first case corresponds to the analysis of the bias due to attitude of the helicopter when using a laser telemeter as reference for the radio-altimeter height measurement validation. In Figure 7, we see the telemeter bias caused by the roll. The correlation between the roll information and the variation between reference and radio-altimeter respective heght prevents the misjudgment on the radio-altimeter behaviour.

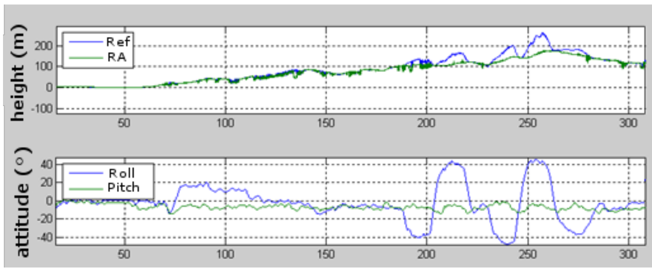

Figure 7 – Effect of pitch and roll on the height measurement.

3.2 Ensuring correct set-up of the antenna

The second case illustrated refers to the use of the spectrum output of the radio-altimeter itself to confirm the correct set-up of the antenna system.

As illustrated in Figure 8, we see appearing with the superposition of three spectrum at three different times a constant peak that corresponds to an helicopter structure reflection. This can then be used to change the antenna characteristics or position typically, and to avoid incriminating the radio-altimeter in the verification process.

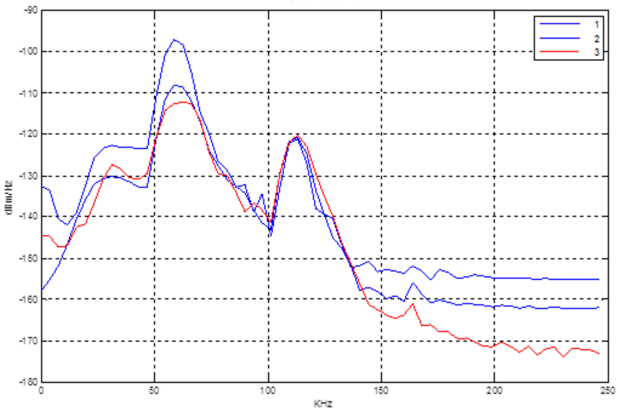

Figure 8 –Spectrum measured at three different times.

3.3 Earning further knowledge to validate the processing adaptation

By doing highly monitored tests with our recording means, we are also able to learn better the environment in which the device will be used and possibly can realise specific tuning of the algorithms, and validate the performance of said specific configurations for the different conditions in which the radio-altimeter has to operate (navigation aid, landing system, ...).

3.3.1. Cable detection example

During the flight test, high voltage cables have been overflown. As it is shown in Figure 9, the wires appear as three shorts peaks in the spectrum, just before, in terms of frequencies, the ground signal. In a common case where we authorise our radio-altimeter to detect a maximum of

3 ground echoes for the height processing, the cables could be erroneously found instead of ground!

In the case of navigation aid where the distance is needed to avoid collision, for an helicopter typically, such demeanour is the one looked for. The distance the radio-altimeter shall provide is the shortest distance before collision, not necessarily the distance to ground. Conversely, when the ground distance is the information that must be provided, that behaviour will not be acceptable. Then the three wires peaks shall not be detected as height information by the signal processing. Knowing their characteristics will help not taking them into account, and process the correct ground one!

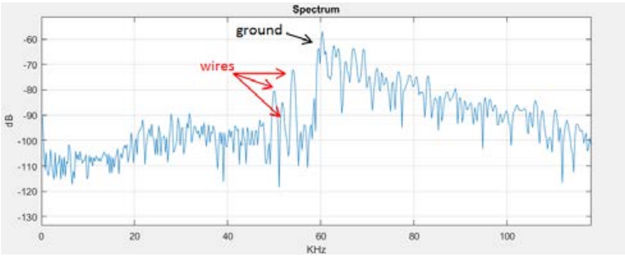

Figure 9– Presence of high voltage cables, that can perturbate the height measurement function.

3.3.2. Acquiring data with MAGNETO

From the previous paragraphs, it is clear that validation procedures can greatly benefit from the availability of both external sensors such as temperature, gyroscope, accelerometer … but also of internal sensors recording capabilities such as the IFM link presented in Section 2.3. Furthermore, being able to record such data during both validation and operational phase would further increase the representativeness of the acquired data, with the extra requirement that these operational data are secured. Another interesting feature would be to allow the system to record on demand or automatically said data. We have designed a board embarking the aforementioned sensors, a processor and a security component. This card, called MAGNETO, will be used in our next field trials.

4. Conclusion

The monitoring system presented in this paper, combining recording of both external conditions (e.g. roll, pitch, …) and internal equipment signals (e.g. spectrum acquired, FPGA temperature …), is a key tool for validation of radio equipment, as was illustrated with measurements of one radio-altimeter. Nowadays, it is even almost impossible to carry efficient validation without such a tool, that ensures that correct analysis of the obtained measurements with respect to their design. Future works include the generalization of such a monitoring tool (using MAGNETO) for other devices.

5. Acknowledgement

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6. References

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[2] J. Darricau: "Physique et théorie du radar"(in French), Sodipe, 1981.

7. Glossary

GPS: Global Positioning System

HUMS: Health and Usage Monitoring System

IMU: Intertial Measurement Unit

RA: Radio-Altimeter