UNLIMITED

Tech Memo
P 1216

Tech Memo
P 1216

②

DEFENCE
RESEARCH
AGENCY
AEROSPACE DIVISION

Technical Memorandum

November 1991

The Changing Role of Experimentation in Aeroengine R & D: The Point of View of the Research Worker

by

J. Dunham

RAE, Farnborough, Hampshire

UNLIMITED

UNLIMITED

DEFENCE RESEARCH AGENCY
Aerospace Division
RAE Farnborough

Technical Memorandum P 1216

Received for printing 13 November 1991

THE CHANGING ROLE OF EXPERIMENTATION IN AEROENGINE R&D: THE POINT OF VIEW OF THE RESEARCH WORKER

by

J. Dunham

UNLIMITED

LIST OF CONTENTS

Third European Propulsion Forum 13-15 Nov 1991

THE CHANGING ROLE OF EXPERIMENTATION: THE POINT OF VIEW OF THE RESEARCH WORKER

by
J.Dunham

Defence Research Agency
RAE Pyestock, Farnborough, Hants GU14 0LS, UK

The pioneers of the gas turbine based their component designs on simple mathematical models which employed many empirical factors. They conducted two types of experiment:-

(1) Trials of engines and components, to develop their mechanical integrity and endurance, and to improve their performance and stability (development tests)

(2) Parametric experiments on simplified components or simulated component geometries, to evolve better models and to generate empirical correlations of component behaviour (research tests).

Fifty years later, the same need for development tests remains, but as design methods have evolved from simple empirical models to complex computational fluid dynamics (CFD) models, the nature of research tests has changed. There is still a need for experiments aimed at evolving better mathematical models, but the empiricism is at a more detailed level (such as transition prediction) and so are the experiments. But component testing has moved away from parameter variation to tests aimed at the development and verification of better CFD models. Meanwhile, instrumentation techniques have also improved a great deal, enabling more accurate and detailed measurements to be made.

This paper focusses on some controversial aspects of the choice of experiments in the 1990's:-

(a) the extent to which inexpensive tests modelling only some of the relevant physical parameters (for example, cold turbine tests and low speed compressor tests) can be used to validate CFD models, and the extent to which full scale high speed tests are essential

(b) the extent to which expensive and time-consuming elaborate instrumentation should be deployed in development tests to aid the research workers

(c) the scope for international collaboration in setting up recognised validation experiments for CFD codes.

1. INTRODUCTION

The internal combustion engine has always been evolved, historically, by prolonged trial-and-error. The complex unsteady flow and combustion processes within a reciprocating engine were never well enough understood to do otherwise, so intensive development, involving the progressive modification of a prototype, became the way of life in aero-engine firms. When the jet engine first emerged, the same firms were generally involved and, with the limited understanding of the new technology, the same well-tried approach was adopted. In parallel, major research programmes were undertaken to improve that understanding so that better designs could be evolved. Progressively over the last half-century all aspects of gas turbine design and behaviour have become more predictable, but because of the overwhelming importance of engine reliability the expensive process of prototype development has remained, and will always remain, the dominant feature of aero-engine evolution.

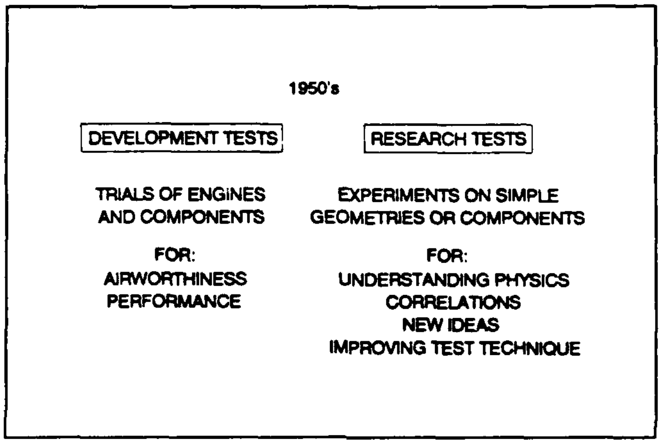
It is interesting to note that although similar R & D patterns are found in many high technology areas including many kinds of aerospace equipment and defence equipment, the design of aircraft themselves is done differently. Once the aircraft fuselage and wing structures have been decided, following appropriate model tests and extensive calculations, the prototype is built and subsequent changes are usually prohibitively expensive. Looking across at the industrial gas turbine and steam turbine, the relatively small production runs or tailored-to-project designs mean that here too designs must be right first time.

The traditional aero-engine development process, described for example by Eltis and Wilde (1974) for the RB211, is long and costly. Considerable thought has been given to how to reduce not only the time and cost of development but also, more importantly to the customers, how to minimise the risk of expensive modifications necessitated by in-service experience. A study of military engine procurement by the Comptroller-General of the United States General Accounting Office (1980) concluded that more money should be spent on early R & D to save much bigger sums later on. In the UK, Ruffles (1988) drew attention to the importance of evolving and demonstrating technology prior to embarking on full engine development, for the same reasons.

It is particularly appropriate that, at a time when the aerospace industry is in recession and trying again to minimise its R & D costs, that consideration should be given to the best strategy for experimental research within this overall pattern, and how it should be planned to take account of the increasingly detailed and increasingly accurate computations now possible in all aspects of engine design.

This paper begins by reviewing the role of experiments in the design process, and how it has changed over recent years. It considers the changing nature of experiments now that instrumentation technology has improved so much. Then it turns to the sometimes controversial questions facing the research manager. To what extent can inexpensive tests reproducing only some of the real engine conditions be adequate for validating design methods? How much instrumentation should be carried in development tests? How can we organise international collaboration in CFD test cases in such a way that the mutual benefit outweighs the natural reluctance to disclose proprietary information?

2. THE ROLE OF EXPERIMENTS IN THE 1950's



1950's

DEVELOPMENT TESTS	RESEARCH TESTS
TRIALS OF ENGINES AND COMPONENTS	EXPERIMENTS ON SIMPLE GEOMETRIES OR COMPONENTS
FOR:	FOR:
AIRWORTHINESS PERFORMANCE	UNDERSTANDING PHYSICS CORRELATIONS NEW IDEAS IMPROVING TEST TECHNIQUE

Fig 1 The role of experiments in the 1950's

Fig 1 shows what experiments were used for in the early decades of aero engines. As already pointed out, development engines or engine components were tested to achieve and to demonstrate durability and performance. In addition, research tests were done on a wide range of configurations from flat plates (measuring boundary layers) to cascades to complete compressors, combustors or turbines, in order to gain a better understanding of the physical phenomena controlling performance or stability or stresses or wear, in order to construct correlations for design use, or in order to try out new ideas. Other research was aimed not at evolving engine components but at improving instrumentation and measurement techniques. At this time, many experiments were parametric; that is, the key parameters were varied systematically one at a time to see what effect each had.

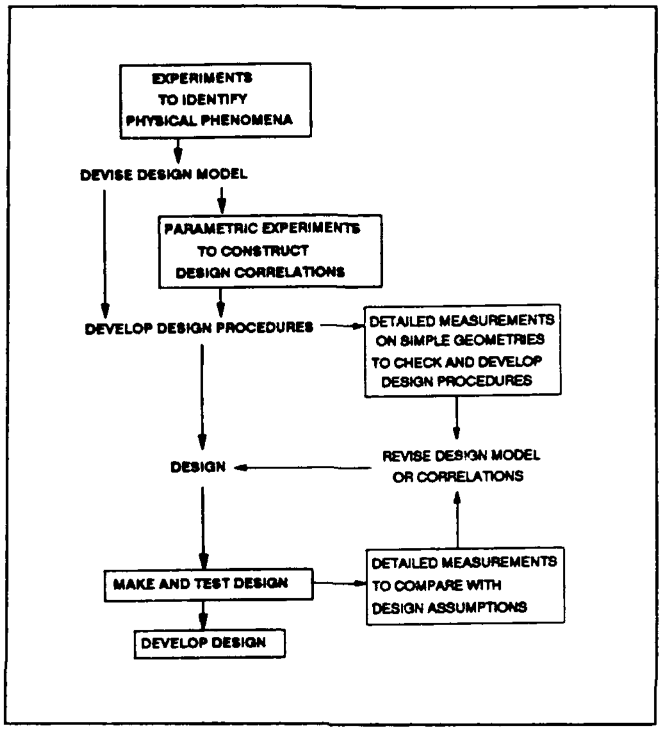


Fig 2 The role of experiments in the design process

The left hand side of Fig 2 illustrates the role these experiments played in the design process. The design procedure was a hierarchy of decisions, taken in turn (and sometimes reviewed later) to optimise the design for the required duty. As time went on, design procedures became implemented increasingly by computer programs. The right hand side of Fig 2 shows additional activities which should have been undertaken as part of the research process but usually were omitted through pressure of the development environment: the design rules should have been checked by detailed measurements on (perhaps simple) components; and following the trial-and-error improvements to the initial build the implications of those improvements for the original design procedure should always have been assessed.

3. CHANGES SINCE THEN

What has changed since those early days? The immense research and development programmes undertaken have greatly increased the knowledge and understanding of the aerothermodynamic, mechanical, and materials aspects of engines, and some of this understanding is used in modern design procedures in the form of computer programs. There are large computational fluid dynamics (CFD) codes and large structural analysis codes, which incorporate both the known equations governing physical laws of nature and empirical formulae believed to provide to engineering accuracy all the other parameters needed. It is important to admit that the scope of these programs and the range of application of the empirical formulae limit the freedom of the designer to try out new ideas; he is constrained to remain within the bounds of past experience.

CFD now dominates the design of turbomachinery (Dunham, 1986). The extra difficulty of modelling recirculating turbulent reacting flows has delayed the application of CFD to combustor design but that is coming. Heat transfer is another important area of advance. Even the process of casting is now treated by CFD. As to the mechanical side, the use of finite element stress calculations is universal.

There have over the same period been massive improvements in experimental technique. In the 1950's, traverses were used to measure pressure, temperature, and flow direction, but using manometers made the process very slow. Wall statics were used. Hot wires were fragile but useful for low speed rigs. Thermal paints were used. Simple acoustic measurements could be made. Straingauges were central to engine testing, with sliprings to look at rotating parts. Gas chromatography for the analysis of combustion products was introduced in the 1960's.

Nowadays, it is possible to use thin film gauges even on rotating parts, to make static pressure and other measurements on rotors and bring them out without noisy sliprings, and to make rapid response pressure measurements using locally-installed transducers. Techniques of acquiring and interpreting unsteady pressures are being developed. The laser anemometer is now in routine use for measuring the velocity and direction of flow even in rotor passages. Particle Image Velocimetry and Coherent Anti-Stokes Raman Spectroscopy are being developed. Heat transfer gauges are accurate and the use of short duration tunnels for measuring with gauges or with liquid crystals is becoming widespread. Arrays of microphones can be used to locate noise sources. X-rays can be used to observe running engine clearances. With these and other new techniques the experimentalist has a wide range of options.

There is undoubtedly a temptation to spend enormous effort massively instrumenting every experiment. But it is expensive to do so and diverts effort from the task of analysing and understanding previous test results. The proper balance between fast, cheap and simple experiments on the one hand and long laborious heavily-instrumented experiments on the other hand can be a serious dilemma. The balance of advantage for research appears to the author to lie with cheap and simple experiments to gain physical understanding or to try out new ideas, but with intensive instrumentation for tests aimed at CFD validation. The instrumentation of development tests is discussed later.

4. THE VALIDATION OF CFD CODES

The process of code validation falls into two phases. The first is to check that the code implements the intended calculation, and the second is to see how well that calculation is capable of predicting what really happens.

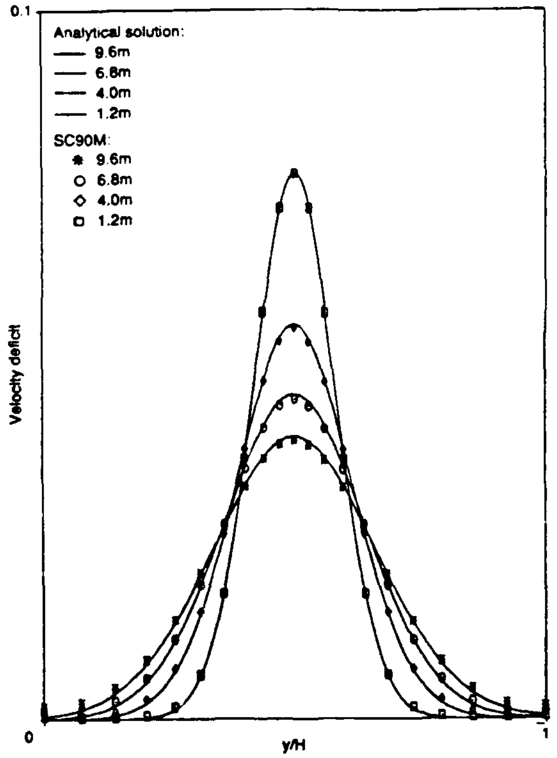


Fig 3 The development of a laminar wake

When a computer program is written which implements a simple calculation, the accuracy of the coding can be checked by hand calculation. Nowadays, however, most CFD codes involve huge data manipulations and long iterations, so hand checking is out of the question except for verifying particular algorithms in it. The most direct check, that is comparison with a known exact solution, is also only possible for special restricted cases. This leaves two possibilities, comparison with the same calculation coded by someone else, and comparison with experiment.

As an illustrative example, the author has recently programmed spanwise mixing terms proposed by Cumpsty and Gallimore (1986) into the RAE streamline curvature program for calculating the meridional flow through an axial compressor. One of the first checks was to compare the predicted development of a laminar wake in a duct 1 m wide with the analytical solution in a free stream. The calculation was started with the exact solution, and Fig 3 shows the comparison at various axial distances downstream. There are small differences due to the finite width of the duct and the finite grid, but the agreement is acceptable. This only verifies some of the terms in the equations, since there is no swirl in that case. To check the swirl terms, another case was run, in which a free vortex swirl distribution was specified at the starting plane, and its development (again with laminar viscosity) into a forced vortex was calculated as it moved downstream (Fig 4). In this case the second form of check was employed, namely comparison with the same calculation done by someone else (Mr M.A.Howard of Rolls-Royce). Precise agreement will be seen. Now these test cases were highly unrealistic in relation to compressor flows; they simply gave the programmer confidence in his coding. Even then, these cases used parallel annulus lines, so they did not check the terms involving streamline slope.

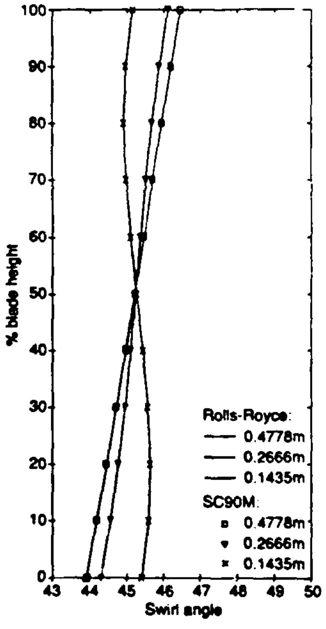


Fig 4 The development of a free vortex

The next phase of the validation process is more difficult and open to question - an attempt to predict experimental measurements. Here, a discrepancy may be due to coding errors, or it may be due to the use of too coarse a grid, or it may be due to inadequate physical modelling of the flow. In the initial development of a new method, it is highly desirable to start with as simple an experimental arrangement as possible, such as a low speed test (if shock waves are not central to the model!) and two dimensions (if vorticity is not central to the model!) So, much use is made of cascade tests in which great care has been taken to ensure parallel stream surfaces at mid-height. As an illustration of this type of test case, Fig 5 is a comparison by Calvert (1983) between his calculation of the transonic flow through a compressor cascade and DLR's measurements. The figure shows satisfactory agreement between calculated and measured surface pressure coefficients. Notice that this test is still a considerable simplification of conditions within an engine, where stream surfaces are rarely parallel, but it represents a necessary step in the systematic evolution of a code towards full applicability.

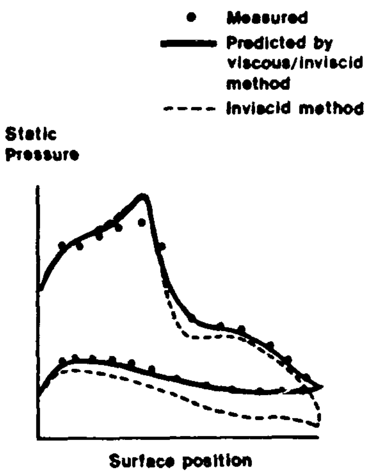


Fig 5 Flow through a transonic cascade

To give another example, the major features of a code for predicting endwall secondary flow may be validated by a low speed experiment with a collateral inlet wall boundary layer in the first instance, as compressibility is of lesser importance. Then skewed inlet boundary layers must be tried. It is probably fair to use a constant section (two-dimensional) aerofoil in a linear cascade for this validation at first, but later on an annular cascade will be necessary to see if the code can predict the effect of spanwise pressure gradients, which are believed to be important. Eventually an annular high speed cascade preceded by a rotating hub will have to be tested.

There is a danger in this stage of code development. Most CFD codes contain empirical constants to represent the viscous effects. They may be superficial ones like blockage or loss coefficient or they may be detailed ones like the constants in an algebraic eddy viscosity formula, but they provide the code developer with adjustments he can apply to tailor his results to the experiment being modelled. In some cases the empirical constants can be amended until agreement is "very good". But matching a single example in this way is unconvincing both to the honest research worker and to the discriminating reader. So it is essential to have a range of test cases covering a realistic range of the key parameters, to see if the chosen empiricisms can be in any way universal.

It is important to recognise that experiments which have not been planned carefully for code validation often prove unsuitable for that purpose. For example, most compressor tests do not report the stagnation pressure profiles in sufficient detail near the annulus walls. The "turbulence level" may be quoted but rarely in the detail needed by the k-ϵ turbulence model. Indeed, many turbomachinery papers do not even mention the axial distance between the blade rows. The conclusion generally reached in meetings is that the code developer must be involved in planning the experiment. An experiment aimed at code validation may not appeal to senior managers because it will not *in the short term* demonstrate to them a better performance than the previous test. There is another step to be taken when a code has been shown to be capable of "predicting" past test results (that is to say "validated" in the sense used in this paper) before a manufacturer will incorporate it into his design system. That is to use the code to design a "better" component, and make and test it to see if it is indeed better than the old design method could achieve. As an example of that, Fig 6 from Calvert et al (1987) illustrates how a new transonic fan rotor designed using his method met its design expectations and did indeed prove good.

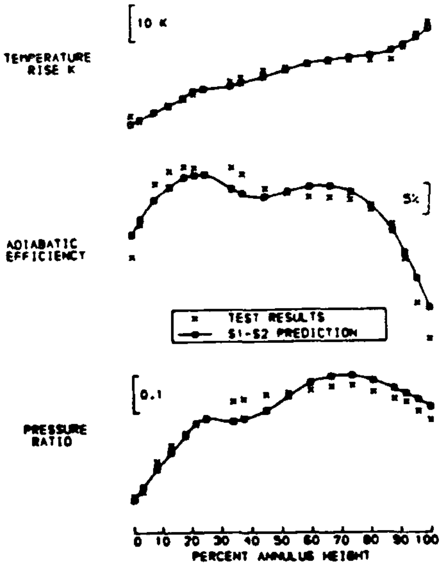


Fig 6 The performance of a new transonic fan rotor

It will be understood that the illustrative examples used in this paper are taken from the author's field and research team for convenience; every successful team could produce its own examples emphasizing the need for a range of test cases posing progressively more challenges to the modeller, and supplying him with all the necessary boundary conditions for his code, together with as many good measurements within the flow as possible for comparison with his predictions, especially in the critical regions of the component.

5. THE ROLE OF EXPERIMENTS IN THE 1990's

Consider now the relevance of Fig 2 in the 1990's. Experiments to identify physical phenomena are still needed, but at a more detailed level; for example, turbulent transfer phenomena are still imperfectly modelled so such matters as pollutant formation and dissipation need careful experiments. However, the emphasis on this type of experiment is less than it was 40 years ago. In the same way, some parametric experiments are still essential at the detailed level, such as boundary layer transition measurements, but the practice of testing families of cascades to produce loss and deviation correlations has long been discontinued. On the other hand, the need for detailed measurements on both simple and engine-representative models to verify new design procedures in the form of CFD codes has greatly increased. So Fig 2 still applies with changed emphasis.

1990's

DEVELOPMENT TESTS	RESEARCH TESTS
TRIALS OF ENGINES AND COMPONENTS	EXPERIMENTS ON SIMPLE GEOMETRIES OR COMPONENTS
FOR: AIRWORTHINESS PERFORMANCE	FOR: UNDERSTANDING PHYSICS VALIDATING CFD CODES NEW IDEAS IMPROVING TEST TECHNIQUE

Fig 7 The role of experiments in the 1990's

Fig 1 can now be updated to the 1990's, as shown in Fig 7; the only element that has changed is the replacement of "correlations" by "validating CFD codes".

So far this paper has noted changes which have occurred, and are well-known. It now turns to consider some of the controversial issues arising from them.

6. THE ROLE OF SIMPLIFIED EXPERIMENTS

It is convenient to use simplified representations of engine parts for understanding physical phenomena, for generating design data, and for verifying design codes. For example, measurements of boundary layer phenomena are often made on a flat plate. Turbomachinery flows are studied in a cascade. Compressor flows are studied in low speed rigs. These simple experiments are cheaper, safer, and allow much more detailed and accurate measurements to be made than the real component environment. As already explained, they are essential for code validation. But they are obviously only valid if the dominating physical phenomena being studied are present in the right proportions. No one supposes that a low speed compressor can be used to study stage matching over the full range of operation because density changes are central to stage matching. However, there are still plenty of measurements of boundary layer transition being made in cascades without any attempt to simulate what is now recognised as a dominant element, namely the periodic arrival of wakes or shock waves from upstream rows. Measurements of base pressure are made and correlations proposed which do not account for the radial equilibrium of base flows within a turbine in which a strong radial mainstream static pressure gradient may exist.

It is usually possible to identify similarity parameters, such as Reynolds number, which must be replicated in experiments. One of the important advantages of the RAE's Isentropic Light Piston Cascade (Brooks et al, 1988) is that it can replicate simultaneously the Reynolds number, Mach number, and gas/metal temperature ratio so that gas-to-metal Nusselt number will be correct. It is not always practicable to get the similarity parameters right; to run a combustor experiment at engine pressure level requires expensive equipment which is hard to instrument. Aerodynamic tests on turbines are usually conducted with a warm air supply instead of hot combustion products, not only because of the difficulty of making measurements at engine temperatures, but because the definition of efficiency becomes problematical if the incoming stream is non-uniform. (What is the isentropic process against which to compare the measured work?) But a warm air test cannot reproduce the radial migration of hot gas within the rotor of a turbine with a non-uniform inlet temperature. In the case of a VSTOL aircraft hovering near the ground, it is impossible to model at small scale all the similarity parameters controlling the recirculating jet exhaust, because conflicting requirements apply in the near field (in which momentum terms dominate) and the far field (in which buoyancy terms dominate).

The strategy adopted for CFD validation previously explained can circumvent such problems to some extent. The program is written to model all the parameters supposed to be significant (if possible!) A set of progressively more realistic experiments is mounted to verify each element of the model systematically. Eventually, a fully representative test of a real component needs to be made. However, there is no need to amass more and more test cases at the simpler levels of modelling. In the author's view, almost enough simple cases have been done, and more attention needs to be paid to using the latest instrumentation to measure flows under more realistic conditions, such as within high speed multistage compressors and turbines.

As already noted, tests of fully representative components are also needed occasionally to assess and demonstrate the potential of new design methods.

In the author's view, the place of linear cascade experiments was to identify the physical phenomena and to establish some test cases, and that has now been done. He sees no place for them now. Similarly, the purpose of low speed compressor tests is to identify phenomena and generate test cases, and there is still scope for improving understanding of endwall effects and validating codes predicting them. But the major unknowns in compressors - as has long been the case in turbines - are associated with compressibility, so the author sees little future for low speed compressor or turbine rigs except in Universities.

7. INSTRUMENTING DEVELOPMENT TESTS

The research worker is always short of "good data". He has his own experiments and can consult the literature. But he is always aware of the development tests being carried out on engines or components which represent a potential source of a great deal of new data in the most realistic environment. Which research worker has never said "if only they would put in a few extra statics...."? The best case lies in component tests, as access within a complete engine can be difficult or hazardous. It would be possible in principle to provide all development compressors with laser windows and apply one of the fast-acting modern laser anemometry systems to be run *during development tests*, but the penalty in time and cost would be great. The author is aware of examples where development units have carried extra instrumentation for the benefit of research teams and at their expense. What would make the proposition acceptable to the development team would be the provision of trouble-free fast-acting fit-and-forget instruments.

The author believes that effort should be devoted to developing a fast-acting automatic traverse unit which would complete an area traverse behind two blade pitches in, say, two minutes, and that this should be used routinely in component development tests. He also recommends continuing efforts to overcome the remaining problems preventing fast laser anemometry traverses between blade rows being used routinely in development testing.

8. INTERNATIONAL COLLABORATION IN CFD VALIDATION

Anyone engaged in developing codes, whether for CFD or stressing, is very conscious of the need for test cases. It is well known that setting up an experiment to provide a good test case is an ardous and expensive task. The level of detail and accuracy in the measurements is demanding; the attempt to run a code on a proposed test case may only reveal inconsistencies in the reported measurements. As modelling moves into the unsteady aspects of the flow, it is obvious that time-resolved measurements must be made. It has already been pointed out that a single test case is not enough since empirical parameters can usually be tuned to fit a single case. Enough examples are needed to show generality.

The value of test cases to code developers and to experimenters was well exposed by the Stanford conference on boundary layers (Kline et al, 1969). Since then, similar exercises have been set up in other fields. The AGARD Propulsion and Energetics Panel first tried a turbine competition 15 years ago (AGARD, 1976) but the aero engine firms were reluctant to expose their results, perhaps for fear of being seen as worse than their rivals. Later, recognising this difficulty, the Panel set up a Working Group not to run a competition but to assemble and document a selection of good test cases for CFD. The result (Fottner, 1990) has already proved most useful.

In principle, it would save every aero-engine firm a great deal of money if they all pooled their test cases in this way. However, there are some obvious commercial worries. In the first place, the disclosure of results on a recent design would expose to their competitors the style and quality of their designs, which would threaten their reputation (if bad) or help their rivals to catch up (if good). Secondly, the best CFD codes are now treated as such an asset that helping a competitor validate his code may be seen as an unacceptable price for helping to validate their own.

In the author's view, it is not necessary to use up-to-date or particularly successful designs as test cases covering a wide range of parameters. It should be the function of a body such as AGARD or (in Europe) the CEC, using the national Research Establishments as principal agents, to acquire and hold test cases, either by doing the tests themselves or by funding firms to do them and release them. No one would be compelled, of course, to disclose how well he could predict his own or anyone else's experiments.

9. CONCLUSIONS

The role of experimental work in aero engine research has changed over the last fifty years as knowledge and understanding have advanced. In principle experiments play the same role as they always did, but the emphasis has swung away from generating empirical correlations by means of parametric testing towards the validation of design codes by a small number of tests with very detailed measurements. There are important questions posed by the availability of expensive modern measurement techniques and the need to validate CFD codes.

To what extent can inexpensive tests modelling only some of the relevant physical parameters (for example, cold turbine tests and low speed compressor tests) be used to validate CFD models, and to what extent are full scale high speed tests necessary? Inexpensive tests are useful in the progressive validation of CFD codes, but the author suggests that the days of linear cascade tests are over, and the days of low speed compressor and turbine tests are numbered. More validation tests in realistic conditions are needed, exploiting modern measurement techniques.

To what extent should expensive and time-consuming elaborate instrumentation be deployed in development tests to aid the research worker? It is not realistic to expect acquiescence in such proposals until the equipment is trouble-free and fast-acting. Therefore it is recommended that effort be devoted to developing fast-acting and reliable probe traverses and laser anemometer traverses.

What is the scope for international collaboration in setting up recognised validation experiments for CFD codes? It is suggested that this is indeed a suitable activity for collaboration and it is recommended that AGARD or other international institutions take the lead, using national Research Establishments as agents.

These questions and ideas are suggested for discussion.

ACKNOWLEDGEMENT

The author has had the benefit of discussions with his colleagues, but the conclusions and recommendations are personal views and not necessarily UK Ministry of Defence policy.

REFERENCES

AGARD: Through-flow calculations in axial turbomachinery. AGARD-CP-195, 1976

Brooks,A.J.et al: The Isentropic Light Piston Cascade facility at RAE Pyestock. AGARD-CP-390, 1985

Calvert,W.J.: Application of an inviscid-viscous interaction method to transonic compressor cascades. AGARD-CP-351, 1983

Calvert,W.J., Ginder,R.B., and Lewis,G.: Performance of a civil fan rotor designed using a quasi-three-dimensional calculation system. I.Mech.E. CP 1987-6, paper C257/87, 1987

Comptroller-General: Are management problems in the acquisition of aircraft gas turbine engines being corrected? General Accounting Office Report to the U.S.Congress, 1980

Dunham,J.: The role of flow field calculations in improving turbomachinery. ICAS paper 86-3.7.3, 1986

Eltis,E.M. and Wilde,G.L.: The Rolls-Royce RB211 turbofan engine. Proc.I.Mech.E. v.188 p.549, 1974

Fottner,L.(ed): Test cases for computation of internal flows in aero engine components. AGARD-AR-275, 1990

Kline,S.J.et al: Proceedings: Computation of turbulent boundary layers. 1968 AFOSR-1 FP Stanford University, 1969

Ruffles,P.C.: Reducing the cost of aero engine research and development. Aerospace v.13 p.10, Nov 1986

REPORT DOCUMENTATION PAGE

Overall security classification of this page

UNLIMITED

As far as possible this page should contain only unclassified information. If it is necessary to enter classified information, the box above must be marked to indicate the classification, e.g. Restricted, Confidential or Secret.

1. DRIC Reference (to be added by DRIC)	2. Originator's Reference RAE TM P 1216	3. Agency Reference	4. Report Security Classification/Marking UNLIMITED

5. DRIC Code for Originator 7673000W	6. Originator (Corporate Author) Name and Location Royal Aerospace Establishment, Farnborough, Hants, UK
5a. Sponsoring Agency's Code	6a. Sponsoring Agency (Contract Authority) Name and Location

7. Title The changing role of experimentation in aeroengine R&D: the point of view of the research worker

7a. (For Translations) Title in Foreign Language

7b. (For Conference Papers) Title, Place and Date of Conference

Third European Propulsion Forum, Paris, 13-15 November 1991

8. Author 1. Surname, Initials Dunham, J.	9a. Author 2	9b. Authors 3, 4	10. Date November 1991	Pages 15	Refs. 10
11. Contract Number	12. Period	13. Project	14. Other Reference Nos.		

15. Distribution statement

(a) Controlled by – Head Propulsion, DRA(P)

(b) Special limitations (if any) –

If it is intended that a copy of this document shall be released overseas refer to RAE Leaflet No.3 to Supplement 6 of MOD Manual 4.

16. Descriptors (Keywords) (Descriptors marked * are selected from TEST)

Aeroengines. Gas turbines. Computational fluid dynamics.

17. Abstract The pioneers of the gas turbine based their component designs on simple mathematical models which employed many empirical factors. They conducted two types of experiment:-

(1) Trials of engines and components, to develop their mechanical integrity and endurance, and to improve their performance and stability (development tests).

(2) Parametric experiments on simplified components or simulated component geometries, to evolve better models and to generate empirical correlations of component behaviour (research tests).

Fifty years later, the same need for development tests remains, but as design methods have evolved from simple empirical models to complex computational fluid dynamics (CFD) models, the nature of research tests has changed. There is still a need for experiments aimed at evolving better mathematical models, but the empiricism is at a more detailed level (such as transition prediction) and so are the experiments. But component testing has moved away from parameter variation to tests aimed at the development and verification of better CFD models. Meanwhile, instrumentation techniques have also improved a great deal, enabling more accurate and detailed measurements to be made.

This paper focuses on some controversial aspects of the choice of experiments in the 1990's.

F5910/1