COMPARISION OF HELICOPTER FLIGHT DATA MEASURED WITH INS/GPS SENSORS WITH NUMERICAL SIMULATIONS

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Abstract

The affordable IMU (Inertial Measurement Unit) developed in Warsaw University of Technology and GPS receiver were used in helicopter flight tests. The objective of the research was to check the efficiency of algorithms for signal processing.
The IMU (Inertial Measurement Unit) was designed and manufactured using piezovibrating gyroscopes and silicon accelerometers. The GPS (Global Positioning System) receiver of middle class was included into the system. These two devices connected to the lap-top computer with A/D card allowed to measure and register helicopter position and attitude with respect to the ground.
The equipment was used in the flight tests of Mi-2 helicopter for in flight data collection. The Kalman filtering was applied for noise rejection and signal integration.
The helicopter computer model was constructed within FLIGHTLAB software. The results of calculations and the data measured in the flight were compared giving insight both on measurement system behaviour and computer model quality.

Introduction

Evaluation of flying qualities is done at different phases of an aircraft design, development and certification processes. During the design phase, aircraft performance is evaluated mainly using simulation tools i.e. validated computer models of flight dynamics and control. Flight tests of the prototype are performed extensively to check the accuracy of the former predictions and actual performance of the aircraft. Helicopters flight tests are more complex comparing to fixed wing airplanes, due to six degrees of freedom of helicopter motion, airframe vibrations and main rotor influence on behavior of the measuring systems.

According to the regulations (see for instance Aeronautical Design Standard [1]) during the investigation of flying qualities translations, velocities, attitude and rates should be measured with required precision. Usually these data are obtained by remote sensing instrumentation i.e. telemetry or external observation. New satellite navigation systems offer more versatile and accurate tool for position measurements. Due to the possibility of space signal degradation, GPS receivers should be supported by other sensors measuring velocities and rates. The Inertial Navigation System (INS) is a natural partner for such collaboration of the systems.

To perform the flight tests a helicopter should be equipped with sensors measuring the required parameters of its motion. In the current research the INS measuring instrument (home made system made with of the shelf components - three piezoelectric one-axial gyroscopes and one three axial accelerometer) integrated with GPS receiver are intended to fulfil this task. The Kalman filtering algorithms were used for suitable signal integration from the applied sensors and also for noise rejection from the signal.
The measurement system was tested laboratory, for static and dynamic behaviour. The results of these tests were used for evaluate sensor errors and for selection of the parameters in filter algorithms to minimize the estimation error. The performance of the sensors of the inertial system was evaluated to decide about feasibility of their use with GPS receiver in the helicopter's flying qualities tests. The current and optional methods of signal integration and filtering and the results obtained during tests are presented in the paper.
Also the effectiveness of the INS/GPS measuring instrument error model is presented based on comparisons of simulation results with data obtained in flight (helicopter and glider).
Combination of flight tests with numerical simulations allows to evaluate both simulation model, thereby simulation method applied, and vehicle testing equipment. As the result the possibility of simulation application to verify aircraft flying qualities in extreme condition without necessity to risk pilot's life or aircraft damage is confirmed.
In the paper the application of INS/GPS equipment in flight tests for selected maneuvers of helicopter is presented. The flight test data are compared with results of numerical simulations, which were done for the same helicopter configuration and the same initial conditions as in experimental tests.

Flight data measured with INS/GPS sensors

During the flight tests some measurements are done by external observation: visual or telemetry. The disadvantage of these methods is the necessity of visual following the aircraft, complexity of the equipment and low accuracy.

Measuring equipment

The INS unit composed of standard, non-expensive off-the-shelf accelerometers and gyroscopes was designed and built in Warsaw University of Technology (Fig. 1). The device is mounted to the airframe during the fight tests to measure attitude, translations and rates of helicopter.

The INS is composed of three ENV-05F-03 Murrata piezoelectric gyroscopes and one, three component accelerometer ADXL150EM-3 manufactured by Analog Devices. The electronic temperature sensor is also mounted inside for prospective temperature compensation.

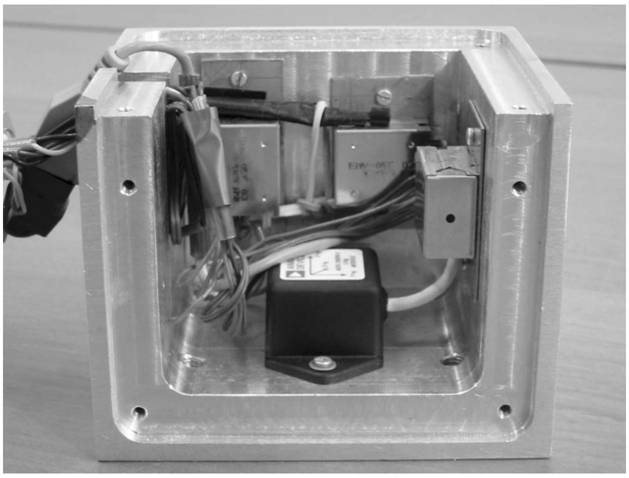

Fig. 1 The Inertial Navigation Unit developed in Warsaw University of Technology

Fig. 2 Point of the placement of the ProPak II Millennium receiver's antenna.

During tests on sailplane GPS Garmin 12XL receiver was included into the system and was mounted in the cockpit. However, in case of the helicopter flight tests two receivers are checked in measurement system. The first one ProPak II Millennium (3151R) receiver, which antenna was pointed in front of helicopter fuselage (Fig. 2) and the second the SmartAntenna GPS receiver, which was mounted on the tail boom (Fig. 3. In these flight tests the sensors were connected to PC laptop with analog digital card allowed to measure and register helicopter position and attitude with respect to the ground.

Fig. 3 Point of placement of the SmartAntenna.

Filtering and INS/GPS integration

The signals from our measurement sensors were filtered using recursive, discrete Kalman filter algorithm [7]. The filter (Fig. 4) was applied for each measuring channel with parameters adjusted for the particular sensors. It was necessary, as the accelerometers and gyroscopes are not high class. The filtering process allows rejecting both external (environment disturbances) as well as internal (sensor) noise.

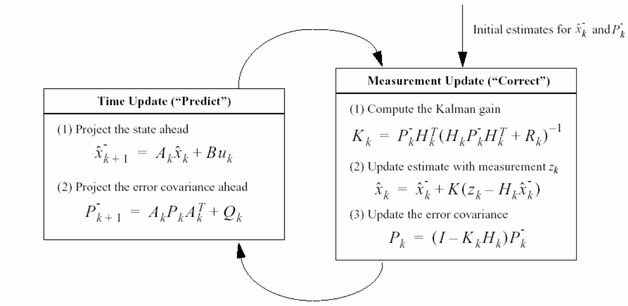

Fig. 4 The flow chart of the discrete Kalman filtering process.

Integration algorithm used in the measurement system based on the open-loop configuration i.e. correction to the sensors is made to the outputs and not fed back to internally correct these sensors.

ADS-33 flying qualities requirements

To calculate the parameters of flying qualities defined in ADS-33 [1], the motion of helicopter has to be identified in terms of measurable quantities

such as translations, attitude, velocity, rates and acceleration. From analysis of the ADS-33 it may be concluded, that all the parameters of helicopter motion should be measured during flight tests.
The suggested accuracies of the measurements, based on the ADS-33 analysis are done in the previous studies [5]. During these studies, the analysis was also done [3, 4], which shows that standard on-board equipment, required by regulations (FAA, JAA) usually does not provide all data needed - the aircraft instruments are dedicated mainly to aid pilot to fly the helicopter.
Application additional non-standard on-board equipment gives opportunity of checking our INS unit as regards requirements of the ADS-33 regulation.

Previous laboratory and field tests

The objective of the laboratory tests presented in [5, 6].was to calibrate sensors and to evaluate the signal noises and efficiency of applied filtering method. After that, some initial tests were conducted on a sailplane to check coefficients assumed in the Kalman filtering process and also values of parameters acquired during dynamic measurements.

Helicopter flights

The next tests were performed in helicopter flight for validation of filters behavior and signal integration in the real environment. The tests were done on the Mi-2 helicopter in the WSK Swidnik. During tests several types of maneuvers were made such as pull-up/pushover, hover, and bob-up/bob-down. In this paper a part of a level flight is used as example of measurements done. The level flight was at the altitude about 50 meters above a ground and velocity close to 100 km/h.
The signal processing, integration and comparison of obtained quantities is presented in flow chart (Fig. 5). Purple arrows on the diagram show the combination of a comparison of result. The gray rectangle stands for comparison of auxiliary results.
The data obtained from INS and GPS measurements are compared with numerical simulation. During flight test additional flight parameters by standard avionics equipment mounted at a helicopter were also recorded. It allowed to increasing the number of parameters analyzed, and to determine both initial numerical simulation conditions and parameters describing dynamics of helicopter motion.

Helicopter modeling

FLIGHTLAB simulation software applied in the study allows to adapt calculation process to configuration of the research helicopter, type of the motion analysed and to different environment conditions.
Helicopter simulation model is constructed in FLIGHTLAB system using model editor interface.
PilotStation provides a software operational environment for real time simulation using FLIGHTLAB models. It combines processing of the aircraft dynamics model with computer generated displays of the out the window scene, the instrument panel, and external views of the aircraft. PilotStation can run models that have been generated from the FLIGHTLAB system or it can interface directly with models running in the FLIGHTLAB system to support real time piloted evaluation in the engineering environment.
Simulation option in the FLIGHTLAB system allows engineer to test model for any flight conditions, any time, freeze simulation process every step of the way – analysis part of a flight, next to continue numerical simulation process for old or new initial conditions.
The model editor is organized into modular construction, which helps put in data easily, and gives possibility of modeling method selection for individual aircraft model modules.

Helicopter model

The numerical model presented in this paper is developed for the MI-2 helicopter from WSK Swidnik. The MI-2 is designed as multipurpose light helicopter. Typical use of the twin engine vehicle is transport, police and emergency service.

The computer model described below can also be used during the design phase of the aircraft modification for prediction of flying qualities and overall performance analysis. This model is used to for real time simulation task and flight test data from experiment and simulation are used to validate the model.

Main rotor

The main rotor is modelled using the blade element formulation. Each blade is divided into segments and the local inertial and aerodynamic loads at each blade segment are separately computed to model the load distribution along the blade.
In this research, the blade element articulated rotor model is used with blade hinges for feathering, flapping and lead-lag. Quasi-steady airloads model is applied Glauert inflow model is used for computation with fore-to-aft linear variation of velocity distribution in forward flight.

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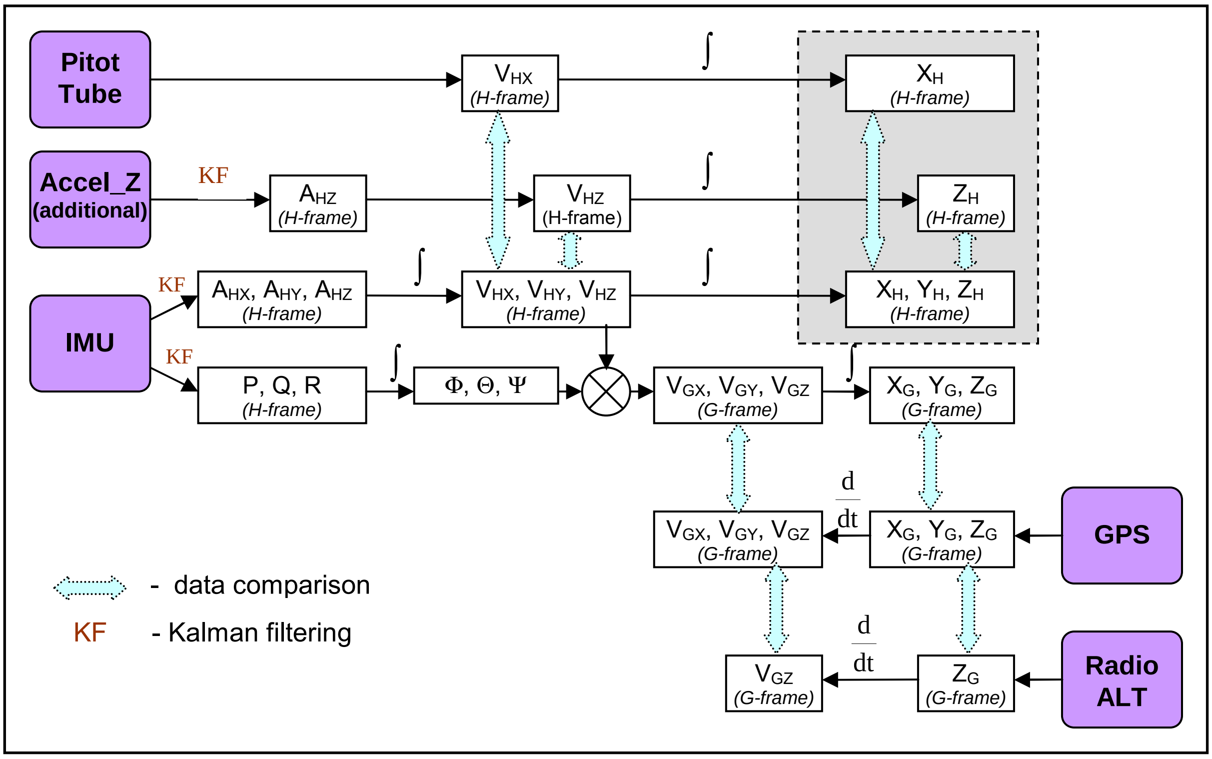

Fig. 5 The flow diagram of signal acquisition and processing

Tail rotor

The tail rotor is modelled as a Bailey rotor model - a rotor disk with only collective pitch and no cyclic pitch input. The induced velocity is computed from a uniform inflow model..

Fuselage

The fuselage is modelled as a distributed mass with six degrees of freedom. The equations of motion of the rigid body are non-linear and applicable for large manoeuvring conditions. Fuselage aerodynamics are calculated from three dimensional aerodynamic data tables obtained from wind tunnel

Propulsion

The propulsion model includes ideal engines; it maintains a constant rotational speed and has no limit on engine power output.

Environment

The environment model includes standard atmosphere table to provide pressure, density, temperature and speed of a sound as a function of altitude.

Comparison of test results

In order to verification of constructed helicopter simulation model, the same maneuver, which was done during the flight test are simulated.

Experimental results for a helicopter level flight (30 seconds) in comparison with simulation results (red curves) are shown in Fig. 6 - 10.

The values and ranges of parameters measured by different devices and the same parameters obtained by simulation are very similar e.g. the trends of the values changes are the same.

Filtering method applied shows good efficiency especially in filtering accelerations (Fig.6) and angular rates (Fig. 7). In the Fig 8, Euler angels from INS are compared with results of the numerical simulations, proving the effectiveness of simulation model.

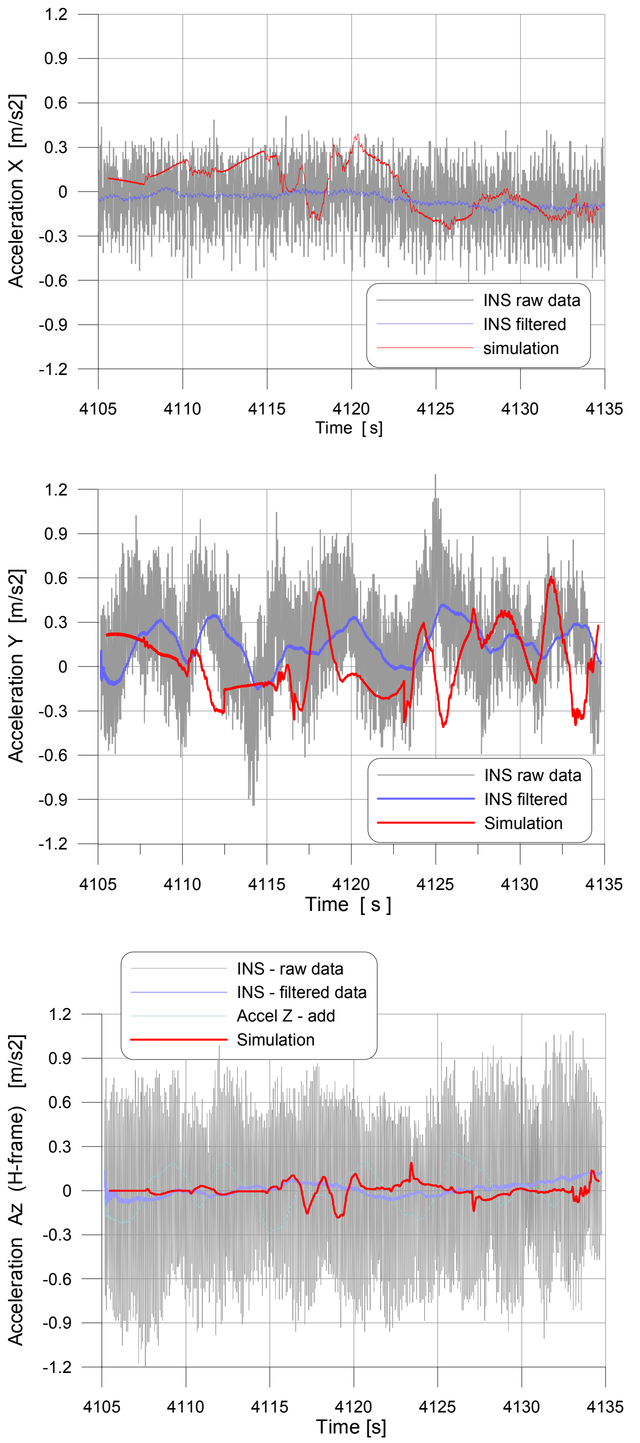

Fig. 6 Three components of acceleration measured by INS and by additional aircraft n_z accelerometer

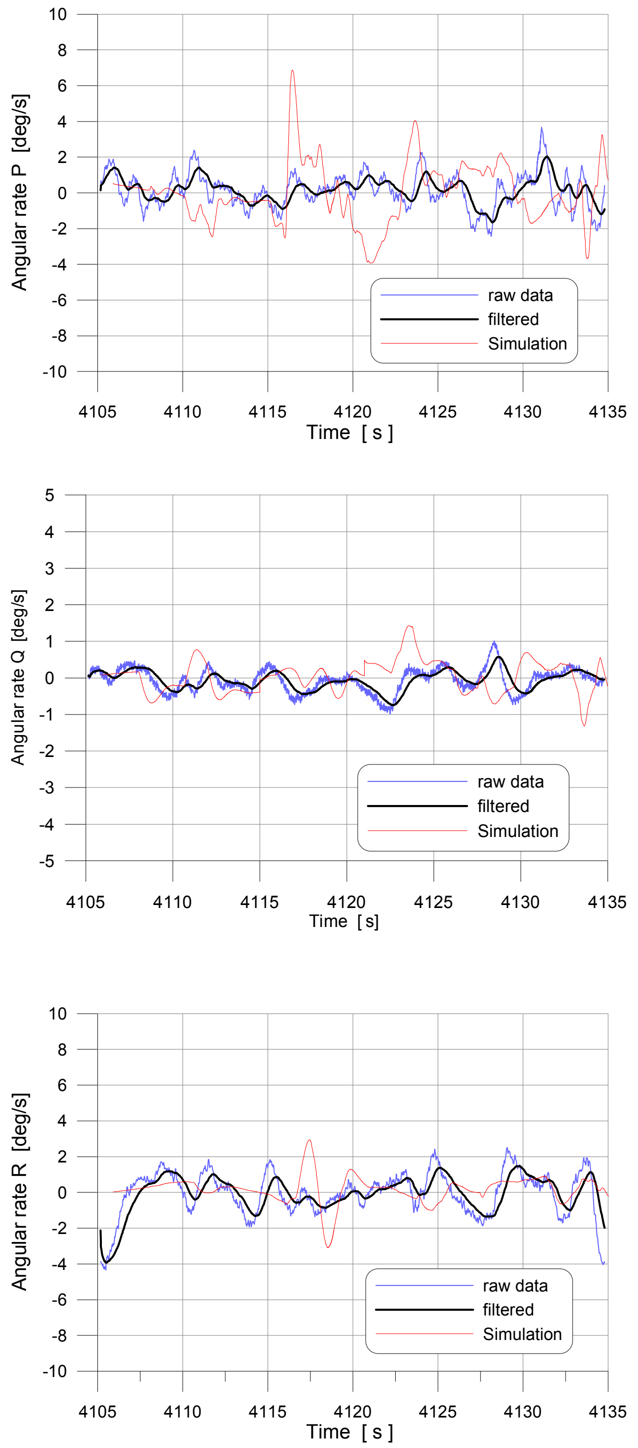

Fig. 7 Rate components measured along three axes by INS

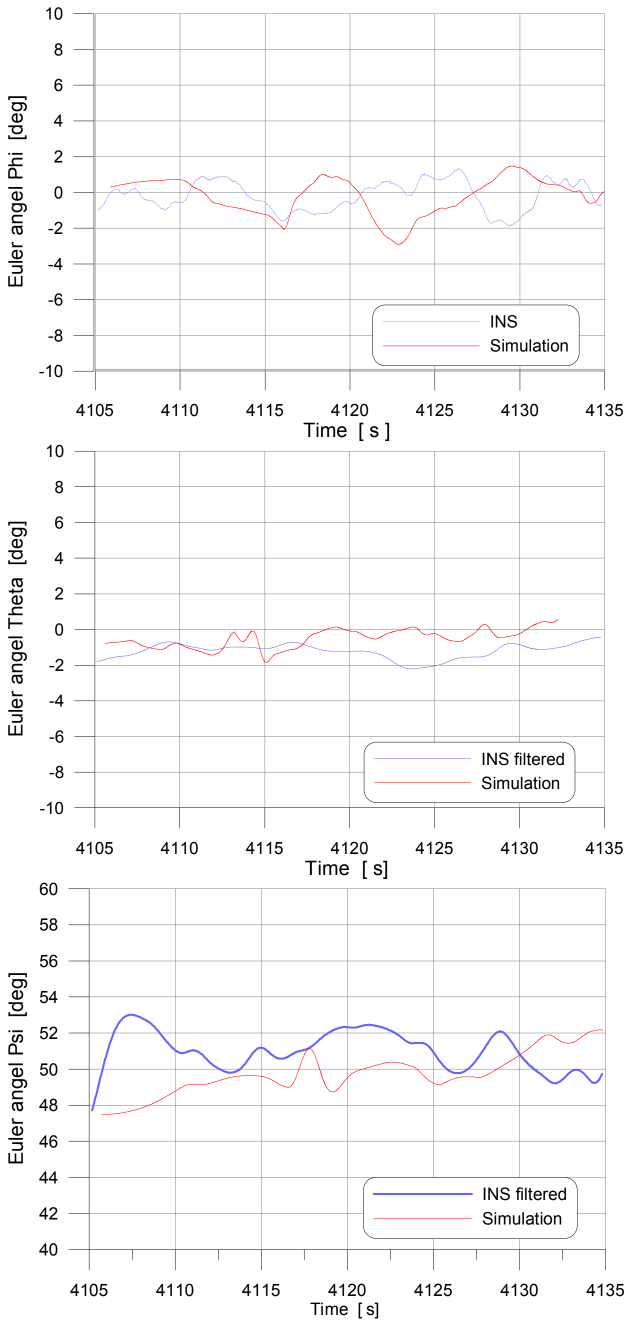

Fig. 8 Euler angels from INS

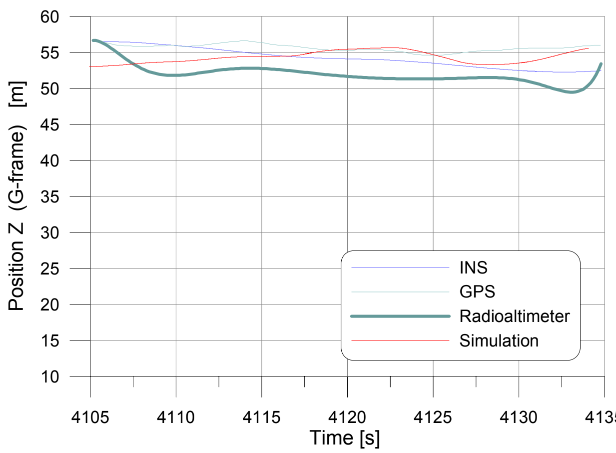

Fig. 9 Altitude of the helicopter's level flight

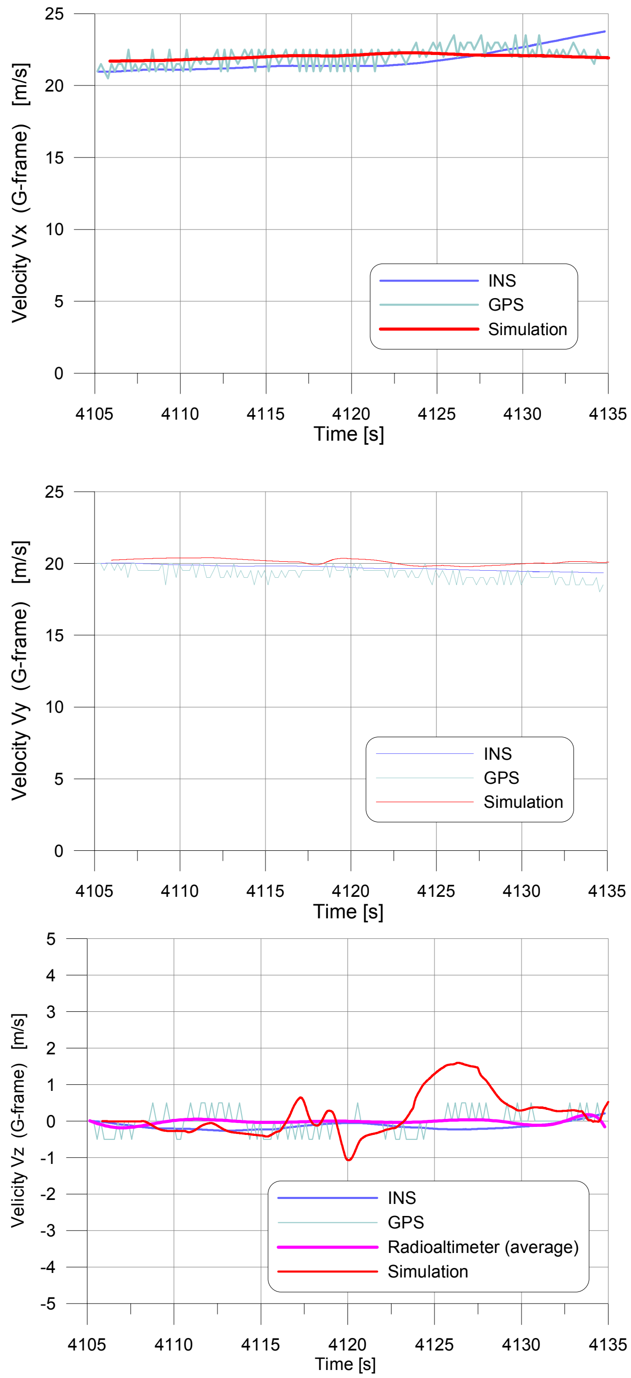

Fig. 10 Velocity in three axes, in geographical coordination

In Fig.9 the helicopter altitude is shown, measured by INS, GPS and radioaltimeter and comparison with simulation results. These results confirm effectiveness of applied INS and GPS systems in respect to the values from radioaltimeter and also the simulation model accuracy. The velocity obtained from INS, GPS and simulation (Fig.10) show good agreement.
These tests prove that despite the low accuracy of sensors due to proper filtering and integration technique the INS/GPS measuring system may be

applied for short term maneuvers providing adequate results.

Conclusions

The INS unit and GPS receiver used in the flight tests showed the possibility of using simple off-the shelf equipment in the flight tests. The filtering algorithm and data acquisition and processing system give the results coherent with measurements by other equipment and simulations. Possibility of the fast creation of simulation model, also the ease to exchange the components of the model and aircraft motion visualization allows to use the FLIGHTLAB software in flight mechanics tests.

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