iNAT-M200/SLN on an Aerobatic Aircraft at RedBull 2016

- Performance Analysis of INS / GNSS & Interruption Behavior -

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Commercial-in-Confidence ☒

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I = Issued; C = Checked
AI = Approved (iMAR)
AC = Approved (Customer)

Rev.	Paragraph	Comments		Date	Name	Function
1.00	All	Document created	I/C/AI	02.09.16	EvH	CEO

DOCUMENT CHECK & APPROVAL REQUIREMENTS

CHECK required	APPROVAL by iMAR required	APPROVAL by Customer required
No	No	No

Acronyms of Functions

Industrial/MIL Projects / Industrie- & MIL-Projekte

CEO	Chief Executive Officer (Geschäftsführer)
CUST	Customer (Kunde)
DE	Design Engineer / Development Engineer (Entwicklungsingenieur)
HD	Head of Development (Entwicklungsleiter)
PGM	Program Manager (Projektmanager)
PJM	Project Manager (Projektleiter)
PM	Production Manager (Fertigungsleiter)
QA	Quality Assurance (Qualitätssicherung)
QM	Quality Manager (Qualitätsmanagementbeauftragter)

Aviation & Space Projects / Luft- und Raumfahrtprojekte

AM	Accountable Manager
CUST	Customer (Kunde)
DE	Design Engineer / Development Engineer (Entwicklungsingenieur)
HD	Head of Design (Entwicklungsleiter)
HoA	Head of Office of Airworthiness (Leiter Musterprüfleitstelle)
HoD	Head of Design Organisation
PGM	Program Manager (Projektmanager)
PJM	Project Manager (Projektleiter)
PM	Production Manager (Fertigungsleiter)
CVE	Compliance Verification Engineer (Musterprüfingenieur)
QA	Quality Assurance (Qualitätssicherung)
QM	Quality Manager (Qualitätsmanagementbeauftragter)

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RELATED DOCUMENTS

Table 1: Related Documents

Name	Content	DocNumber
iNAT-M200 datasheet	Technical Product Specification	several
ICD iXCOM Protocol	iXCOM Protocol Specification	DOC141126064
MAN_iXCOM-CMD	iXCOM-CMD description for iXCOM systems (GUI)	DOC151211010
iMAR ARINC825 ICD	ARINC825 CAN iMAR Implementation	DOC141106133
ICD iNAT-M200	ICD iNAT-M200 Systems for MEMS based systems	DOC140301006
MAN_Introduction-into-Inertial-Measuring-Technology	Overview to coordinate systems etc.	DOC151228003
MAN_User-Manual_iNAT-Systems	General User Manual for iNAT Systems	DOC151228001
ICD iNAT-RxFxHx	ICD for RLG/FOG/HRG based systems	DOC141203029

1 INTRODUCTION

The iNAT-M200 INS/GNSS systems are designed for navigation, localization and attitude / heading measurement and control. The are equipped with an integrated MEMS based inertial sensor assembly (several classes of performance available), an integrated GNSS receiver (up to L1L2 GPS+GLONASS+GALILEO RTK), an integrated wheel sensor (odometer) interface (A/B RS422 level), an integrated powerful miniaturized strapdown computer with data fusion (27+ state Kalman filter) and all required interfaces (Ethernet, UART RS422/RS232, CAN, USB) to communicate with external systems. Supported data protocols are TCP/IP, UDP, NMEA183 and many others as well as customized communication layers.

Details can be found in the related Interface Control Documents (ICD) and the manuals for hardware and software.

The systems can be directly integrated into the user's application or they ca be operated via the provided iXCOM-CMD user software (GUI), which is available under MS Windows™ as well as under LINUX.

Figure 1: iNAT-M200/SLN (INS/GNSS based navigation, surveying and control system)

The following report summarizes the results of the qualification flights during RedBull AirRace 2016 in Ascot / UK in the Master's Class. The iNAT-M200/SLN had been mounted on the aerobatic aircraft of Matthias Dolderer, the German's participant in the Master's League and the current field leader (rank 1 world list). He performed the shortest tie on the parcour and hence this aircraft with this pilot s the best base to demonstrate iNATM200/SLN performance under most challenging environment.

The following videos of the RedBull AirRace World Championship give an impression:

https://www.youtube.com/watch?v=AcpXAX00BHU

https://www.youtube.com/watch?v=UuD6_QfkwOo

https://www.youtube.com/watch?v=9jQNxPObYMA

Note:

The same system is also available as iNAT-M200-FLAT/SLN or even as OEM card for direct integration into customer's measurement rack.

Figure 2: iNAT-M200-FLAT/SLN (INS/GNSS/ODO system)

2 EVALUATION SETUP

The iNAT-M200/SLN had been mounted inside Matthias Dolderer's racing aircraft. The y-direction of the INS iNAT-M200 was oriented in forward aircraft direction, the z axis had been directed downwards, the x axis was oriented sideward. For the integrated GNSS receiver a L1L2 GPS+GLONASS setup had been chosen, RTK corrections intentionally had not been available. EGNOS capability of the GNSS receiver had been activated and used where accessible.

Figure 3: Aircraft of Matthias Dolderer at RedBull AirRace

The data output rate had been 500 Hz, the **iNAT-M200/SLN-30** was manufactured with

- Part Number: P/N 00190-00001-5101
- Serial Number S/N: 0001 (30 g version)
- Project Number: KFP-I000675.001

The GNSS antenna had been of type ANTCOM L1L2 GPS/GLONASS with 4 mounting threads and SMB connector for temporarily mounting.

Our iNAT-M200/SLN had been operated stand-alone as a data logger, and collected data had been downloaded post-mission using our iXCOM-CMD configuration & visualization software. The iXCOM-CMD software is available on MS Windows as well as on LINUX machines.

In parallel a data link is available to display via iXCOM-CMD the artificial horizon, angular rate, speed, moving map as well as g-force (load factor) in real-time if desired.

Figure 4: iXCOM-CMD software for iNAT INS/GNSS system operation, data visualization and command

3 DATA VISUALIZATION / ANALYSIS

In the following chapter several plots of the 2nd qualifying on RedBull AirRace in Ascot at August 13 2016 at 16:24 UTC are shown (Master's Class of World Championship).

The following plot shows the configurable flight and supervision display of the iXCOM-CMD software. A configurable speed meter, heading instruments as well as artificial horizons, G Force Meter, time charts (here shown is the altitude as an example) or position plots (in local coordinates or in Lon/Lat) are available.

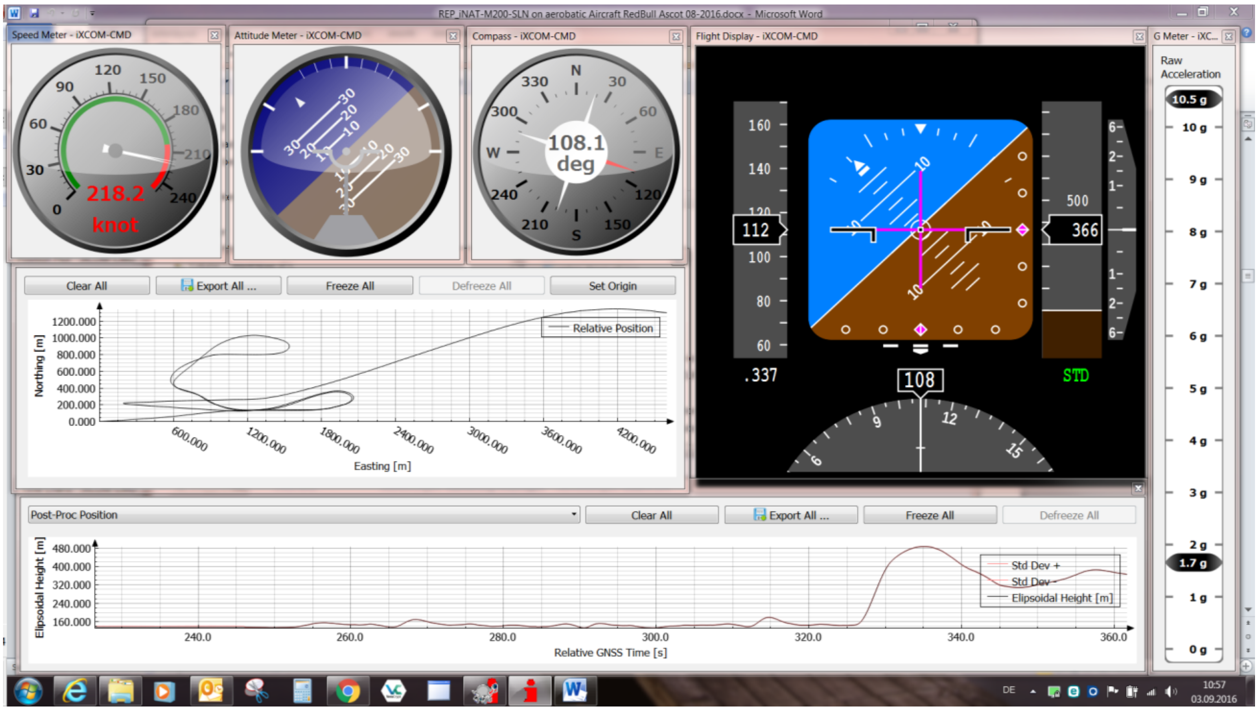


Figure 5: Display configuration example with iXCOM-CMD software

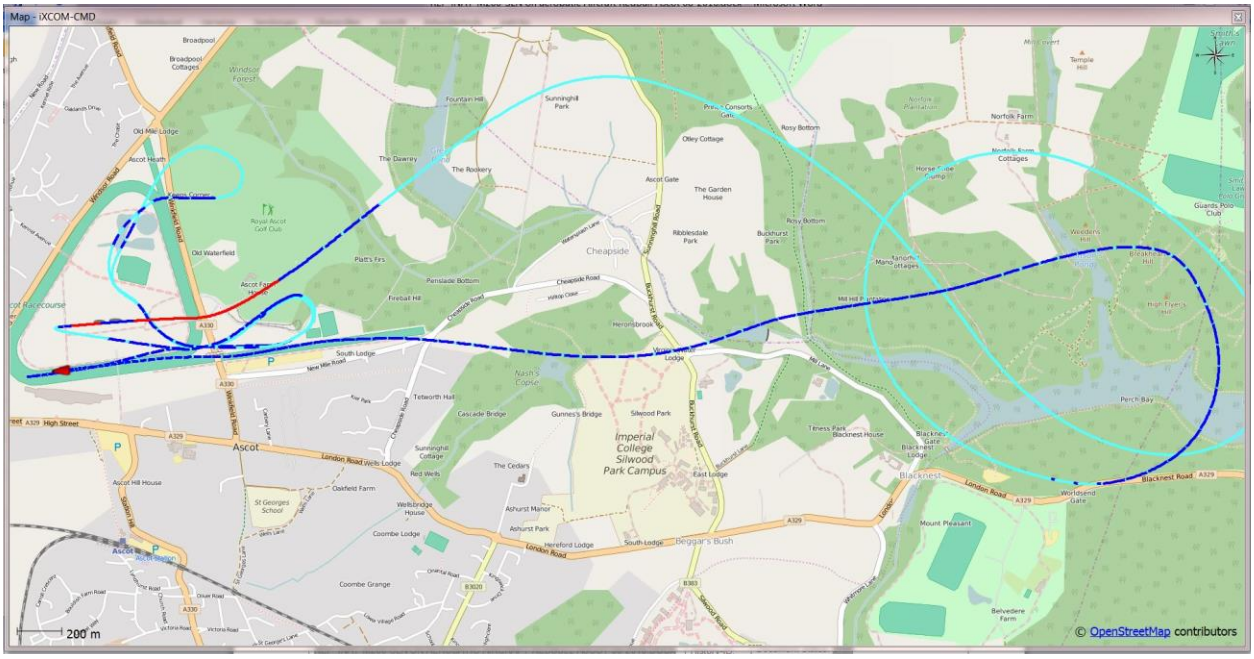


Figure 6: Travelled trajectory, shown on the moving map inside iXCOM-CMD software

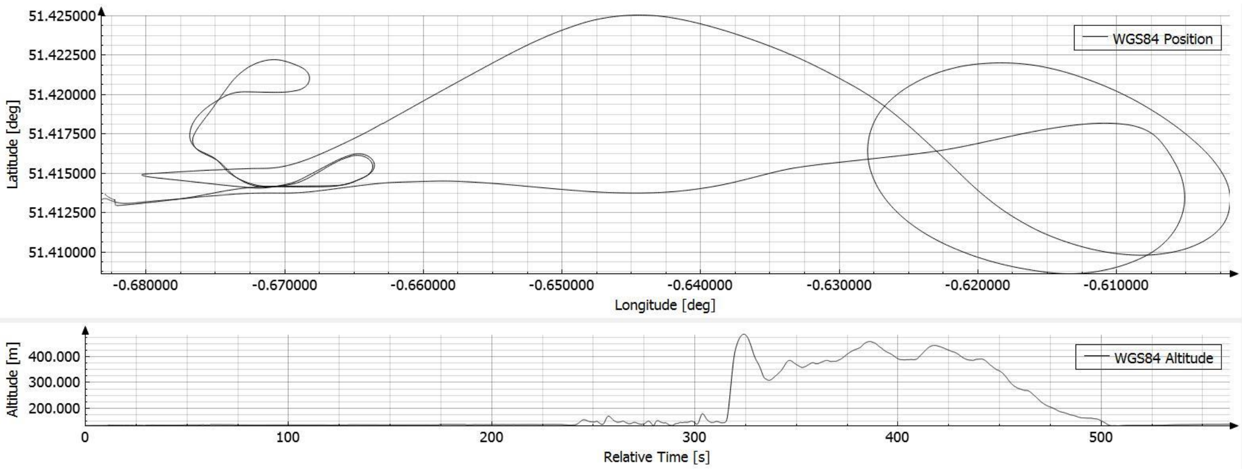


Figure 7: Travelled trajectory and altitude, shown inside iXCOM-CMD software

The following plot shows the travelled velocity as well as roll, pitch and yaw (heading) of the aerobatic aircraft as obtained from the real-time INS/GNSS solution.

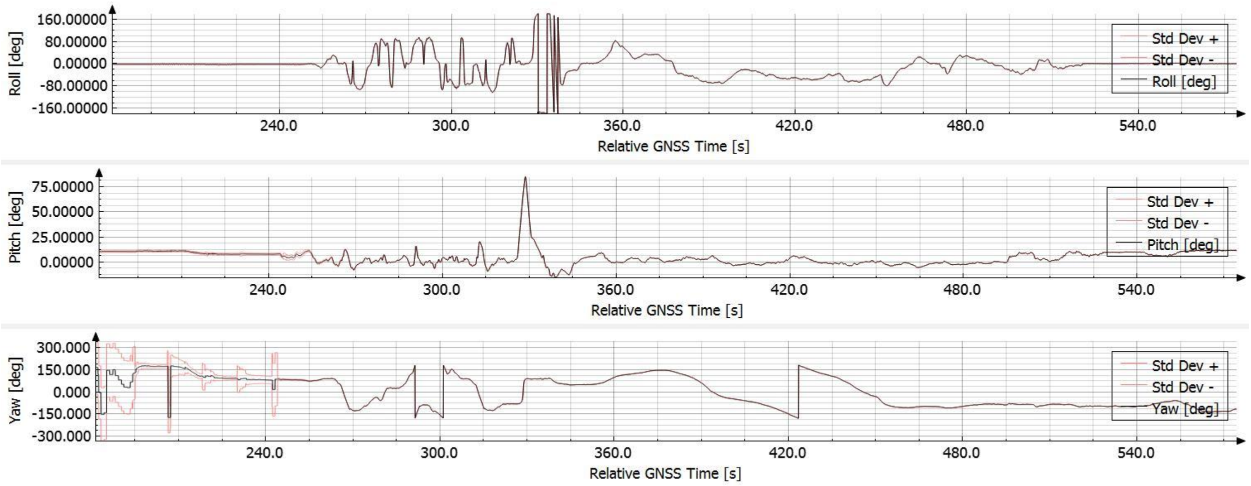


Figure 8: Aerobatic aircraft roll / pitch / yaw over time

It can be clearly identified that the 80 deg pitch at 325 sec relative time occurs when the altitude changes with very high change rate.

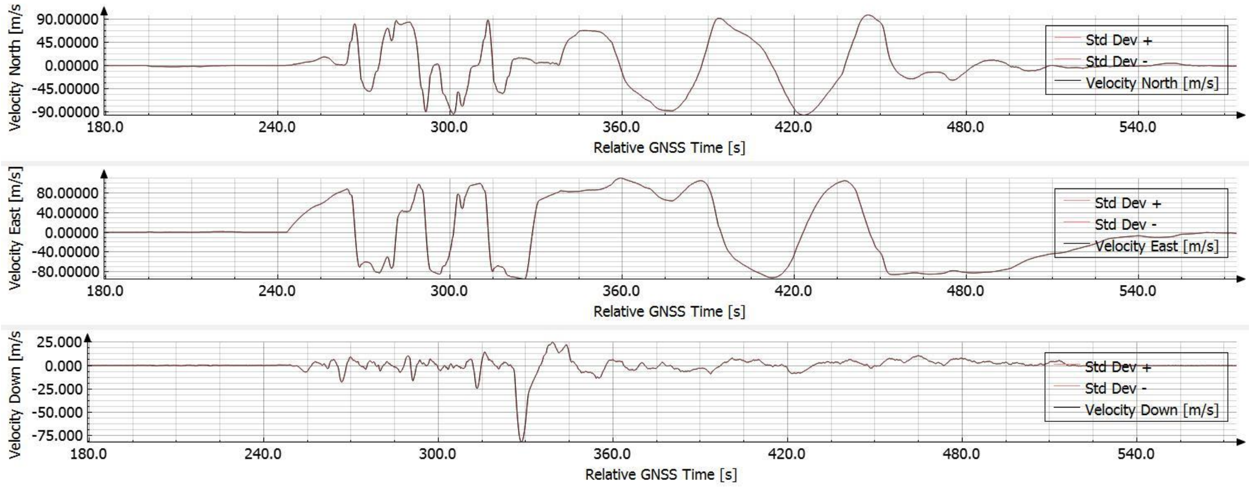


Figure 9: Aerobatic aircraft velocity over time

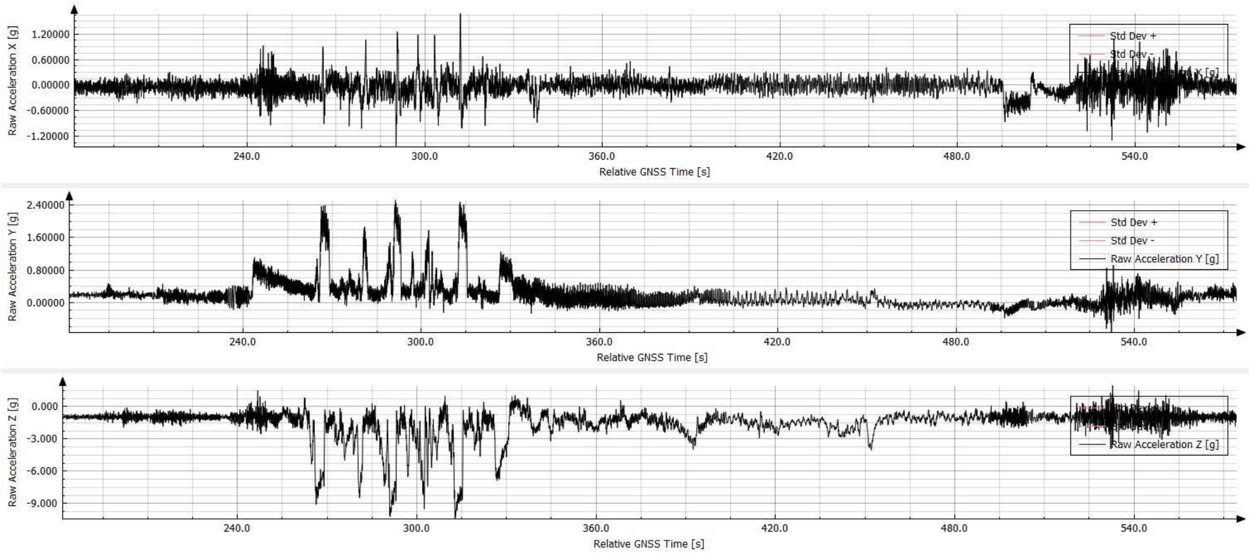


Figure 10: Aerobatic aircraft acceleration (incl. gravity) over time

The aircraft had suffered up to 10 g acceleration in z direction (the RedBull AirRace regulations limit the acceleration to 10 g).

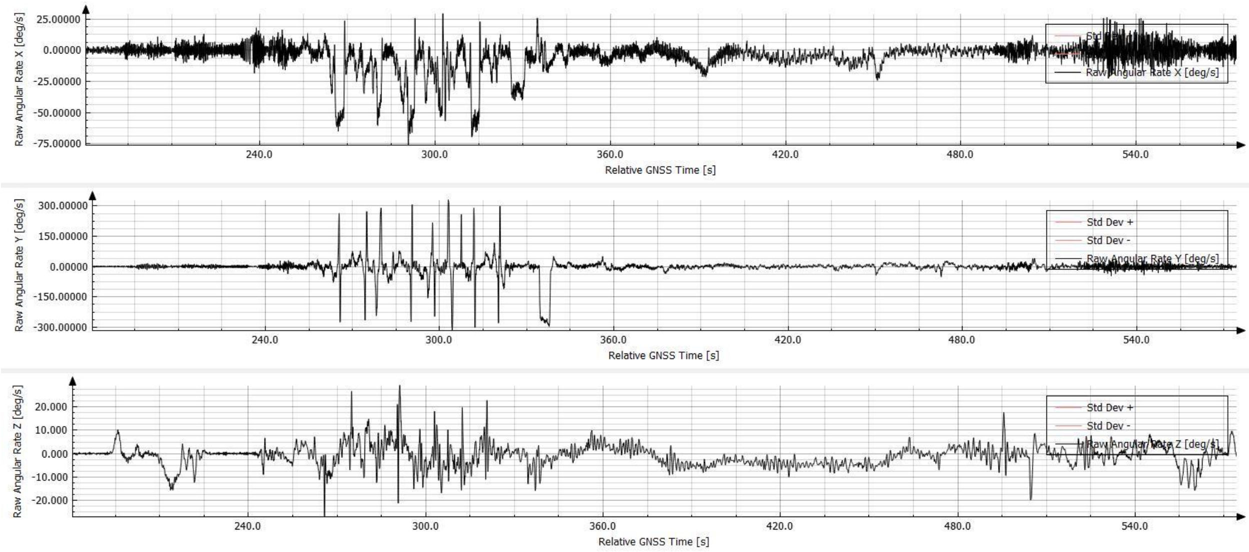


Figure 11: Aerobatic aircraft angular rate over time

Angular rates of up to 300 deg/s are present around the roll axis (y axis of INS). Remember that the “IMU raw y axis” is oriented along the aircraft roll axis and the “IMU raw x axis” is oriented along the aircraft transversal axis – the iNAT-M200 also provides the “corrected IMU data” (coordinate system rotated to aircraft body coordinate system) as well as “compensated IMU data” (additional compensated by gravity and earth rotation rate).

3.1 Example: GNSS Interruption for 15 Seconds

The following figures show the behaviour of the real-time data fusion when GNSS data are not available for aiding for about 15 seconds due to over-head flight maneuvers.

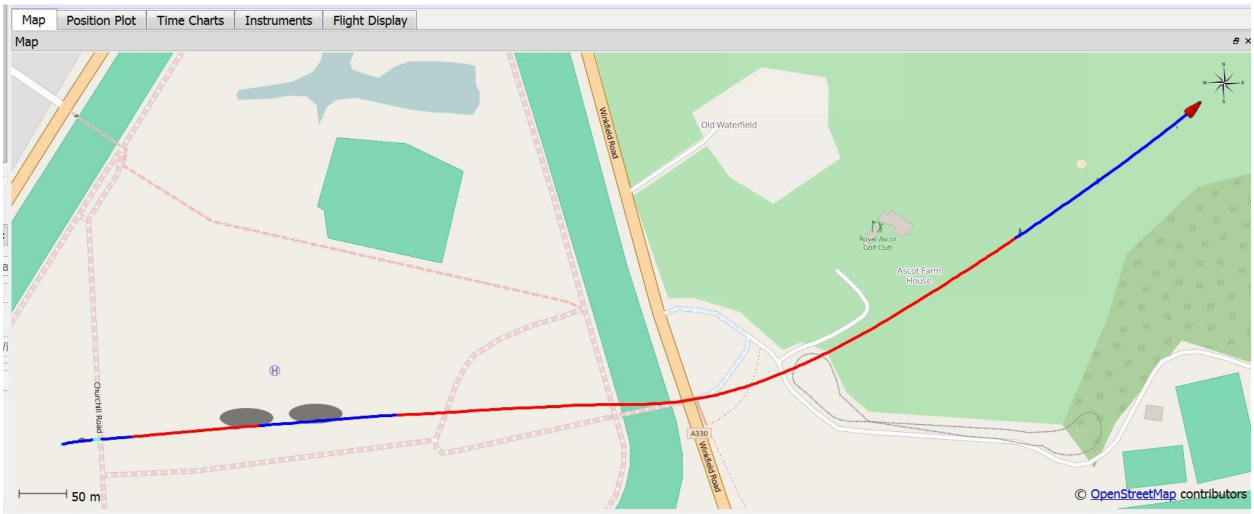
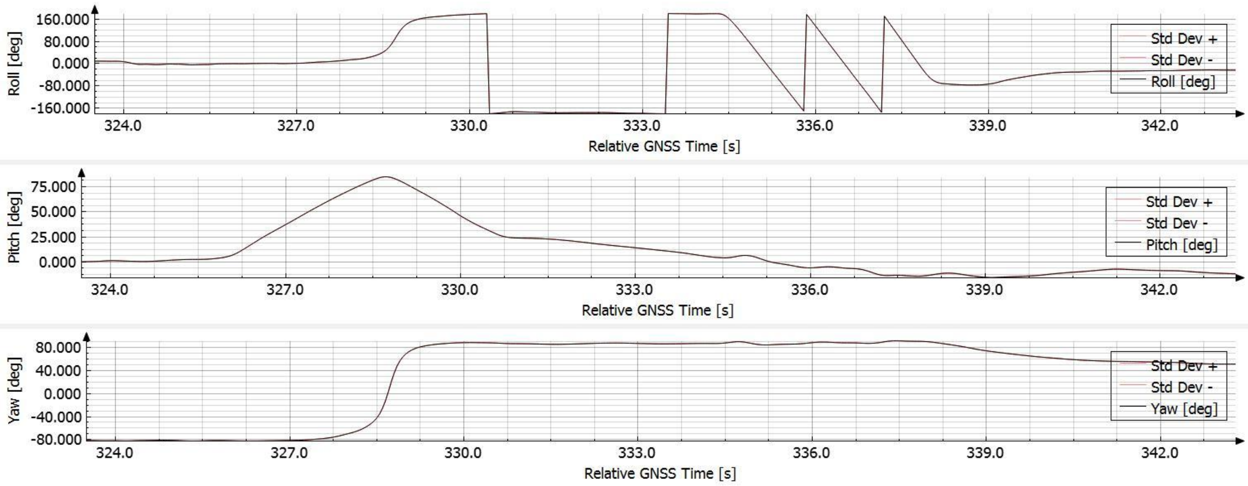


Figure 12: 15 seconds GNSS outage during high dynamics flight maneuvers



In the above figure the GNSS signal was interrupted for about 15 sec, after the pilot changed from head-up flight (epoch 327 sec) to head-down flight (epoch 330 sec). The position deviation during GNSS loss keeps within better than 3 m. The following plots show the status at certain times (before, during and after GNSS outage).

Before GNSS outage the roll/pitch uncertainties are about 0.03 deg and heading uncertainty is about 0.05 deg. Position uncertainty is less than 1 m (remember, that the iNAT-M200 had been operated without any RTK aiding, only EGNOS correction data had been used if available).

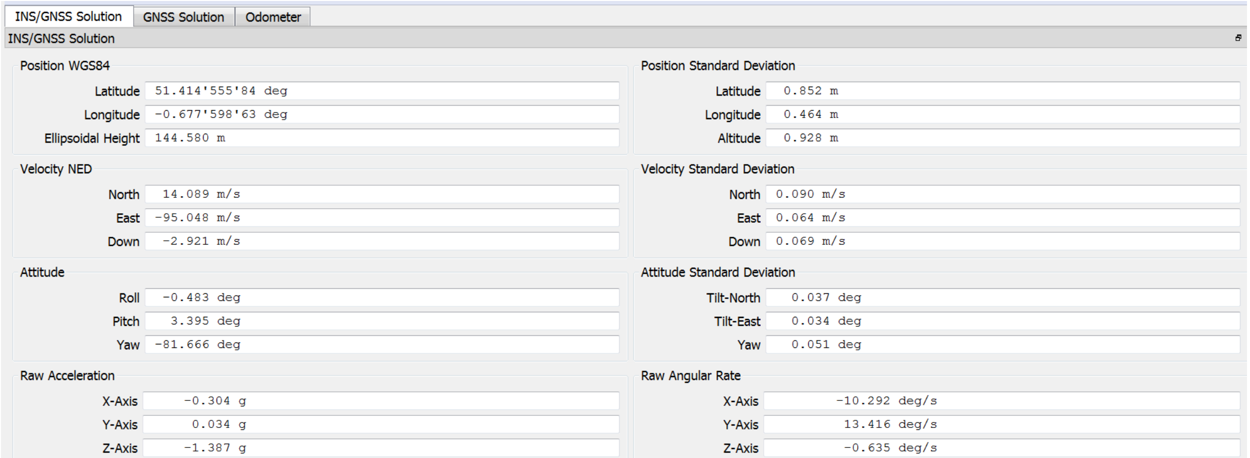


Figure 13: Accuracy before GNSS outage

The next screenshot shows the data about 2 sec after head-down flight (roll about 180 deg) began.

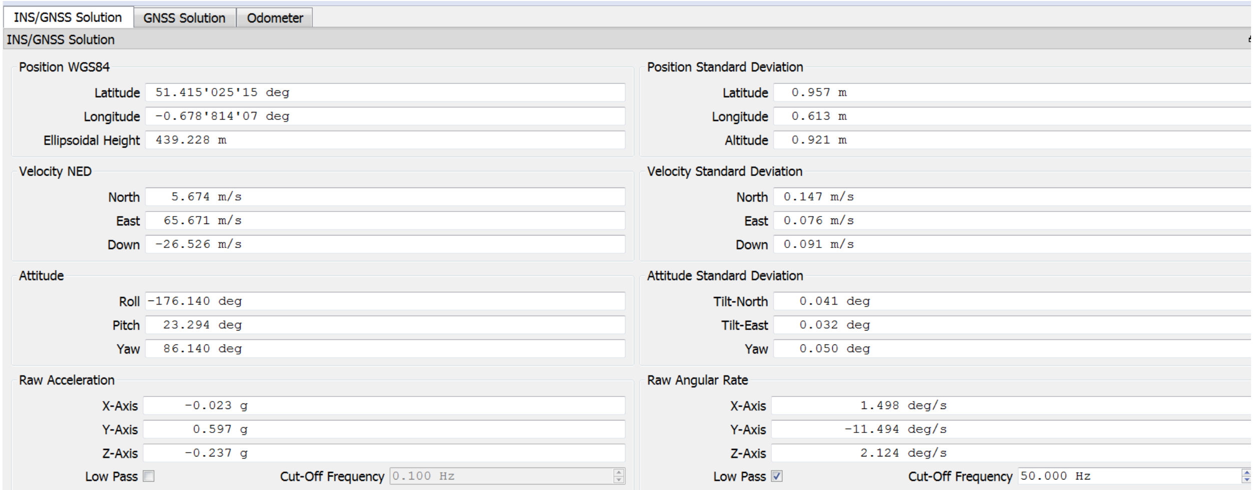


Figure 14: Accuracy during GNSS outage at 180 deg roll

The next figure shows the estimated position and attitude deviation at the end of the GNSS outage period, i.e. 15 sec after loss of GNSS aiding. The position error had been increased to only 2.5 m in latitude (totally 3.5 m).

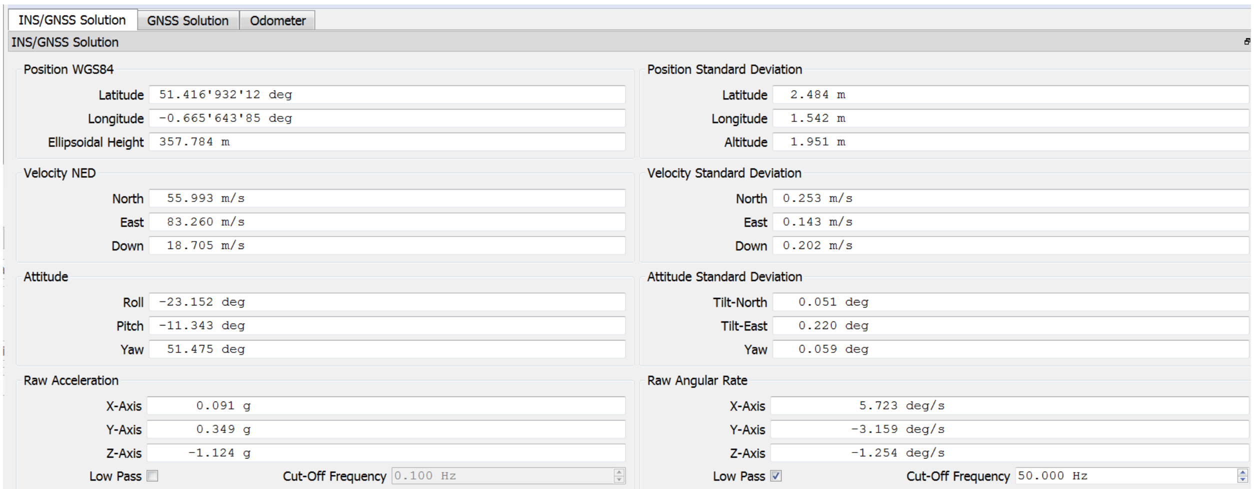


Figure 15: Accuracy at the end of GNSS outage phase (maximum deviations)

The next figure shows the INS/GNSS performance 3 sec after GNSS had been recovered again. The roll/pitch uncertainties are well below 0.1 deg and heading uncertainty is about 0.05 deg again. Position uncertainty is less than 2 m (remember, that the iNAT-M200 had been operated without any RTK aiding, only EGNOS correction had been active).

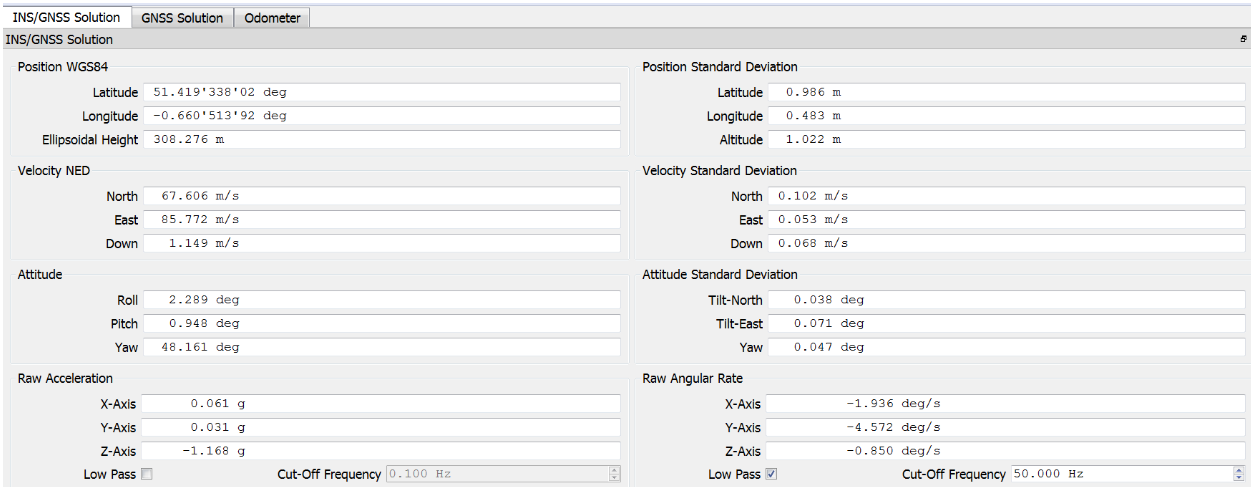


Figure 16: Accuracy 3 sec after recovery from GNSS outage

The following figure shows the smooth correction of the sophisticated Kalman filter based data fusion inside the iNAT-M200.

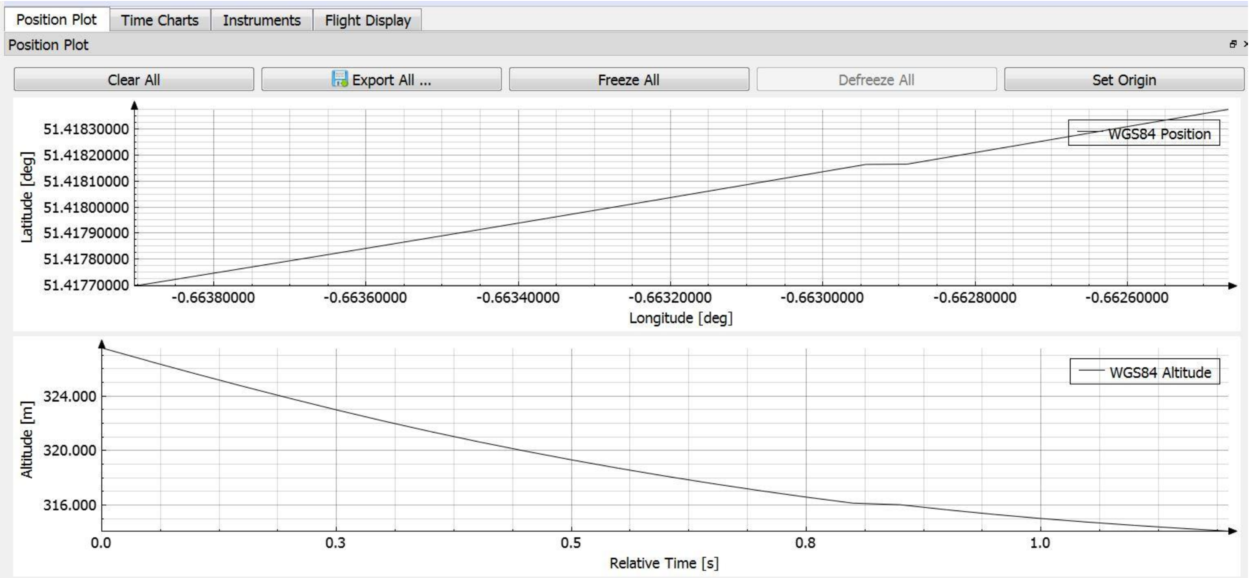


Figure 17: Position correction with new GNSS update after GNSS outage

Validation of Accuracy:

With an assumed accelerometer bias of about 1 mg (0.01 m/s²) the expected position error after 15 sec of free inertial (unaided) navigation will be in the range of 1.1 m in each direction, i.e. totally about sqrt(3) x 1.1 m = 1.9 m, assuming that the attitude determination had been free of any deviations at the beginning of the period of GNSS outage. Considering additionally an initial heading deviation of 0.05 deg and a roll and pitch deviation of each 0.03 deg at the beginning of the GNSS outage, just by such angle deviation the lateral position error after 10 seconds flight with a speed of about 100 m/s resp. 200 knots (i.e. during 10 sec the aircraft travels about 1 km!) will be additionally sqrt([1 m]² + [0.5 m]² + [0.5 m]²) = 1.2 m, so the estimated total position error will be in the area of sqrt([1.9 m]² + [1.2 m]²) = 2.3 m (1 sigma) or 4.6 m (2 sigma).

4 CONCLUSION

The given report showed the challenging application to install a MEMS based INS on an aerobatic airplane. The race plane had to fulfil extreme dynamics conditions with up to 10 g acceleration and 300 deg/s angular rate. This lead to high requirements regarding the inertial sensor bias stability, scale factor accuracy and time stamping to perform an most accurate signal processing inside the INS in real-time. To be able to handle also the significant GNSS outages with high accuracy, the integrated INS/GNSS data fusion contains a 27+ state model which is also able to estimate – beside of other values – also the scale factors of the inertial sensors.

The above presented data of the iNAT-M200 show, that a high accuracy is achieved even under challenging dynamic requirements. Under standard flight dynamics the results are even more accurate as long as the flight dynamics is sufficient for a reasonable state observability of the data fusion algorithms.

5 SUPPORT

5.1 Asking for Support

For our support management system, we need to know the project number (Proj.No.) or alternatively P/N and S/N of the system you are speaking about.

These numbers are for example provided on the type plate (example shown in the Fig. on the right side).

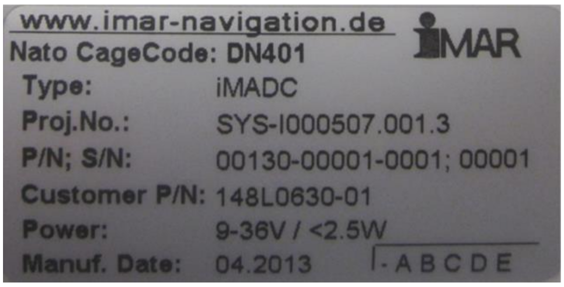


Figure 18: Example of iMAR type plate

5.2 Contact

You can find general information about our products, used technologies, and about inertial navigation, and GNSS based navigation at www.imar-navigation.de.

You can reach iMAR Customer Support as follows:

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