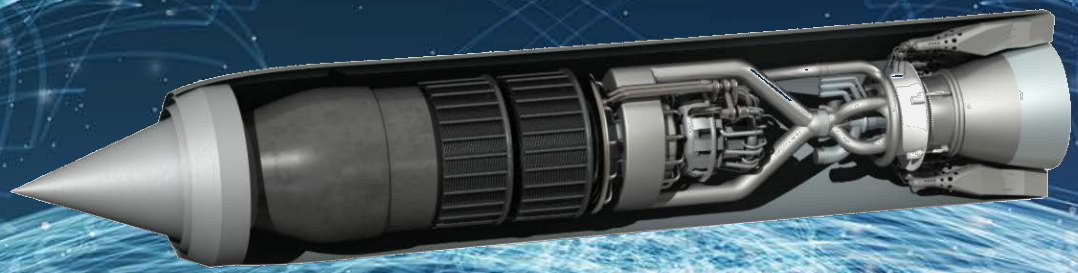
REACTION ENGINES

SABRE

FOR HYPERSONIC & SPACE ACCESS PLATFORMS

Mark Thomas
Chief Executive Officer

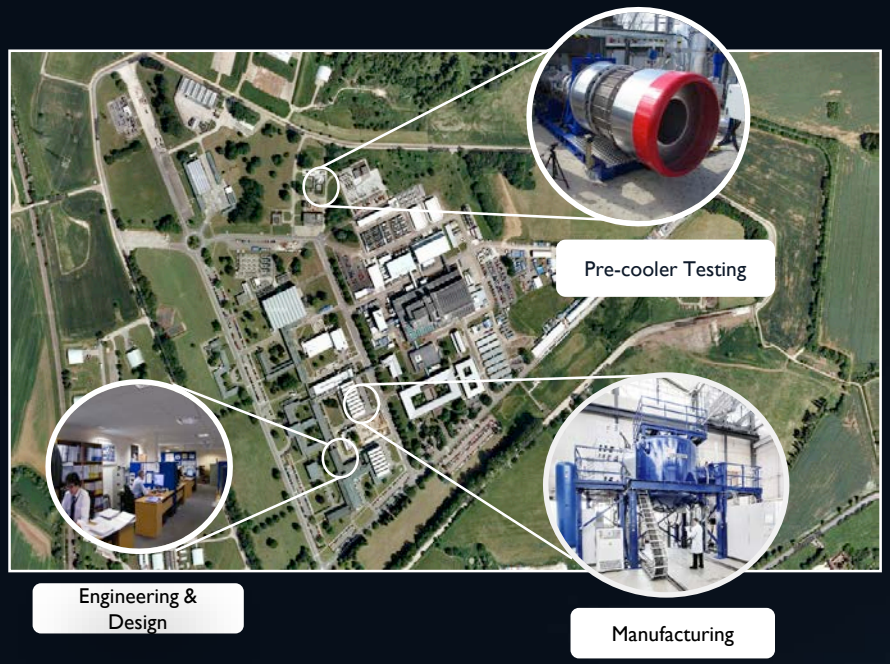


12th Appleton Space Conference
RAL Space, 1st December 2016

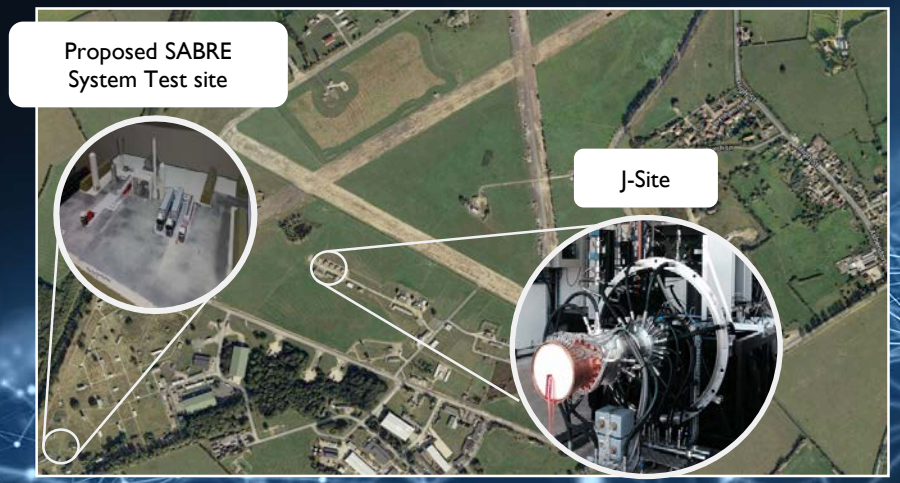
Reaction Engines Limited

- **REL's primary focus** is developing SABRE, a new class of aerospace propulsion, and its enabling technologies (notably, very advanced heat exchangers).
- **Grown** from 72 employees to 110 over last 12 months and continuing to hire.
- **Skills across aerospace disciplines,** from design & analysis through to manufacture and testing
- **2 sites: -**
  - **Culham Science Centre, Oxfordshire** – HQ, Design Offices, Lab Testing, Manufacturing, Heat Exchanger and Lab testing
  - **Didcot Park, Oxfordshire** – Precision Manufacturing and Metal Fabrication
- **Rocket testing** undertaken at Westcott Venture Park, Buckinghamshire

REL HQ
Culham, Oxfordshire, UK



Rocket Test Site
Westcott, Buckinghamshire, UK

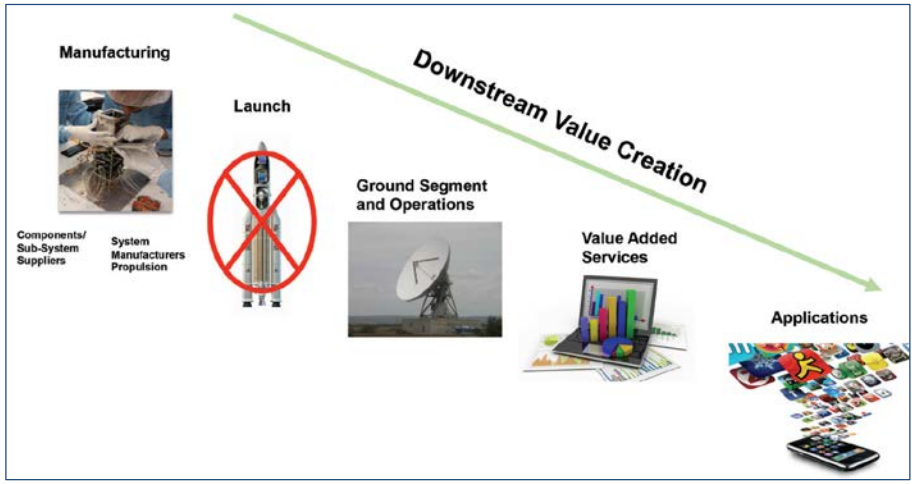


* Current testing is outsourced

REL Manufacturing
Didcot Park, Oxfordshire, UK

Space Value Chain and Growth

- Launch underpins the space industry
- Reduced satellite costs, size and lead times are opening up new business opportunities
- Low launch availability and high launch costs restrict space innovation and growth
- Significant new opportunities with improved space launch and the UK is playing a role…



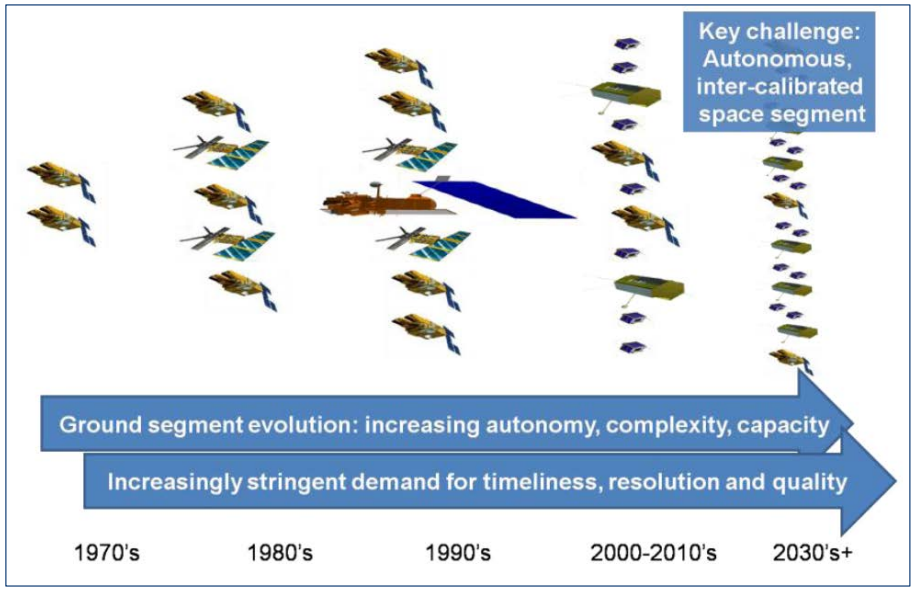


Image credits: Space Growth Partnership, Space Innovation and Growth Team

Launch Vehicles – Propelled by Rocket Engines

Rocket Characteristics:

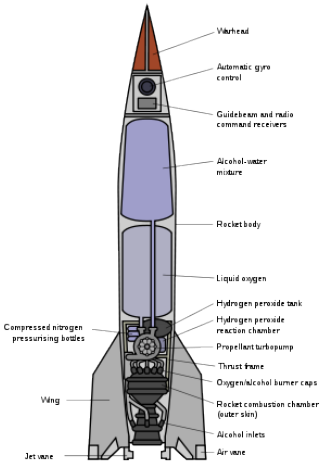
- Vertical Take-off
- High Thrust
- Accelerate to Orbital Speeds

Need to Carry:

- Payload (e.g. satellite)
- All their Fuel and Oxygen
- Vehicle 'Dry' Structure

Typically require significant launch infrastructure & resources.

Launch Vehicles – Propelled by Rocket Engines

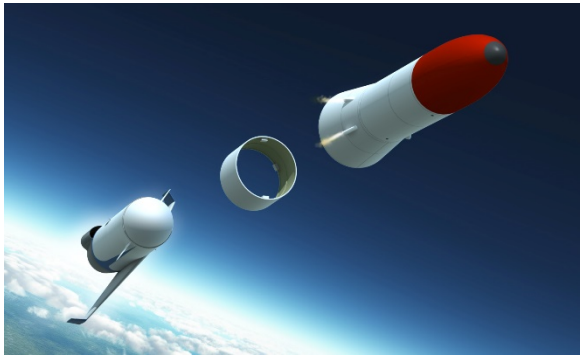


- The rocket has carried us to great places… however current launchers are:
  - **Expensive** (~$10,000/kg)
  - Have **Long Lead Times** (years to build, months to prepare)
  - **Unreliable** (2-5% of launches fail)
- Outcome:
  - **Only 50-100 launches/year** globally
  - **Restricts** economic opportunity
  - Life **confined** to Earth

Launch Vehicles – Evolution and Innovation

Evolution of **launch vehicle configurations** to drive improvements in cost via reusability:

- Methodology includes using conventional rocket propulsion with **vertical take-off and landing** reusable first stage
- Allows **reduction in launch cost** by reusing first stage
- Option **being pursued** e.g. by SpaceX and Blue Origin
- Still issues with improving **reliability**, inability to **abort** a mission with the payload (once launched committed), **heavy vehicle** due to high fuel consumption of the rocket engine



Alternative approach is to **Innovate…**

Spaceplane Innovation – British heritage

Blue Streak & Black Arrow

BAC Mustard Study

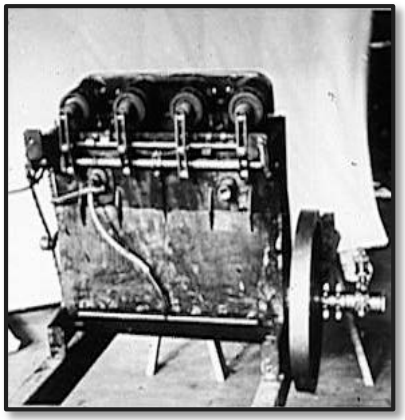
Image credits: BAE Systems and Rolls-Royce plc

Propulsion: Drives New Vehicle Capabilities

- Innovation in propulsion leads to step changes in transport capability

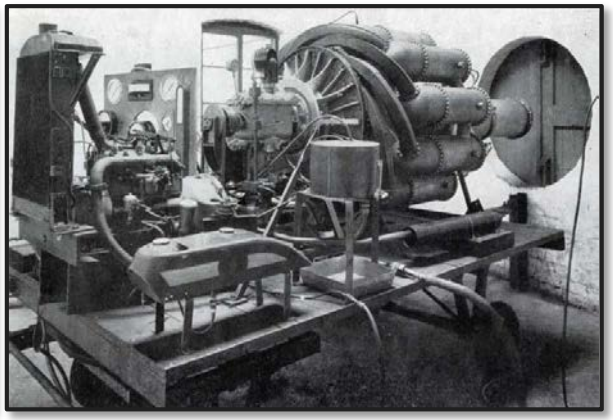
- Reaction Engines Ltd is focused on achieving a breakthrough in high speed aerospace propulsion - the SABRE class engine – to enable revolutionary launch capability

Fundamental Breakthroughs In Propulsion



1903

First Flight Piston Engine



1937

First Jet Engine Demonstration

1942

First V2 Liquid Rocket Flight

2012

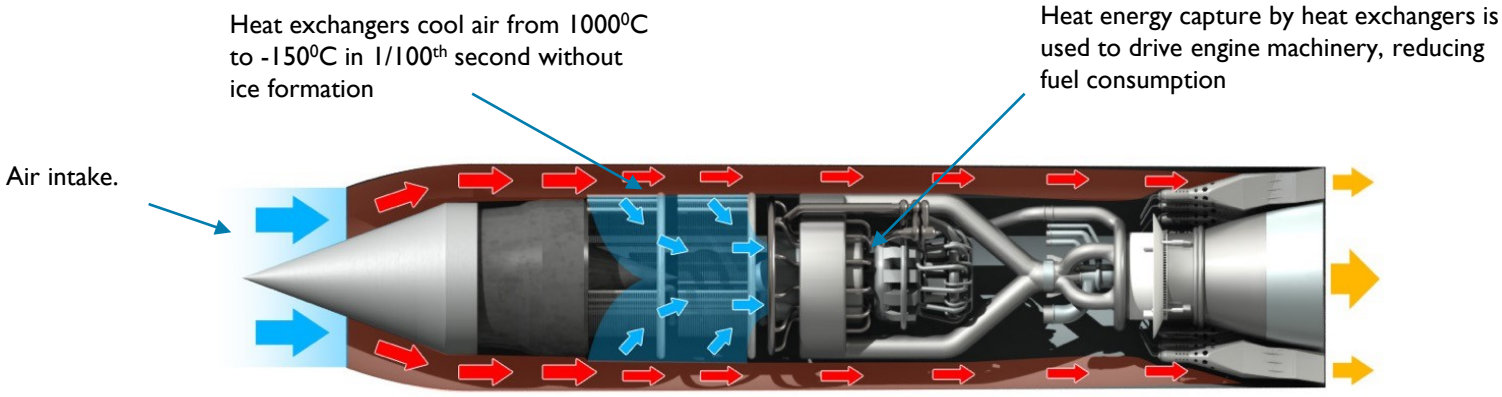
First SABRE Engine precooler Demonstration

SABRE - A New Engine Class

- **S**ynergetic **A**ir-**B**reathing **R**ocket **E**ngine is a **new hypersonic and space access** propulsion solution being developed by REL
- SABRE **air-breathes from Mach 0 to 5+,** then can **transition to rocket mode** for higher speeds and altitude
- SABRE **feasibility confirmed by AFRL and ESA** after extensive assessments
- In the last decade, privately funded **demonstration** of key SABRE technology **has greatly increased credibility**
- Based on this technical success, **UK government and BAE Systems are investing £60m and £20m** respectively towards a SABRE engine core system test
- SABRE and its enabling technologies are **unique to Reaction Engines**

SABRE Basics

SABRE engines use advanced heat exchangers to double the air breathing speed of jet engine technology and significantly reduce fuel consumption relative to conventional rockets.



Heat Exchangers in SABRE Engines:

1: Cool

Cool the hot incoming air allowing jet propulsion to operate at speeds twice as fast as current technology i.e. above Mach 5

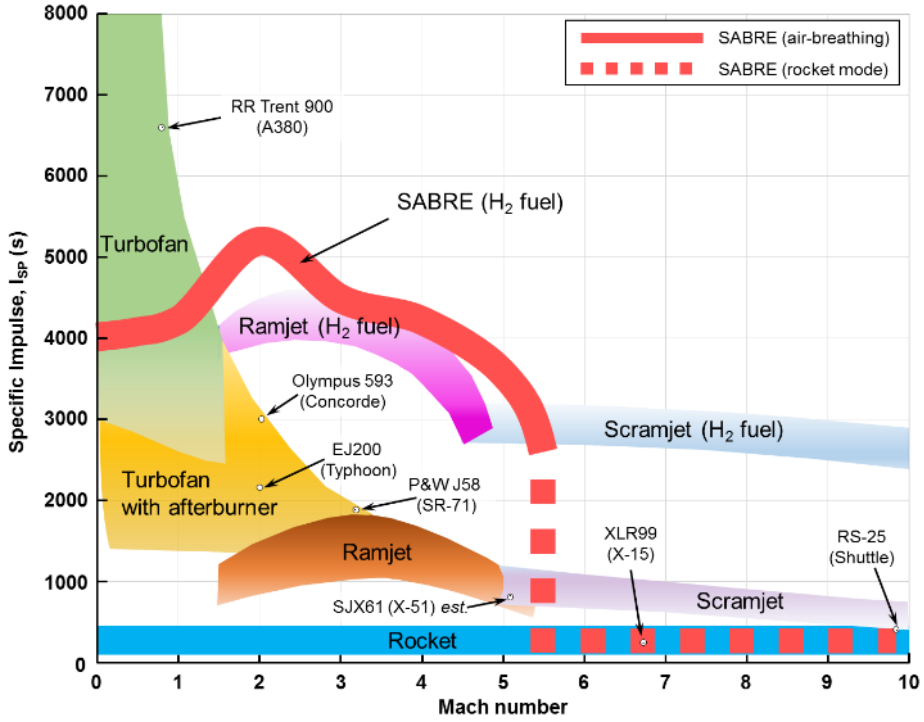
2: Regenerate

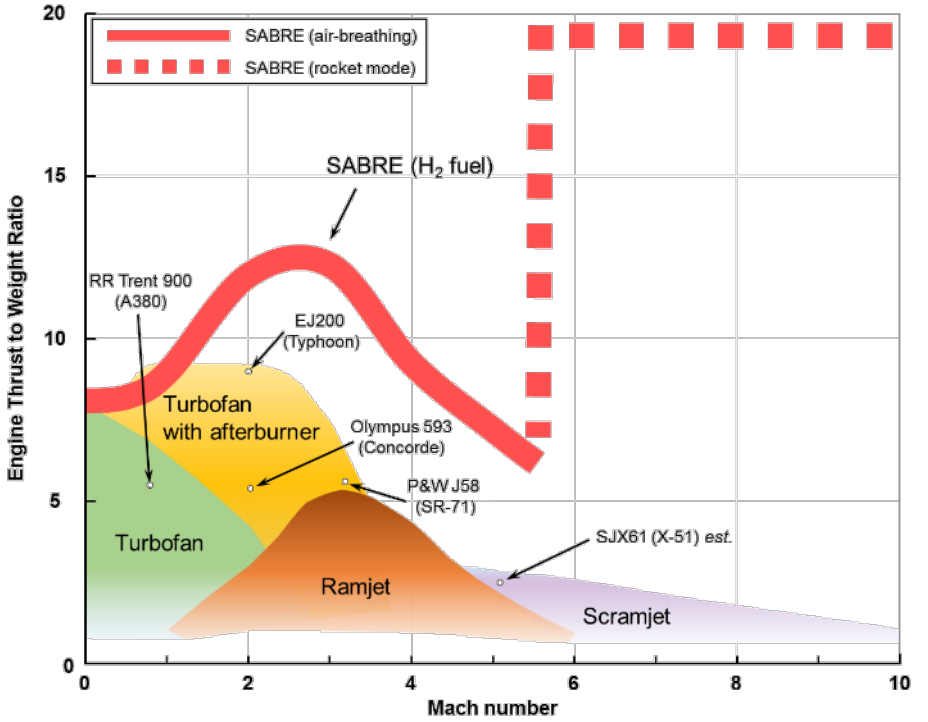
Re-inject the heat captured at the hot intake back into the engine to drive components, significantly reducing fuel consumption

3: Integrate

Allow jet propulsion to be integrated with rocket propulsion creating an engine class capable of high Mach atmospheric and space flight

SABRE: New Combination of Thrust, Weight and Fuel Consumption





…a Two Stage To Orbit system based on SABRE-class propulsion **may be game-changing**.

SABRE System Demonstration

Ground-based demonstration for low cost, rapid technology maturation

Heat Exchanger	SABRE Core System	Combustion Chambers & Nozzles
High temp air simulating high speed flight can be produced using existing ground-based facilities	The core system sees a constant inlet temperature and pressure from Mach 0 to 5 Allows core system to be tested on the ground	Conventional ground-based development and testing

SABRE Space Access Utility

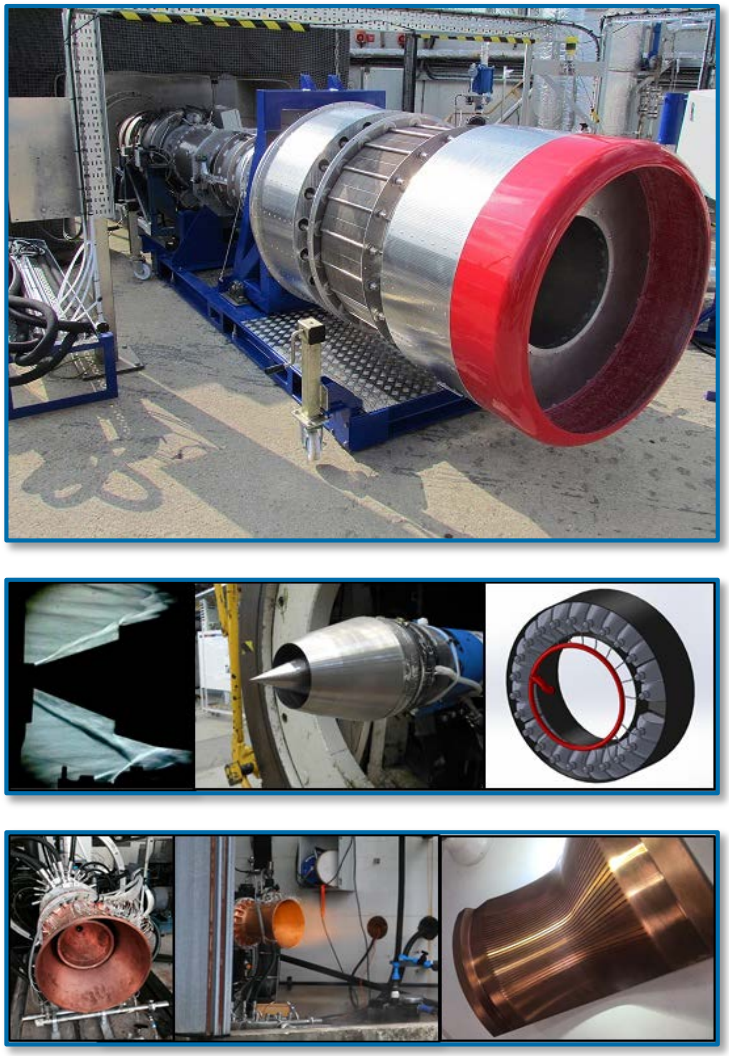
- **Responsive, high cadence operation**
- **Low cost, highly reusable system**

KEY DIFFERENTIATORS:

- Air breathing capability will enable **smaller and more capable launch systems** through reduced propellant load and efficient air breathing flight.
- SABRE class applicable in either **Two Stage or Single Stage** architectures.
- System performance enables horizontal takeoff & landing operations which **reduce cost, infrastructure, and operations timelines**.
- **Increased system reusability** achievable for TSTO systems compared to all-rocket systems.

Summary

- Current space launch limits growth opportunities
- Breakthrough propulsion is a viable path to revolutionary space access capability– SABRE
- SABRE is under development at REL, in partnership with investors, government and industry
- UK is at the forefront of a next generation space launch and high speed propulsion system!



Thank You