

**AEROSPACE
TESTING
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Flight Testing the Autonomous Take Off and Landing Functions of the SHARC Technology Demonstrator

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Outline

- The SHARC Platform
- History of the SHARC Project
- ATOL Project
 - Goals, Motivations
 - Way of working
 - Challenges
 - Design Choices
- Test Program
- Results (VIDEO)
- Conclusions

The platform

- Wingspan 2.1 m
- Length 2.5 m
- Speed 80 - 320 km/ h
- TOW: 60 kg
 - Including fuel 18 kg
- Gas Turbine
 - AMT Olympus
 - 20 kg thrust
- MC75 fuel JET A-1
- Autonomy: ca 30 min
- Altitude: < 2000 m
- TO Distance: ca 500 meter (15m)
- Range: max 25 km
- Payload: CCD Camera



History of the SHARC Project

2001 August
Kick Off

An agreement between
SAAB and FMV leads to
SHARC and **FILUR** projects



2003 April
1st Autonomous Flight



2003 September
1st BVR Flight

2004 January
Kick Off
ATOL

2004 August
ATOL Demo

ATOL: Autonomous Take Off and Landing
BVR: Beyond Visual Range
FMV: Swedish Defense Material Administration



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The ATOL project

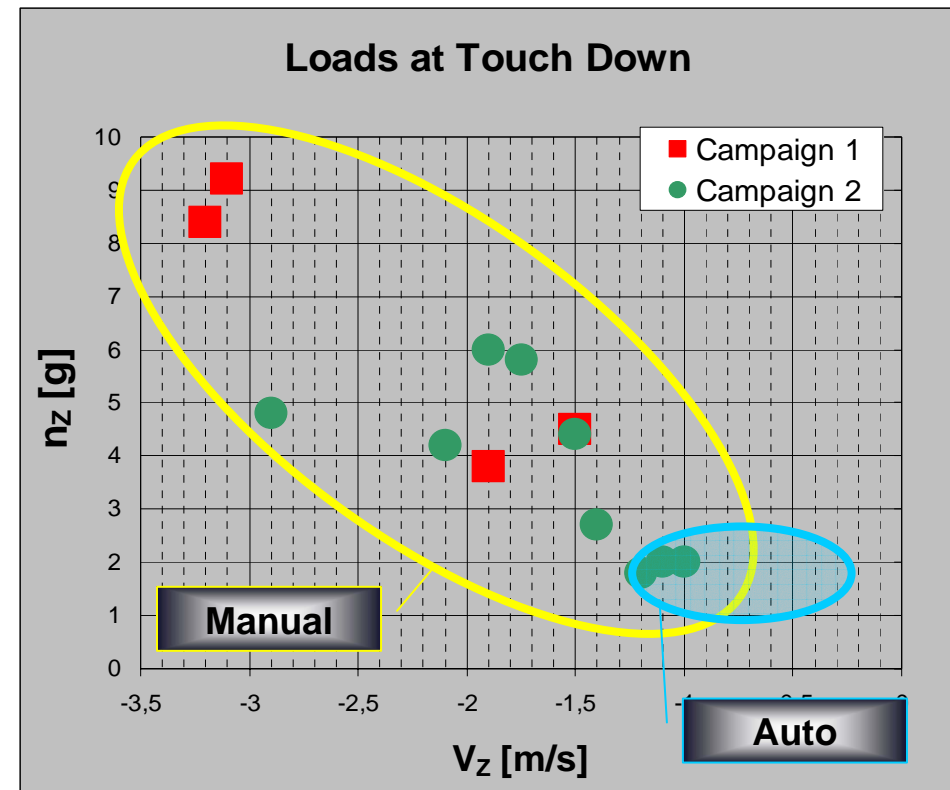
(ATOL Autonomous Take Off and Landing)

GOAL

- To provide ATOL capability, with a self-contained onboard system (hands-off operations)

Motivation

- ATOL reduces risks for UAV operations
- This was confirmed even by initial results with the SHARC
- Algorithms & Methods can be re-used on future platforms
- A step further in the Autonomy scale



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Way of working

- Project run by experienced full time people involved

- Design according to **Product Development** process with appointed external design reviewers

- **FLYGI** (Swedish Military Flight Safety Inspectorate) involved early in the development

- Flight operations driven under formal **Flight Test Permit (FUT)**

- Application for FUT based on an **Airworthiness Declaration**

- **Airworthiness Basis** derived from Australian CASA based on FAR23



Process

with



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Project Challenges

- **Project management**

- Very tight schedule (7 ½ months from kickoff to demo)
- Delays not acceptable, due to operational limitation of the RFN/Vidsel site after equinox (ineffective testing due to darkness, poor weather)
- Limited Budget, very limited
- Authorities/Media Exposure: Failure is Not an Option (severe impact on future UAV developments)

- **"One shot" opportunity**

- Only one short flight test campaign (test/demonstration)
- Reduce the need to modify the software during the campaign
- Need of a quick method/process to do it (less than 1 day turn around)

- **Technical:**

- ATOL "retrofitted" into a platform originally not designed for it
- Reduced margins for the operator to take over to manual control
- Sub-scale aircraft:
 - Sensitivity to wind/turbulence
 - All natural frequencies scale up with square root of linear dimensions
 - "High" landing speed (130 km/h)

Design Choices

- **Localization ("where am I ?"):**
 - Horizontally:
 - DGPS, corrections received from SWEPOS stations (EPOS service)
 - Blending with AHRS, in-flight calibration of biases
 - Vertically:
 - ground zeroed pressure altitude, calibrated right before touch down by measurements from an onboard Radar Altimeter
- **Takeoff:**
 - triggered by operator after lining up in proximity of the runway centerline
 - Brake release, acceleration, rotation, climb fully autonomously
 - Connection to navigation route at 50 m altitude
- **Landing:**
 - No flare, shooting at 1.2 m/s at touch down
 - Touch down detected by angular speed sensors on the main landing gear wheels
 - Braking thereafter until standstill, fully autonomously

Modifications on the platform

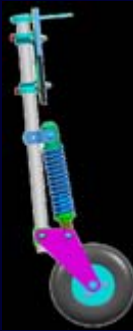
Integration of
Radar Altimeter



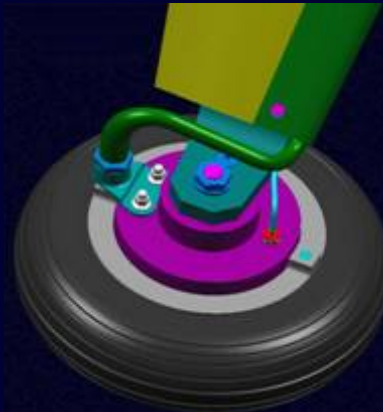
D-GPS EPOS
Corrections
Receiver

New GPS
Antenna

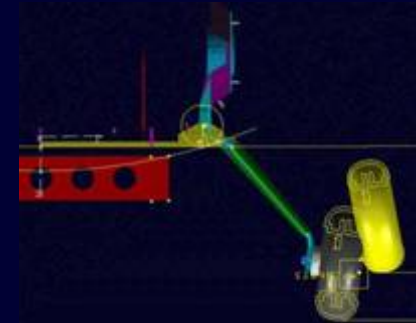
Modified Nose
Gear, capable
of absorbing a
higher energy
level



New Tires, dimensioned for
170 km/h, and Angular Rate
sensors



New Main Landing Gear,
capable of absorbing a
higher energy level



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Test Program

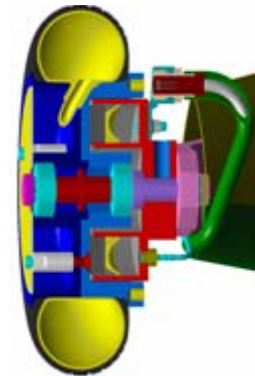
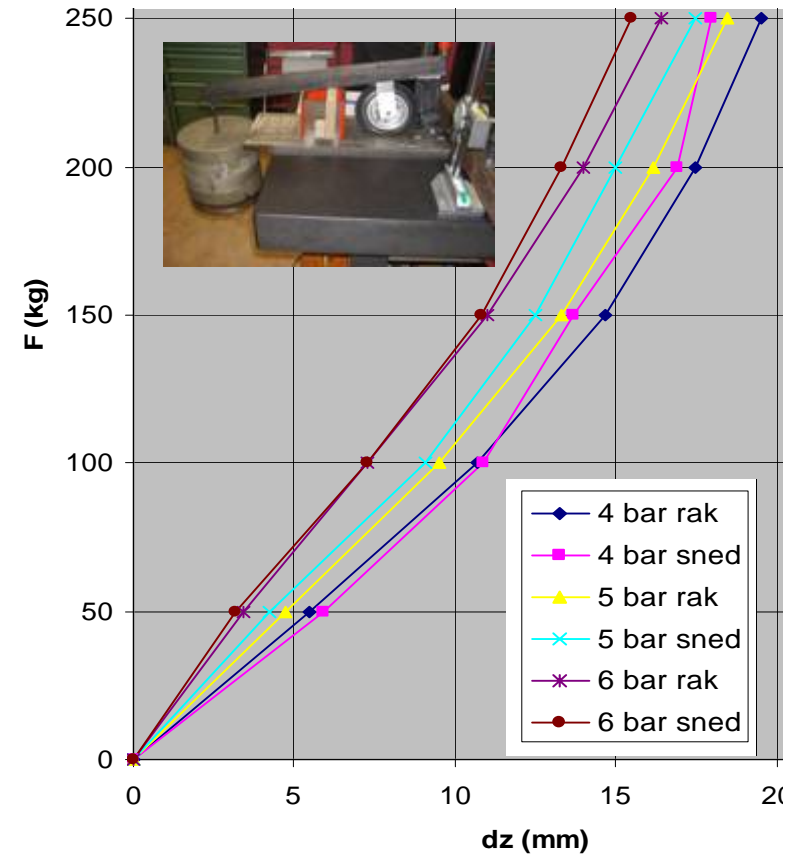
- STYRSIM (Gripen simulator, control laws verification)
- Tests at Sub-System level
 - Radar Altimeter
 - Wheels
- HILS (Hardware In The Loop Simulations)
- Integration Tests (constrained A/C, running engine)
- Ground Rolls in Linköping (manual and autonomous, up to 50 km/h)
- Flight Test Campaign



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Bench tests on wheels/tires

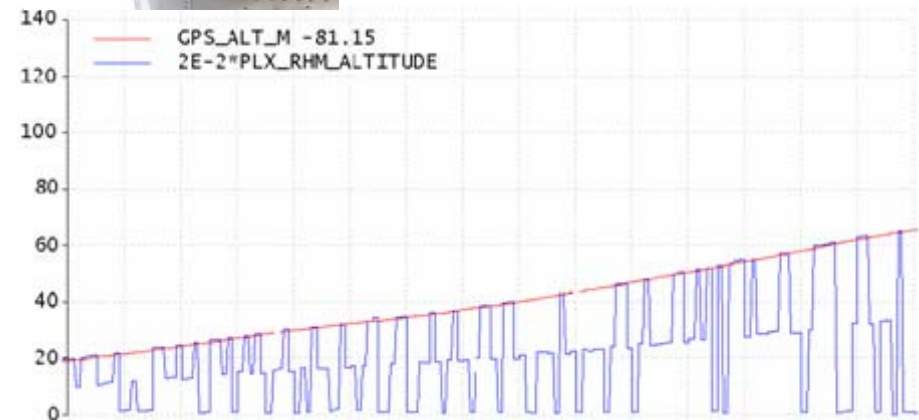
- Requirements initially underestimated
- The tires initially chosen tended to separate from the wheel due to the centrifugal forces at high rolling speed
- New tires purchased and verified regarding:
 - Deformation properties
 - Maximum roll speed : 170 km/h
 - Maximum allowed load



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Radar Altimeter test

- *Roke Manor*
Miniature Radar Altimeter Mk V
- In-flight landing trials on light aviation aircraft
- *“The Mk V is particularly suited to Vertical Take Off and Landing (VTOL) UAVs”*

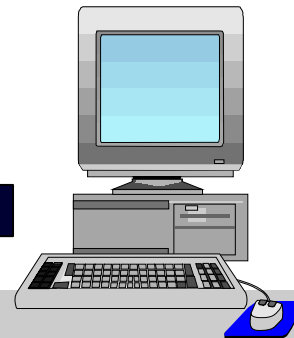
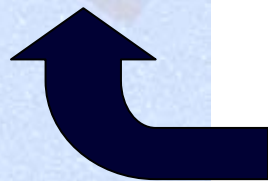
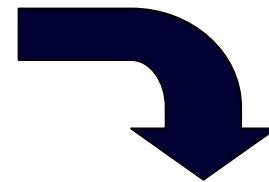
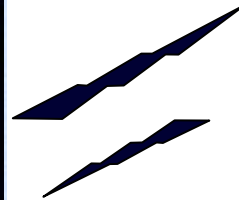


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Hardware In the Loop Simulations



- **Fault Simulations at real**
Control Link Failure
GCS Power Fault, etc.



- **Complete System Verification**

Servo dynamics

Non-linearities

- Dead zones
- Free Play
- Latencies
- Hysteresis

- **Test Team Training**

- Test Pilot
- Test Conductor
- Test Engineers

- **Check Lists and Procedures**



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Ground Rolls in Linköping

- Before Flight Test Permit
- Restrictions:
 - $V_G < 50$ km/h
 - Stabilator constrained to "flush", to prevent unintended rotation
- Test Program:
 - Manual taxiing
 - Auto taxiing, nominal
 - Auto taxiing, side offset
 - Auto taxiing, heading offset



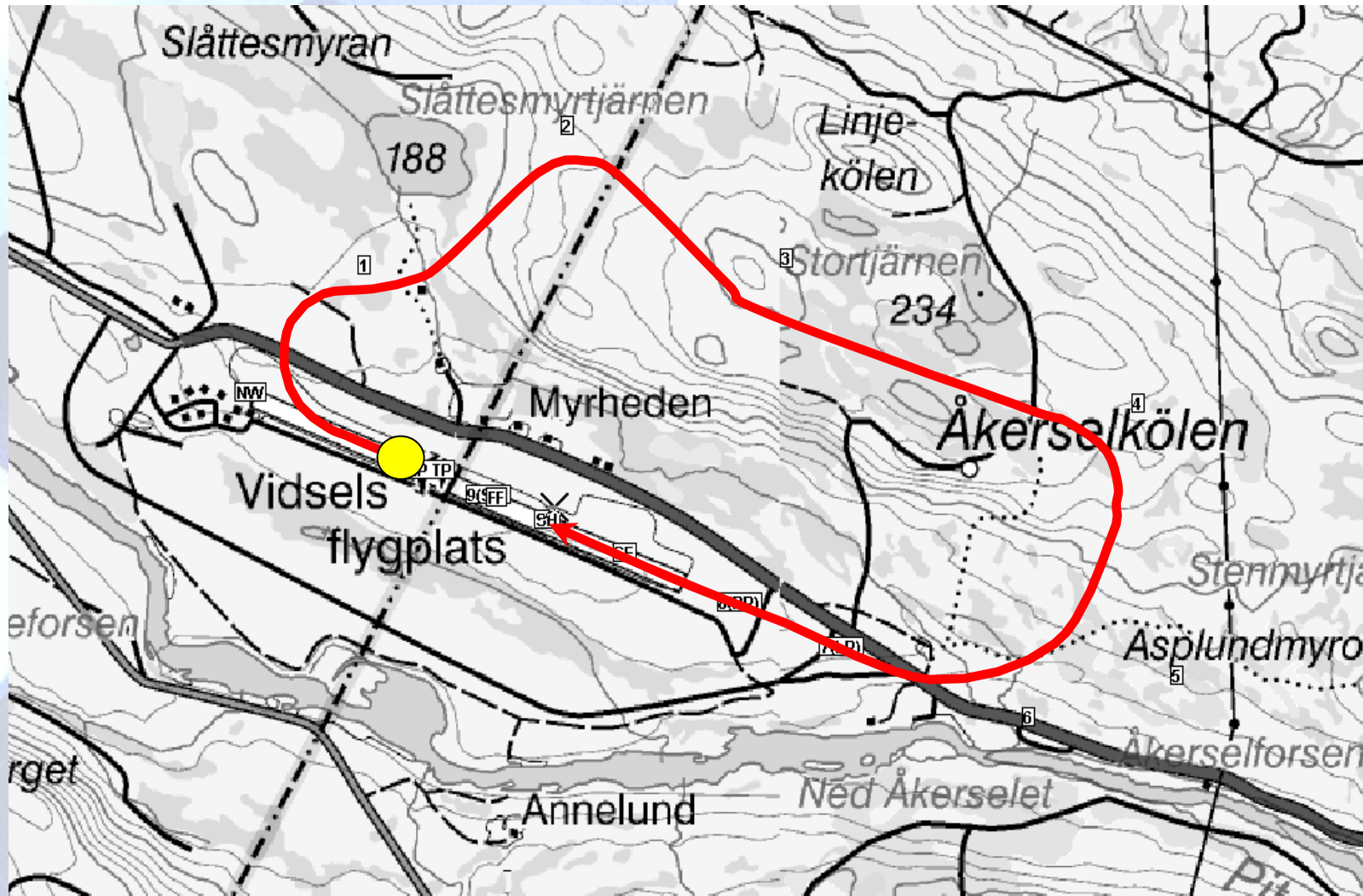
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Flight Test Campaign

- **NEAT/Vidsel Test Range**
- **Flight Test Program:**
 - High speed rolls (manual/autonomous)
 - Manual check-out flights for testing of UAV-system
 - Autonomous Take Off
 - Manual Landing patterns to collect data from the Radar Altimeter
 - Landing "on the cloud"
 - Autonomous Landing
 - Complete Autonomous Flight
- **Method**
 - Back-up pilot ready to take over at any time
 - Extensive use of *FTF lists*, to change control gains and other parameters, in-situ simulations/validations
- **Process**
 - Test data analyzed at test range and at Saab
 - Formal approvals from Material Group Managers from Saab/Linköping
 - Final GO-NOGO decision for next flight from Head of Flight Tests



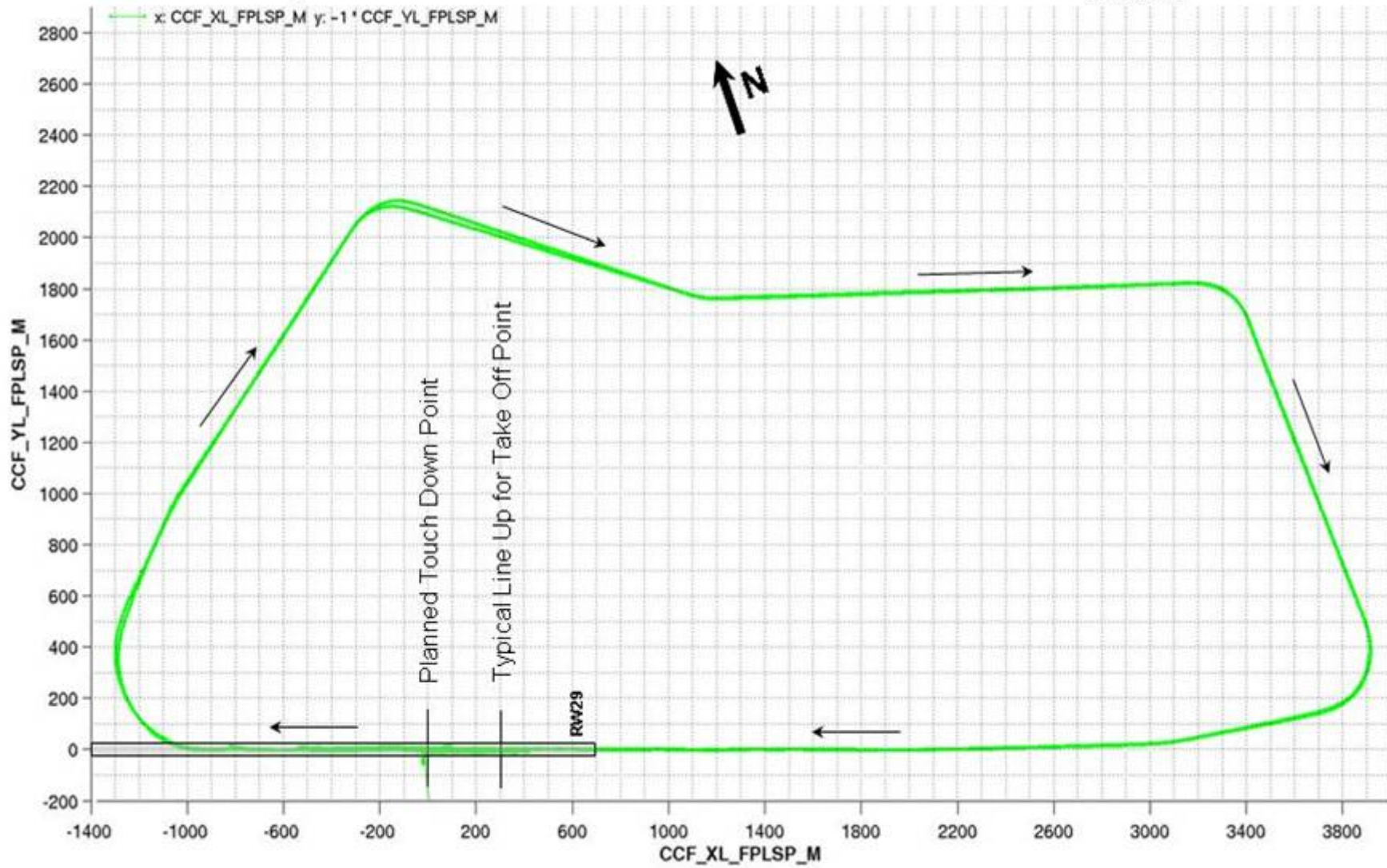
Typical demonstration mission (VIDEO)



Route - Plan View

File: /tda/BS-2/2017/BS-2_2017.h5

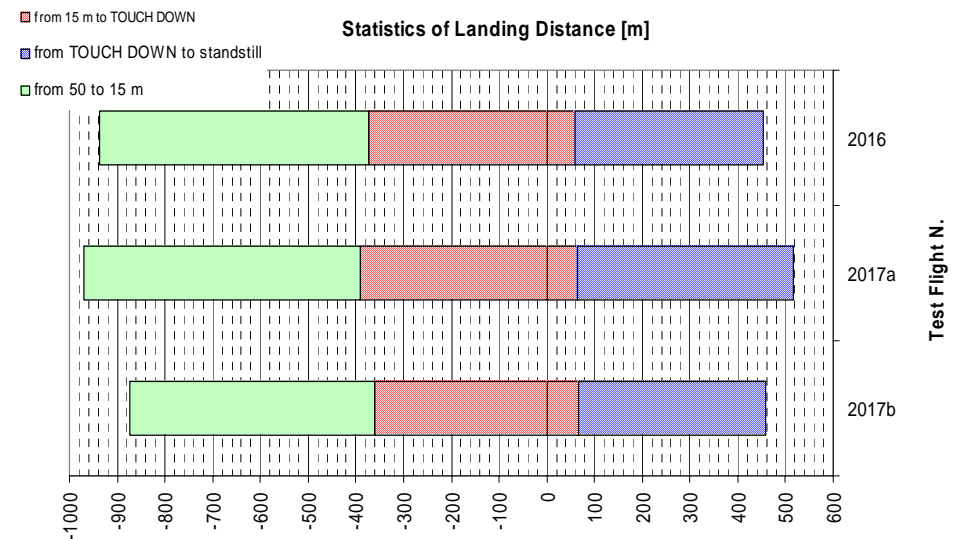
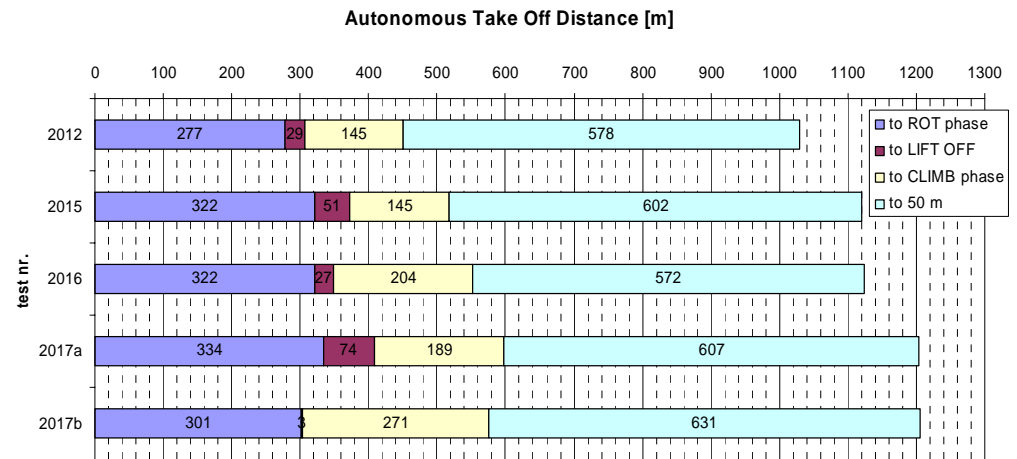
BS-route.imt



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Results

- **Very Successful Campaign**
- **Some minor problems**
 - Suboptimal control laws for rotation phase, still good enough
 - Low directional control on ground at high speed (common channel for rudder/nose wheel steering)
 - Radar Altimeter, performance worse than expected
 - DGPS corrections available only above 1 m altitude
 - Steel bars sunk in the runway's concrete → strong local deviations of magnetic field



Conclusions

- **Lesson Learnt (general)**

- COTS and their specifications should never be trusted until proven by test
- Tests at Sub-System level in the early stages can save money and time
- HIL simulations done with the actual flight hardware has been a very cost effective way to validate the complete system

- **Lesson Learnt (about ATOL)**

- Easier than expected (smoothest campaign with the SHARC)
- A pilot in the loop is not always the best option, especially if on ground
- Self-protecting mechanisms in the onboard autonomy are a *must* (if you plan a dumb mission, a smart system should not listen to you !)

- **Autonomy:**

- We are just scraping the surface
- Challenges for FT engineers: new test methods, new approach
- *How will we verify more advanced Autonomy, i.e. the capability of coping with a dynamic, a-priori unknown, unstructured environment ?*

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