Solar Impulse, First Round-The-World Solar Flight

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Solar Impulse

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Key Takeaways

1. Why Solar Energy ?
   – Renewable, no fossil fuel or polluting emissions
   – Demonstrates that clean technologies can achieve impossible goals
2. Simulation made it possible, “model-as-you-go”
   – Simulations and analysis accelerated the mission by 10x over the last 3 years
   – Design iterations completed in hours, not days
   – Golden reference established enterprise-wide, low hanging fruit!
3. Time-consuming testing tasks eliminated
4. Confidence in “production” code quality maintained

Introduction to Organization and Mission

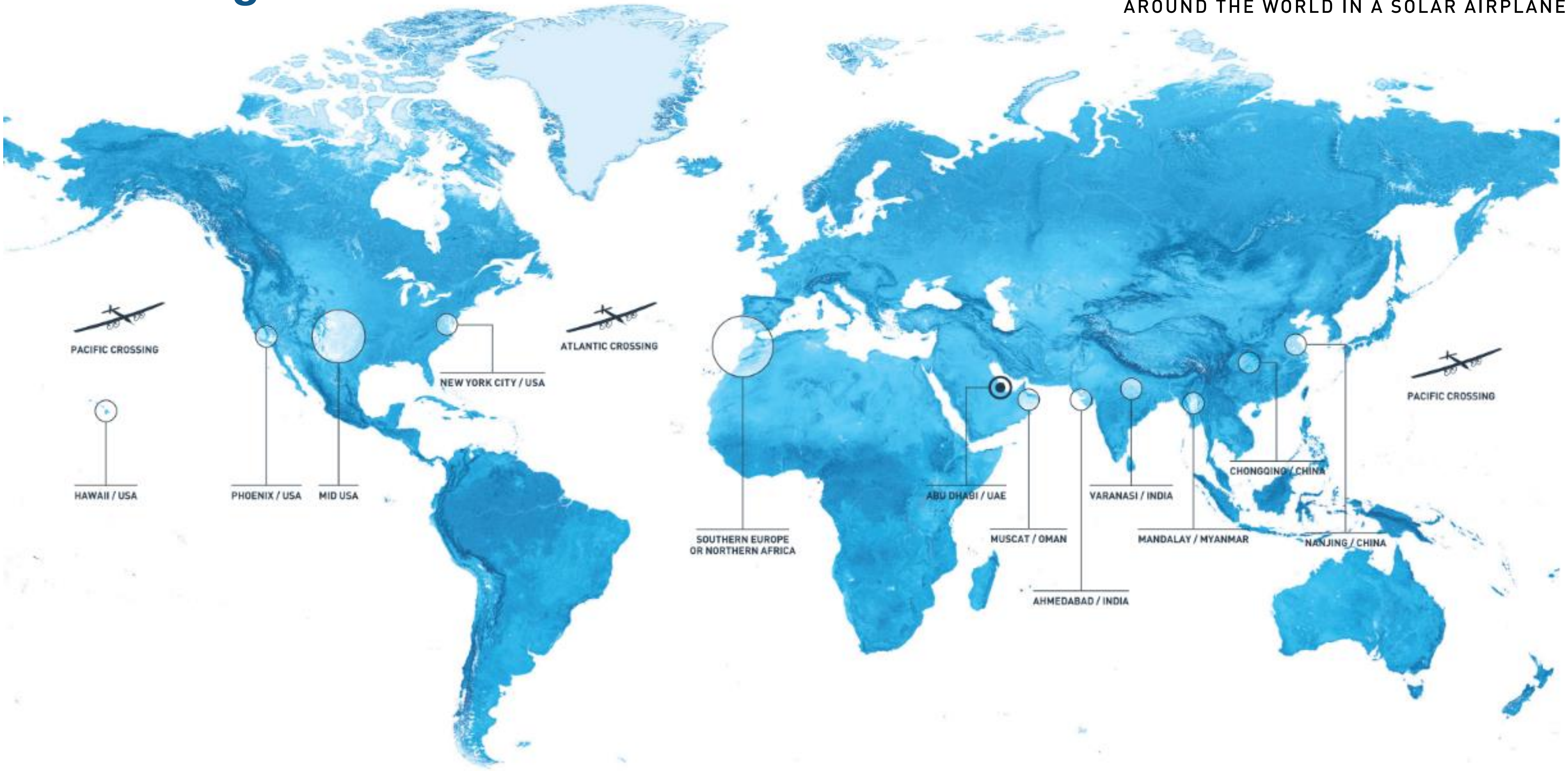
BERTRAND PICCARD
PSYCHIATRIST-EXPLORER
HANG-GLIDING CHAMPION
GOODWILL AMBASSADOR
1ST ROUND WORLD BALLOON FLIGHT

ANDRÉ BORSCHBERG
ENGINEER-ENTREPRENEUR
GRADUATE OF MIT
SWISS AIRFORCE PILOT
WORLD’S LONGEST SOLO FLIGHT

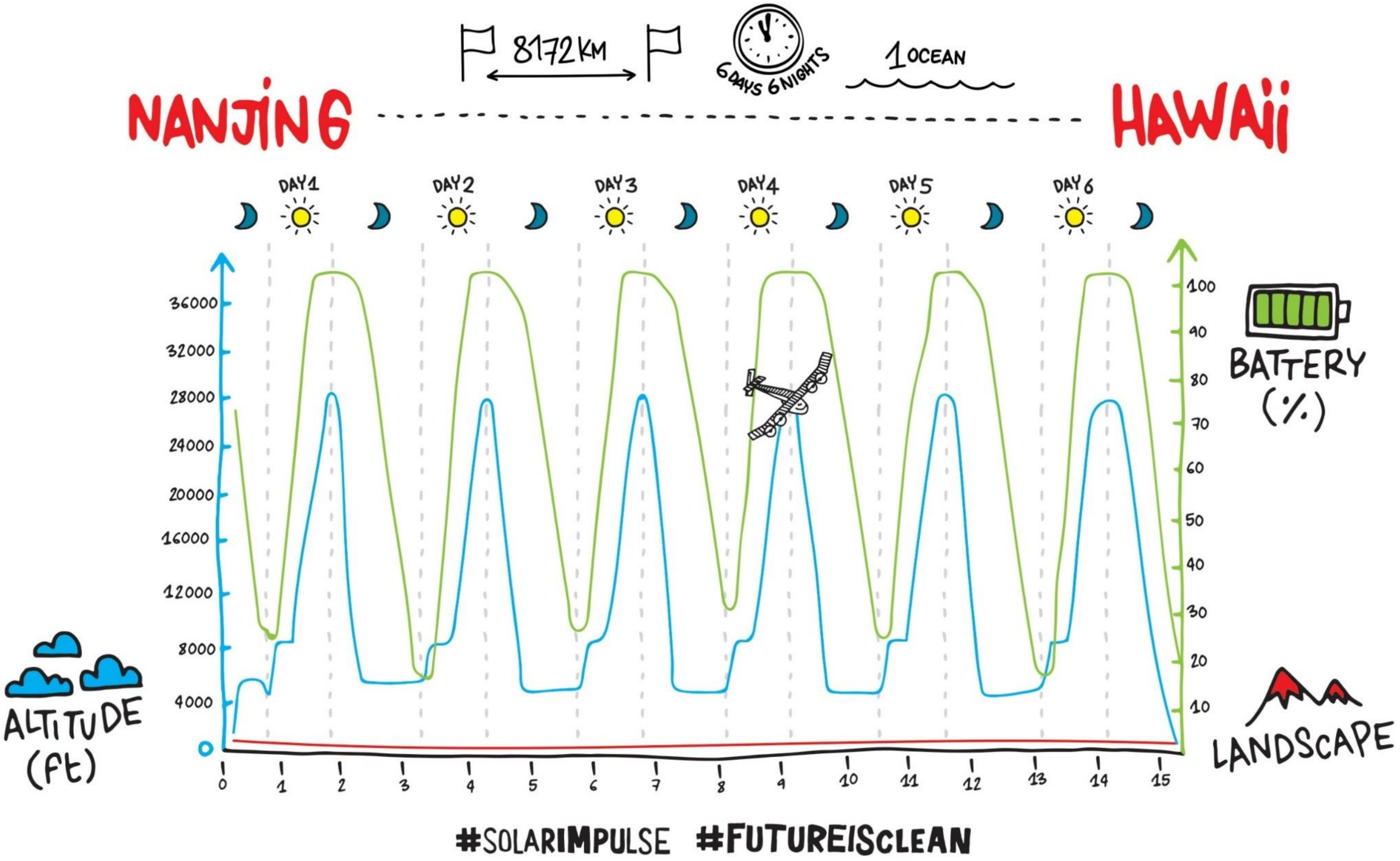
SOLARIMPULSE

AROUND THE WORLD IN A SOLAR AIRPLANE

Challenges



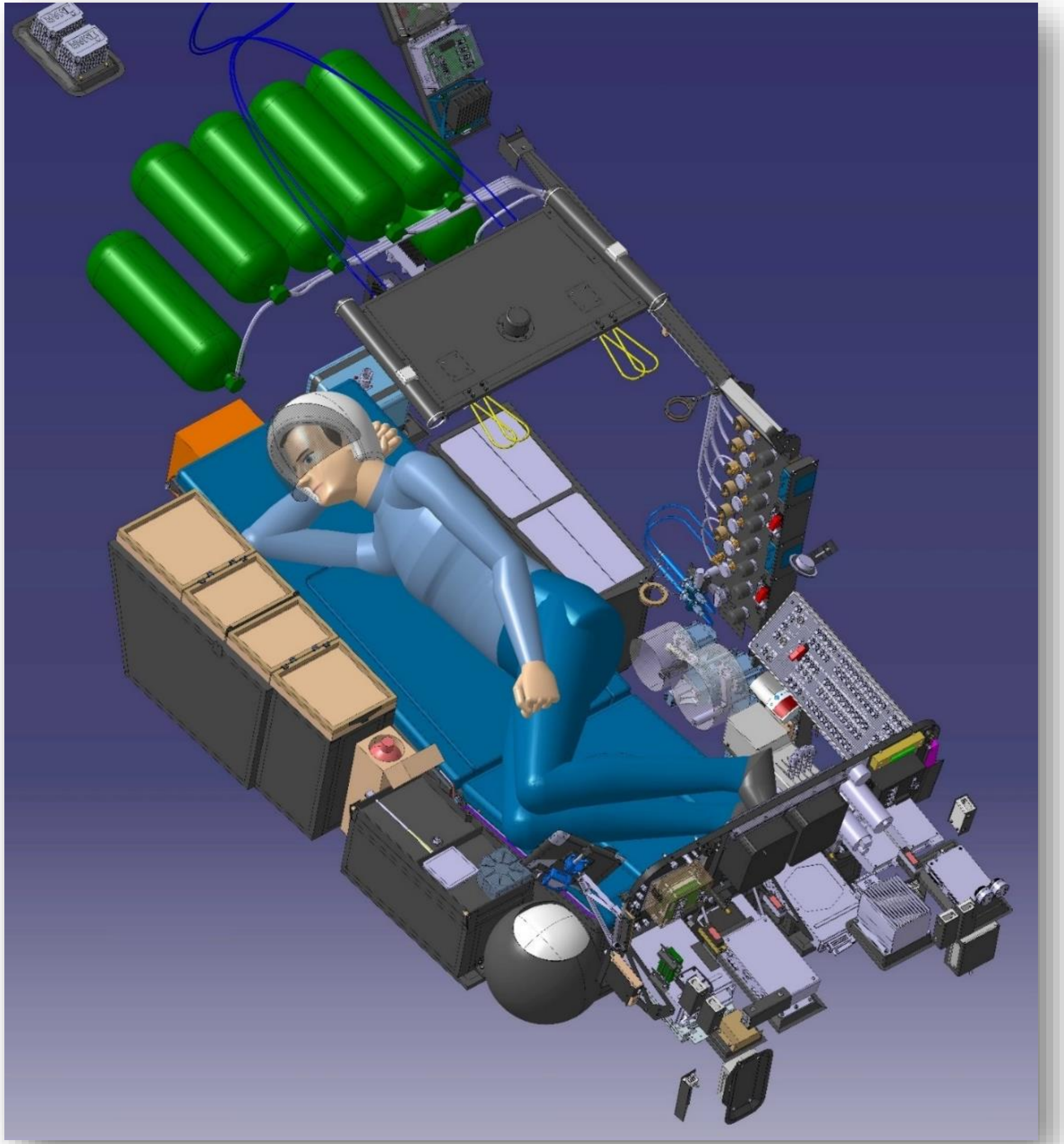
Design Mission Flight as a Golden Reference



Design Drivers

- **$3.8\ m^3$ Space for 6 Days**
  - Fly
  - Work
  - Live
  - Drink and Eat
  - **<u>Sleep</u>**

- Critical Systems
  - Oxygen
  - Electric
  - Avionics / Navigation
  - Autopilot



Innovation Challenges and Achievements

- Completing the historic round-the-world trip!
- Transitioning a vision into reality within tight schedules and limited budget
- No references, first of its kind!
- Top down mission to aircraft and cockpit design
- CAD drawings to high fidelity simulations
- Establishment of training activities using the simulations
- Lack of reusable Commercial off-the-shelf systems

Bertrand's Model in 2007

Innovation Challenges and Achievements

- Create trustworthy baseline with simulation for Federal Office of Civil Aviation (FOCA) approval
  - Aircraft design
  - Operational aspects with emphasis on multiday flying
- Redesign and certification impact of software and hardware
  - Maximize Power Efficiency
  - Reduce Weight

Innovation Challenges and Achievements

- Redundancy management per ARP4754A and ARP4761
  - ARP4754A:
    Guidelines For Development Of Civil Aircraft and Systems
  - ARP4761:
    Guidelines and Methods for Conducting the Safety Assessment Process on Civil Airborne Systems and Equipment

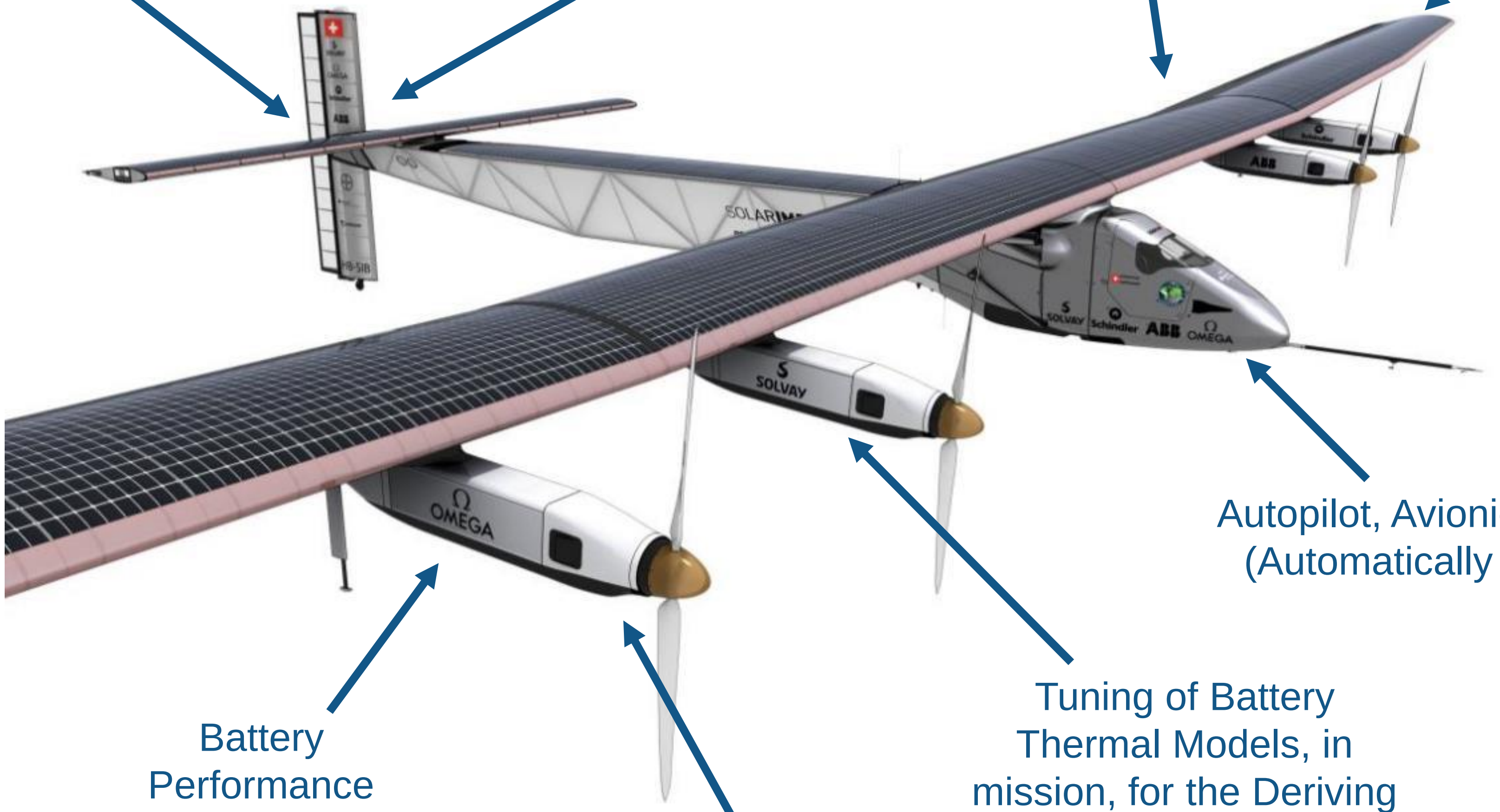
Model-Based Design of the Aircraft

Study to Decide
<u>One</u> Aileron Servo vs. **<u>Two</u>** Rudder Servos

Tail Sizing,
Fuselage Shape

Modelling of
Solar Panel

Wing Dihedral,
Ailerons



Autopilot, Avionics, Inertial Platform
(Automatically Generated Code)

Battery
Performance
Assessment

Engine
Position

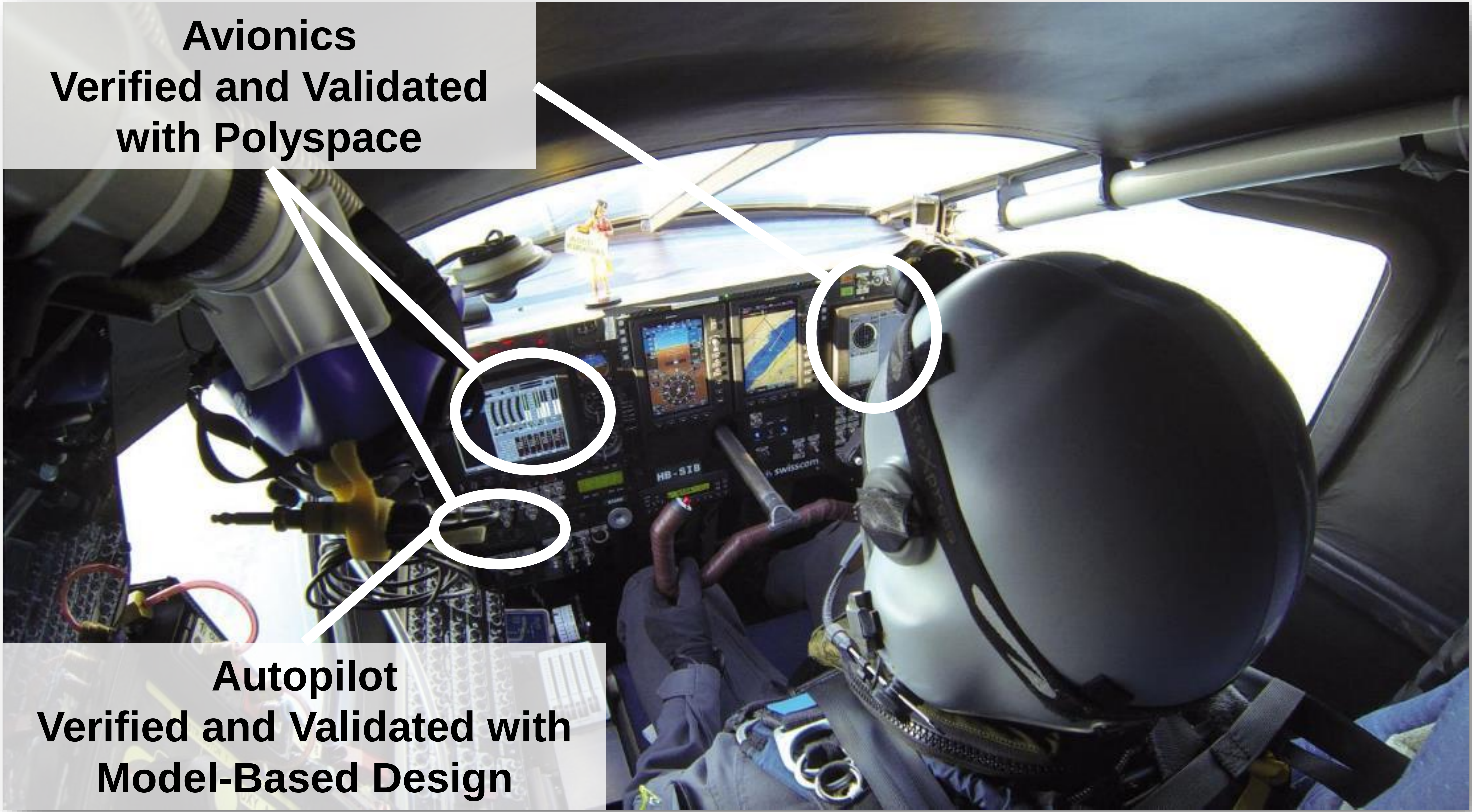
Tuning of Battery
Thermal Models, in
mission, for the Deriving
of Flight Plans

Formal Analysis of Avionic Software to DO-178B, Multiple Platforms

MathWorks Code Verification Technologies for Various Design Assurance Levels

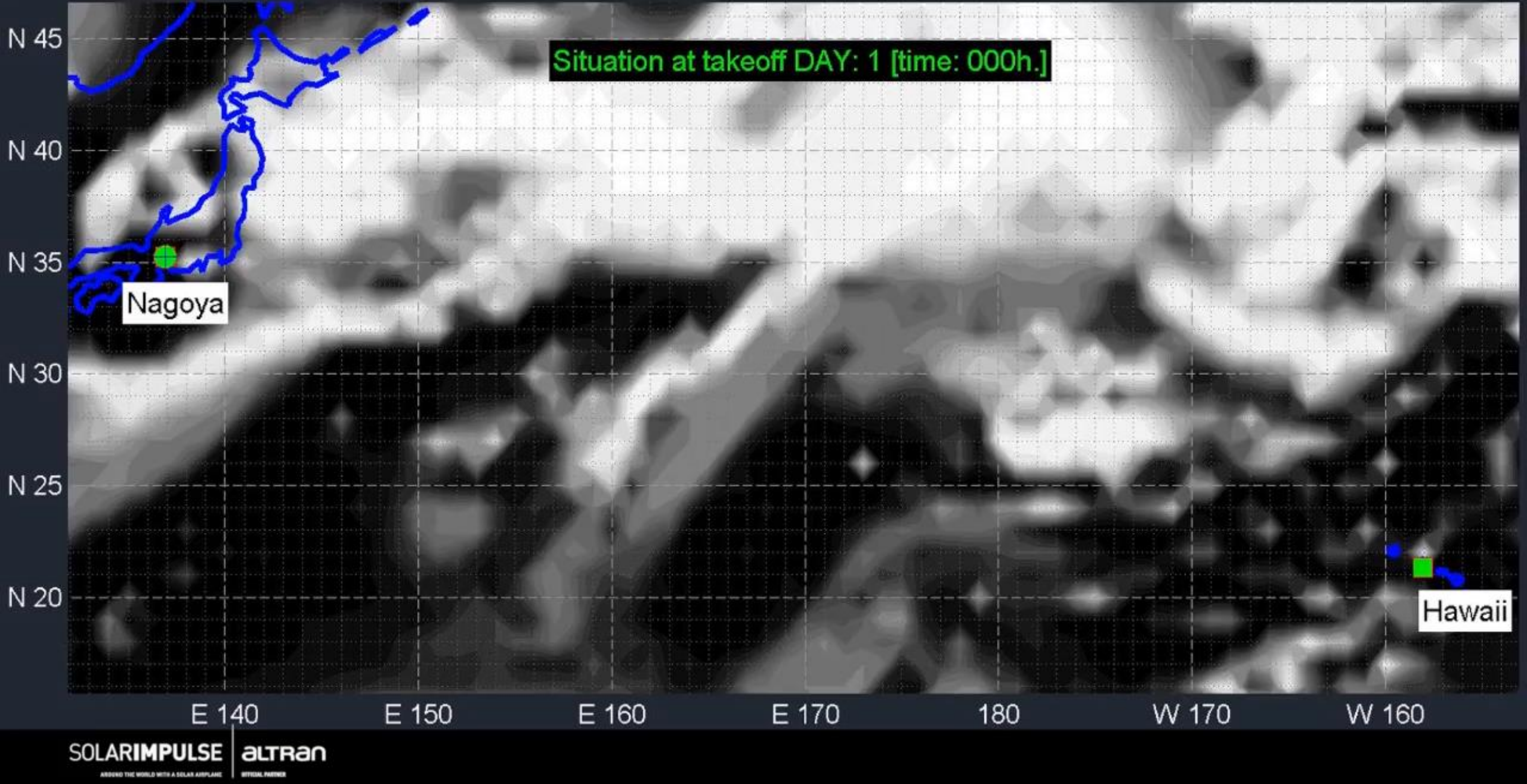
- > 350k Lines of Code from the Power Management Computer (PMC) alone
- Power Management / Mission Information Computer
  → QNX on COTS Board (x86, 32 Bit, 500 MHz, UNIX RTOS)
- Throttle Box, Air Data Computer, Independent Display
  → ATMEL on SI Boards (ATCAN90, 8 Bit, 8 MHz, No OS)
- Monitoring and Alert System
  → ARM on ALTRAN Board (Cortex-M4F, 32 Bit, 168 MHz, No OS)

Flight Testing



André is flying at low altitude

Bertrand is Resting



Flight Plan over Time, Created and Animated with MATLAB

Two Critical Issues During the Mission, Japan to Hawaii

Simulation, Analysis, Prediction and Verification Helps Resolve the Issues in a Timely Manner

1. False alarm in the monitoring and alert system
   - MathWorks code verification technologies were applied to solve both software and hardware specific issues

2. Overheating of all four batteries
   - Thermal behaviour of the battery compartment was modelled to predict and prevent overheating issues
   - Models were injected back into the telemetry system and used to guide the pilot to enable manual timely vent control

Significantly Improved Thermal Monitoring System

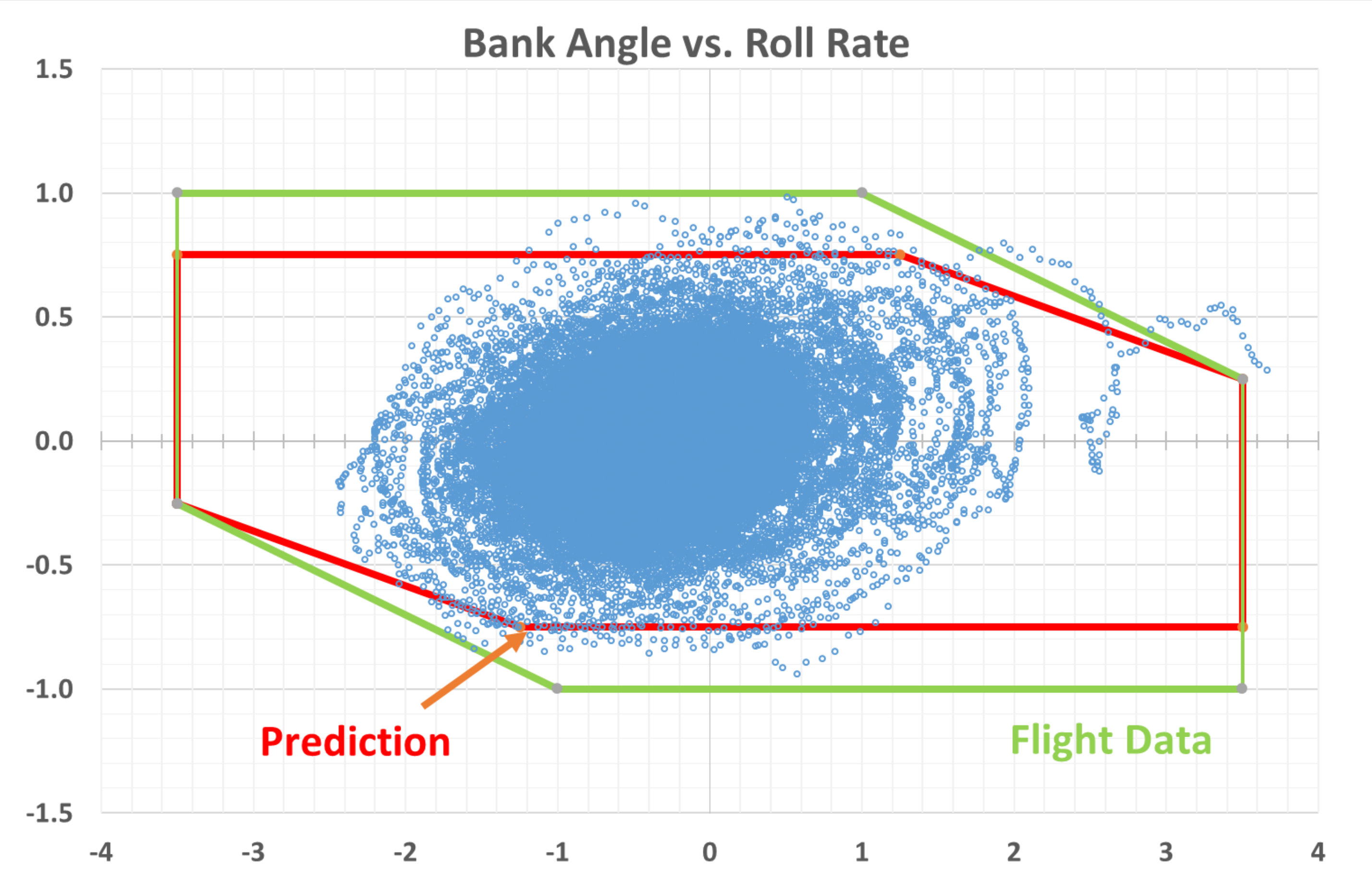
First Mission Flight of 2016

Used > 1TB of flight data for data analytics, improved predictions and fixed issues

Final Landing, Last Leg Flight 17, Cairo to Abu Dhabi

Autopilot Use: Prediction versus Reality

Flight	Autopilot ON [%]	Airborne [h]
RTW01	63%	12:59:11
RTW02	64%	15:20:16
RTW03	88%	13:15:02
RTW04	57%	13:35:01
RTW05	30%	20:29:07
RTW06	49%	17:22:35
RTW07	88%	44:10:13
RTW08	86%	117:49:16
RTW09	86%	62:29:10
RTW10	77%	15:52:24
RTW11	86%	18:09:35
RTW12	76%	16:33:54
RTW13	61%	16:46:47
RTW14	56%	4:40:59
RTW15	84%	71:08:37
RTW16	84%	48:50:19
RTW17	80%	48:36:56
Total	79%	558:09:22



*RTW Round The World

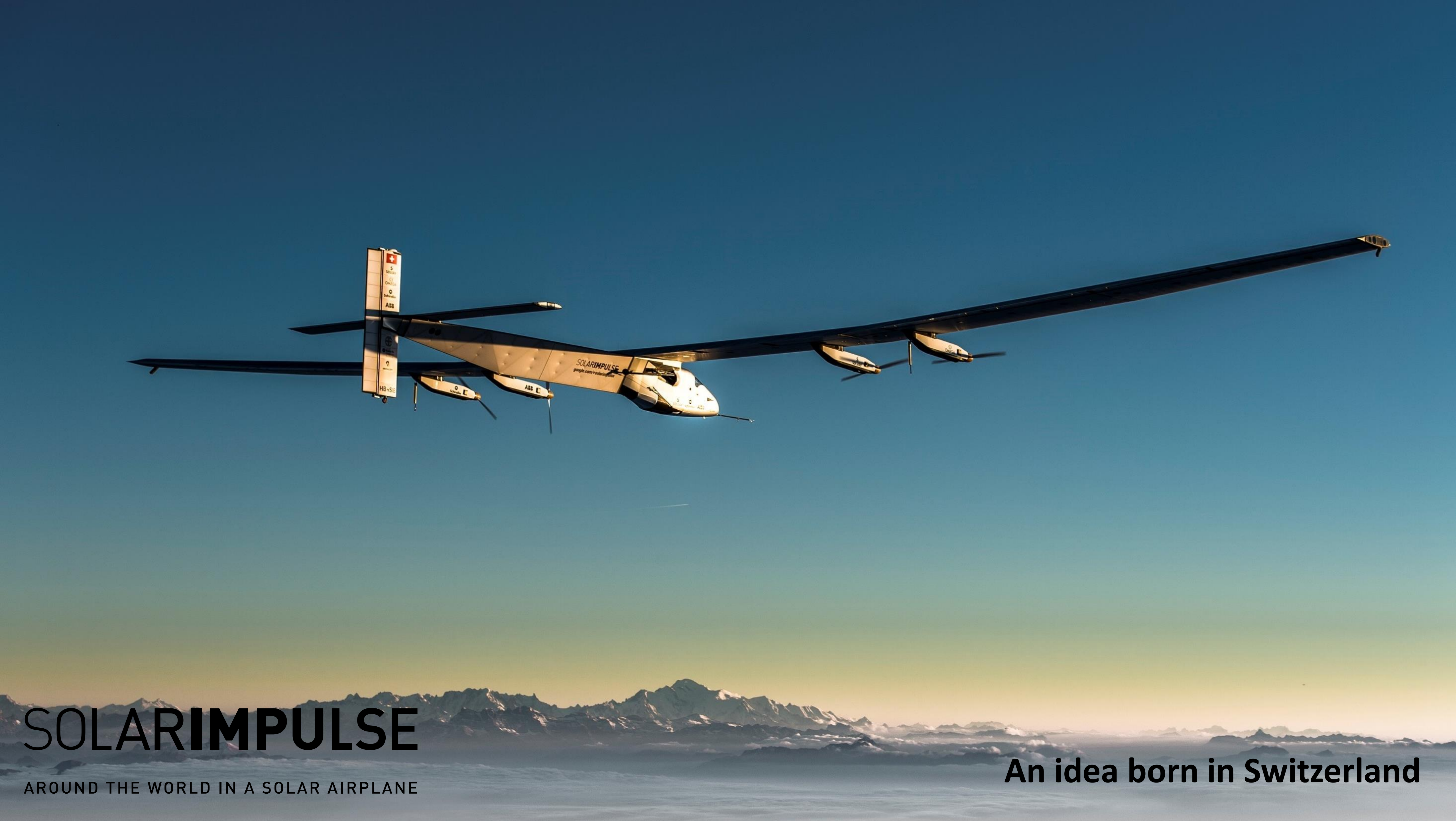
Concluding Remarks

Model-Based Design with MATLAB and Simulink helped us

- Complete the historic round-the-world trip!
- Prepare emergency scenarios, for example weather and system failures
- Reuse, build, test, tune and fly whilst exploring new ideas and concepts
- Make key design decisions early, saving time and avoiding manual coding errors
- Focus on design and development instead of low-level coding
- Survive in-flight emergencies and provide critical data to the pilot

Saved 2+ Man-years using Polyspace Code Verifiers

- Identified and fixed run-time errors and unsafe code
- Formally verified codebase, statically analysed “without test cases”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AROUND THE WORLD IN A SOLAR AIRPLANE
An idea born in Switzerland