Solar Impulse, First Round-The-World Solar Flight

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Solar Impulse
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An idea born in Switzerland
TWO PILOTS, Borschberg and Piccard

Inspiring
Clean technologies
Political reach

Leading
Managerial experience
Innovative solutions
Flight Testing
Ground Tests and Flight Missions
Civil Aviation Certification
Challenges and Achievements
THE ROUTE

ABU DHABI, UAE

MUSCAT, OMAN
VARANASI, INDIA
CHONGQING, CHINA
AHMEDABAD, INDIA
MANDALAY, MYANMAR
NANJING, CHINA
HAWAII, USA
PHOENIX, USA

PACIFIC OCEAN
I can’t fit in there, I am larger than a Boeing 747!
AHMEDABAD 1095 KM 75 HOURS VARANASI

#SOLARIMPULSE
6 Bottles of Oxygen

2.5 L of Water

2.4 kg of Food

-20°C

+20°C
Model-Based Design of the Aircraft

- Tail Sizing, Fuselage Shape
- Engine Position
- Wing Dihedral, Ailerons
- Autopilot, Avionics, Inertial Platform (Automatically Generated Code)
December 2009 – The flea hop

2011
European
Solar Flights

2013 – Across America

Summer 2014 – Test Flights

July 2010 Solar Impulse Night Flight

2012 – Crossing Frontiers

April 2014 – Unveiling Solar Impulse 2

2015
The Round-The-World Solar Flight
Where It All Started: Flight Simulation in 2007
Mission Simulation in 2007
Flight Simulator in 2008 for 25h Test
Combined 72h Mission and Flight Simulation 2012 and 2013
Combined 72h Mission and Flight Simulation 2012 and 2013
How did we Leverage MathWorks Design Flows

Avionics Verified and Validated with Polyspace

Autopilot Verified and Validated with Model-Based Design
Autopilot (Basic Loop) in Simulink

Study to Decide
One Aileron Servo vs. Two Rudder Servos
Formal Analysis of Avionic Software to DO-178B applying Polyspace Bug Finder and Code Prover

- > 260k Lines of Code, e.g. Power Management Computer (PMC)

- Power Management / Mission Information Computer
  → QNX on COTS Board (x86, 32 Bit, 500 MHz, UNIX RTOS)

- Throttle Box, Air Data Computer, Independent Display
  → ATMEL on SI Boards (ATCAN90, 8 Bit, 8 MHz, No OS)

- Monitoring and Alert System
  → ARM on ALTRAN Board (Cortex-M4F, 32 Bit, 168 MHz, No OS)
Latent bug or defect hunting, e.g. incorrect temperature in throttle box

No test cases or compilation needed

```c
// Enabled ADC
ADCSRA |= (1<<ADEN);

// --- wait stabilizes Aref rising level after Enable
for (i=0; i<(1<<ADC_WAIT)); i++) asm("nop");

// Clear Status Trig.
// Start ADC
ADCSRA |= (1<<ADSC);

while((ADCSRA & (1<<ADSC)) == 1);
```

```c
// Clear Status Trig.
// Start ADC
ADCSRA |= (1<<ADSC);

while((*(volatile uint8_t*)(0x7A)) & (1<<6)) == 1);
```

Probable cause for 'Dead code':
while((ADCSRA & (1<<ADSC)) == 1);

Press 'F2 for focus
```

While((ADCSRA & (1<<ADSC) == 1)
Formal Analysis of Avionic Software to DO-178B applying Polyspace Bug Finder and Code Prover

- Independent, systematic code reviews, compliance to MISRA-C
- Complexity results to support DO-178B “simple system” argument for case where we had to “re-engineer” design assurance level equivalence
- Bug Finder and Code Prover provided 1-2 Man-Year savings and automated capability in parallel to development which were not available otherwise
Concluding Remarks

Model-Based Design with MATLAB and Simulink helps us
- Reuse, build, test and fly whilst exploring new ideas and concepts
- Make key design decisions early, saving time and avoiding manually coded errors
- Focus on design and development instead of low-level coding
- Understand the system and its interdependencies
- Validate and verify the final performance including pilot training
- Adapt to new situations in pre- and during- flight

Using Polyspace code verifiers
- Identified and fixed potential run-time errors and unsafe code
- Reliably analyzed C codebase early, without test cases and compilation!
Current Status:
- Aircraft “works”
- Pilot flew 44 hours non-stop while sleeping 4h/day (!)
- Aerodynamic and Energy performance is within model predictions

What's Next:
- Finish maintenance and fly to Hawaii (=4 days)
- Improve global 5-6 day weather prediction models 😊
- Finish the Round the World Tour
An idea born in Switzerland