Evaluation of Single Engine Aeroplane Spinning by Measured Data and the Use of CFD

A research collaboration between:

Osnabrueck University of Applied Sciences,
Mid-Sweden University, and
The University of the West of England, Bristol

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THE PROBLEM

The Spin

Stall entry may lead to a spin

→ more aeroplane losses due to spins than by all other manoeuvres together

→ confusing

→ disorientating

→ over-stress the aeroplane structure

Certification Specification CS 23 requires:

Single Engine (normal category) aeroplanes must be able to recover from a `1-turn-spin` within 1 turn after the recovery was initiated → that is not a fully developed spin.

Single Engine (utility and aerobatic category) aeroplanes: after a `6-turn-spin` the recovery must be possible at any time within 1 ½ further turns

Multi Engine aeroplanes: no spin trials required

Aims

•To better understand the flow phenomena of spinning

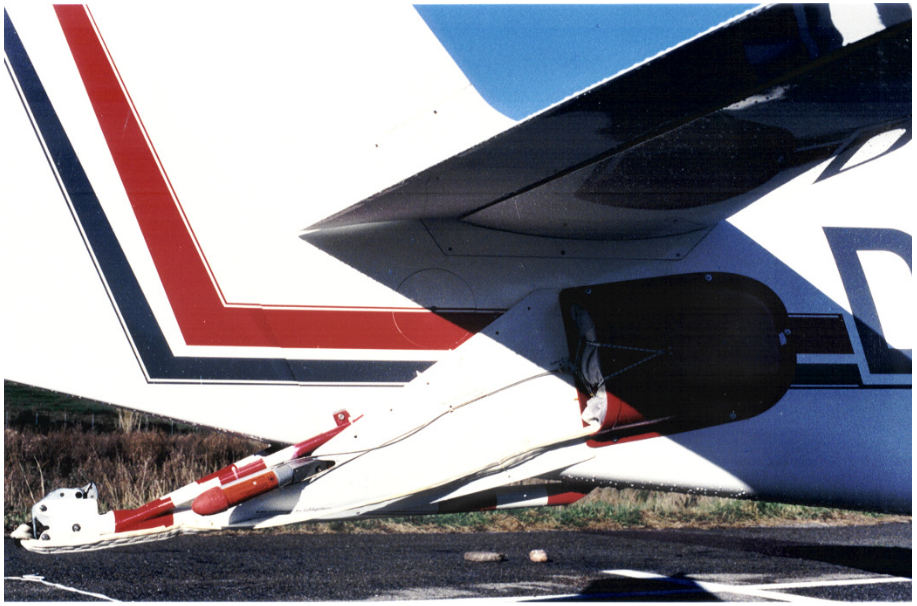
•To instrument an aircraft which is capable of being initiated into a spin – and which can be safely taken out of that spin

• To calibrate and correct the sensor data – using static and dynamics tests

•To establish a set of suitable sensors for gathering test data with a corresponding set of post-processing software to ensure suitably accurate results are produced

•To produce a prediction tool that will give flight testers & aircraft operators the facility to determine which combinations of spin relevant parameters are dangerous for a specific aeroplane (flat spins, control surface shielding and potentially improve the certification procedure for spin in reducing the need for some cases.)

COMPLEX SPIN DYNAMIC



→ Spin - Video National Test Pilot School, USA

→ spin dynamic is highly non linear and today not entirely understood

→ during certification test flight the spin matrix is very large, critical areas are not identified beforehand

→ high number of flight accidents during spin test flights (esp. in fog & clouds)

Data presented in the following slides is from UAS‘ Fuji FA 200-160

Parameter space > 60

During the certification process of an aeroplane the spinning trials are one of the most extensive parts of the entire process because spinning is influenced by a large number of factors.

Among these factors are:

•control surface deflections or inputs,

•aeroplane mass, mass distribution in the aeroplane (wing or fuselage heavy), centre of gravity position,
• power settings,

•atmospheric conditions (mainly the density),

•aeroplane configuration like flap settings and gear position,

•tail configuration of the aeroplane, aerodynamic profile of the wings, the longitudinal position of the horizontal and vertical stabilizer and the vertical position of the horizontal stabilizer. etc

Experimental methodology

Extract from a spin matrix

Test Point	Flaps	Gear	Power	Turning Flight	Spin Dir.	Aileron	Entry	Procedure
193	0	Up	OFF	contra	LH	neutral	accelerated	Contra turn, accel.entry
194	1	Down	OFF	contra	LH	neutral	accelerated	"
195	2	Down	OFF	contra	LH	neutral	accelerated	"
196	3	Down	OFF	contra	LH	neutral	accelerated	"

→ **shrinking** down the flight test matrix to the relevant parameter permutations by

understanding and

simulating

the spin

→ non – critical aeroplane designs

Antispin rudder deflection followed by a elevator control input in the full forward direction is the fastest and most effective recovery procedure (neutralise as spin stops).
In addition the initial application of these recovery control inputs did not always stop the spin motion.

Amendment to the existing aircraft

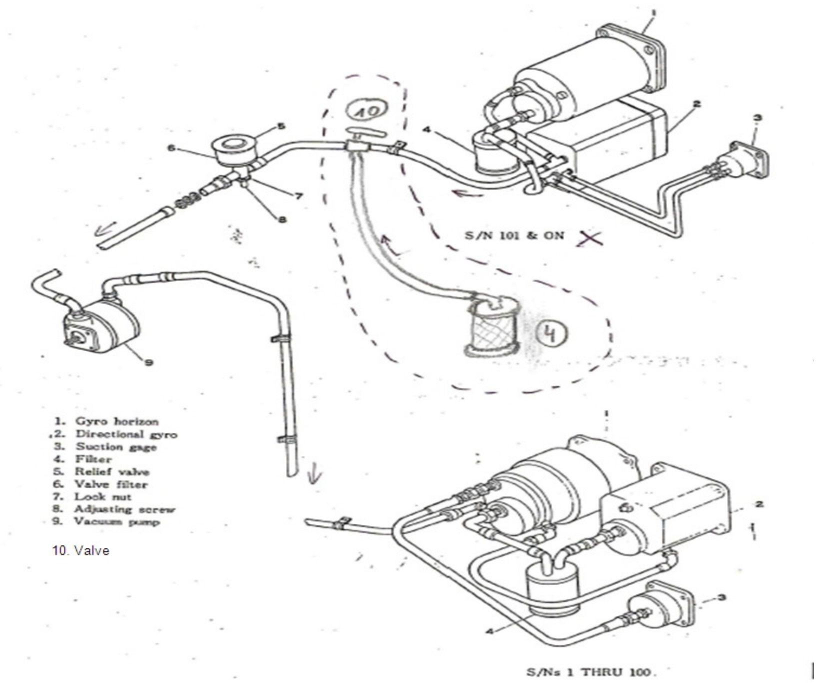


FIG 11—4 VACUUM SYSTEM

D-EGWN

The test aeroplane has a standard suction system to drive the artificial horizon and the directional gyro. These instruments are not designed for aerobatic (spin) use.

High turn rates and pitch and bank angles which are higher than 60° may destroy these expensive devices.

To avoid such a destruction the suction system – which is driven by the aeroplanes engine by a drive shaft – the system was modified so that the artificial horizon and the directional gyro
can be disconnected from the suction system. This is possible by directing the suction airflow not through the corresponding instruments.

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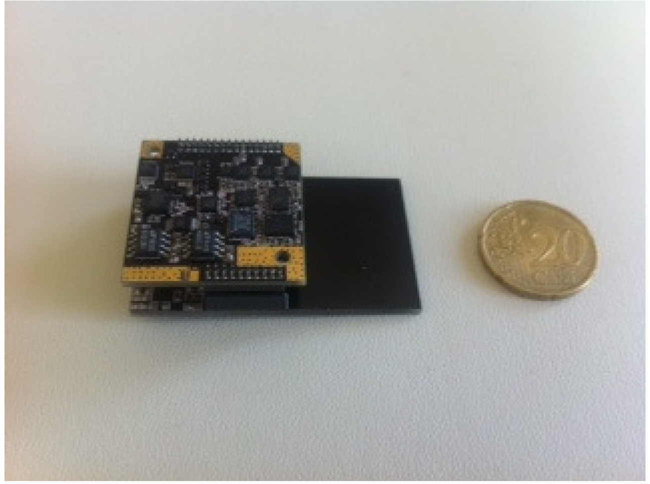
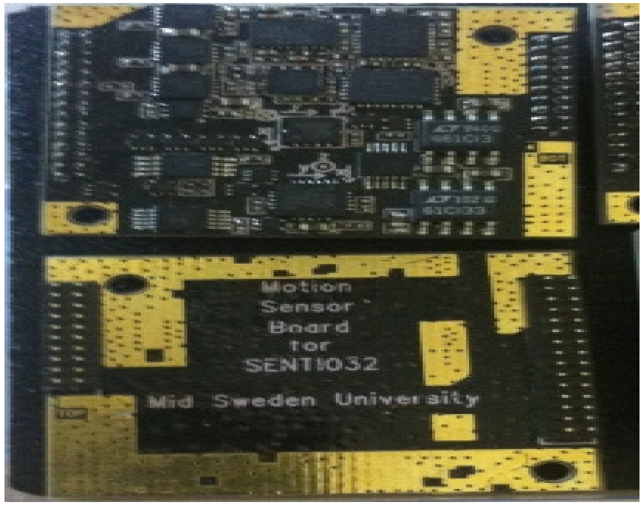
Solving the problem – instumenting the aircraft

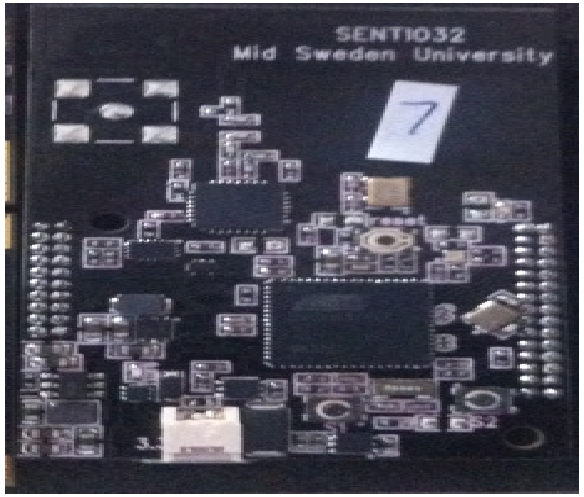


SENTIO 32 (designed by Mid-Sweden Uni)

micro-controller (32 bit) : AT32UC3B0256
Chip : CC 2520
3D accelerometer : KXSD9 - 2520
X,Y-gyroscope : IDG 500
Z- gyroscope : ISZ 500
AD converter : AD 7980
(vibrating-structure gyroscopes, capacitive principle accelerometer)



Motion Sensor Board



Micro Sensor Platine (hardware platform)

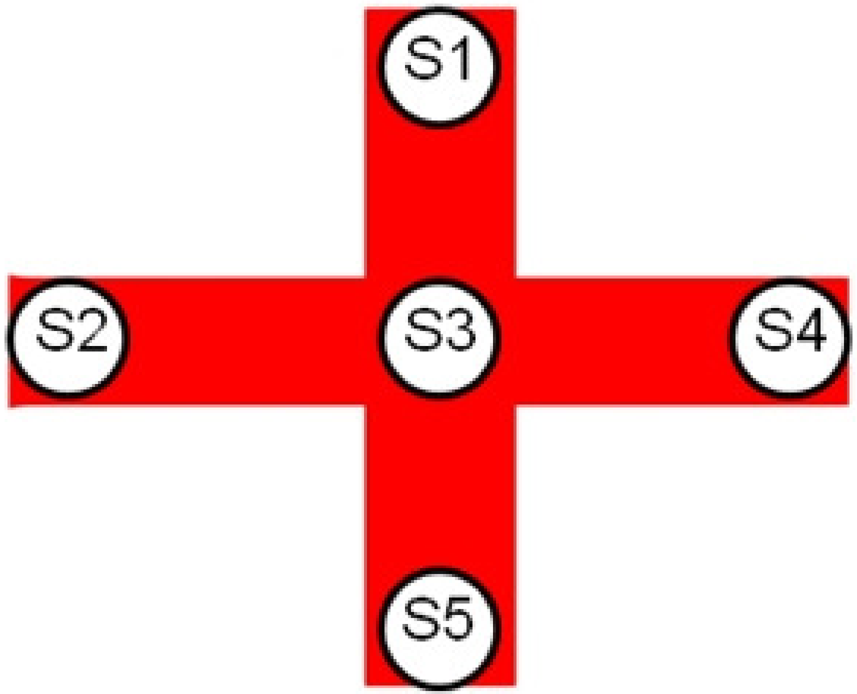
The IDG-500 gyro includes the integrated electronics necessary for application-ready functionality. It incorporates X- and Y-axis low-pass filters and an EEPROM for on-chip factory low-pass filters and an EEPROM for on-chip factory calibration of the sensor.

500°/sec turn rates and accelerations of more than 50g can be measured in a temperature range from – 40°C to 105°C.

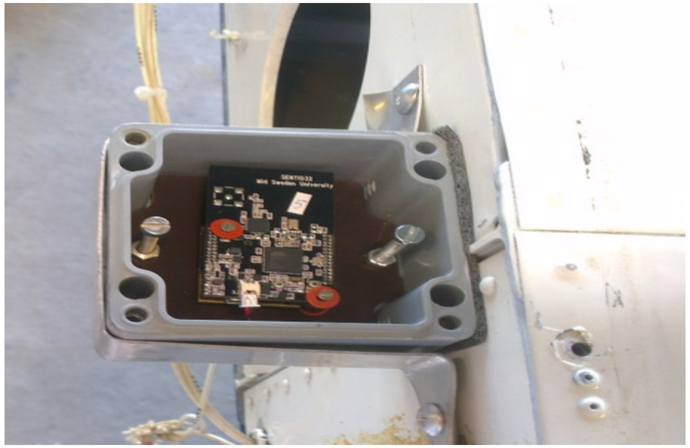
Additionally the small size, the low mass of this system and the mobile power supply by accumulators makes this system especially usable for this application.

Application of the motion sensor system

Schematic diagram

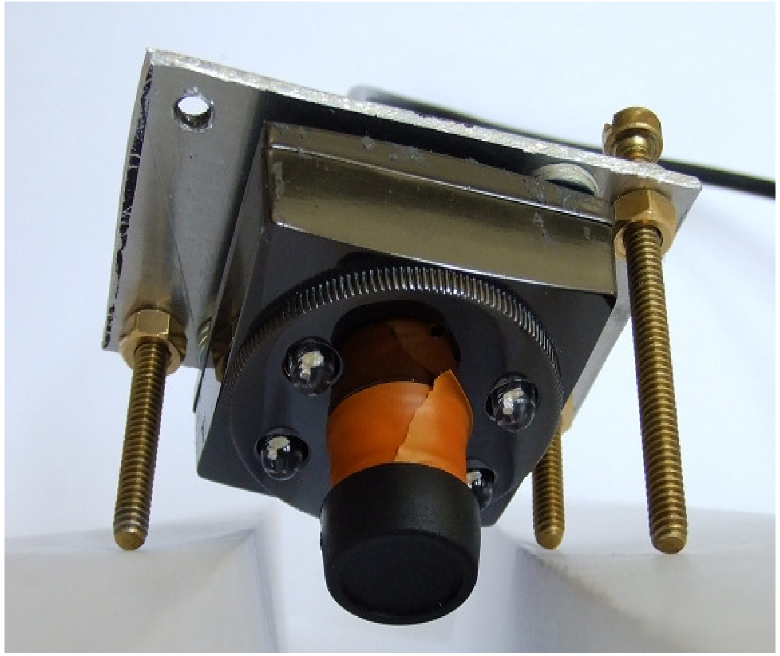


Test Aeroplane Fuji FA 200



SENTIO 32 at the wing tip

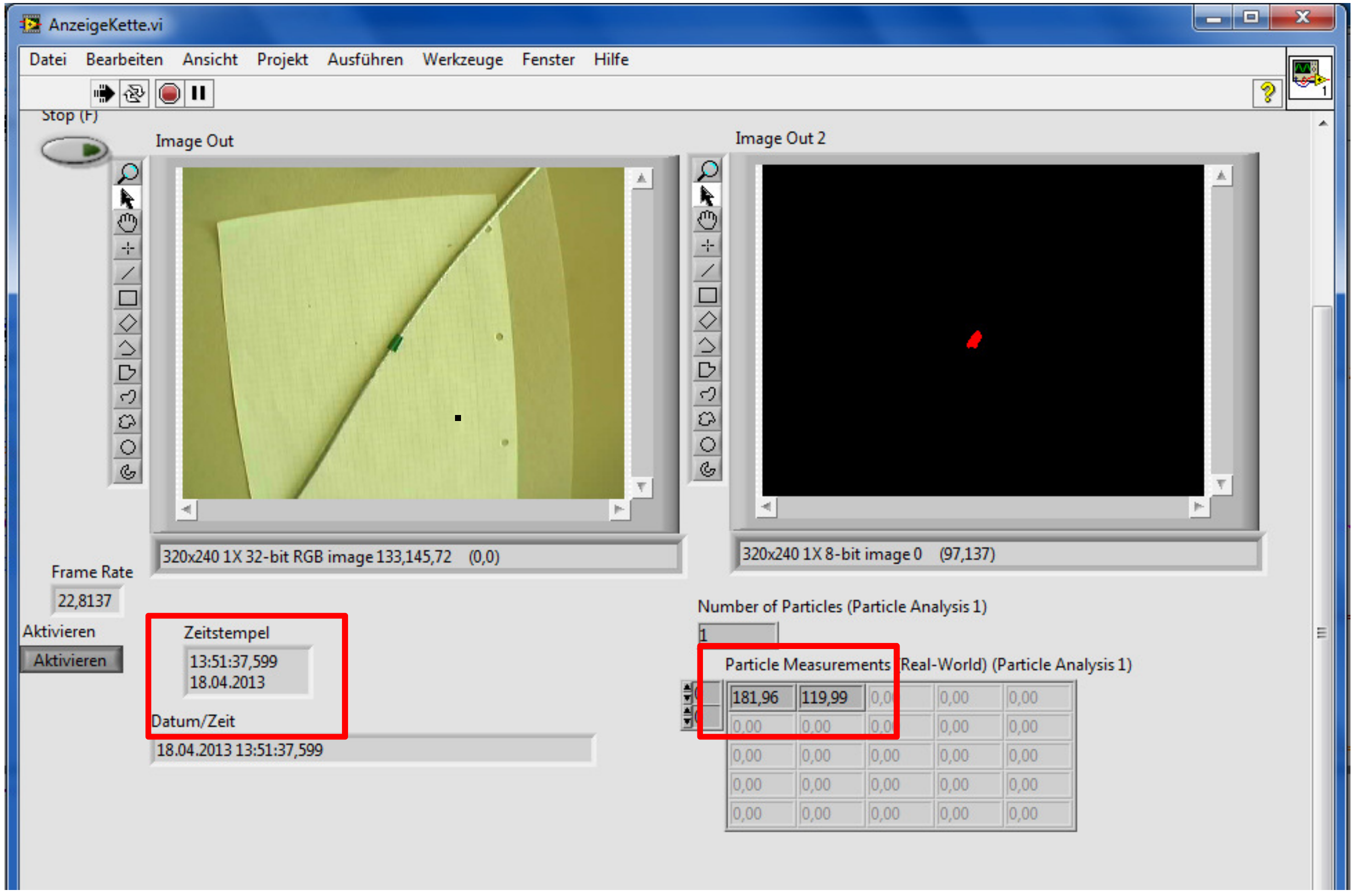
Detection of control surface deflections



Applied camera system
(Hercules Optical Glass 4780715)

Field of view of the camera

Laboratory tests using LabView

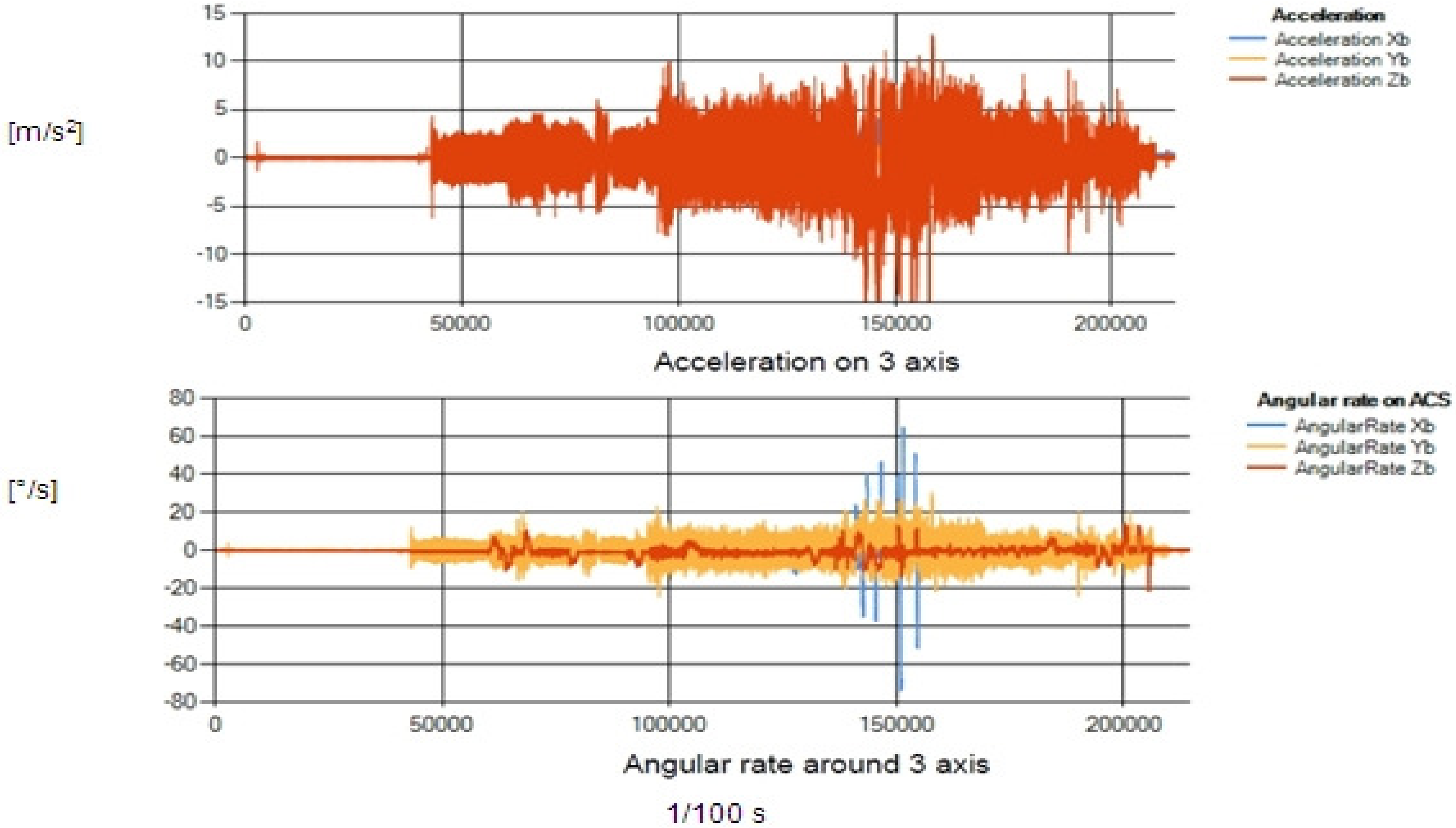


LabVIEW was utilised to convert movements of steering cable markers onto the screen into x, y - ‘pixel – coordinates’. With that information a conversion into distances and thus into deflection angles is possible.

Picture of camera tracking system during Lab tests

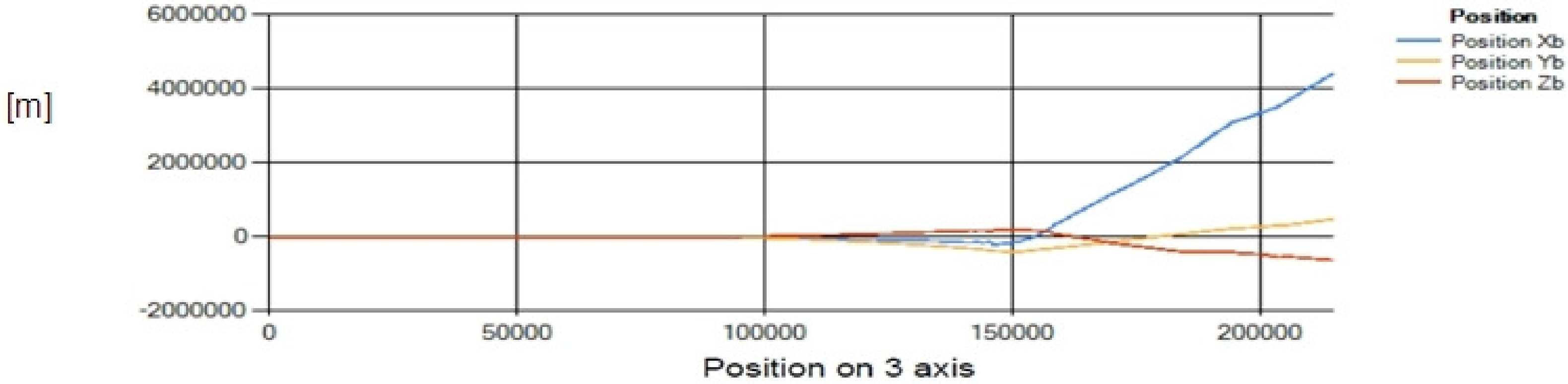
Because distortion of the camera object would lead to incorrect measurement, the correction of the radial and tangential distortion had to be understood by comparing with a known standard picture.

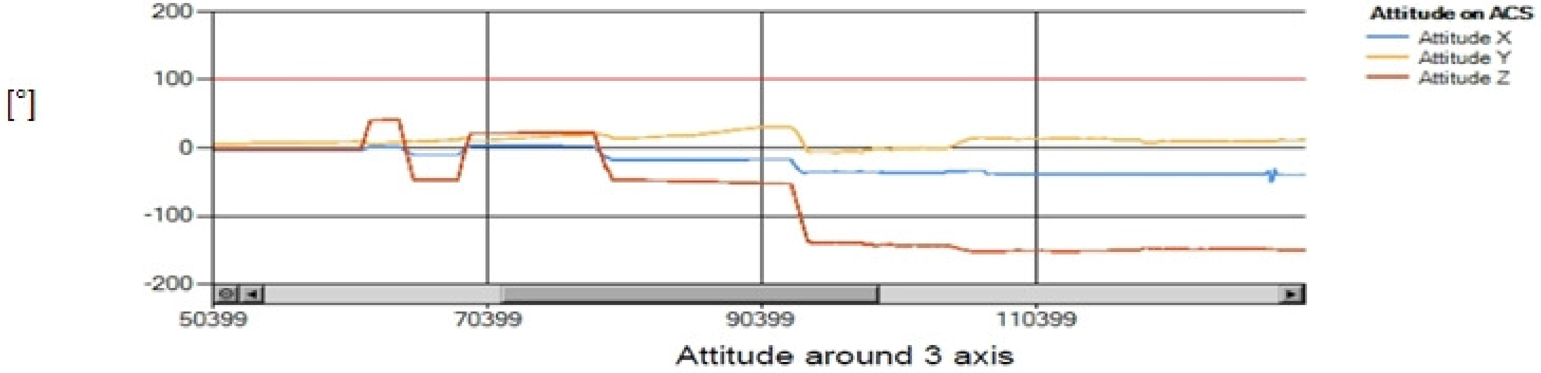
Results of acceleration and angular rate tests (in-flight test)



Test results of acceleration and angular rate – used to calculate positions & attitudes (From sensor3 at CofG)

Results of position and attitude tests





1/100 s

Test results for the position and attitude

Displacement drift low until around 100000 samples

Drift in the attitude data builds up during the entire test

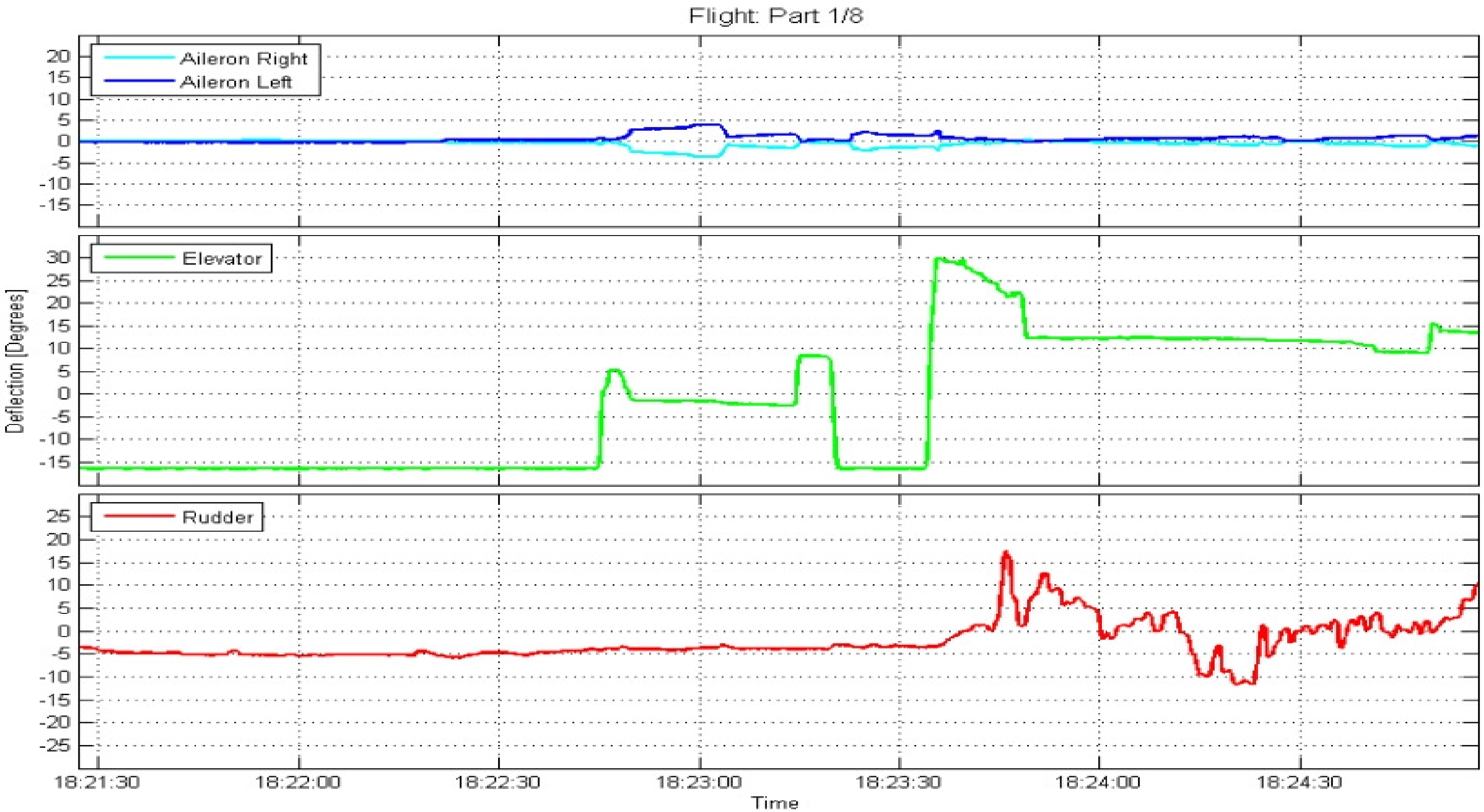
The required precision of 1 metre after 30 minutes of flight was not initially achieved. In the best case, displacement varied by 0.2 metres /minute which resulted in a 15 metre error after only 30 mins of flight

Control surface deflection results

		deflection in degrees (scaled to measured deflection ranges adjusted)			
Date	Time	AileronR	AileronL	Elevator	Rudder
12-Jul-2013	18:21:26.890	0,16232659	-0,18614286	-16,2568765	-3,41589987
12-Jul-2013	18:21:26.961	0,16232659	-0,18619964	-16,3488972	-3,43500072
12-Jul-2013	18:21:27.034	0,16232659	-0,19819034	-16,3490427	-3,43922934
12-Jul-2013	18:21:27.097	0,16232659	-0,19819034	-16,3490427	-3,43922934
12-Jul-2013	18:21:27.169	0,16194566	-0,20561102	-16,3490427	-3,43995329
12-Jul-2013	18:21:27.240	0,16152509	-0,20893731	-16,3490427	-3,49304734
12-Jul-2013	18:21:27.375	0,16152509	-0,20928868	-16,3490427	-3,50227768
12-Jul-2013	18:21:27.447	0,16132774	-0,21197757	-16,3490427	-3,54663519
12-Jul-2013	18:21:27.591	0,16132774	-0,21411903	-16,3490427	-3,55788544
12-Jul-2013	18:21:27.655	0,16104506	-0,21760066	-16,3490427	-3,67330388
12-Jul-2013	18:21:27.799	0,16104506	-0,23407784	-16,3518169	-3,67330388
12-Jul-2013	18:21:27.871	0,16104506	-0,23407784	-16,3518567	-3,67330388
12-Jul-2013	18:21:27.935	0,16104506	-0,21570451	-16,3518169	-3,64042789
12-Jul-2013	18:21:28.079	0,16104506	-0,21570451	-16,3512749	-3,58348172

Calculated angles of the control surfaces
(from the cable movements)

Control surface deflection time plot example



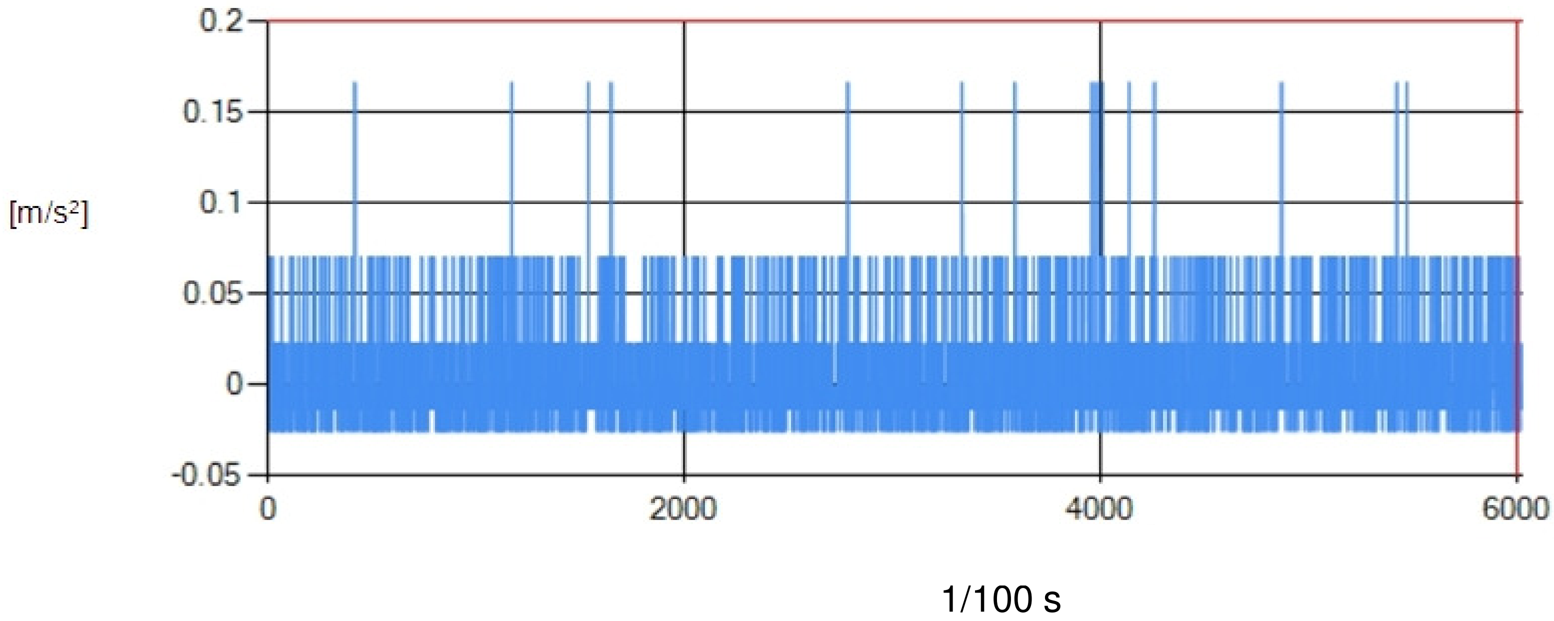
Time plot of measured data of the control deflections

The accuracy after post-processing is within 0.3 degrees

Evaluation of the results

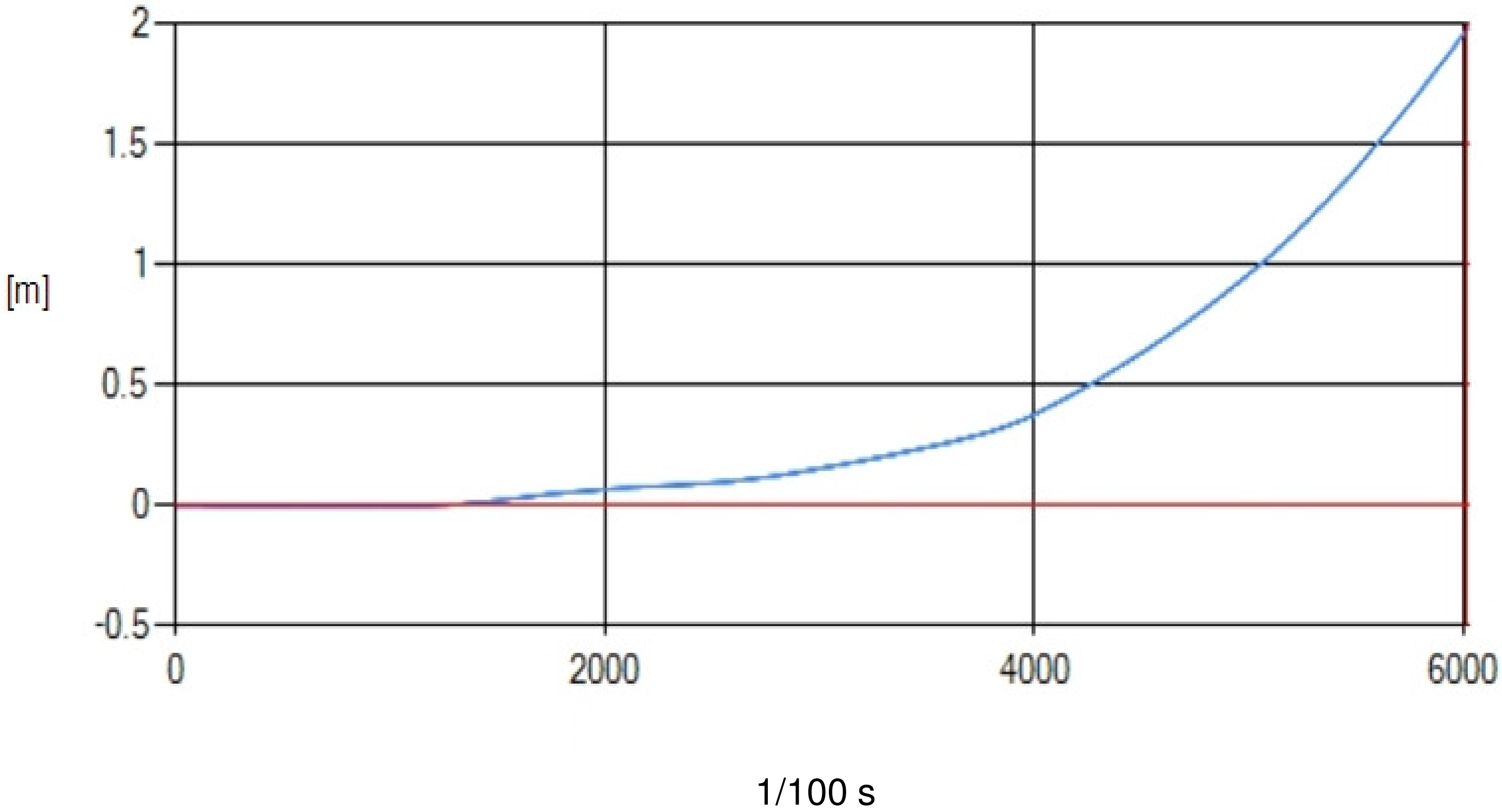
Camera Tracking system:
After calibration and first tests: sensor system is producing proper data for this application

SENTIO 32: (note the asymmetric noise)



Noise of the acceleration sensor

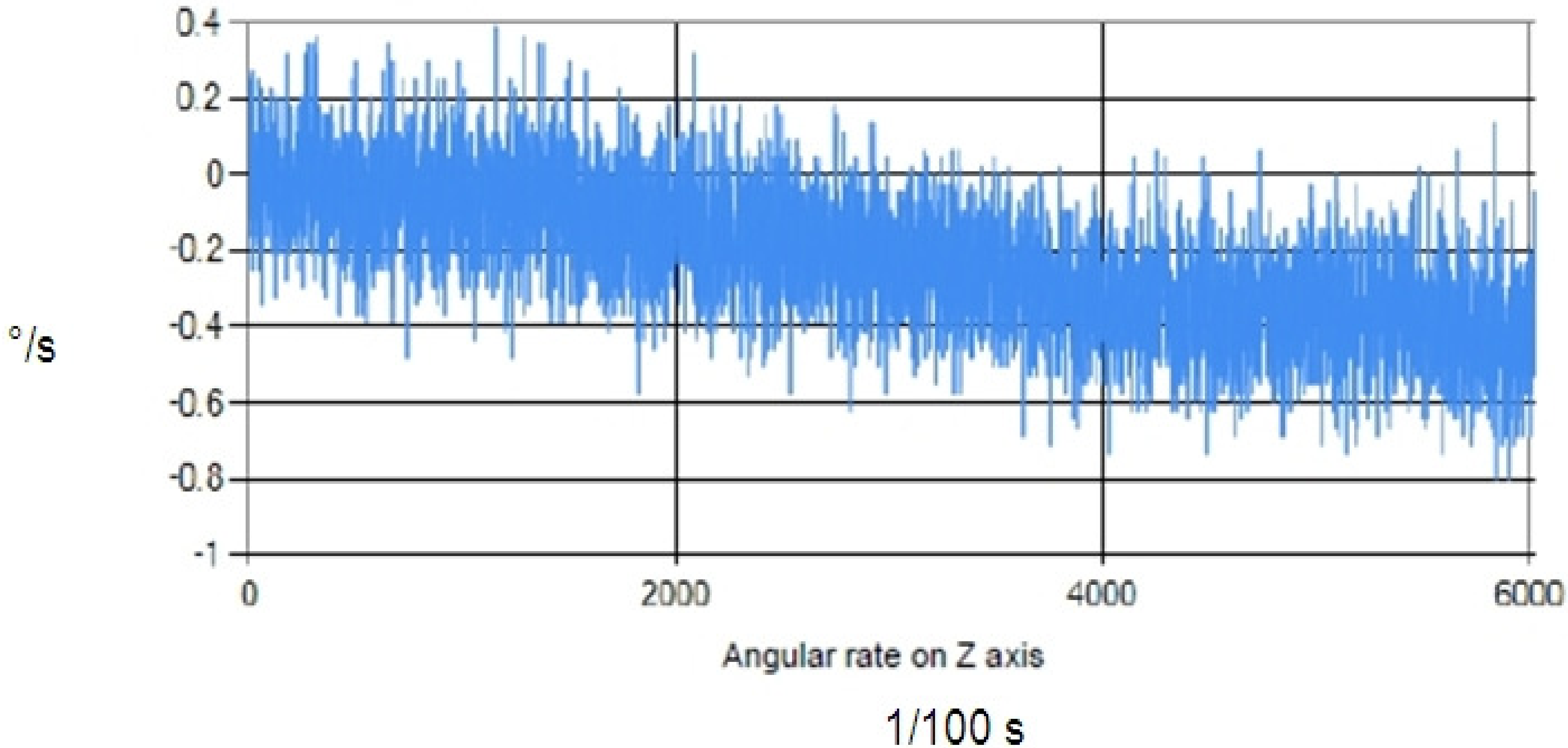
Evaluation of displacement calculation



Calculated displacement of the acceleration sensor (60s)

Due to asymmetic noise in the measurements, the initial post-processing produces the above errors in the displacement – which needs a further correction

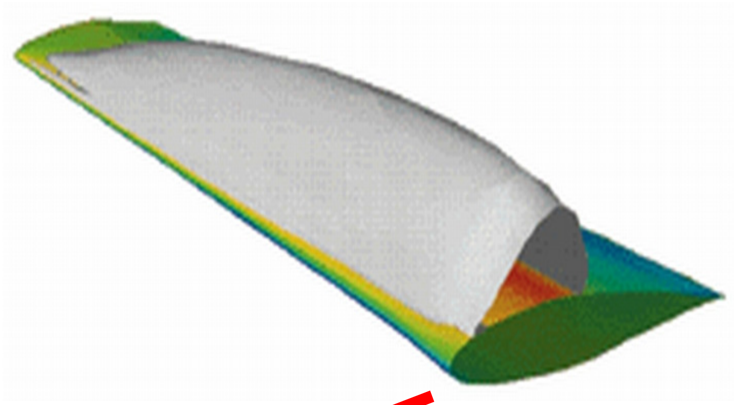
Evaluation of the Z axis angular rate results



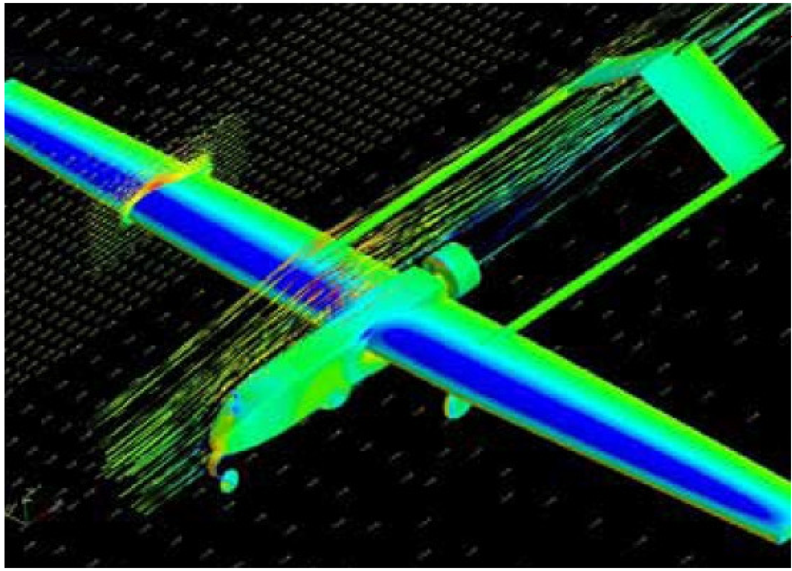
Test results of the motionless test

So although there is no movement of the aircraft here, the gyros record changes – this is due to the warming-up phase. So the measurements must be taken after– but it is to be noted that care must be taken as the gyros are temperature sensitive. Gyros suffer from drift which is easily corrected

Analysis of data with CAD, CFD and FEA



Geometry (here: Scan of the entire aeroplane)



CFD (TAU)

Multi disciplinary simulation of spin runs

Summary

- Both used sensor systems can be used to detect aeroplane movements

- The tests have shown that the synchronization of all five SENTIO 32 systems is possible for all selected mounting positions

- The synchronization for the evaluation of SENTIO 32 data combined with the camera tracking system is realized by the time stamp

- During rapid movements of the aeroplane the SENTIO 32 system produces too large random errors

- Due to that a proven system will be implemented for further test flights and the succeeding analysis of spin dynamics

Please feel free to ask any questions?

Thank you for your attention

For further information and questions please contact:

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