

Simulation and Modelling Advances in the Field of Aero engines

MATLAB EXPO 2013

Kevin Daffey

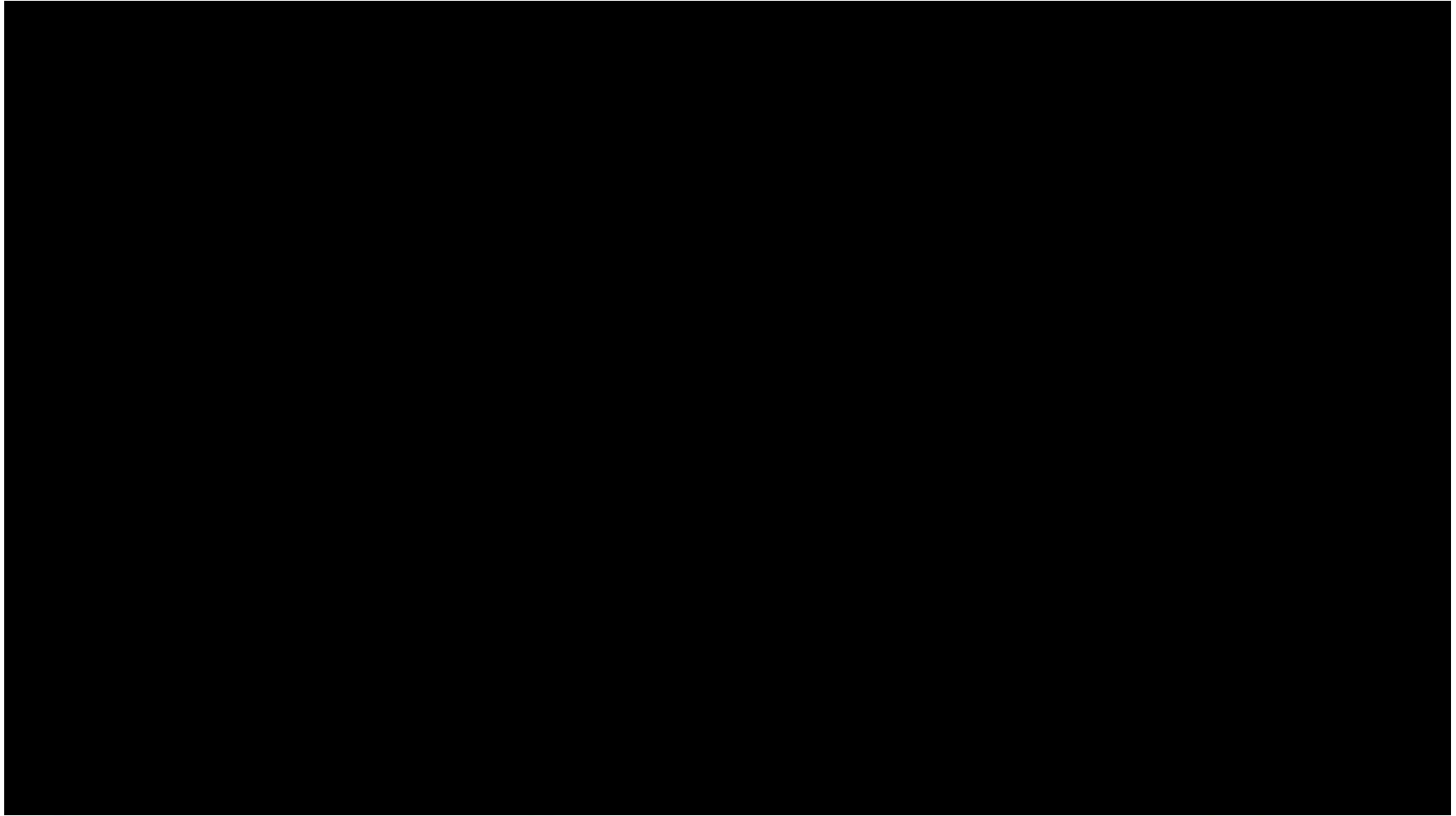
Global Head of Electrical Power and Control Systems

Trusted to deliver excellence



Rolls-Royce

An Introduction to Rolls-Royce



Better power for a changing world



Rolls-Royce

Group profile

Rolls-Royce is a global company, providing integrated power solutions for customers in civil and defence aerospace, marine and energy markets.

We support our customers through a worldwide network of offices, manufacturing and service facilities.



Rolls-Royce

Business model and strategy

Our business model and strategy place the customer at the heart of our business.

The DNA of the organisation is built around innovation and responding effectively to the needs of customers.



Rolls-Royce will be relentless in the pursuit of quality, reliability and on-time delivery



Rolls-Royce

A consistent approach to business

Values

- **trusted to deliver excellence** - we have one of the world's most powerful brands and this statement encompasses our values

Vision

- **better power for a changing world** - we are committed to working at the forefront of science and technology to meet the demands of our fast-changing world

Strategy

- **understanding our customers**
- **innovation**
- **profitable growth**
 - we aim to be world-class in these and achieve our ambitions by operating to high ethical standards



Rolls-Royce

2012 financial highlights

order
book

£60.1bn

underlying
Group revenue

£12.2bn

underlying
profit

£1.4bn

original
equipment

48%

services

52%



Underlying Group revenue by business segment

Civil aerospace	53%
Defence aerospace	20%
Marine	18%
Energy	8%
Engine Holding	1%



Rolls-Royce

Civil aerospace

A major manufacturer of aero engines for all sectors of the airliner and corporate jet market. Powering over 30 types of commercial aircraft. A Rolls-Royce powered aircraft takes off or lands every 2.5 seconds.

- over 12,500 engines currently in service
- almost 300 airline and leasing customers
- 4,000 corporate aircraft, utility aircraft and helicopter operators



2012 financial data

order book	£49.6bn
revenue*	£6,437m
profit*	£727m

*Underlying figures

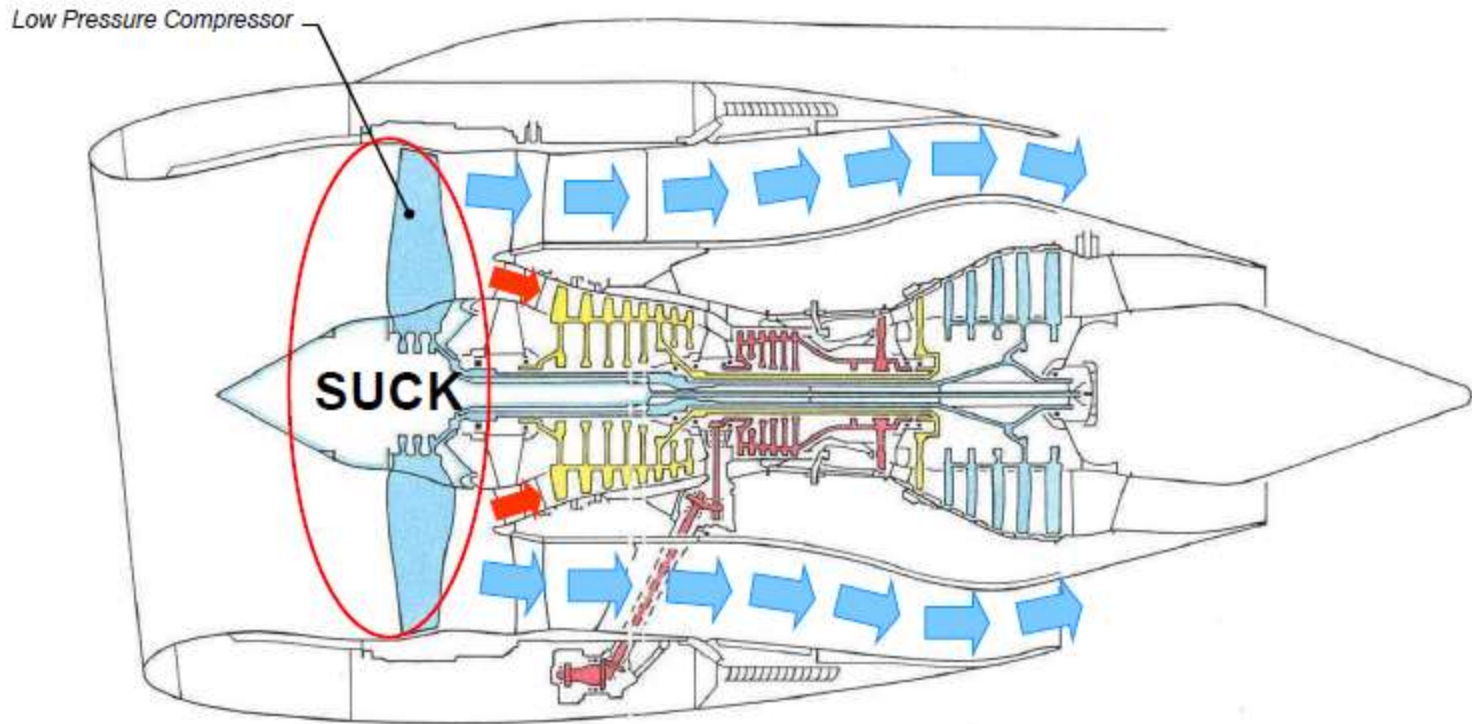


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Engine Facts and Figures



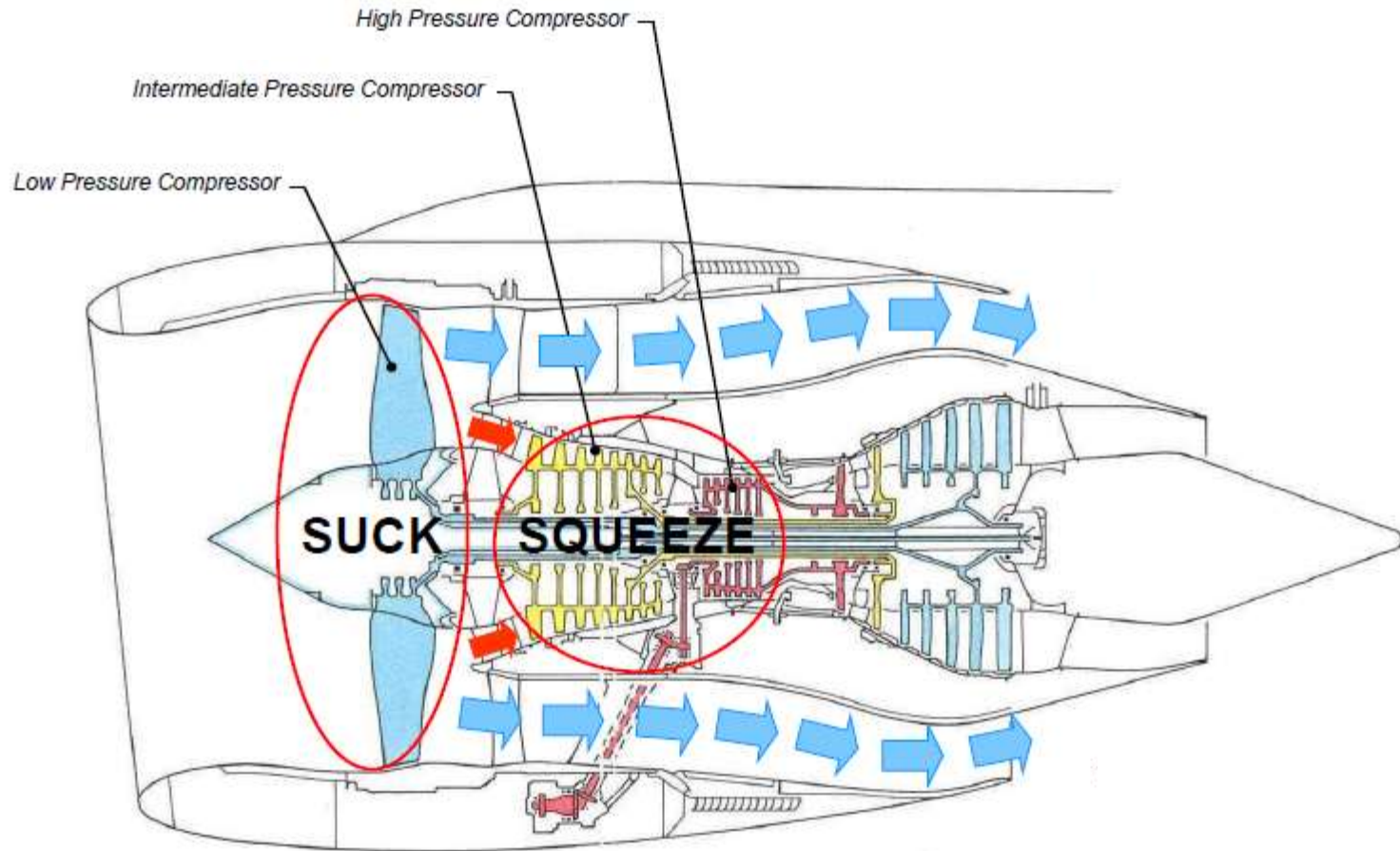
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How a Gas Turbine Works



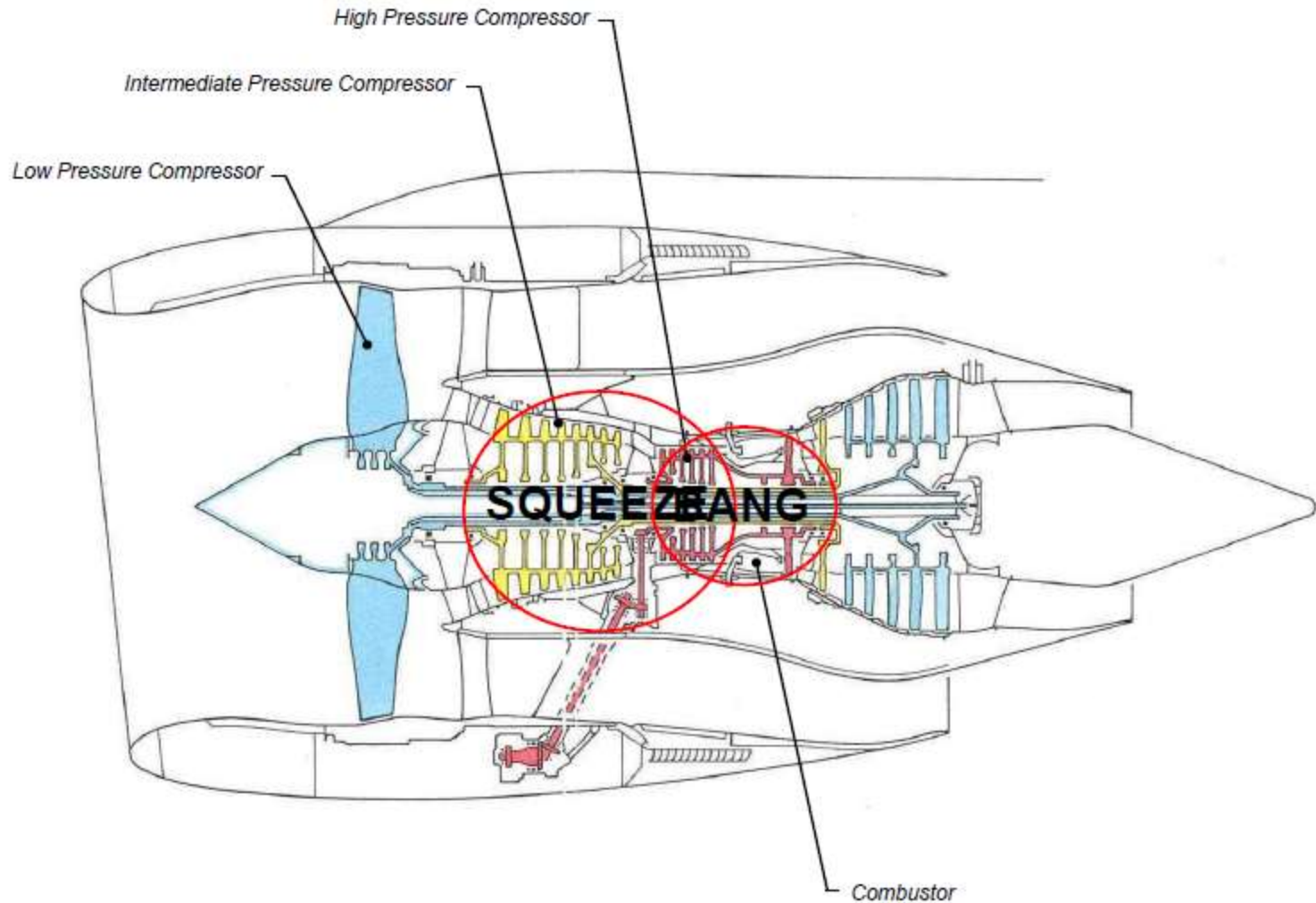
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How a Gas Turbine Works



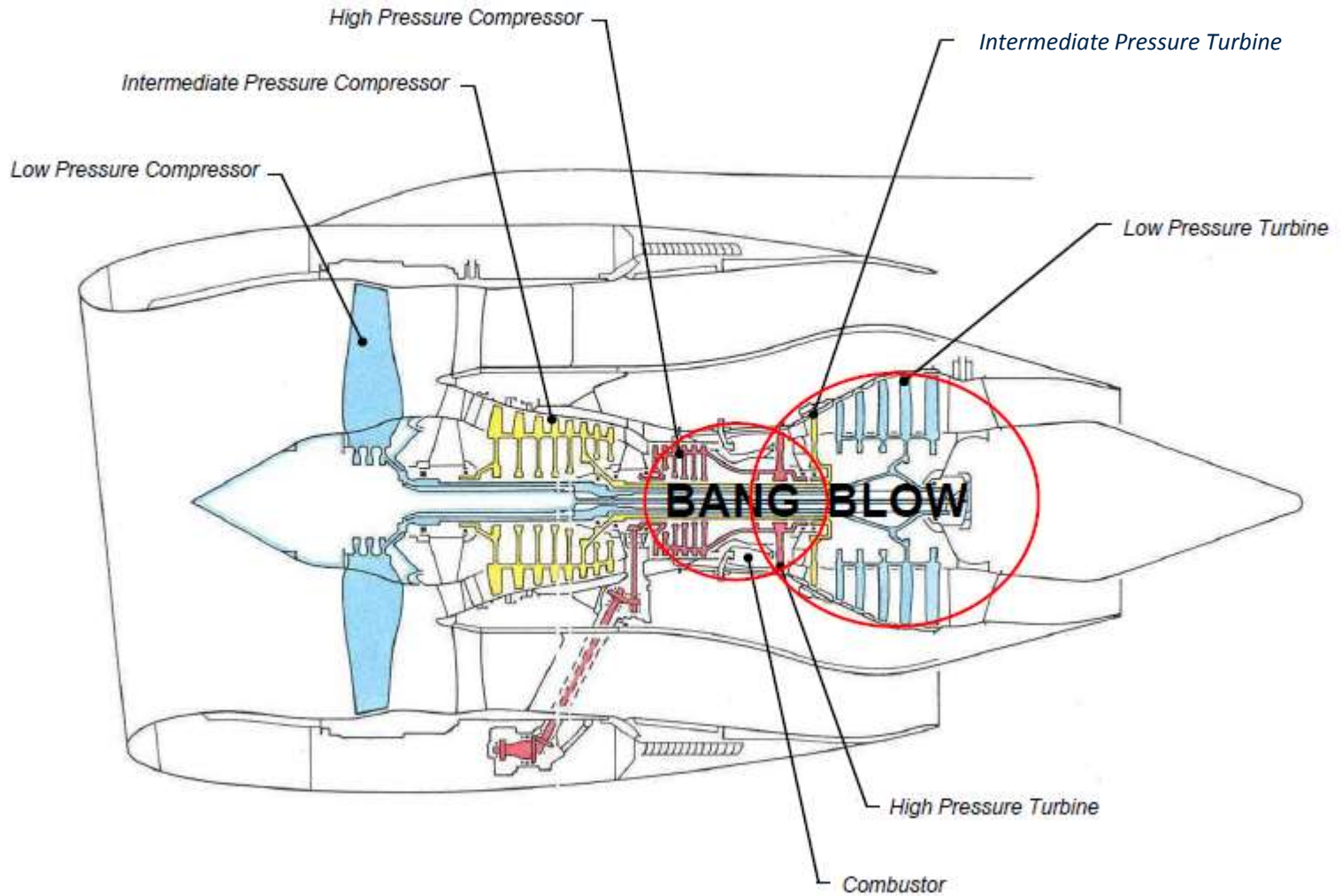
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How a Gas Turbine Works



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How a Gas Turbine Works



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Testing and Trials



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Fan Blade Off Certification Test

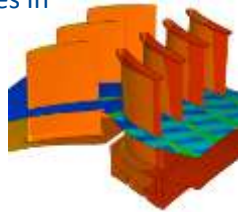
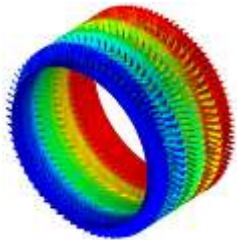


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Simulation in Design

- **Rolls-Royce uses a wide variety of analysis techniques for design verification from whole engine to component**

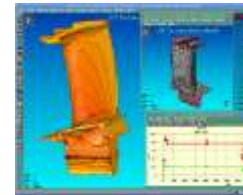
Computational fluid dynamics is used to understand the aerodynamics of engines in order to maximise performance.



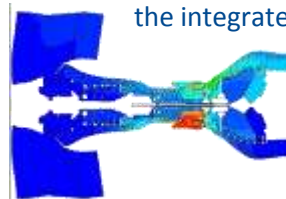
Cost modelling is used to identify cost drivers and maximise value



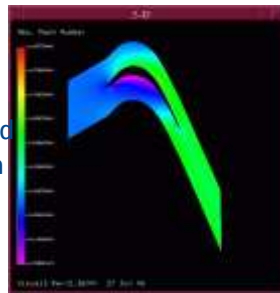
Finite element analysis is used for structural, vibration, lifing and thermo-mechanical analysis, both linear and non-linear at whole engine, component and sub-system level.



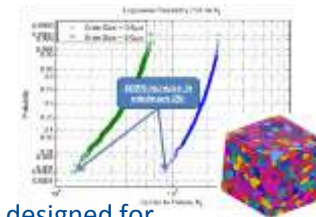
Multi-disciplinary Whole Engine Design Systems predict the behaviour of the integrated product



Combined CFD and Structural analysis is used to study forced vibration on turbomachinery

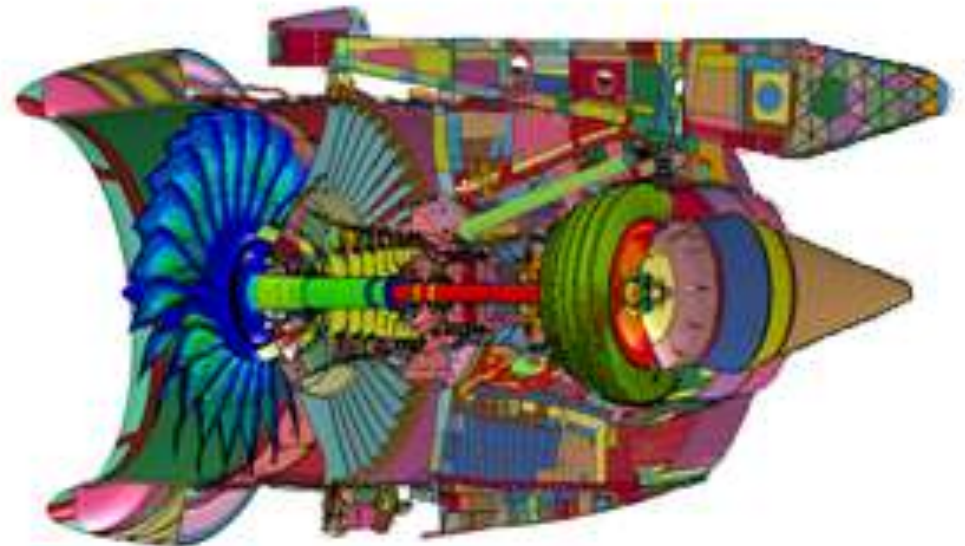
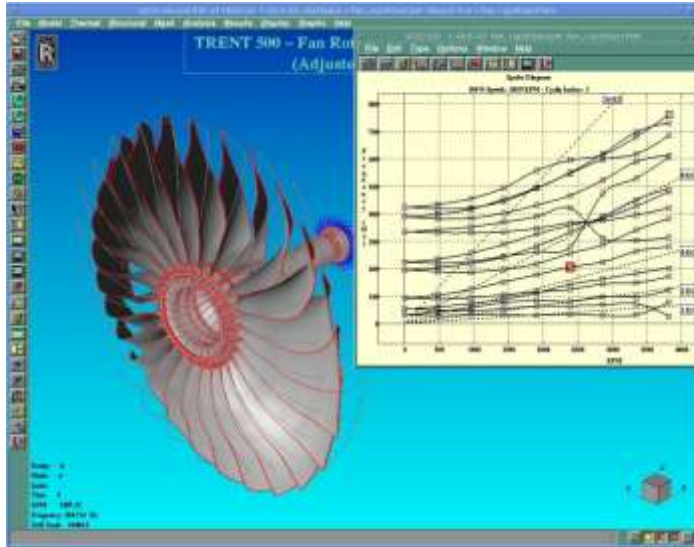


Materials designed for required properties

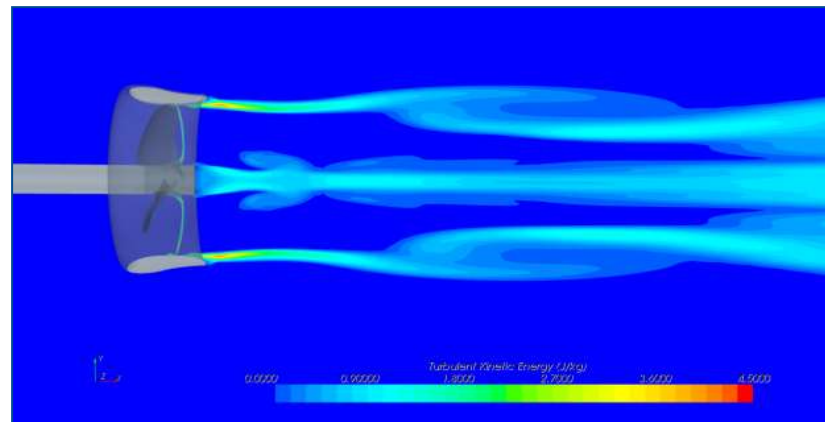
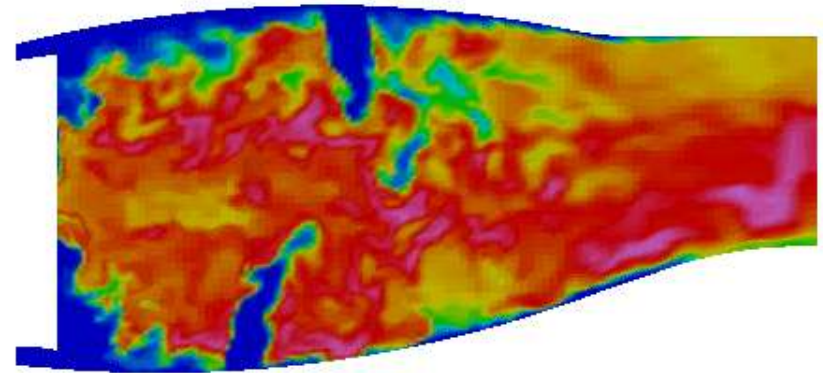
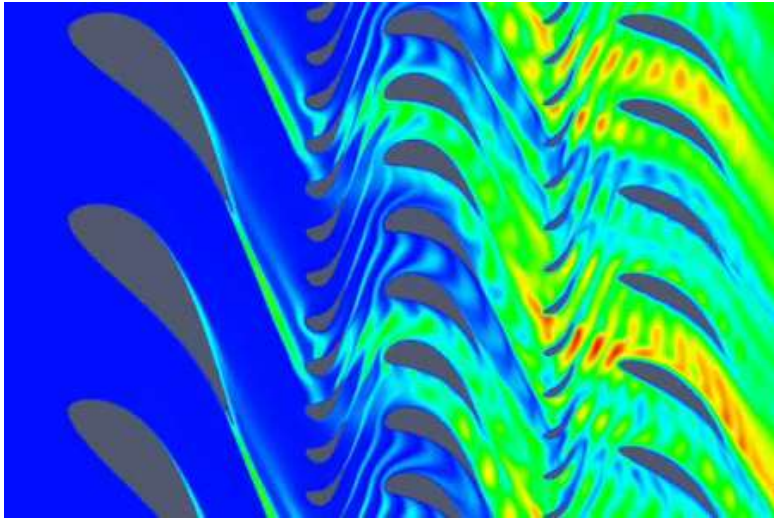


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Mechanical Simulation

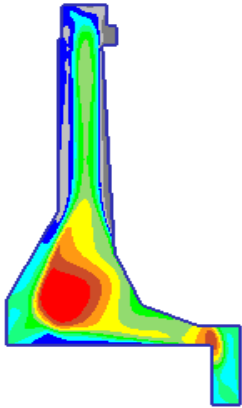


Computational Fluid Dynamics



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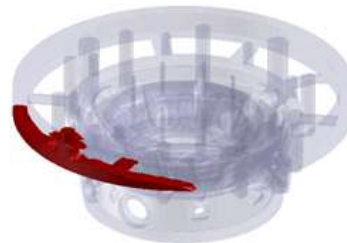
Materials and Manufacturing Simulation



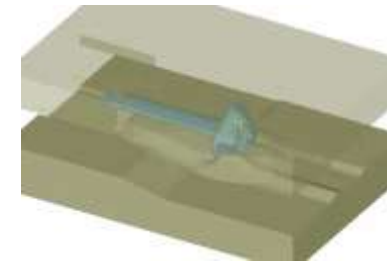
**Predictable distortion &
Machine System / Tooling**



**Complex Metal
Crystal Casting**



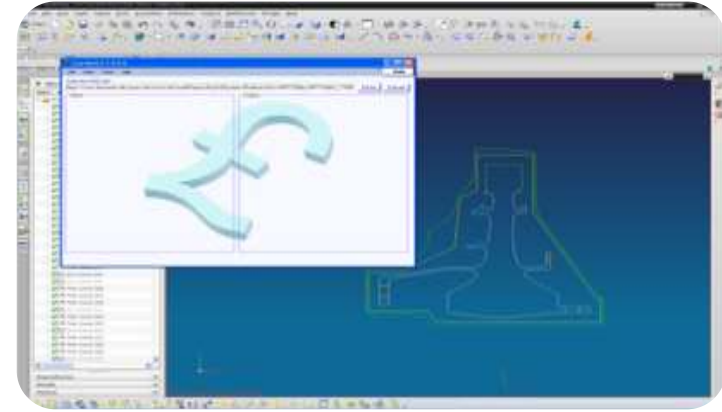
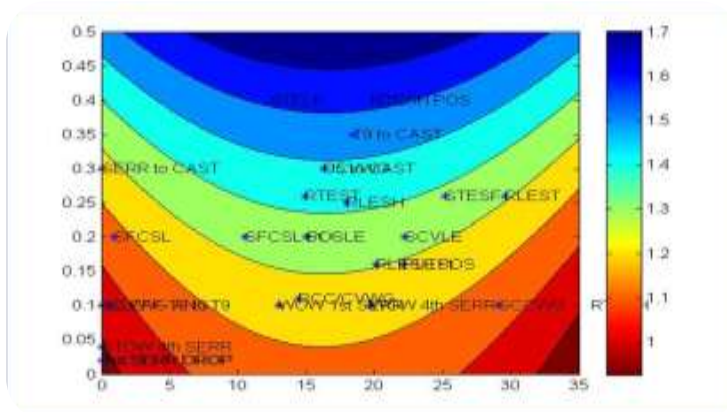
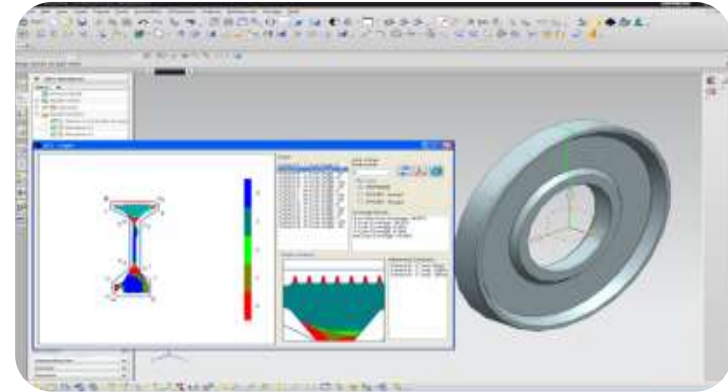
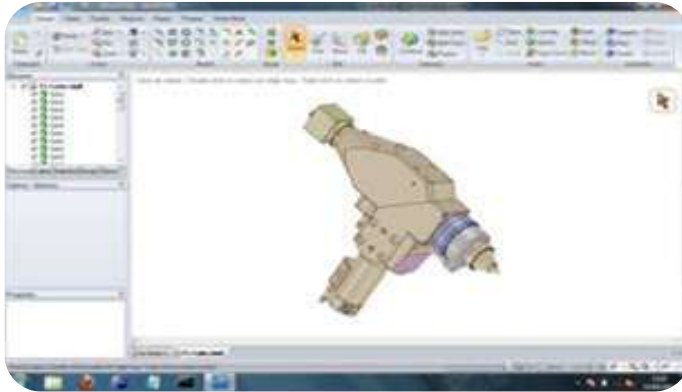
**Filling and Solidification
(Defect free castings)**



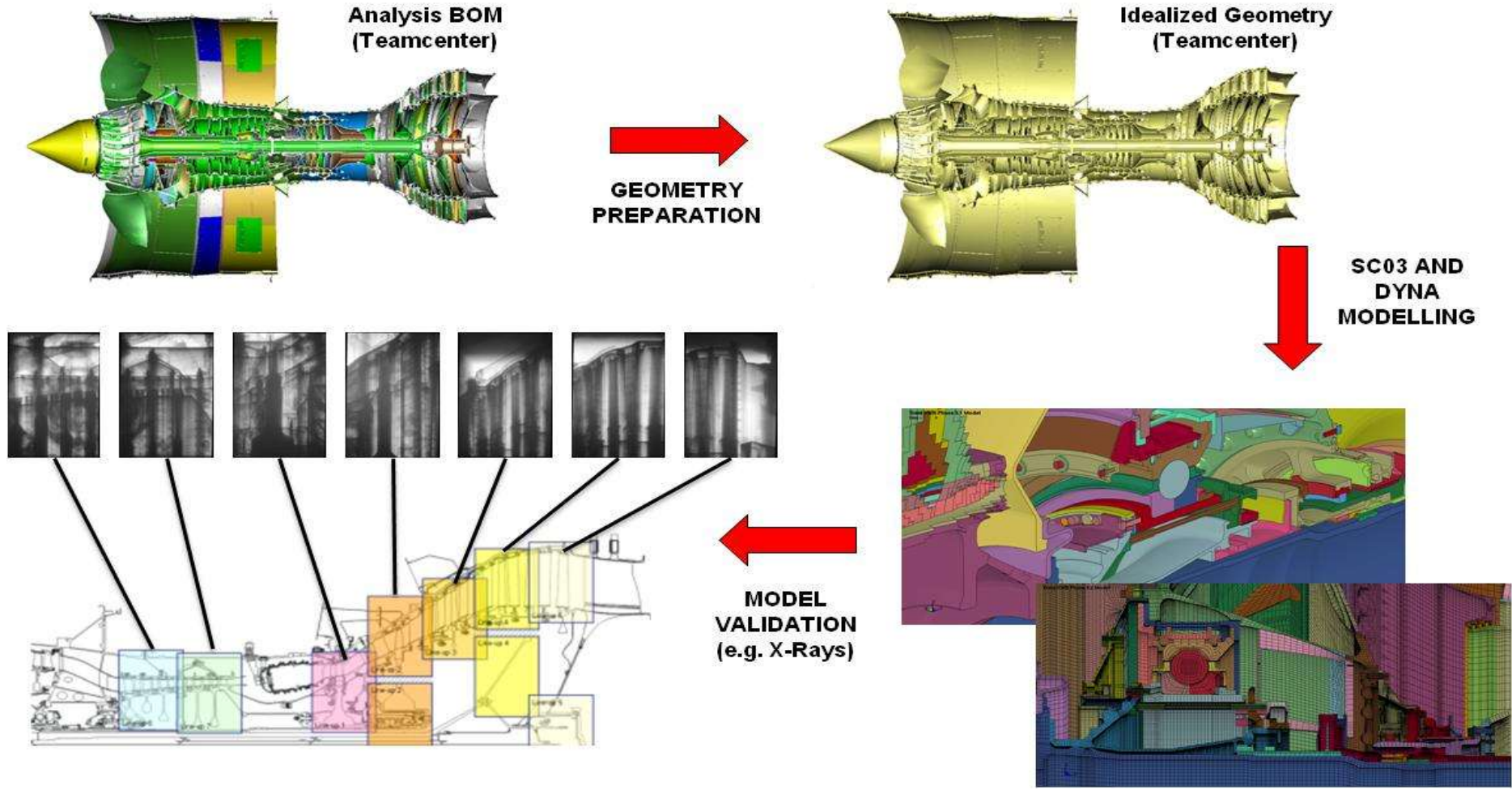
**Predictable Forming
(Minimised Material Use)**



Product Cost Engineering



Whole Engine Thermomechanical Modelling



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Examples of MATLAB Usage in RR

- System design teams use MATLAB SIMULINK to develop models, simulations and prototypes of control systems;
- System verification teams use MATLAB to analyse large volumes of test data;
- MATLAB SIMULINK is used for the development and running of state-space, or real-time, engine models (RTEM);
- MATLAB SIMULINK is used to create thermodynamic engine models (ARTEMIS);
- Post processing and visualisation of data generated from SCO3 thermal codes;
- MatLab Image Processor for thermal paint analysis data;
- Analysis of Engine Health Monitoring Data;
- Birdstike slice Calculations;
- Air flow transients in Bearings;
- Auto-code from SIMULINK for Development Engine Control Systems.

Extracted from RR Intranet Site on MATLAB Tool

Technical Limitations:

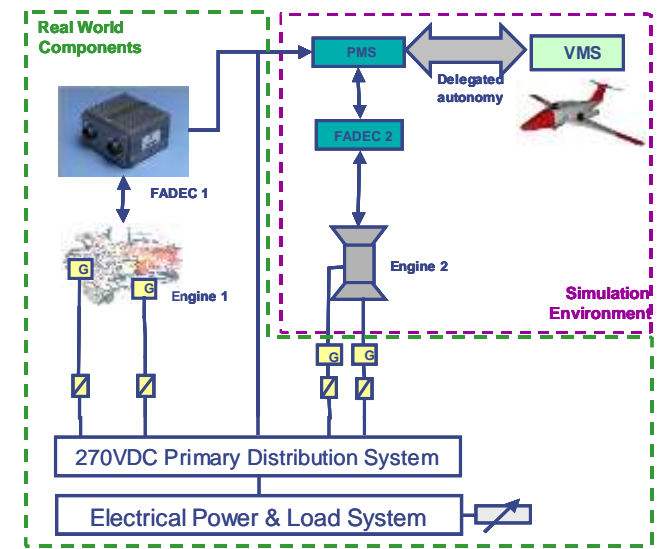
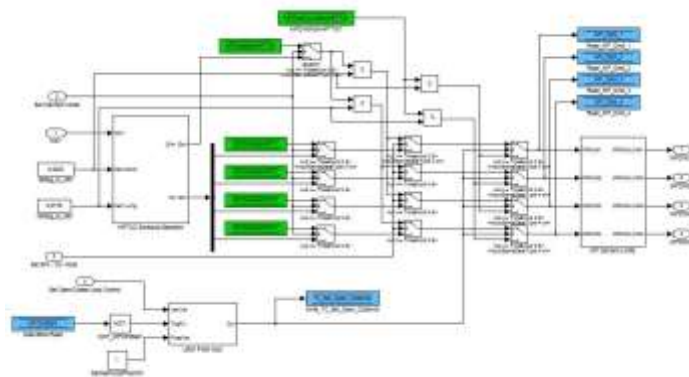
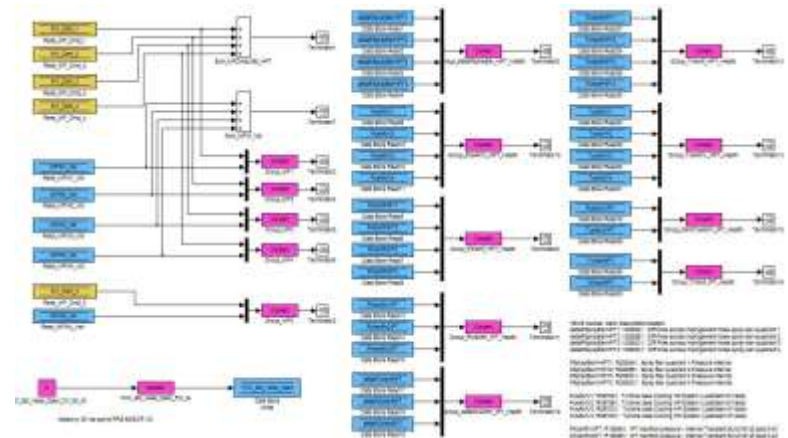
- None. It is infinitely capable, limited only by the users' imaginations and the amount of memory in the computer! It's a bit slow though. I prefer Fortran & ES37.



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MATLAB uses in Electrical and Controls

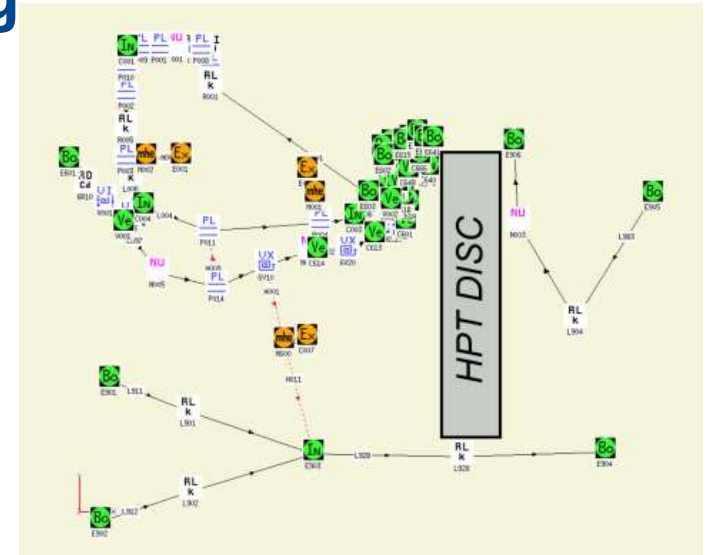
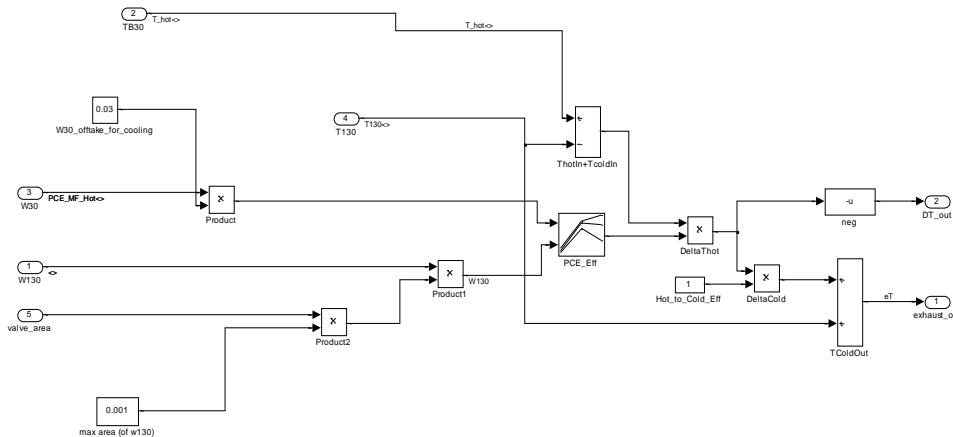
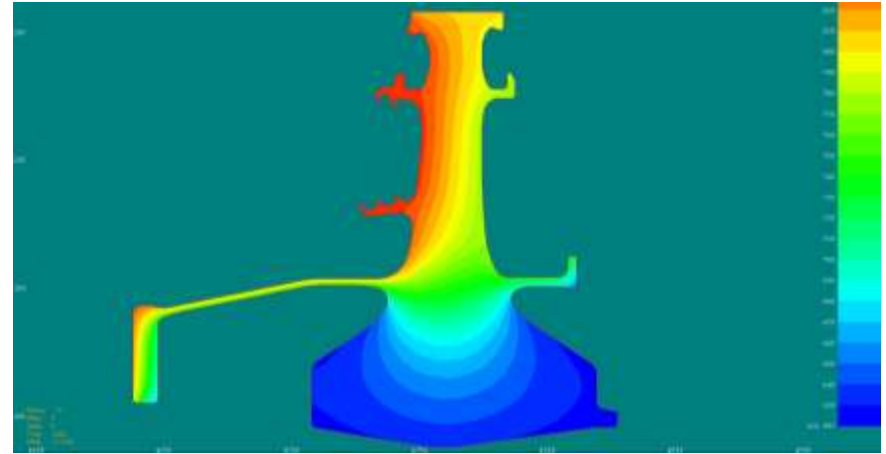
- **Dynamic modelling of complex system**
 - Validation & verification
 - Multi-system optimisation
- **Design of complex systems**
 - Model-to-Code on development hardware platforms
- **Electrical Systems**
 - System design, power system analysis, transient studies.



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MATLAB uses in Electrical and Controls

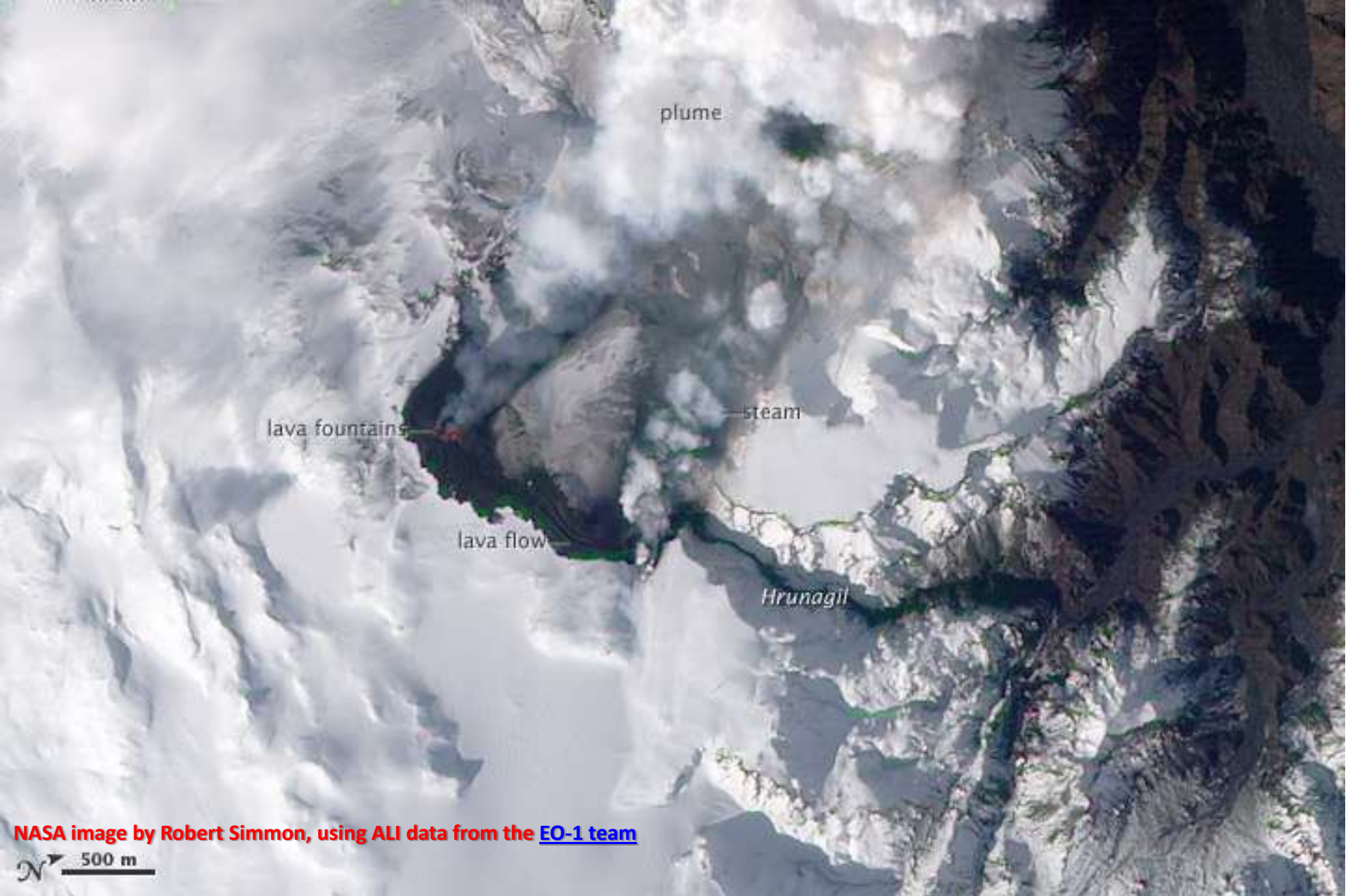
- **Control laws design**
 - Performance optimisation
- **Software packages integration**
 - MSL, SPAN/Simulink
 - Multi-platform application
- **Data processing and conditioning**





Photograph by Orsolya and Erlend Haarberg – National Geographic





NASA image by Robert Simmon, using [ALI data from the EO-1 team](#)

500 m

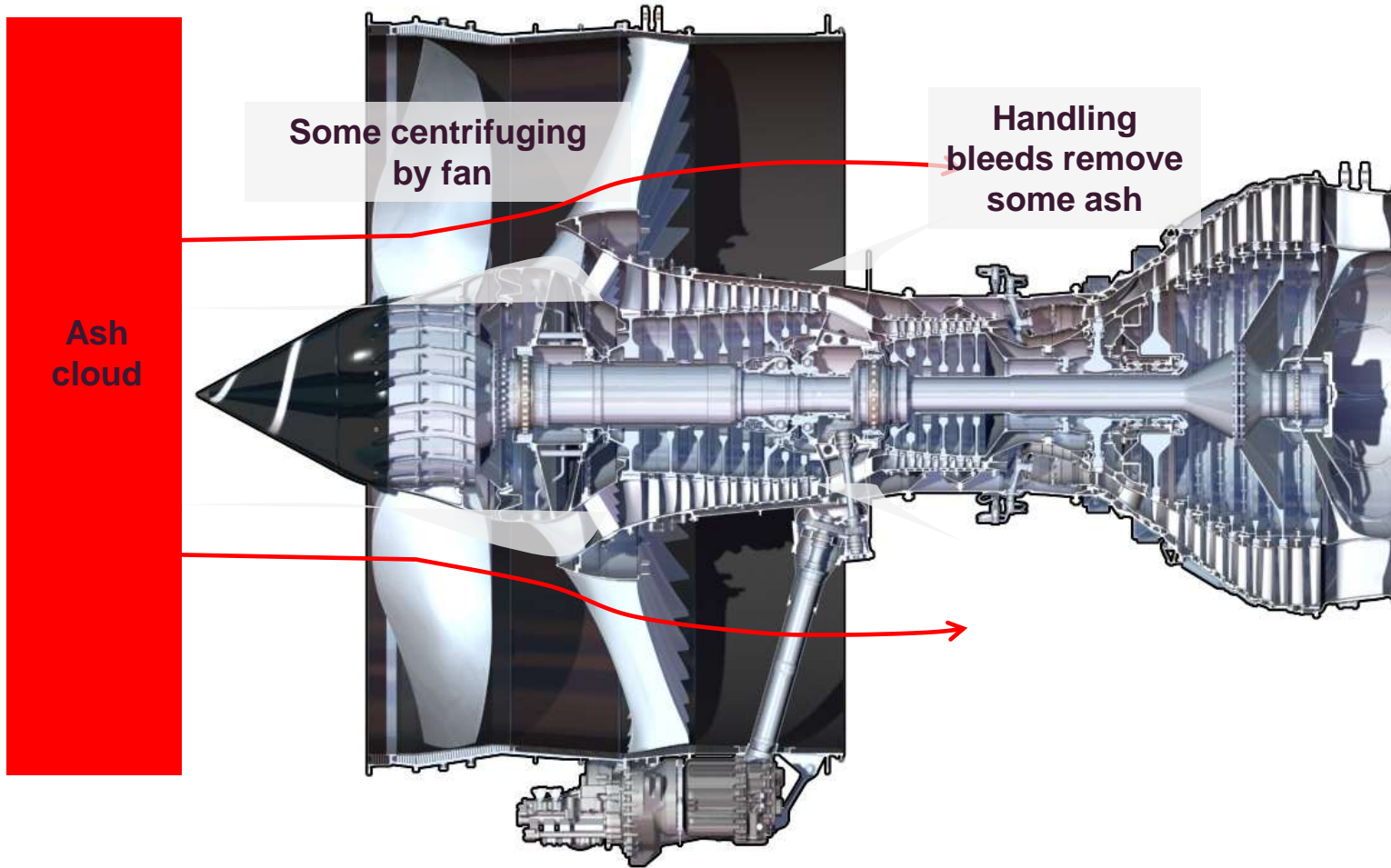


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GLASGOW AIRPORT
CLOSED VOLCANIC
ASH ISSUE

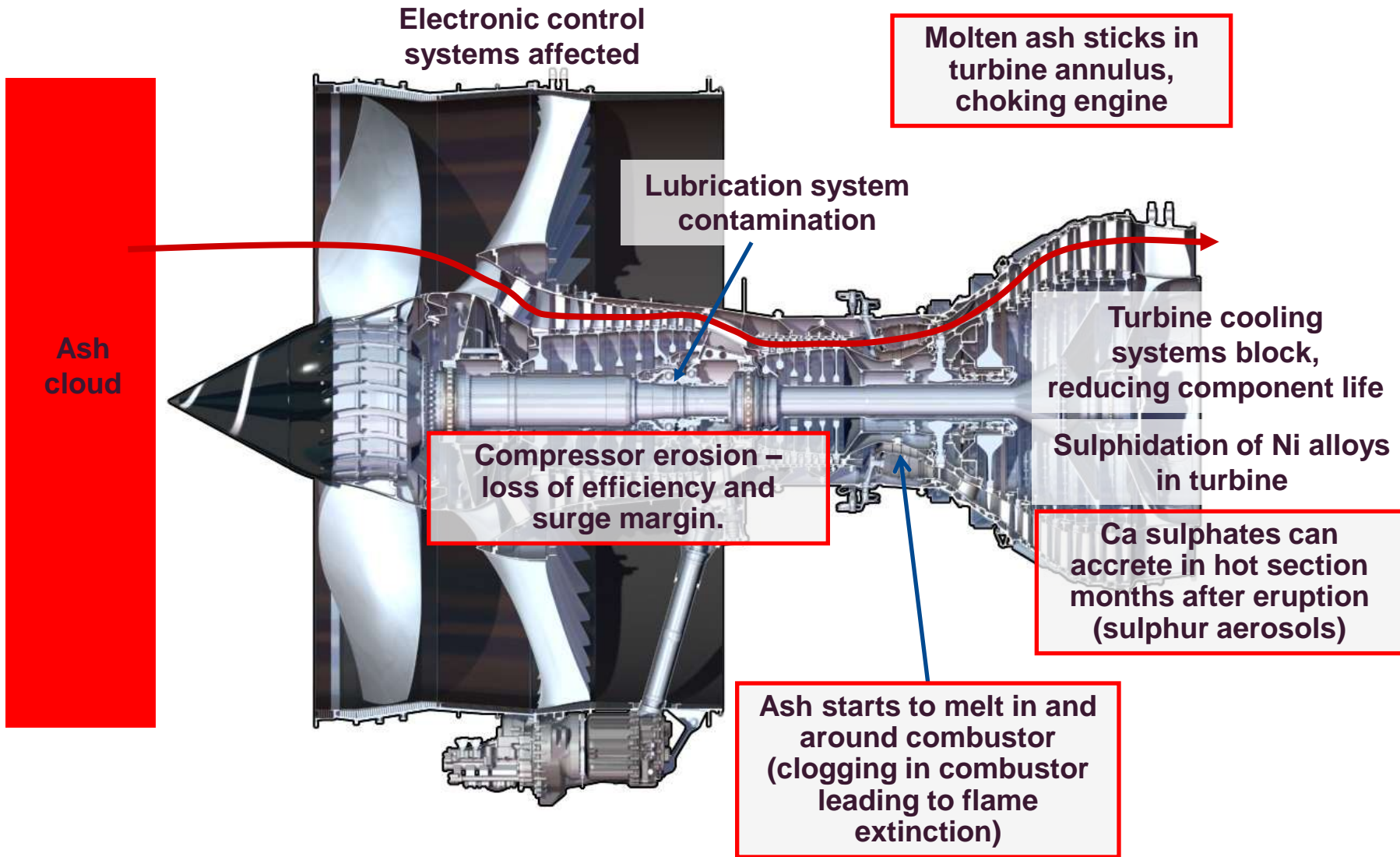
Photo by Craig Murphy

Encountering An Ash Cloud

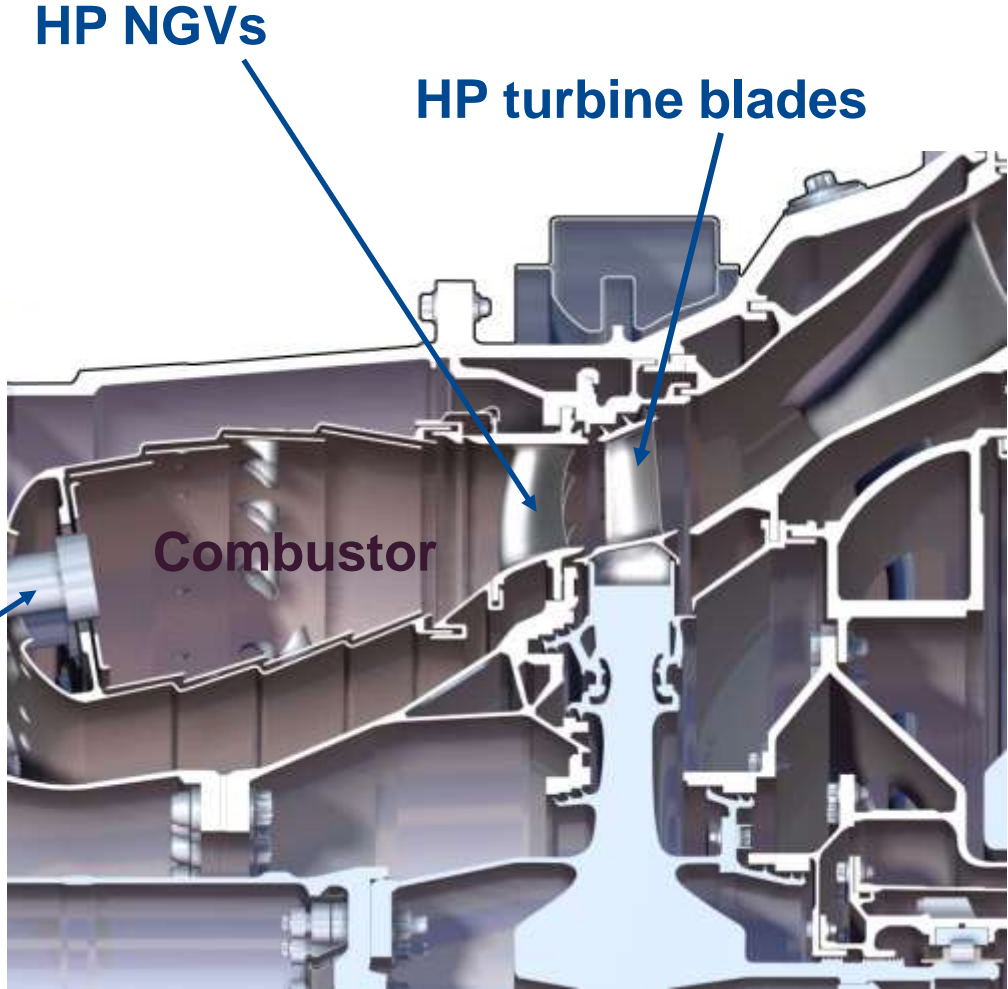
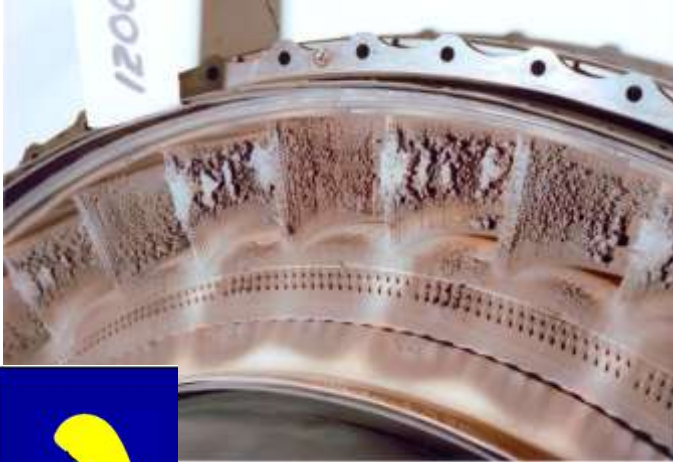


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VA Gas Turbine Engine Damage Mechanisms



Engine Damage Mechanism



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Ash Hazard - Factors

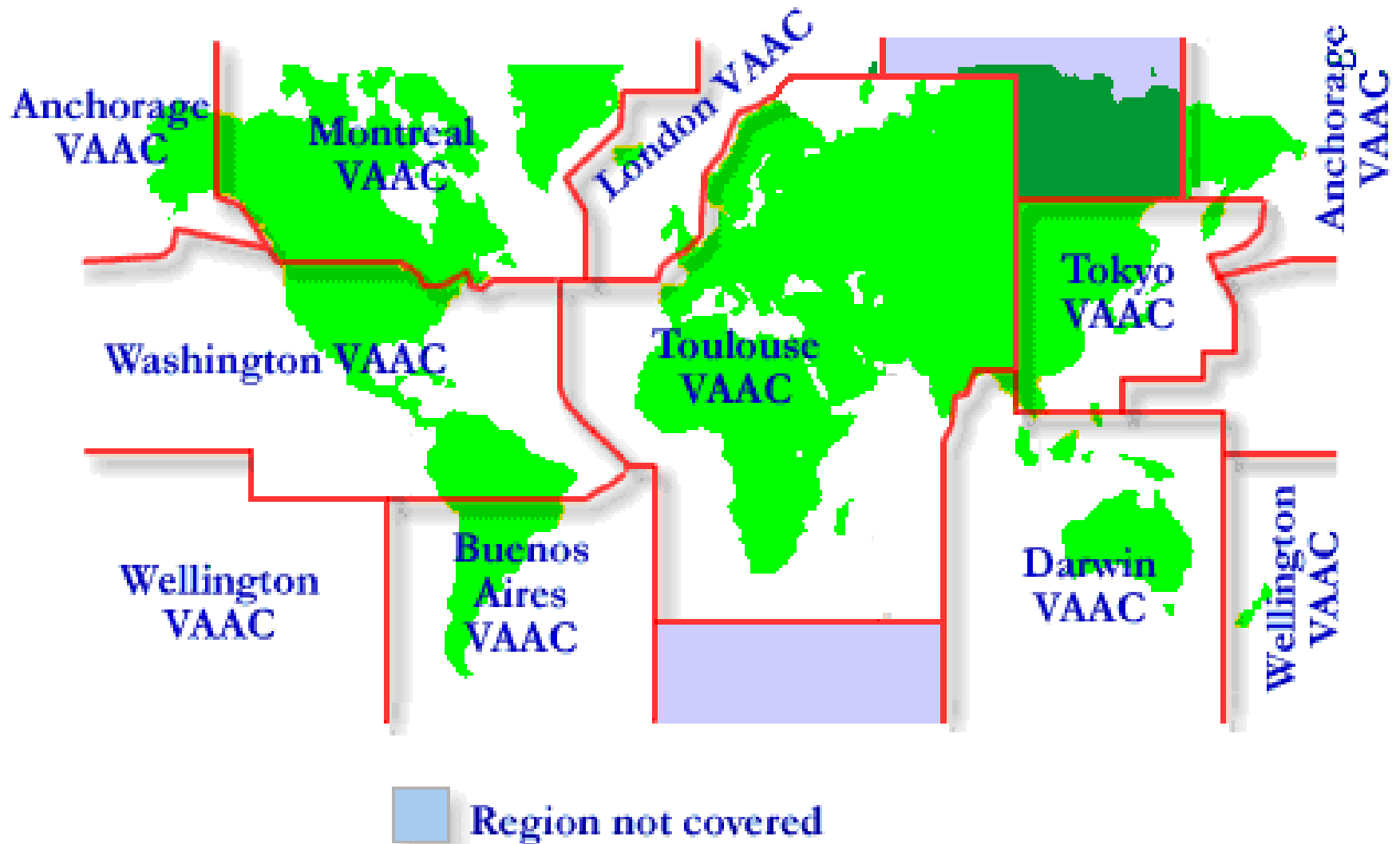


DC-10 at Cubi Point Naval Air Station, Philippines



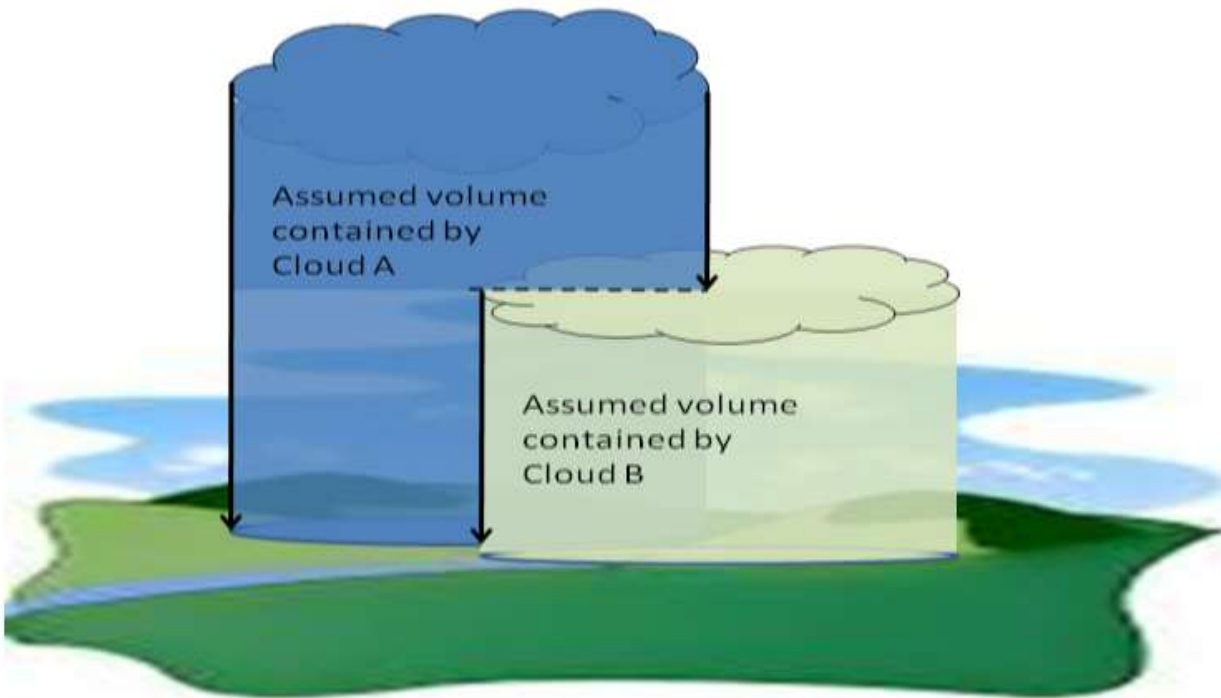
Eyjafjallajokull 2010. Photo: Brynjar Gauti,

Monitoring Solution – VAAC global coverage



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Monitoring Solution – VAAC Data

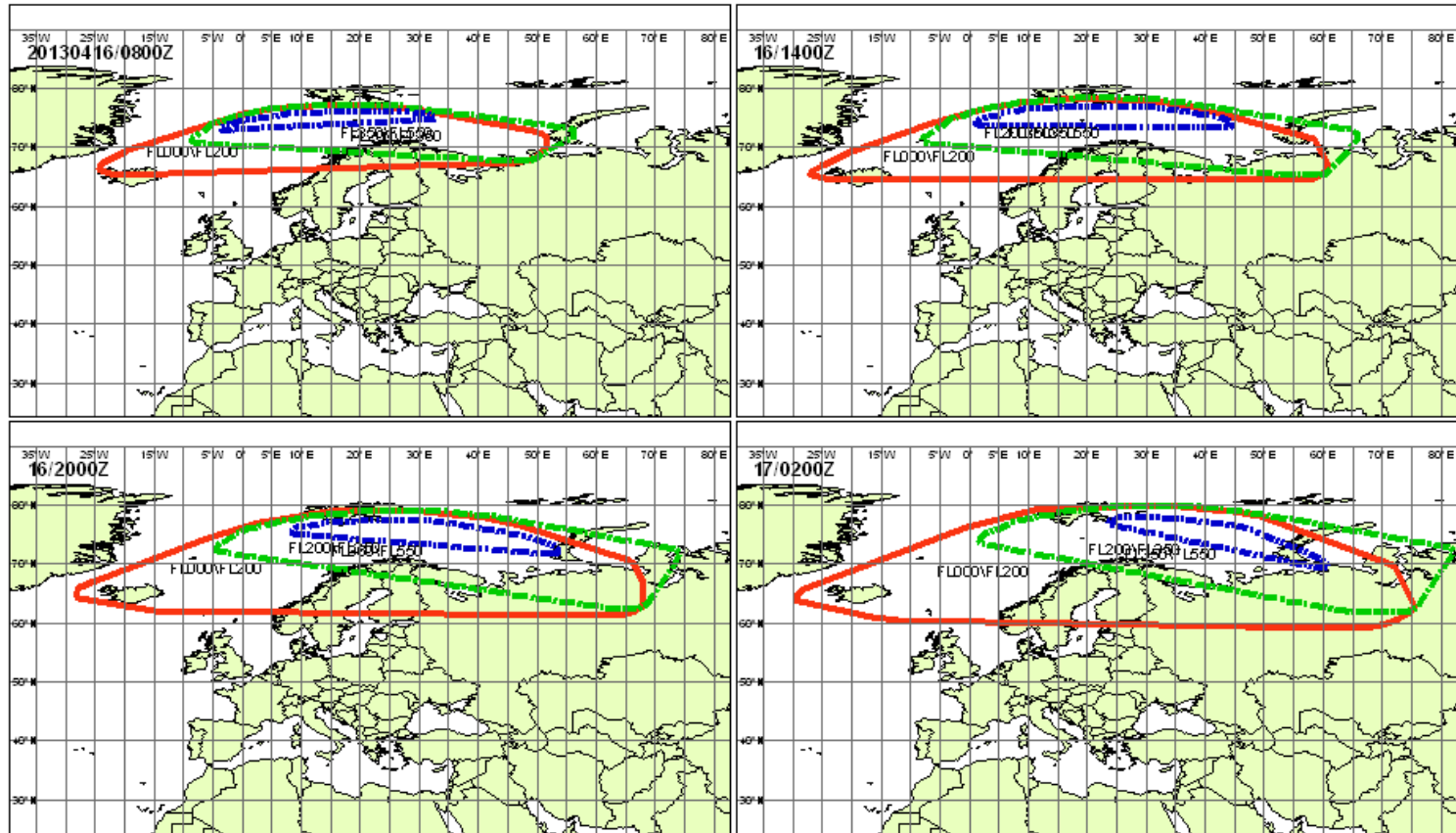


VOLCANO: EYJAFJALLAJOKULL 1702-02	
PSN: N6338 W01937	
VOLCANIC ASH CONCENTRATION: RED	
MODEL RUN: 20100519/0600	
VALIDITY TIME: 20100519/0600	
FLIGHT LEVEL: SFC/FL200	
REMARKS: MODEL DATA	
Poly 1	
N451118	E0051914
"	"
N451118	E0051914
Poly 2	
"	"
"	"
"	"
"	"
"	"
Poly n	

Volcanic Ash Advisory from London

Volcanic Ash Graphic (VAG)

FL000 to FL200  FL200 to FL350  FL350 to FL550 

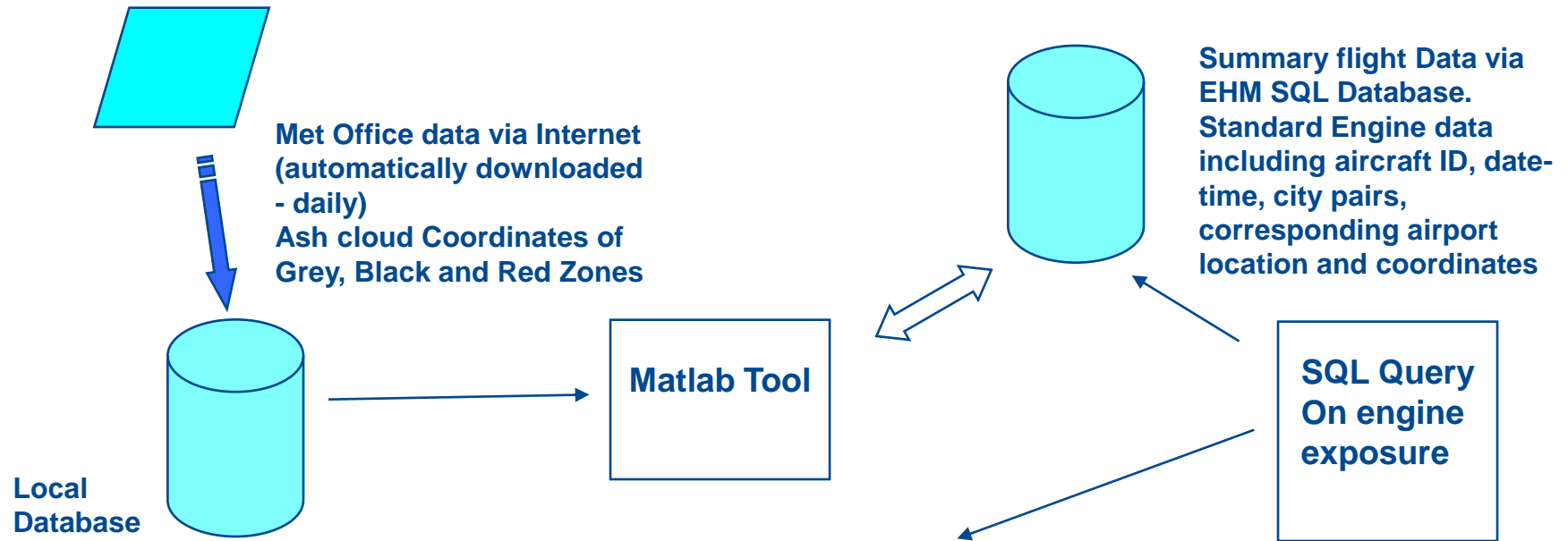


VA ADVISORY
 DTG: 20130416/0800
 VAAC: LONDON
 VOLCANO: HEKLA 1702-07
 VOLCANO_NO: 1702-07
 PSN: N6359 W01942
 AREA: ICELAND

SUMMIT_ELEV: 1491M
 ADVISORY_NO: 2013/000
 INFO_SOURCE: ICELAND MET OFFICE
 COLOUR_CODE: UNKNOWN
 ERUPTION_DETAILS: THIS IS A TEST THIS IS A
 TEST PLEASE IGNORE

RMK: THIS IS A TEST THIS IS A TEST PLEASE
 IGNORE THIS IS A TEST THIS IS A TEST PLEASE
 IGNORE THIS IS A TEST THIS IS A TEST PLEASE
 IGNORE
 NEXT_ADVISORY: NO FURTHER ADVISORIES
 WMO_SUFFIX: 01

Monitoring Solution – Data-flow



ESN	ACID	CITYPRFF	From	From Lat	From Lon	CITYPRCT	To	
1	41179	935 EDOF	Frankfurt	N6001	E00832	CYYC	Calg	
2	41192	935 EDOF	Frankfurt	N6001	E00832	CYYC	Calg	
3	41192	935 EDOF	Frankfurt	N6001	E00832	CYYC	Calg	
4	41179	935 EDOF	Frankfurt	N6001	E00832	CYYC	Calg	
5	41193	935 EDOF	Frankfurt	N6001	E00832	CYYC	Calg	
6	41179	935 EDOF	Frankfurt	N6001	E00832	CYYC	Calg	
7	41193	935 EDOF	Frankfurt	N6001	E00832	CYYC	Calg	
8	41193	935 EDOF	Frankfurt	N6001	E00832	CYYC	Calg	
9	41088	937 LFPG	Paris	N4900	E02035	CYYZ	Term	
10	41102	937 LFPG	Paris	N4900	E02035	CYYZ	Term	
11	41662	A40 DB	EDDF	Frankfurt	N6001	E00832	OMMS	See
12	41662	A40 DB	EDDF	Frankfurt	N6001	E00832	OMMS	See
13	41667	A40 DO	LFPG	Paris	N4900	E02035	OMMS	See
14	41667	A40 DO	LFPG	Paris	N4900	E02035	OMMS	See
15	41730	A40 DE	EGLL	London	N5128	W00027	OMMS	See
16	41731	A40 DE	EGLL	London	N5128	W00027	OMMS	See
17	41237	A6-EAH	LFMN	Nice	N4339	E00712	OMCB	Dat
18	41265	A6-EAH	LFMN	Nice	N4339	E00712	OMCB	Dat
19	41190	A6-EAJ	LMVL	Malta	N3551	E01426	LCLK	Lam
20	41215	A6-EAJ	LMVL	Malta	N3551	E01426	LCLK	Lam
21	41127	A6-EHQ	EGNT	Newcastle	N5502	W00141	OMCB	Dat

Map interface showing engine exposure data over Europe. The map displays various engine exposure zones in red and green. The right-hand panel shows settings for 'Route Interactions ESN' and 'Route Engine Swath Number Attached: 1500'. Below the map, there are controls for 'CDV file', 'SQL query', and 'GSPQAR routes'.

Future of Air Travel could be Electric



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And finally, Voice of the Customer.....

- **Although MATLAB is used throughout Rolls-Royce it has to continue to earn its place.....**
 - Cost of ownership is not just licenses, but includes the time to develop new routines, deb-bug, execute, interpreting, configuration management, training and updating people. MATLAB is there to save engineering costs, if it doesn't save us money in product development we will change;
 - People - Graduates who use MATLAB products during their studies, come into Rolls-Royce with varying levels of proficiency. It would be nice to have a future state where all students are taught a basic level of proficiency that can be built upon when in employment.
 - Business Critical Decisions (technical and commercial) are often supported by modelling scenarios. The providence of the model must meet the level of criticality of the decision. With known levels of accuracy and limitations of the model.
 - Integration with other modelling tools and Model Based Systems Engineering toolsets incorporating SysML is critical to helping Rolls-Royce remain competitive. We will continue to push for integration, MATLAB is not a universal tool for us, but part of a total suite of modelling and simulation tools..



Questions & Answers



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