AD-A171 837 AERODYNAMICS RESEARCH AND DEVELOPMENT AT THE ROYAL AIRCRAFT ESTABLISHMENT..(U) OFFICE OF NAVAL RESEARCH LONDON (ENGLAND) L L COBURN 09 JUL 86 ONRL-R-5-86 1/1

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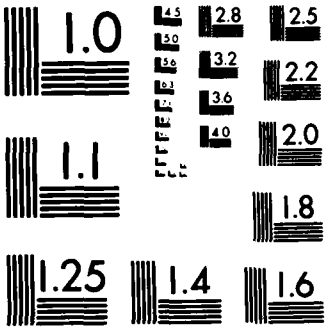

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ONRL Report R-5-86

AD-A171 837

Aerodynamics Research and Development at The Royal Aircraft Establishment (RAE) Farnborough in the UK

CAPT L. Laddie Coburn, USN

July 9, 1986

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SECURITY CLASSIFICATION OF THIS PAGE

AD-A171837

REPORT DOCUMENTATION PAGE

1a. REPORT SECURITY CLASSIFICATION UNCLASSIFIED	1b RESTRICTIVE MARKINGS
2a. SECURITY CLASSIFICATION AUTHORITY	3. DISTRIBUTION/AVAILABILITY OF REPORT
2b. DECLASSIFICATION/DOWNGRADING SCHEDULE	
4. PERFORMING ORGANIZATION REPORT NUMBER(S) R-5-86	5. MONITORING ORGANIZATION REPORT NUMBER(S)
6a. NAME OF PERFORMING ORGANIZATION US Office of Naval Research Branch Office, London 6b. OFFICE SYMBOL (If applicable) ONRL	7a. NAME OF MONITORING ORGANIZATION
6c. ADDRESS (City, State, and ZIP Code) Box 39 FPO, NY 09510	7b. ADDRESS (City, State, and ZIP Code)
8a. NAME OF FUNDING/SPONSORING ORGANIZATION 8b OFFICE SYMBOL (If applicable)	9. PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER
8c. ADDRESS (City, State, and ZIP Code)	10. SOURCE OF FUNDING NUMBERS PROGRAM ELEMENT NO. / PROJECT NO. / TASK NO / WORK UNIT ACCESSION NO.

11. TITLE (Include Security Classification)
Aerodynamics Research and Development at The Royal Aircraft Establishment (RAE) Farnborough in the UK

12. PERSONAL AUTHOR(S)
CAPT L. Laddie Coburn, USN

13a. TYPE OF REPORT	13b. TIME COVERED	14. DATE OF REPORT (Year, Month, Day)	15 PAGE COUNT
Technical	FROM _____ TO _____	9 July 1986	6

16. SUPPLEMENTARY NOTATION

17. COSATI CODES			18. SUBJECT TERMS (Continue on reverse if necessary and identify by block number)
FIELD	GROUP	SUB-GROUP	Aerodynamics Wind tunnels
20	04		
14	02		

19. ABSTRACT (Continue on reverse if necessary and identify by block number)

This report is a survey of the organization and division of functions of the RAE research and development. It includes a summary that compares the UK MoD research establishments with the US Navy laboratories.

20 DISTRIBUTION/AVAILABILITY OF ABSTRACT ☒ UNCLASSIFIED/UNLIMITED ☐ SAME AS RPT ☐ DTIC USERS	21. ABSTRACT SECURITY CLASSIFICATION UNCLASSIFIED
22a NAME OF RESPONSIBLE INDIVIDUAL C.J. Fox	22b TELEPHONE (Include Area Code) (44-1) 409-4340 22c OFFICE SYMBOL 11

DD FORM 1473, 84 MAR 83 APR edition may be used until exhausted
All other editions are obsolete

SECURITY CLASSIFICATION OF THIS PAGE
UNCLASSIFIED

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AERODYNAMICS RESEARCH AND DEVELOPMENT AT THE ROYAL AIRCRAFT ESTABLISHMENT (RAE) FARNBOROUGH IN THE UK

Introduction

The Royal Aircraft Establishment (RAE), with primary locations at Farnborough and Bedford, is the aircraft and aerospace research and development (R&D) establishment of the UK Ministry of Defence (MoD) Procurement Executive (PE). To support the three armed services and the aerospace and aeroengine industries in the UK, the establishment conducts and coordinates research into all aspects of aircraft, weapons, satellites, and aeroengines. Some aspects of radar and avionics R&D which are exceptions are performed at the Royal Signals and Radar Establishment (RSRE), Malvern.

In general terms, the majority of the UK government's basic and applied research for aerospace systems is conducted at RAE Farnborough, while engineering development work leading to experimental flight test and evaluation is conducted at RAE Bedford. At Bedford emphasis is placed on development and flight test of terrain-following systems, flight control systems for future aircraft, flight simulation for aircraft control systems, and advanced cockpit displays and controls. Although both sites have suitable airfields for flying experimental aircraft, the bulk of the experimental flight tests are conducted at Bedford. The remainder of this article will discuss the organization at RAE Farnborough with emphasis on the Aerodynamics Department and its associated research divisions. A summary section will compare aerodynamic R&D at UK research establishments with the US Navy laboratories' R&D efforts.

RAE Research Aerodynamic Research Activities

The RAE research activities are part of the integrated MoD PE research program, under the overall direction of the Controller R&D Establishments, Research and Nuclear (CERN), which directly relate to the research interests of the three UK armed services. The RAE organization within the UK MoD is shown in Figure 1. RAE is the lead establishment for five major components of CERN's research program, as shown below:

Major Field A--air vehicles
aerodynamics
structures and materials
Major Field B--gas turbines
Major Field C--flight systems navigation
Major Field D--space programs
Major Field M--guided and air-launched weapons.

The breakdown of expenditure for extramural research funding within these major fields for RAE is shown in Figure 2. Note that aerodynamics research is about one-third of major field A and is about 5 percent of the total extramural research budget.

Within the RAE management structure the Aerodynamics Department, headed by Dr. L. F. East, is under Deputy Director (A), as shown in Figure 3, who has responsibility for leading research activities for major fields A and B. The overall RAE management structure is provided in Figure 3, and the departmental division research activities under Deputy Director (A) are shown in Figure 4.

Aerodynamics Department Research Activity

Aerodynamics research has been a major activity at RAE since 1909, and the Aerodynamics Department, which is also divided between Farnborough and Bedford, has a worldwide reputation for advanced work in this field. The overall objectives of the department's research are: to advance the state of aerodynamics research, to improve aircraft/weapons performance, to reduce aerospace systems costs, and to enhance flight safety. To accomplish these objectives, the Aerodynamics Department works closely with the UK aircraft and engine industries, other departments in RAE, and other MoD organizations. The department's activities include project support for MoD systems projects as well

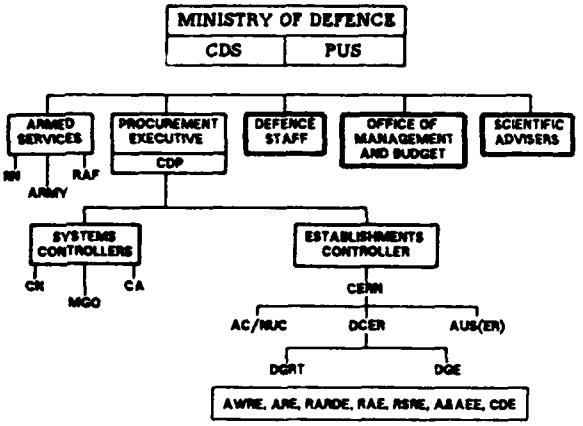

Figure 1. UK R&D establishments within the Ministry of Defence.

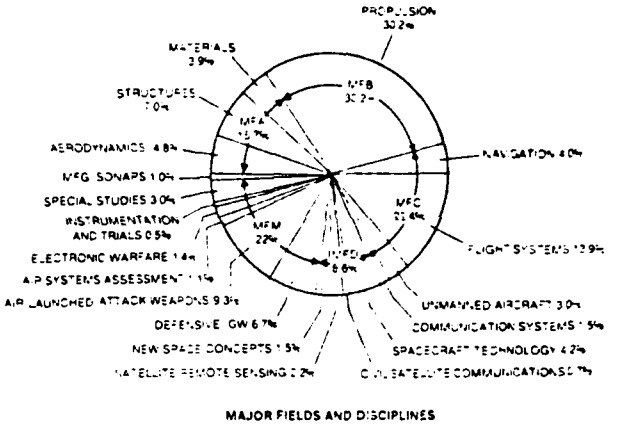

Figure 2. RAE extramural research funding for 1985-1986.

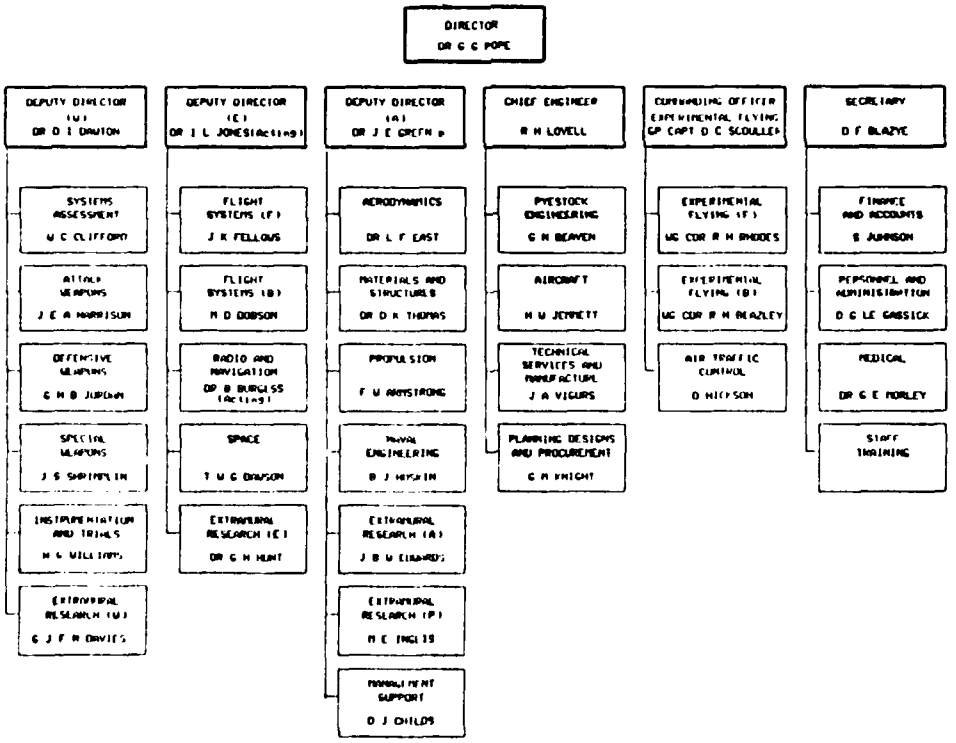

Figure 3. RAE organizational management structure.

as a wide range of research topics, as shown in Figure 4, including: fluid mechanics, aircraft and weapons aerodynamics, aircraft flight dynamics, and aircraft aerodynamic design. Work on these topics covers long-term, broad-based research as well as more specifically defined shorter term research

programs. The major part of this work is intramural, but a substantial contribution is made by government-funded extramural research, monitored by the department.

A key activity in the department's aerodynamics research is the development of accurate methods of computing subsonic, transonic, and supersonic flows around aircraft and weapons configurations in ways which allow for the effects of boundary layers and wakes. Fundamental work in this area is closely linked to research on the design and performance of wings, including multielement high-lift systems, for application to the design of military and civil aircraft and their associated engine, missile, and external store installations.

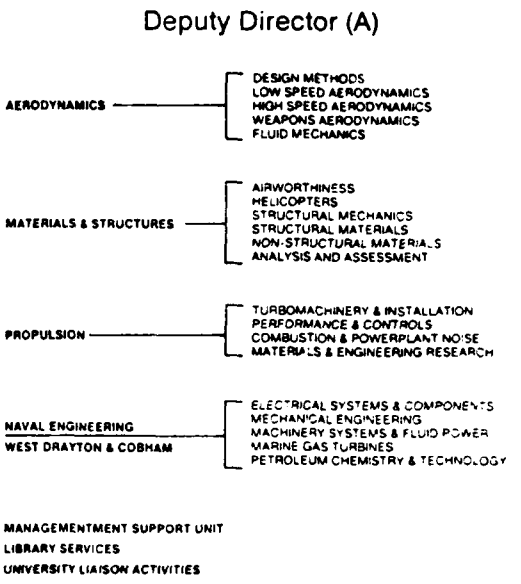

Figure 4. Research Activity under Deputy Director (A).

Experimental Aerodynamics Research Facilities

A consistent feature of the department's contribution to progress in aerodynamics is the emphasis placed on the validation of theoretical and computational methods by correlation with carefully planned and executed experimental programs. The Aerodynamics Department is well equipped with experimental and computational facilities. In addition to using a large number of special-purpose minicomputers, the department has access to the RAE CRAY-1S system which was installed and made operational in June 1984. Due to the heavy demand of a large number of computational aerodynamic research projects, over 60 percent of the RAE CRAY-1S CPU utilization is taken up by the Aerodynamics Department.

The principal experimental facilities for aerodynamics research and development are the wind tunnels located at Farnborough and Bedford which cover the entire flight regime from low-speed, for takeoff and landing, to high supersonic speeds for high-performance jet aircraft and guided weapons. These wind tunnels provide the major national facilities for UK MoD aerodynamics R&D and provide a significant contribution to the UK's and Western Europe's industrial aerodynamics research efforts. A chart which summarizes the capabilities of the wind tunnels at Farnborough and Bedford is provided in Figure 5.

Experimental flight test and evaluation is equally important to support an aerodynamics research program, and this is achieved by maintaining at RAE Farnborough and Bedford a fleet of aircraft, both fixed-wing and helicopter, with each of them specifically adapted to RDT&E project test flying. As shown in Figure 3, all experimental flying falls directly under the RAE Commanding Officer, with an experimental flying department located at both Farnborough and Bedford to support each establishment's individual flight test requirements.

Aerodynamics Department Organization

The Aerodynamics Department is currently staffed with some 120 scientists, engineers, technicians, and support staff. The department is divided into five divisions as shown below.

AE1--Design Methods
AE2--Low-Speed Aerodynamics
AE3--High-Speed Aerodynamics
AE4--Weapon System Aerodynamics
AE5--Basic Aerodynamics

Tunnel	Type	Speed Range	Maximum Power	Main Use	Location
11½ft x 8½ft	Subsonic-unpressurised	Up to 122 m/s	3.6 MW	V/STOL research and weapons.	F
13ft x 9ft (1)	Subsonic-unpressurised	Up to 91 m/s	1.1 MW	Civil & Military aircraft, weapons and research.	B
5m x 4.2m	Subsonic-pressurised	Up to 110 m/s	12.6 MW	High quality tests on Civil and Military aircraft for landing and take-off and research.	F
24ft	Subsonic-open jet Anechoic	Up to 52 m/s	1.5 MW	Noise, rotors and propellers. Full-scale tests on radar.	F
8ft x 6ft	Subsonic/Transonic-pressurised	M=0 to 1.25	15 MW	Civil & Military projects, research on swept wings.	F
8ft x 8ft (1)	Subsonic/Supersonic-pressurised	M=0.15 to 0.9 and 1.4 to 2.5	60 MW	High quality tests on Civil and Military projects and research.	B
3ft x 4ft	High Supersonic-pressurised	M=2.5-5.0	66 MW	Weapons R&D;	B

NOTES: (1) Models easily interchangeable with the ARA 9ft x 8ft Transonic Tunnel.

(2) In addition there are several small hypersonic facilities that cover the speed range M=7 to 20.

Figure 5. The main wind tunnels at RAE.

A summary of each division's technical efforts and research emphasis is provided below.

Design Methods Division

This division is concerned with the study of the aerodynamic characteristics and flight behavior of combat aircraft from subsonic to supersonic speeds and acts as a focal point within the department for the investigation of new design concepts and the application of new design methods. In addition to steady aerodynamic characteristics, the division is responsible for the study of aircraft dynamic behavior using free-flight models and special measuring rigs in wind tunnels, and the investigation of time-dependent aerodynamic phenomena affecting aircraft control. The division is responsible for the 8-ft×6-ft and 2-ft×1½-ft transonic wind tunnels at Farnborough.

Low-Speed Aerodynamics Division

This division is concerned with applied aerodynamic research and development related to helicopter airframes, fixed-wing aircraft, and weapons at low subsonic speeds, with particular emphasis on the influence of Reynolds number. The work includes experimental programs on the problems of weapons, helicopters, combat aircraft, transport aircraft (including propeller-driven types), and components thereof. The division is responsible for the management and enhancement of the 5-m low-speed tunnel and for the remaining low-speed tunnels at Farnborough. The division also carries out extensive repayment work in these facilities.

High-Speed Aerodynamics Division

This division is located principally at Bedford and is concerned with applied aerodynamics related to the

performance of weapons and aircraft in subsonic, transonic, and supersonic flight and with improved methods of prediction and design. The principal areas of work are weapon and aircraft intakes and transonic/supersonic viscous flows over wings. The division is responsible for the 3-ft×4-ft-high supersonic, the 8-ft×8-ft subsonic/supersonic, the 13-ft×9-ft low-speed wind tunnels and for the Central Computing Facilities at RAE Bedford. The Division Superintendent is also the Deputy Chief Superintendent of RAE Bedford.

Weapon System Aerodynamics Division

This division is concerned with providing the aerodynamic knowledge and computational tools required to assess and enhance the performance of aircraft/weapon systems, giving particular attention to the overall layout of combat aircraft, the carriage and release of air-to-air and ground-attack weapons on both fixed-wing aircraft and helicopters, the free flight of weapons (particularly guided weapons), and unmanned aircraft (UMA). The division is responsible for the study of the interactions between configuration changes intended to reduce radar cross-section and aerodynamic performance, and for hypersonic and low-density aerodynamics related to re-entry problems. In addition, the division coordinates project support and assessment within the Aerodynamics Department. The division is responsible for the hypersonic facilities at RAE Farnborough.

Basic Aerodynamics Division

This division is concerned with obtaining a fundamental understanding of fluid mechanics phenomena which influence the aerodynamic design of aircraft and weapons, and with devising means of calculating, and thus predicting, the resultant flow fields. The strategy adopted includes the calculation of flow fields at transonic and supersonic speeds, the study of boundary layers, wakes, and separated flows with the emphasis on application to practical three-dimensional shapes. The work is predominantly theoretical with some experimental support, and relies heavily on the use of large-scale computers in the "supercomputer" class.

CFD Research in the Basic Aerodynamics Division

The Basic Aerodynamics Division, currently headed by Mr. Steve Fiddes, is divided into four sections. Two of these sections are involved with developing methods for calculating the characteristics of complex flows about general aerodynamic shapes, including complex configurations. A third section focuses on viscous-inviscid interactions and develops calculation methods for boundary layers, wakes, and separated flows. The fourth section, concerned with viscous flows, develops advanced techniques for solving the Navier-Stokes equations as well as fast-solution algorithms for solving the Euler equations (see *ESN* 40-9:326-327 [1986] for a discussion of this work).

Summary

Two factors stand out when comparing UK MoD research establishments with US Navy laboratories. First, with the exception of the Naval Research Laboratory (NRL), where considerable in-house, unique, or basic research is conducted, the UK MoD research establishments, such as RAE Farnborough, conduct considerably more intramural (in-house) basic and applied research than do most US Navy laboratories and development centers. As an example of this, RAE Farnborough's aerodynamics research encompasses a broad spectrum of theoretical, applied, and experimental research activities similar to what is done at the Naval Air Development Center, Warminster, Pennsylvania, the Naval Air Test Center, Patuxent River, Maryland, and Naval Weapons Center, China Lake, California, as well as at various NASA and DARPA research sites.

Our US Navy laboratories (with the exception of NRL) and development centers are more involved with advanced development (6.3) and full-scale

engineering development efforts (6.4) in support of OPNAV/SYSCOM directed projects. In the UK, when basic or applied research efforts transition into a specific project, the project development effort is usually taken on by industry, and the government establishment only monitors the development effort, but does not necessarily manage it or control it unless so directed by the UK MoD.

This leads into the second difference between UK MoD research establishments and US Navy and other DoD service laboratories. The UK research laboratories are organized to conduct research across a variety of scientific disciplines in support of all the armed forces under UK MoD direction and control. This means that the Aerodynamics Department of RAE Farnborough and Bedford has aerodynamics research and development responsibility for not only the Royal Air Force, but the Royal Navy air arm and the Army's land-based airborne assault forces as well as some aspects of civil aviation and the UK space program. Thus the UK MoD scientific and technical cadre of expertise in aerodynamics research is concentrated within the Aerodynamics Department at RAE Farnborough and Bedford. Conversely, within the US DoD, one would have to visit over 10 service laboratories and development centers as well as DARPA and NASA facilities to ascertain the breadth and scope of US government directed aerodynamic research in the US.

This then allows the drawing of some general comparisons between aerodynamics research in the UK MoD research establishments and US government laboratories. First, the UK research establishments have fewer assigned personnel, in total, engaged in aerodynamics research and development than in the US, but the UK effort is concentrated in one or two locations, so economies of scale and efficiencies are generated that may not occur in the US with aerodynamics researchers located at a variety of government laboratories. The UK aerodynamics research is focused and prioritized to work on specific UK MoD programs that are of highest government interest; hence a broad scope of research activity across all aerodynamic fields of interest may not be possible. The aerodynamic research efforts at RAE Farnborough, however, have long been recognized by US aircraft R&D and industry personnel as first rate, and close collaboration between US and UK government aerodynamics research personnel has been on-going for many years. This close collaboration should certainly continue in the future.

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