Flight Test of the Autonomous Take Off and Landing Functions of the SHARC Technology Demonstrator

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ABSTRACT

The Saab's unmanned technology demonstrator SHARC has completed in August 2004 a third flight test campaign, at the NEAT test range, in northern Sweden. For the first time the SHARC conduced fully autonomous missions, including Autonomous Take Off and Landing (ATOL). The focus of the test campaign has been in verifying the newly developed ATOL functionalities.

Simulator and Hardware-In-the-Loop test sessions paved the way to flight testing. The importance of reliable dynamic models has been once more highlighted. Ground roll dynamic and ground effect aerodynamic models had been refined ad-hoc in order to predict the behaviour of the aircraft during the critical phases of rotation and touch down.

In preparation to the flight test campaign, ground rolls have for the first time been performed at the Saab's flight test centre in Linköping. The flight test campaign has been fully successful. The autonomous landing functionality is operationally invaluable, since it lowers the risks embedded in manual remote piloting during high-gain tasks.

A number of specific functionalities had been designed into the avionics to allow safe and effective flight testing of the new capabilities; most of them regarded the possibility of the UAV operator to condition the behaviour of the aircraft in order to limit the authority of the onboard autonomy.

1.0 BACKGROUND

1.1 SHARC and FILUR

Since the late 90-ies SAAB had been carrying out preliminary studies about several Unmanned Aerial Vehicles (UAV) concepts but not taking them into flying demonstrators. In 2001 it was decided to start the SHARC Technology Demonstrator (SHARC TD) project: a small dedicated team was given the task to develop, manufacture and flight test an UAV system including an avionic system and a Ground Control Station (GCS) that could be re-used later in a second demonstrator called FILUR (see Figure 1).

Because of a limited budget and good in-house experiences from flight tests of instrumented sub-scale aircraft, it was decided that the SHARC TD should be in 1:4 scale of the original SHARC design. One of the major goals of the project was to test the airworthiness process for a military UAV, and this could well be achieved even with sub scaled aircraft. Even the goal of testing a lean development process for demonstrators could be achieved in that way.

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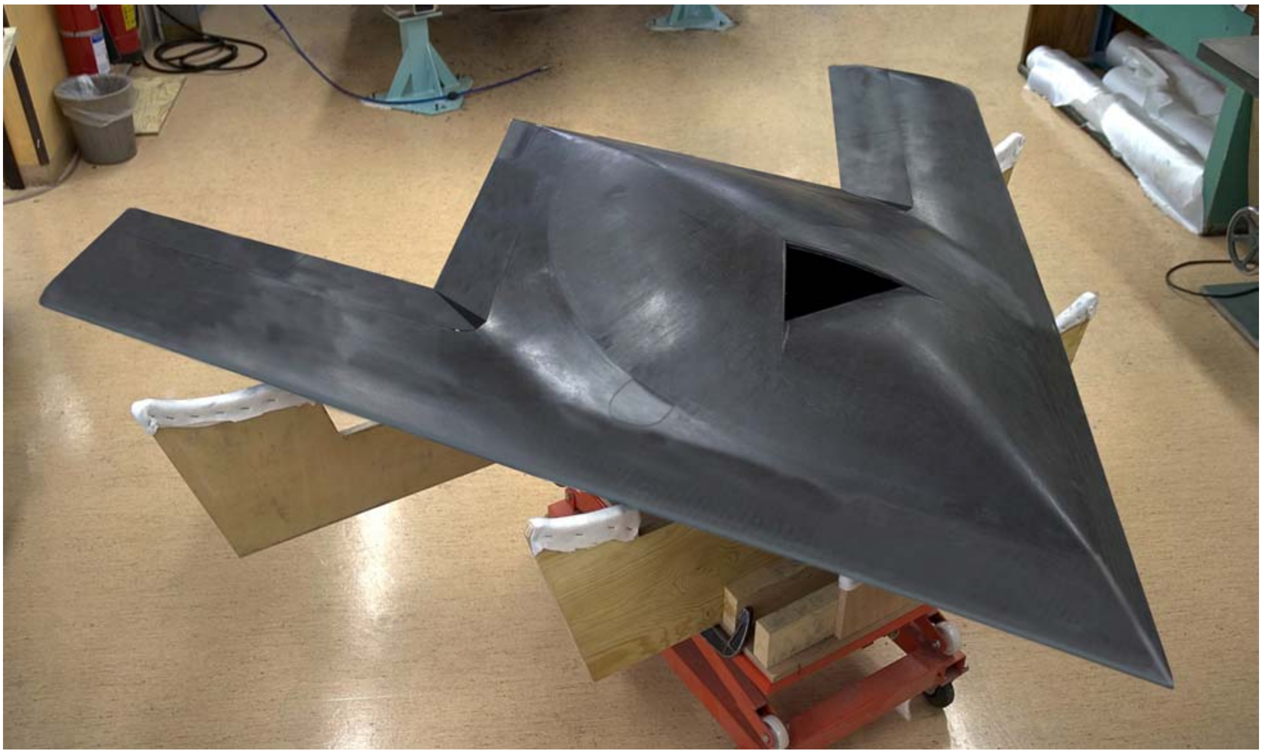

Figure 1: The Stealth Technology Demonstrator FILUR in the Workshop at Saab.

The SHARC TD project was initiated in 2001 with first flight less than one year later, on February 11th 2002, with the basic version. The more advanced version made its maiden flight on April 9th 2003, less than two years after project start. In September 2003 the SHARC flew a number of missions out of visual range, ranging around 20 km from the control station location. In January 2004 the effort towards the development of the ATOL functionalities was initiated, and led to a successful flight test campaign in August 2004, during which fully autonomous mission were demonstrated, from standstill to standstill (Figure 2). The details about this latter effort are the object of this paper.

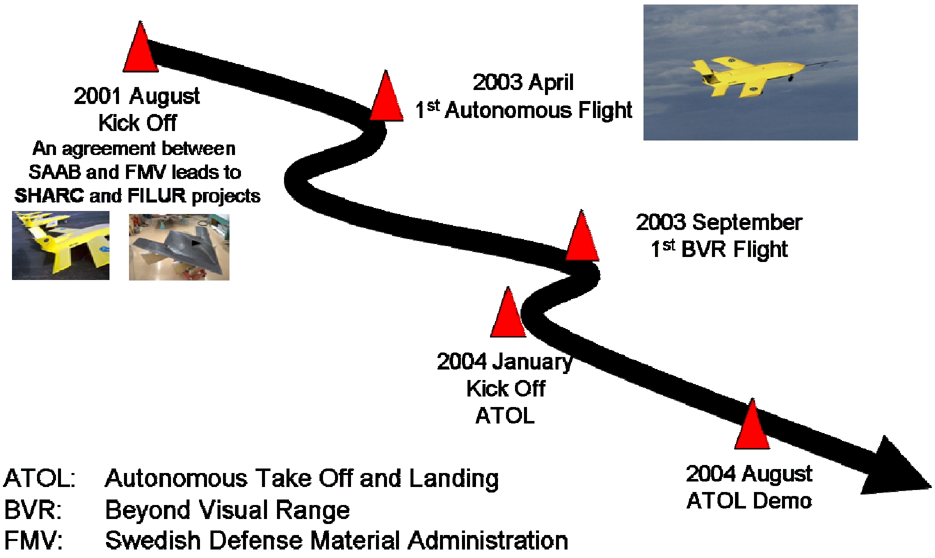

Figure 2: History of the SHARC Project.

Early in the project it was decided that SHARC should be operated on a Swedish Military Flight Test Permit (FUT), just like any other Swedish military test aircraft, in order to provide experience from the airworthiness process for an UAV.

Application for FUT in Sweden is based on an Airworthiness Declaration and means that the UAV system should be:

- Correctly designed according to a Product Development process with designated design reviewers;
- Design should meet well defined Airworthiness Standards;
- Manufacturing according to processes with quality assurance and inspections;
- Correctly maintained according to specific publications i.e. Maintenance plan and Maintenance instructions by certified technicians;
- Correctly used according to specific publications, i.e. Flight Manual and Maintenance instructions by certified pilot and technicians;
- Operated in compliance with approved ground and flight test plans.

SAAB is authorized for UAVs design, manufacture, maintenance and flight operations from Swedish Military Flight Safety Inspectorate (FLYGI) in accordance with the Swedish Rules for Military Aviation (RML). FLYGI was involved early in the project and agreed to refer to an Airworthiness Standard from Australian CASA, based on FAR 23, as a base for the FUT. FLYGI followed the project closely from early design to completed flight test campaigns.

1.2 The SHARC Platform

The SHARC system is composed by two flying demonstrators (BS-001 and -002), a GCS and some GSE for engine start and cooling air supply on ground. A basic version of the flying platform is available in two units (BT-001 and -002), called Trainer Model, used for early aerodynamic and flying qualities evaluations, and still in service for pilot training.

The SHARC TD is a 60 kg jet-engine driven aircraft. A fixed robust tricycle landing gear has been chosen taking into account the tests of autonomous take-off and landing (direct landing without flare); COTS components have been used as much as possible (engine, servos, valves, many sensors, etc.). The airframe is manufactured in light-weight composite materials; the airframe weighs only 8 kg (without landing gear).

The payload consists of a forward looking colour video camera.

The avionic system (hardware and software) is designed and manufactured by SAAB and is based on Flight Test Instrumentation system COMET 15 used in the Gripen and Viggen fighter a/c. Before the decision to develop an in house avionic system, a market survey was conduced, but no existing system was fulfilling specifications. Electro-optic fibres, or “fly-by-light”, are used to the actuators in order to minimize the risk for Electro Magnetic Interference. SHARC has a complete FTI with a SAAB designed and manufactured nose-boom.

Many software functions are re-implementations of existing algorithms previously developed for other SAAB aircrafts: the waypoint navigation algorithm comes from the AJ 37Attack-Viggen and AHRS from JA37 Fighter-Viggen and JAS 39 Gripen.

1.3 Operating Modes

The aircraft can be operated both in manual and in autonomous mode. In autonomous mode the aircraft flies a route of pre-programmed waypoints, including autonomous take-off and landing, if so is wished.

When flying autonomously, no control-link to the GCS is virtually needed to fly, but it is of course required to be able to terminate the flight in emergency cases. Therefore some functions have been built-in to detect and react to control-link losses. If loss of control link is detected, the aircraft enters automatically the so-called "Return To Base" (RTB) mode, i.e. it turns back to the GCS, trying to restoring the link by decreasing the distance from the transmitting antenna. The RTB route can be pre-programmed, so that no-fly zones can be avoided even during this phase. If the control link is not restored after a predefined amount of time, the aircraft enters the "termination" mode, i.e. it heads to the closest assigned termination area, where it shuts down the engine and initiates a controlled descending spiral. A detailed explanation of the available flight modes is available in Ref. 1.

In manual mode the pilot operates the aircraft by a control-box, which is connected to the GCS by a 100 m long cable (Fig. 3), so that the pilot doesn't need have to sit in the GCS, and can have direct visual contact with the aircraft during take off and landing. Manual flight BVR is possible thanks to a pair of video-glasses where the on-board camera view can be presented. In case of video link failure, even a virtual reality presentation can be supplied to the pilot, animated by the incoming telemetry data. A Head Up Display presentation has been developed, being able to present overlaid video and flight parameters.

Antennas and transmitters/receivers were designed and built by a small company in Gothenburg (PECAB), well known for its high quality products to a reasonable price. Antennas for up-link (control) and down-link (telemetry) are omni directional, while the video antenna, which was initially omni directional too, has been replaced by a set of directional antennas, a Yagi on the roof of GCS and a Helix mounted on the same tripod as used by the ground photographer for his video camera (so that correct beaming of the antenna is obtained by simply letting the photographer do his job).

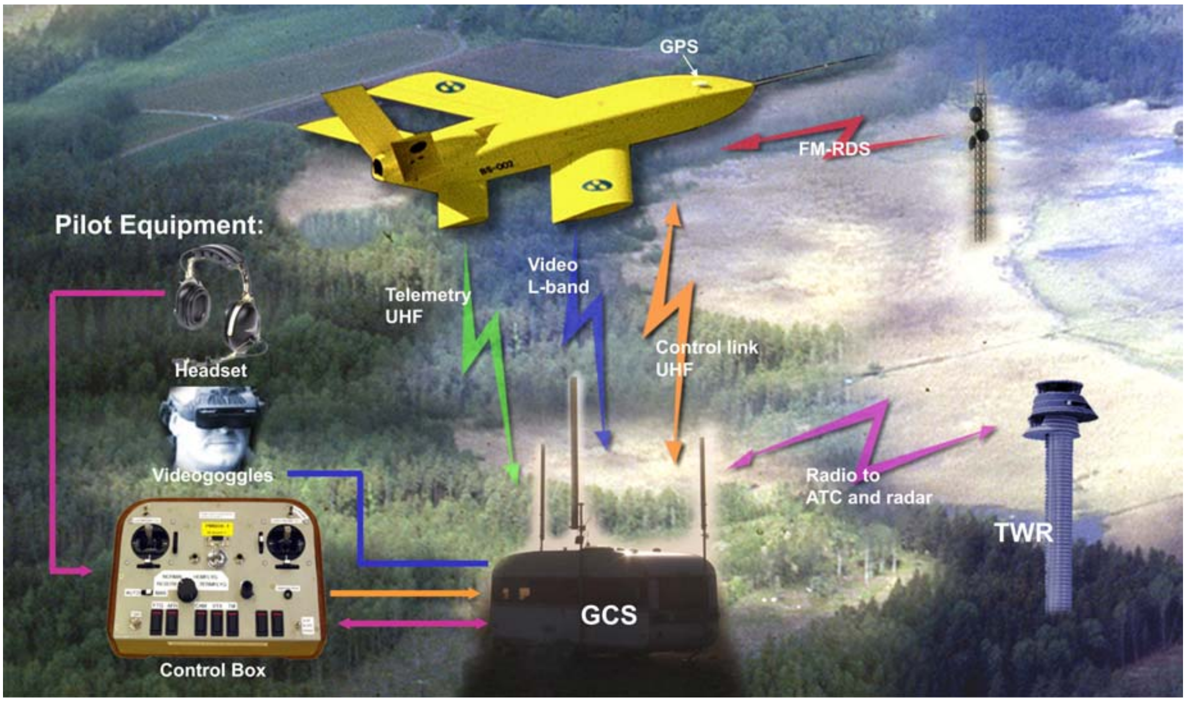

Figure 3: Overall View of the Communication and Control System.

1.4 Why Autonomous Take Off and Landing?

A large variety of take off and landing techniques have been historically employed by UAV designers all over the world. Many of them have been very unsuccessful, exposing the vehicles to considerable risks. Today's unmanned aircraft still report poor reliability statistics, about one third of the accidents occurring during the take-off and landing phases (operational procedures and technical failures equally sharing the remaining two thirds, Ref. 2).

During the initial attempts to develop unmanned vehicles, the tendency was to simply move the pilot from the cockpit to the ground, by inserting a remote control mechanism, without changing the operational procedures: the pilots were still controlling directly the control surfaces, through sticks and pedals in a cockpit on ground, in the best cases aided by some kind of FCS. An inherent vulnerability was thus built into the systems, the safety of which was completely hanging on the reliability of the communication links. In modern UAVs high level automation, or autonomy, is an unspoken requirement. By automating the take-off and landing phases the impact of human factors can be sensibly reduced, thus lifting the global safety level and reducing the workload of the operator.

These concepts were confirmed by the initial experience collected during the first two flight test campaigns with the SHARC. Take off and landings had been performed manually, with the pilot standing on the side of the runway holding the remote control box in his hands. Major problems had been reported during the initial attempts, mostly due to poor cue of the lateral position of the aircraft relative to the runway centreline, and to an instinctual tendency of the pilot to slow down the approaching aircraft, ending up on the backside of the drag curve when attempting the flare (see Ref 1 for more details). Only after several attempts, and a very careful definition of the landing procedure (including the introduction of a "decision heights" and observers on the ground aiding the pilot in assessing the lateral position of the aircraft during the final descent) flawless landings became a routine issue. Anyway, the pilot does still now define the manual landing procedure as "very unpleasant". In Figure 4 a statistics of a sample of the landings performed during the first two test campaigns is reported; the spread of the outcomes highlights the impact of the human factor.

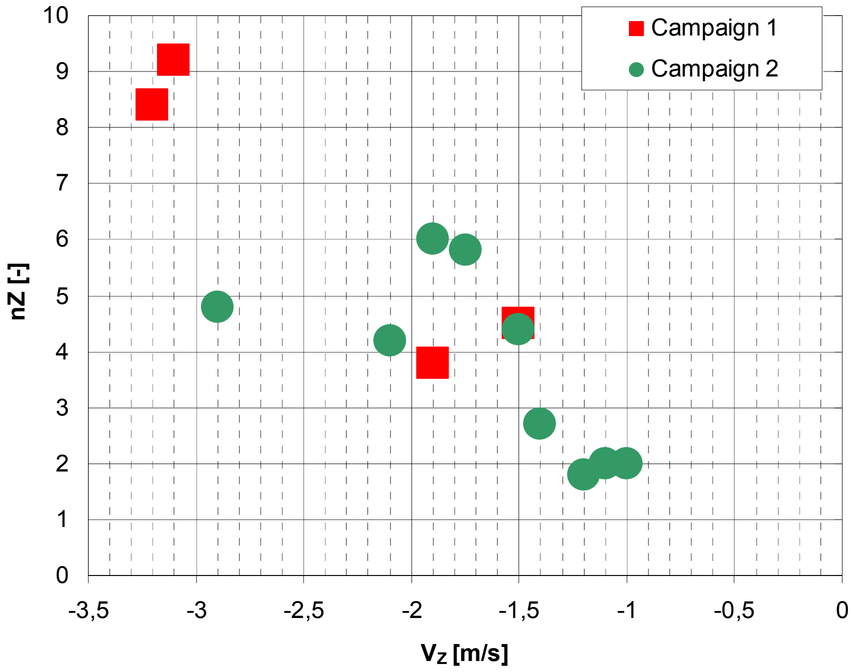

Figure 4: Loads at Touch Down (vertical velocity on the x- axis).

Strengthened by these experiences, the ATOL system for the SHARC was specified according to the following guidelines:

- The system should be *fully autonomous*, designed for hand-off operation, i.e. relegating the pilot to a monitoring function; in particular there should be a clear distinction between the manual mode (pilot-in-command) and the autonomous mode (autonomy-in-command);
- The system should be self-contained, without landing aids of any sort on ground.

2.0 DESIGN CHOICES AND CHALLENGES

2.1 General

The major challenge for the automation of precision tasks like take-off and landing is the localization problem. The problem for the UAV is to know with high accuracy and robustly its position relative to the runway, during the airborne phase as well as during the ground phase, both in elevation and sideways.

Differential GPS (DGPS) was a natural choice; since selective availability has been removed (May 2000) the accuracy is fully satisfactory for precision landings, at least sideways. Blending with the onboard Attitude and Heading reference System (AHRS) gave the needed robustness, and a certain resistance to drift in case of GPS fall-out.

It has to be highlighted here that a number of issues must be considered before employing the GPS as only localization mean for operational systems (these issues are only partially applicable for technology demonstrators as the SHARC), in particular:

- A weak point of the use of GPS is that the satellites are so far controlled by only one nation, which makes the opportunity to use it as ordinary localization source a political question: a military system that localizes uniquely by GPS can fail exactly when its use is more needed. With this as background, the Swedish Armed Forced have issued a directive stating that military navigation system must not rely uniquely on technologies that Sweden does not have full control on. This doesn’t automatically mean that GPS can not be employed, but that there must be alternative sources as back-up.
- Another weak point of the GPS signal is its weak resistance to jamming and interference: the area around an airport can be easily jammed with a 1 Watt, hand portable scrambler, the assembling instructions of which can be found on the internet. Moreover, if the jamming action is intermittent, it’s even virtually impossible to localize its source.

For localization on the vertical channel, GPS is less accurate (typically by a factor 3 compared with accuracy on the horizontal plane). To accurately measure the altitude relative to the runway is critical for the precision of landings. Even if a direct landing technique is employed (i.e. without flare), the altitude uncertainty causes an uncertainty of the touch down location with a ratio of about 1:20 (10 m uncertainty in altitude gives 200 m uncertainty along the runway direction).

To cope with the requirement on the accuracy for the altitude measurement it was chosen to integrate into the avionics system a Miniature Radar Altimeter (Mk V from *Roke Manor*), in order to be able to automatically recalibrate the barometric altitude right before landing.

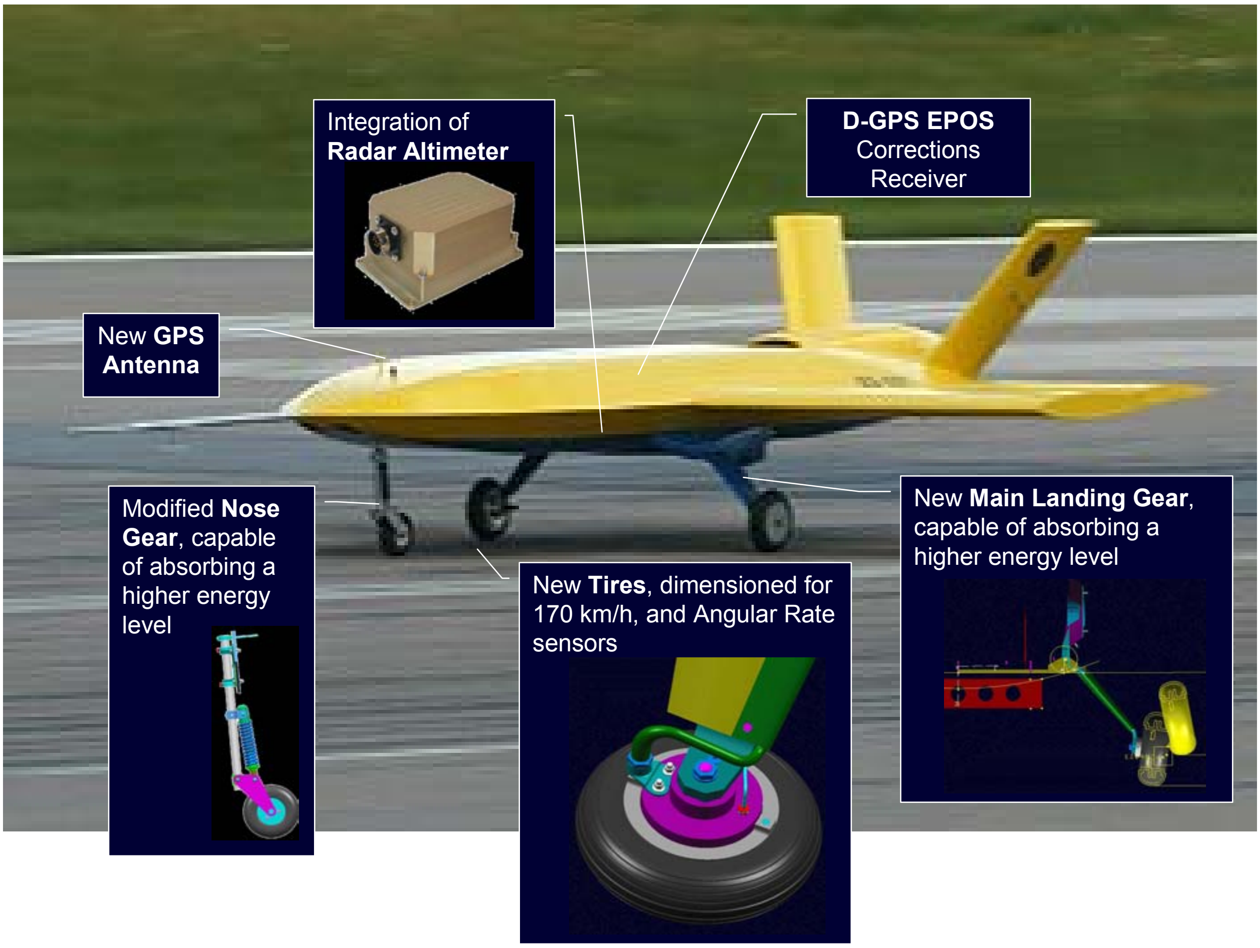

Figure 5: Modifications on the Platform Introduced for the ATOL Campaign.

2.2 Autonomous Take Off

To lift a UAV from the ground with a conventional take-off is relatively difficult compared with other techniques (catapult, etc.). The difficulties lie mostly in holding a good directional stability during the ground acceleration, including the rotation phase: the FCS has to smoothly shift from a “ground mode”, where directional stability is mainly obtained by acting on the nose wheel, to an “airborne mode”, where the heading is controlled by the rudder. This issue was worsened in the SHARC case by the fact that nose wheel and rudders are controlled by a common channel, i.e. independent control of rudders and nose wheel is not possible. This forced the FCS designers to find a sub-optimal tuning to achieve a satisfactory compromise between the directional characteristics on ground and in flight.

The autonomous take off procedure has been designed as follows:

1) The operator lines up the aircraft in proximity of the runway’s centerline, in manual mode (autonomous or semi-automatic taxiing has not been implemented yet);
2) After having obtained the take-off clearance from the tower and the green light from the test conductor, the operator selects “AUTO” mode;
3) Brakes’ release, acceleration, rotation, and climb occur fully autonomously, until connection to a pre-programmed navigation route at 50 m altitude; during the whole sequence the aircraft navigates by minimizing the lateral distance to the runway’s centerline;

4) The operator can abort the autonomous take-off at any time, until rotation is initiated, by triggering a contingency mode that makes the aircraft braking until standstill: this function has shown to be invaluable to gradually test the autonomous ground roll capability. When rotation is initiated the take-off can not be aborted anymore (of course the operator can always take over to manual control, or trigger the emergency termination at any time);
5) In case of control link loss the same logic applies: the aircraft brakes autonomously if the failure occurs before rotation is started, and otherwise neglects the failure until connection to the navigation route, switching to "Return to Base" mode only then.

2.3 Autonomous Landing

The autonomous landing procedure has been designed as follows:

1) A precision flight path following mode is engaged around 2 km before the appointed touch down point, at 150 m altitude: in this mode the aircraft tracks a descending path (γ -4°), aligned with the runways' centerline;
2) At 30 m altitude the flight path is changed in order to keep a gliding angle of -2°;
3) At 4 m altitude, the FCS switches to a "vertical speed mode", holding a constant vertical speed of -1.2 m/s, until touch down; no flare is attempted;
4) Touch Down is detected by angular speed sensors mounted on the wheels of the main landing gear; when the "on ground" condition is obtained the engine is set to idle, and the braking phase initiated;
5) At 30 m an autonomous decision altitude has been defined: in case of control link loss below 30 m the landing is simply continued, until standstill. If the loss occurs above 30 m the landing procedure is aborted, and the standard RTB sequence is initiated instead.

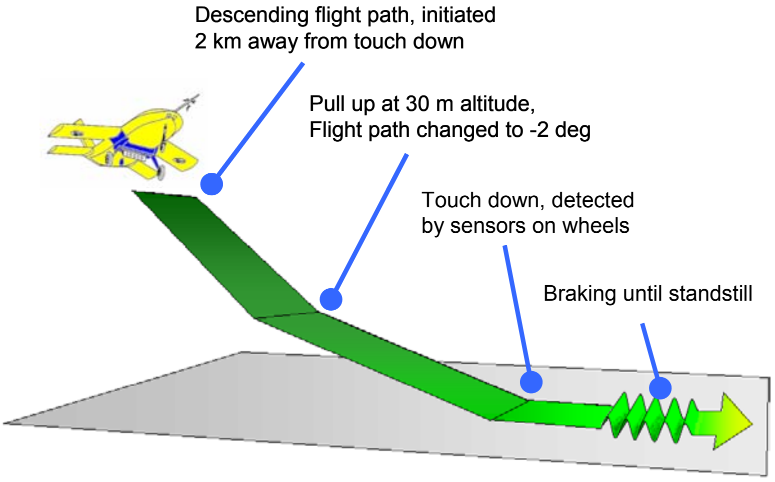

Figure 6: Schematics of the Autonomous Landing Sequence.

3.0 TEST PROGRAM

3.1 Preliminary tests

The previous campaigns had highlighted a number of deficiencies regarding the tires of the main landing gear, which showed a tendency to separate from the wheel due to the centrifugal forces at high rolling speed. New wheels have been designed and built (without modifying the old brake), and new tires where purchased. The new wheel set has been verified regarding to:

- Maximum allowed load and deformation properties: the stiffness of the tire (function of the inflating pressure) affects the peak loads that are transferred to the airframe at touch down. The stiffness properties have been therefore measured with a dedicated device (Fig. 7) as a function of the inflating pressure, and the optimal pressure identified;
- Maximum roll speed: the wheels/tires have been spun up to an angular speed corresponding to V_G 170 km/h, and it has been verified that the radial deformation kept below the allowed tolerance (Fig. 8).

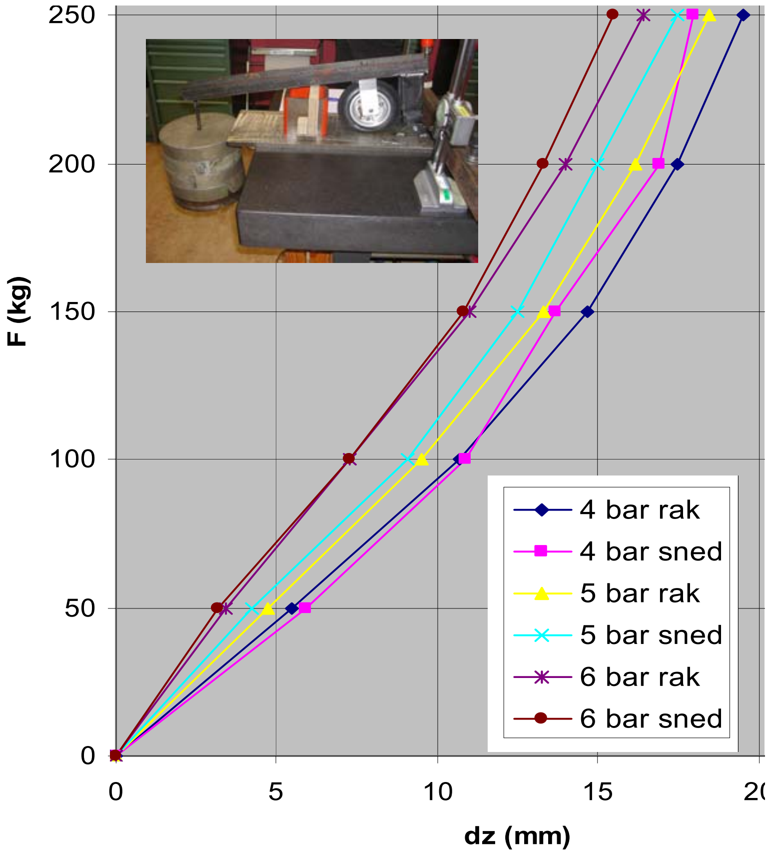

Figure 7: Measured Deformation Properties of the Tire.

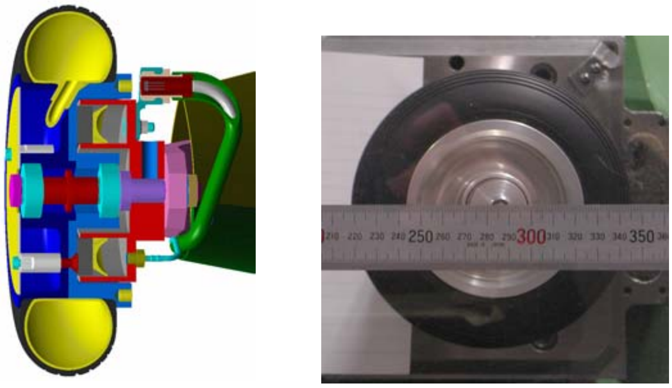

Figure 8: Centrifugal Test on the Wheel Assembly.

Detail information about the performances of the Miniature Radar Altimeter (MAR) was missing; neither could the dealer make any statement about the behaviour of the equipment when integrated into a high speed aircraft. Therefore a number of in-flight trials were performed with a light aviation aircraft (otherwise publicly available for commercial purposes, like photogrammetry, Fig. 9a), during which the MAR was mounted on an aperture on the floor of the fuselage (Fig. 9b), looking down, and data were collected during take-off and landings, on several surfaces.

Figure 9: Flight Trials of the Miniature Radar Altimeter.

To have a reference to compare with, the whole avionics rack of the SHARC was fastened on the passenger sit during the trials (Fig 9c), including the GPS antenna/receiver, and data were recorded by the standard data-logging function. Initial data showed immediately that the MAR signal quality was not satisfactory (Fig. 10); the trials were repeated with a different aircraft, but the same results were obtained, and showed that:

- The maximum altitude at which some reading was obtained was in the range of 45 meter, vs. 100 m specified;
- False readings lying at 0 and 50 % of the actual value were obtained at very high rate, due to systematic Doppler problems triggered by the relatively high velocity; in other words the Roke Manor Mk IV was suitable for helicopters, not for airplanes. This had not been specified at that time in the available data sheets;
- No reading at all was obtained when flying over natural ground (grass, forest), only when flying over a runway. This was probably due to the high frequency (77 GHz, 4 mm wavelength) which interacts with grass and forest.

Thanks to these early flight tests of the MAR performed before the test campaign the deficiencies could be detected in time and compensated for with ad-hoc filtering algorithms in the pre-processing functions belonging to the SHARC avionics (the MAR was not modified), highlighting once more the importance of timely tests COTS components.

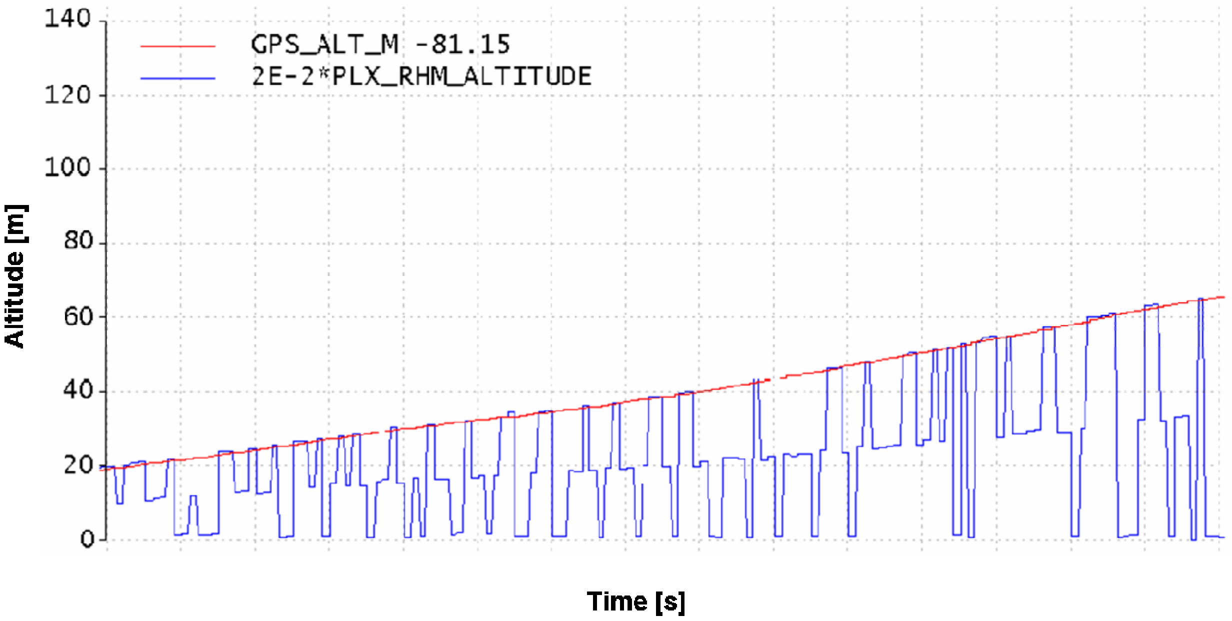

Figure 10: Comparison between GPS and MAR Data during a Take-Off Trial.

3.2 Hardware in the Loop Simulations

The simulator (already developed for the preparations before the maiden flight in 2003), consisted simply of the aircraft BS-001 coupled to a SUN workstation (Fig. 11). All aircraft sensors were disconnected and replaced by digital inputs generated by the simulation SUN workstation. The inputs to the workstation were the positions of the control surfaces of the aircraft, measured by potentiometers. In that way all avionics (except the sensors) could be tested in a very realistic environment, where latencies, servo dynamics, surface free-plays, wirings and all interfaces were “real”.

The sensor properties were simulated: the simulation models included sensor noise properties, beside all typical blocks composing a flight simulator (aerodynamics, engine performance, landing gear, atmospheric and turbulence data). The facility included the possibility of simulating a number of failures, such as engine flame-out, sensor failure, GPS failures, etc. Control link failures could be reproduced, being the GCS was part of the hardware in the loop (it was sufficient to unplug the transmitter power supply).

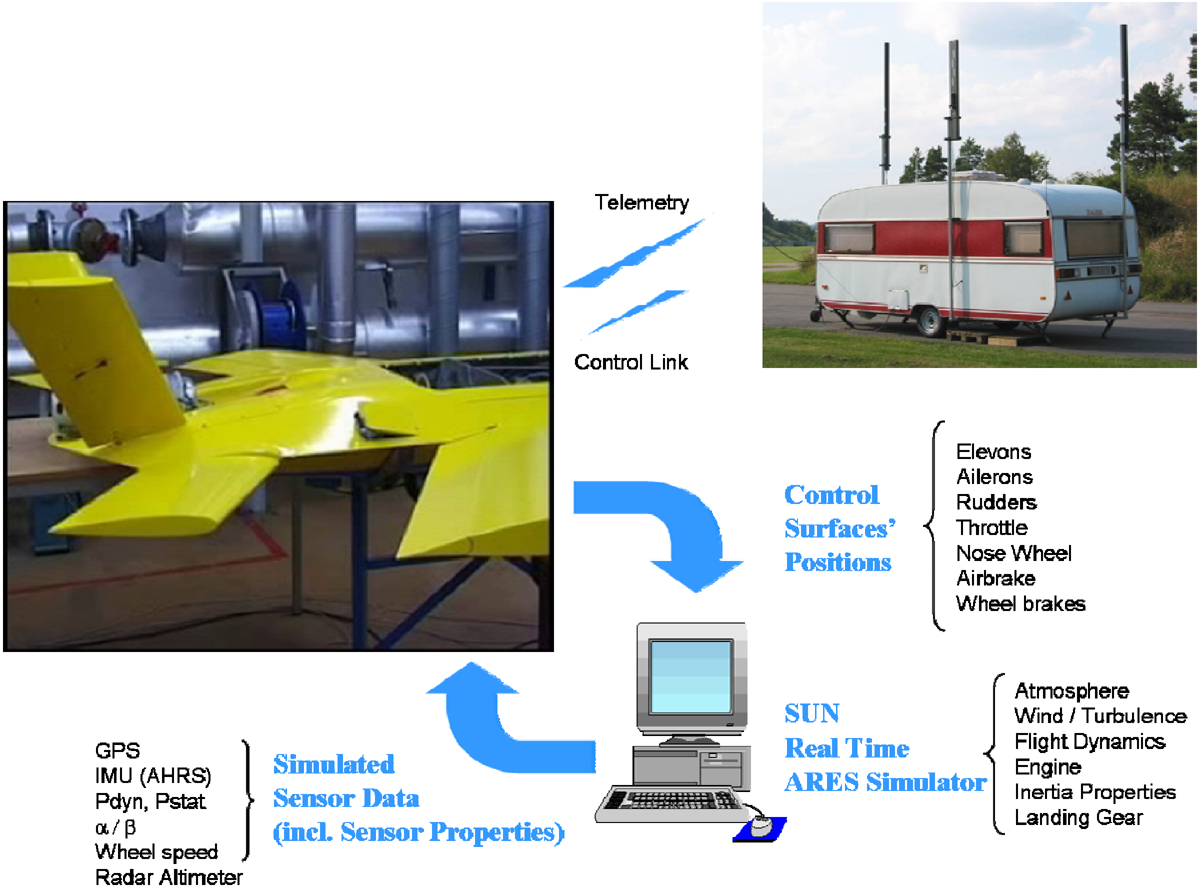

Figure 11: Hardware in the Loop Setup.

In preparation for the third test campaign, a number of features have been added to the simulator, in order to reproduce a more realistic environment particularly focused on the critical phases of take-off and landing:

- A ground effect model has been added, after an accurate aerodynamic analysis of the available take-off and landing data collected during the first two campaigns. The analysis showed that ground effect was clearly noticeable during take-off (thus affecting the rotation phase), while it was negligible during landing;
- The stiffness of the main landing gear has been accurately modelled, in order to be able to predict the tendency of bumping at touch down.

3.3 Ground Tests

Ground rolls have been performed in Linköping, prior to the release of the Flight Test Permit, in order to reduce the risks of detecting malfunctions during the flight test campaign. The tests have been run on the Saab's runway, even operated by regular civil air traffic.

A number of restrictions have been applied, including:

- The ground speed was limited to $V_G < 50$ km/h;
- The elevons were mechanically constrained to the aerodynamically neutral position, and the servos disconnected, in order to prevent unintended rotation;

- The engine throttle was initially limited to 50% by a hard limitation introduced in the PWMDR card (i.e. “downstream” and outside the flight control system);
- A ground test program was issued, and passed through the standard process including a Flight Safety Review.

Figure 12: SHARC Rolling on the Runway of Linköping Airport.

The ground test program included:

- Manual taxiing;
- Autonomous taxiing: the aircraft was lined up on the runway’s centerline, and autonomous accelerations were tested, interrupted at increasing values of ground speed (10, 20, 30, 40 and 50 km/h) by autonomous decelerations;
- Autonomous taxiing with side offset: same test point as previous but started with the aircraft lined up with a lateral offset (5 and 10 m) from the centerline;
- Autonomous taxiing with heading offset: same test point as previous but started with a heading offset (10, 20 and 30 degrees) relatively to the runway direction.

3.4 Flight Tests

Flight tests took place at the NEAT/Vidsel test range in northern Sweden, in restricted and controlled airspace, and with almost un-populated ground, in August 2004.

To provide some level of flexibility to the software editions, and to be able to solve at least the minor glitches during the test campaign, the concept of Flight Test Functions (FTF) has been largely employed; a large number of parameters figuring in the control laws have been listed in text files so that they could be changed without re-compiling the software. The requirement of clearing for flight new FTF lists through simulation was met by having a workstation (SAAB developed desktop simulation s/w tool used for the JAS 39 Gripen) on the field, and running dedicated simulation sessions before flight.

The flight test program had been organized in the following order:

- High speed rolls (manual and autonomous), including the same test points run during the ground rolls in Linköping, but at ground speeds up to 120 km/h; the gains of the yaw control loops have been fine-tuned during this phase;
- Manual check-out flights for general testing, and to verify the modifications introduced both in the hardware and in the software, excluding the ATOL functions;
- Autonomous Take Off (nominal procedure);
- Manual Landing patterns to collect data from the installed Miniature Radar Altimeter: the results showed that the *ad-hoc* developed filtering algorithms of the MAR functioned as intended, and that no particular integration issue was noticeable, more than the deficiencies already noticed during the preliminary in-flight trials;
- Autonomous Landing ”on the cloud”: the complete autonomous landing sequence was tested, with a 30 m altitude offset on the nominal flight path; the test was considered completed when the nominal touch down point (at 30 m altitude) was passed: the pilot could then take over the manual control of the aircraft and perform a manual landing;
- Autonomous Landing (nominal procedure), with a decision altitude at 30 m, where the test conductor was supposed to make a Go-No Go call for the continuation of the landing, based on the current state of the aircraft relatively to the nominal landing path; an ad-hoc presentation of the flight path, overlaid on the nominal path with acceptable tolerance levels has been developed in the telemetry presentation program (VuSOFT), and supplied to the test conductor (Figg. 12 and 13);
- Complete Autonomous Flight, including autonomous take-off, a pre-programmed navigation route, and autonomous landing.

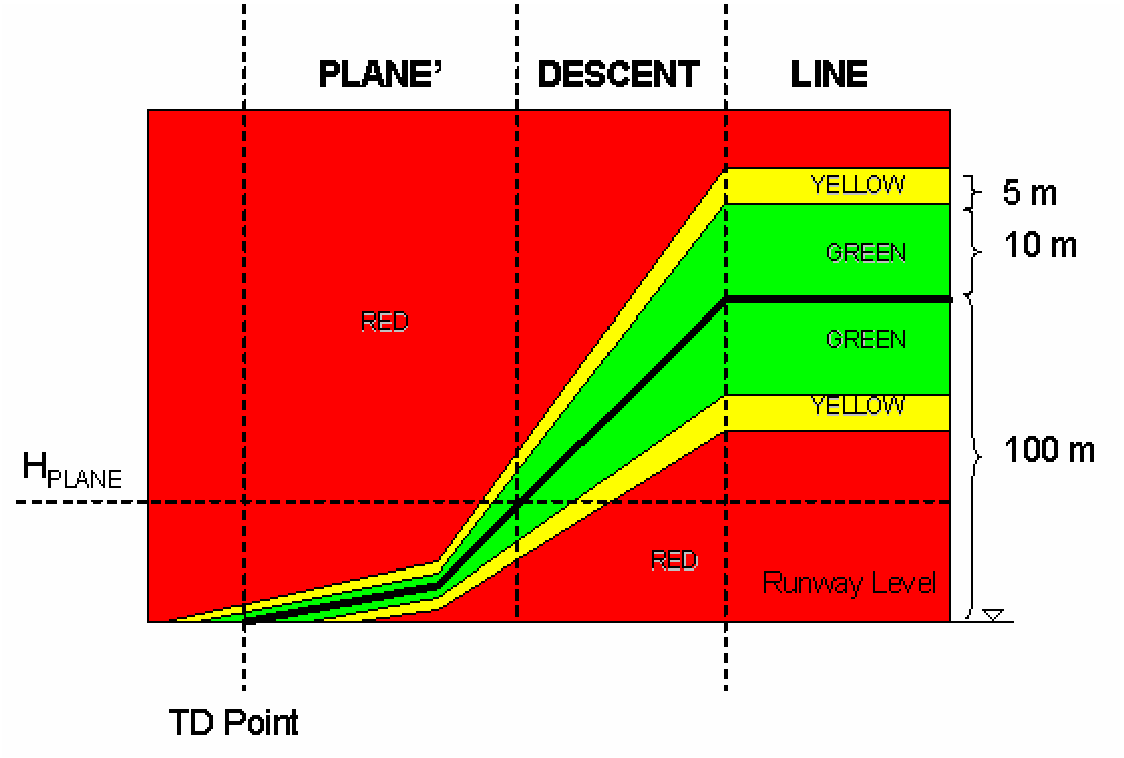

Figure 12: VuSOFT Graphical Object Visualizing the Nominal Longitudinal Flight Path and the "Warning" (yellow) and "Abort" (red) Areas. On the plot (XY type) the measured distance to TD point was plotted in real-time on the X-axis, and the measured altitude on the Y-axis.

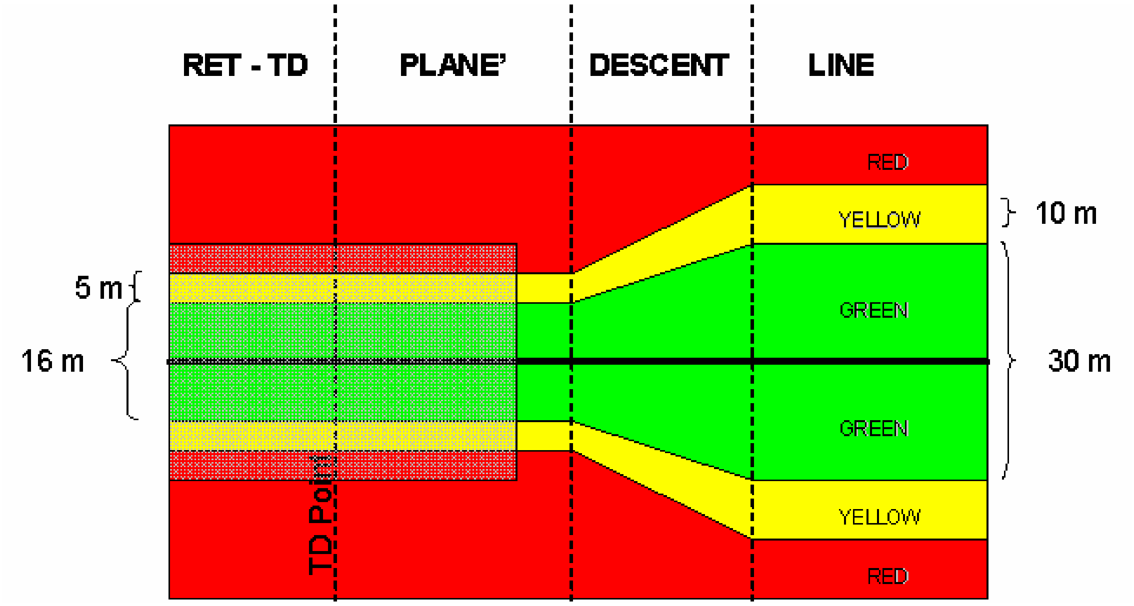

Figure 13: VuSOFT Graphical Object Visualizing the Nominal Lateral Flight Path and the "Warning" (yellow) and "Abort" (red) areas. On the plot (XY type) the measured distance to TD point was plotted in real-time on the X-axis, and the measured lateral error relative to the runway's centreline on the Y-axis.

The test data and videos were analyzed after each flight at the test range and sent to Saab on a cripted internet tunnel for further analysis by the Material Group Managers, who were demanded to release a formal statement about the obtained results. On the basis of these statements, those released by the test engineers at the test range, and on the debriefings with the pilot, the test conductor and the chief test engineer, a final GO-NoGo decision for the next flight was taken directly from the Head of the Flight Tests Department.

The test campaign has been very successful, and carried out without significant problems. A number of fully autonomous missions have been completed, in several wind conditions, during which the ATOL functions showed a repeatable and robust behavior. In fig. 14 the ground trace (from DGPS) recorded during a fully autonomous mission is reported; in particular the trace refers to a mission that was run twice, i.e. taking off autonomously right after having landed autonomously: the flight paths do almost coincide.

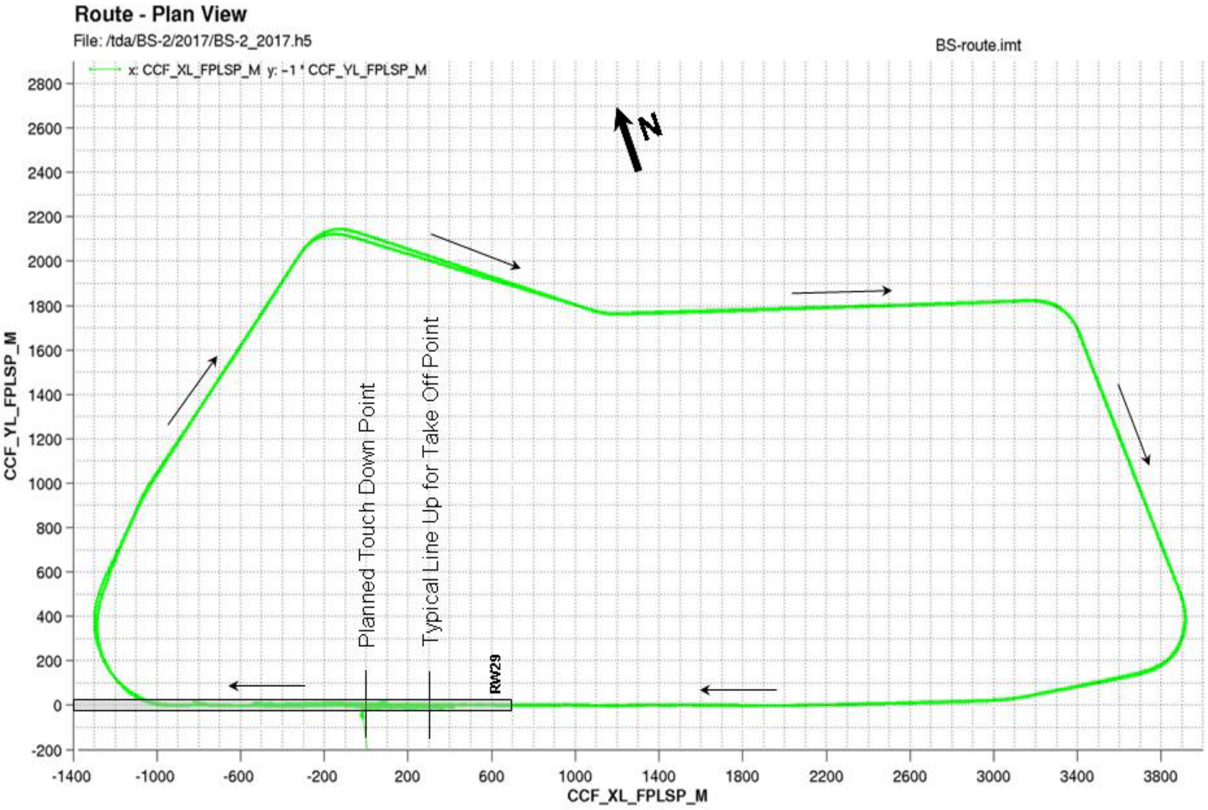

Figure 14: Ground trace recorded during a mission that was run twice, showing the almost perfect overlay of the flight paths (longitude and latitude in meters on the X- and Y- axis).

Some minor problems have been highlighted, without requiring any immediate action:

- Less-then-optimal directional control on ground at high speed and during rotation: the problem is mainly due to the fact that rudders and nose wheel steering belongs to a common channel, which prevents independent control and optimal gain-tuning (for both the ground and airborne phase);
- The performance of the Miniature Radar Altimeter was worse than expected, but still good enough for precision landings on concrete runways;
- The EPOS differential GPS correction has never been available on ground, at RFN. The signal has been obtained first when the aircraft was already in the air or on a support on ground that lifted it

off the ground around 1 meter. This means that no DGPS could be available for autonomous takeoff.

- A tedious problem that has been encountered is that the magnetic compass showed to be very sensitive to local magnetic fields induced by the iron bars below the runway surface. Due to the SHARC dimensions and configuration, the compass is located about 35 cm above the runway surface. Below a given velocity, no information about the heading is available from the GPS, and the magnetic compass is the primary source for heading measurement. In practise it has been necessary to find by try-and-error a good position to line up for take off, where the local perturbations of the magnetic field was negligible.

4.0 LESSONS LEARNT

- COTS components and their specifications should never be trusted until proven by test; even in smaller projects you gain time in dedicating time to comprehensively testing them, without giving the intended functionality for granted or, - even worse, -believing in their specifications. This applies especially to products with lower qualifications or not qualified at all. Anyway, COTS integration is seldom painless!

- Tests at sub-system level in the early stages of a project can save money and time: testing only the integrated system can make troubleshooting a nightmare.

- Hardware in the Loop simulations done with the actual flight hardware has been a very cost effective way to validate the complete system.

- A pilot in the loop is not always the best option, especially if the pilot is on ground; automating critical phases like take-off and landing can drastically reduce the overall risks.

- Sub-scale demonstrators can be very cost-effective tools to evaluate new concepts and new technologies.

5.0 NOMENCLATURE

ATOL	Autonomous Take-Off and Landing
BVR	Beyond Visual Range
COTS	Commercial Off-The-Shelf
FLYGI	Swedish Military Flight Safety Inspectorate
FTF	Flight Test Functions
FUT	Swedish Military Flight Test Permit
GCS	Ground Control Station
GSE	Ground Support Equipment
HILS	Hardware In the Loop Simulations
MAR	Miniature Radar Altimeter
RTB	Return To Base

6.0 REFERENCES

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