# 'Windows of opportunity' for global leadership in key emerging technologies:

The case for 'disruptive innovation laboratories' working at the interface of scientific discovery and technology development

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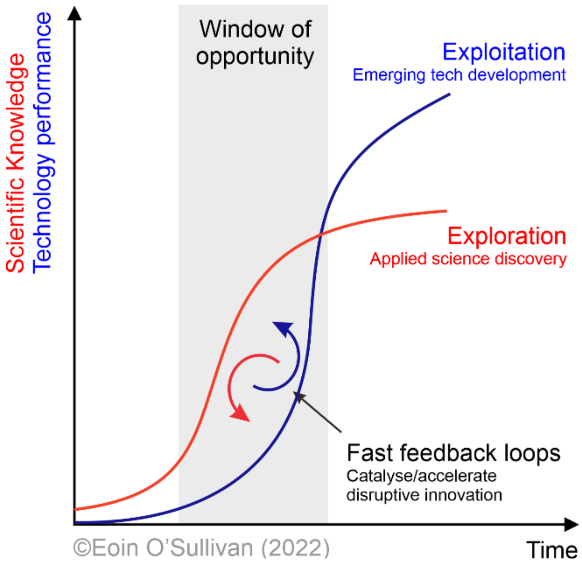
## Overview

The UK has a world leading university research base, an effective network of applied R&D Catapult centres, and several leading R&D-intensive industrial/academic ecosystems. In this paper, however, we argue that there is an important gap in the UK research and innovation landscape. In particular, we make the case for a model of 'disruptive innovation laboratories' which bring together a critical mass of highly talented people with the right skills, tools, culture and environment to work effectively at the interface of scientific discovery and engineering development. These laboratories would target critical early stages in the lifecycles of disruptive technologies, where there are 'windows of opportunity' to translate national scientific strengths into global technological and industrial leadership.

## The gap in the RD&I landscape

Within the current landscape, translation from university to industry works effectively when scientific disciplines are relatively mature, when technology development pathways are relatively well-understood, and when appropriate engineering tools and innovation infrastructures are established.

The UK RD&I landscape is, however, less effective at supporting critical early stages of an emerging technology's lifecycle when the exploration and exploitation phases are strongly coupled. This is the phase when early engineering efforts may have begun but significant scientific discovery continues and promises significant potential for performance improvements. The functionality of the new technology (the scientific principles underpinning its behaviour, the limits of its performance, etc) are still being explored, but so too are the opportunities for application.




***'Windows of opportunity'* for disruptive innovation - scientific and technology strongly coupled**

At this moment it becomes possible to catalyse disruptive advances – 'windows of opportunity' for countries to gain (or lose) leadership in important technology domains. These are moments when the UK has opportunity to build whole new industries, as it did for the modern ship in the 1830s, the steam turbine in the 1880s, and the Whittle Jet engine in the 1940s.

## Disruptive innovation laboratories

History has shown us that such labs are extremely rare (i.e. Bell Labs, the Laboratory for Molecular Biology in Cambridge, and the Janilia Research Campus) and their culture notoriously difficult to recreate. We argue that the key characteristics of such labs, which underpin their ability to support fast feedback loops between discovery and development phases are[1-14]:

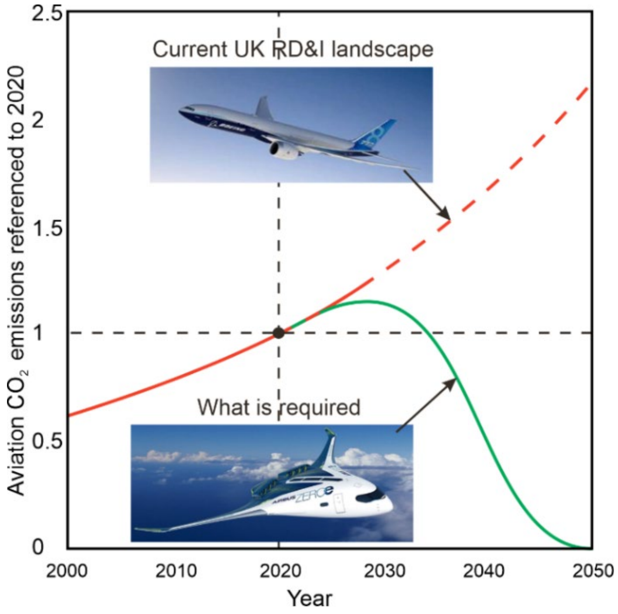
- **The right mix of people**: The skills necessary to play across disciplinary and developmental domains.
- **The right tools**: The ability to reinvent the tools/testbeds necessary for both science and technology.
- **The right culture**: An 'open door' mindset, interested in both exploration and exploitation.
- **The right environment**: An environment which facilitates rapid feedback between science and technology.

It is important to understand how difficult it has been historically to create such labs. It is therefore important that the UK only invests in disruptive innovation laboratories in technology networks which have already exhibited this behaviour over a sustained period of time. The characteristics are discussed in more detail (illustrated with examples from Cambridge's Whittle Laboratory) in the following sections.

## Whittle Laboratory – A disruptive innovation laboratory for zero emission flight

The aviation sector has been disrupted by the race to achieve zero emission flight. A number of emerging zero emission technologies (e.g. battery electric, fuel cells and advanced hydrogen gas turbines) are at a critical early stage of development where their exploration phase (fundamental concept studies and scientific developments) and their exploitation phase (industrial demonstration and application) are being undertaken in parallel. The aerospace RD&I landscape is ill prepared to take on this challenge. Stable for over 50 years it is highly siloed. Over the last 10 years the Whittle Laboratory and its industrial network has prototyped, the key characteristics (people, tools, culture, and environment) required to introduce fast feedback into the aerospace RD&I landscape. Without such a disruptive innovation laboratory the sector will not reach net zero by 2050. Illustrations of each characteristic follow.

**Whittle technology network -** 50 years ago the Whittle Lab was set up by the Cambridge team who with Frank Whittle invented the jet engine, as a way of making sure the UK developed the technologies which underpinned the emerging jet age. Along with its global industrial network (Rolls-Royce, Mitsubishi, Siemens amongst others) the Whittle has become the world's leading technology network in the field, having developed and translated hundreds of technologies, won over a hundred international awards (including the American Society of Mechanical Engineers highest honour a record 15 times) and in 2018 brought in 9.5% of the University of Cambridge's industrial income.




***Limitation of the current aerospace RD&I***

### The right mix of people

Central to a disruptive innovation laboratory is the range of skills necessary to play across disciplinary and developmental domains. In the Whittle Laboratory this is embodied by the 'tea table', famous in the field, for the place where industrial designers and academics, have come together with a broad enough range of skills, to reinvent the field.


***Aviation RD&I technology siloes***

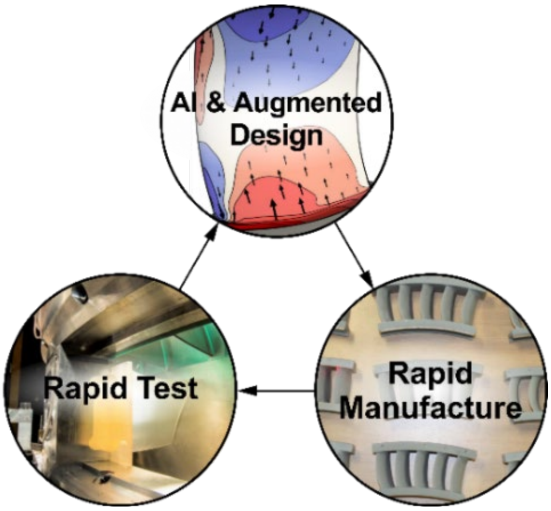
**Example** – In 2000 Rolls-Royce had major problems with their Industrial Trent engine. Despite a large internal Rolls-Royce team working on the problem, it was solved by Dr Ivor Day, from the Whittle and Dr Chris Freeman from Rolls-Royce, talking around the Whittle tea table, followed up with a series of experiments in the lab. The solution was found by rethinking the underlying physics in a completely new way. Sir Ralph Robins, the Chairman, was quoted in the Guardian[15], in August 2000, as saying that the '*company had been forced to "go back to basic physics". A breakthrough, which had been confirmed only in the last couple of weeks, offered tremendous opportunities.'* The Industrial Trent problems cost Rolls-Royce around £750m, and this would have been much more if it hadn't had been for the right mix of people around the Whittle tea table.

The race to zero emission aviation requires a different range of skills than has historically been required by aerospace RD&I. Analysis at the Whittle Laboratory[16] has shown that over 80% of future zero emission aviation technologies are highly multidisciplinary in nature, meaning that the future tea table must contain a wider range of disciplines (e.g. chemical engineering, electrical engineering, systems engineers) and the skills to demonstrate these technologies at speed. A famous example of the importance of getting the right mix of people in one location is the Bell Labs team, made up of solid-state physicists, physical chemists, metallurgists, and engineers, who co-developed the first semiconductor transistor.

### The right tools

Central to a disruptive innovation laboratory is the ability to reinvent the tools, methods and testbeds which are necessary to undertaken new science and to demonstrate new technologies. The tools required are often not available off the shelf and therefore disruptive innovation laboratories must not only work on the technologies themselves but also on the development of the tools that develop those technologies. In particular, the tools may need to be more flexible, tackle more complex problems, work at faster speeds, or be able to explore new physical principles.

**Example** – The Whittle Laboratory led the development of Computational Fluid Dynamic (CFD) methods for jet engine design. In the 1970s the Whittle design methods were already commonly used throughout the global industry. In 1974 Prof John Denton, and a few years later Prof Bill Dawes, from the Whittle, pioneered the development of the CFD tools used for the design of jet engines, power stations, and other turbomachinery. By the mid-1980s nearly all the world's industry in the field, around 40 companies, used Denton's and Dawe's codes. These tools allowed industrial designers to design better products faster. The inhouse R&D departments in these companies simply did not have the capability to reinvent the tools in the way that the Whittle Laboratory was doing.



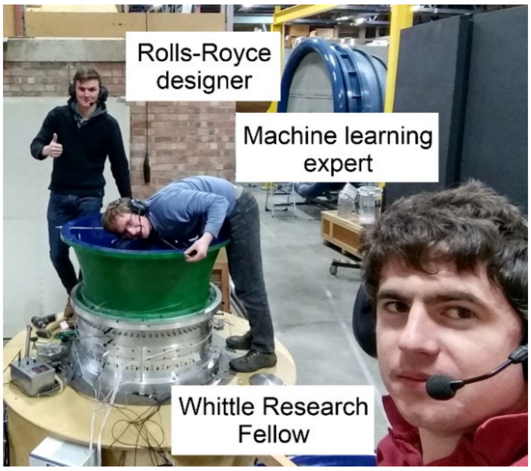
***Rapid Technology Development loop***

Over the last decade the Whittle Lab has focused on reinventing the tools used in the aerospace RD&I process, with the aim of creating fast feedback loops between idea and demonstration. By innovating across the whole technology development process (computational design, manufacture, and testbeds), and drawing on many of the techniques used in the Formula 1 sector, the Rapid Technology Development process has demonstrated a reduction in the time required to take an idea to demonstration of a factor of 100. A formal trial in 2017 in partnership with Rolls-Royce, funded by the Aerospace Technology Institute, showed that a process which in 2005 had taken 2 years, was reduced to less than a week, a time reduction of a factor of 100. (https://www.re-tv.org/articles/reworking-innovation). It should be noted that such reductions in time are only possible in the aerospace sector because of the highly siloed, and sequential nature of the current global RD&I process.

### The right culture

Central to a disruptive innovation laboratory is an 'open door' mindset. There needs to be a culture of interest in other domains, with scientists interested in technology translation and engineers interested in the underlying science. Such a culture has been exhibited by all of the great disruptive innovation laboratories (e.g. Bell Labs, Janelia) and has been central to the success of the Whittle Laboratory and its technology network.

The emergence of a number of new zero emission aviation technologies, all at the critical early stage of development makes creating this culture a priority in aviation. When working in new design spaces where the science and technology translations are occurring in parallel, it is often not clear what the right questions to focus on are. Critical in gaining focus in such situations is an ability for scientists and industrial engineers to understand, and creatively play with each other's ideas and constraints.




***'Open door' mindset***

**Example** – Over 50 years the 'open door' mindset between the Whittle Lab and Rolls-Royce has been key to the successfully linking new science to application. In 2004 Prof Rob Miller, Whittle Lab, was working with Rolls-Royce engineers on the production line. This sparked tests at the Whittle which showed a fundamental sensitivity of the flow to the first 0.5mm of each of the thousands of blades. The findings won the American Society of Mechanical Engineers highest honour in the field. The subsequent changes to the manufacture process are now estimated to save $219m of fuel burn per year and to have reduced $CO_2$ emissions from aviation by 1.1m metric tonnes per year. 20 times the University of Cambridge's Scope 1 and Scope 2 annual emissions.

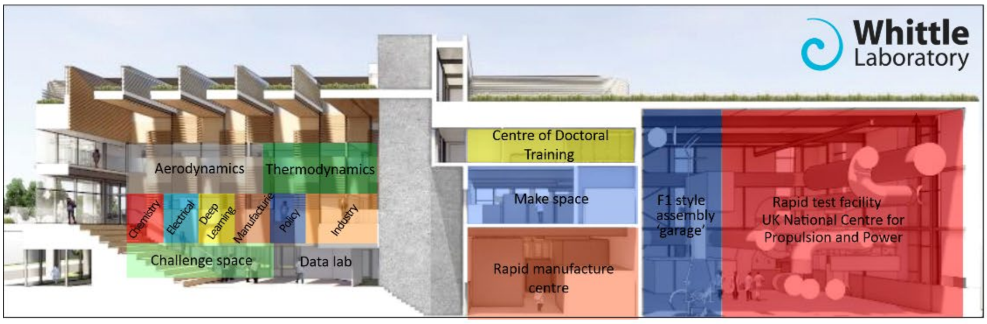
**The right environment**

It is important to keep in mind how difficult it has historically been to produce the characteristics described above. Great disruptive innovation laboratories of the past (e.g. Bell Labs, Janelia) are the exception not the rule. The key is building the right environment which embodies the characteristics discussed above.

**Example -** Mervin Kelly, Director of Bell Labs, had a hands-on involvement in the architectural design of the Murray Hill building. He devised flexible modular rooms promoting connectivity and access between offices, workspaces, and labs. 50 years ago, the Whittle Laboratory was designed along the same principles with spaces connected by multiple routes passing through the tearoom to promote creativity. Embedded industrial offices maximised the random connections between science and application. This created an environment referred to by the former Director of Research & Technology of Rolls-Royce as 'the Whittle Lab magic'.

To ensure that the UK leads the race to achieve zero emission flight the Whittle Laboratory has spent the last four years developing a design for a disruptive innovation laboratory (shown below). The building has been designed as a machine which embodies the characteristics and tools discussed in this document.

50 years ago, the Whittle Laboratory provided the UK with a unique disruptive innovation laboratory capable of exploiting the 'windows of opportunity' provided by the advent of mass jet travel. Today, in a similar way, the new Whittle Laboratory offers the UK the next generation of disruptive innovation laboratory, design to exploit the 'windows of opportunity' created by the international race to achieve zero emission flight.

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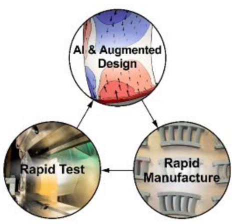


Rolls-Royce SIEMENS MITSUBISHI HEAVY INDUSTRIES dyson BOEING Reaction Engines BLUEBEAR LILIUM

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A version of this paper was submitted to the Sir Paul Nurse '*Independent Review of the UK research, development and innovation organisational landscape*' (Department of Business, Energy & Industrial Strategy, 2022).

https://www.gov.uk/government/publications/research-development-and-innovation-organisational-landscape-an-independent-review