MINISTRY OF SUPPLY

AERONAUTICAL RESEARCH COUNCIL

Review for the Years 1949-1954

LONDON: HER MAJESTY'S STATIONERY OFFICE

1955

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I. INTRODUCTION

The last review of the work of the Aeronautical Research Council dealt with the period 1939-1948. Since that date the Council has reported confidentially to the Minister of Supply but no attempt has been made to review for publication the progress of aeronautical research on which the Council advises the Minister. We have welcomed the Minister of Supply at several of our Council meetings during these years.

We pointed out in our last review how the basis of aeronautical research had started again to expand. Throughout the long history of the Aeronautical Research Committee the chief subject of study has been that of Aerodynamics, and this continues to be the case within the ever broadening front of aeronautical engineering. The Power Plant and the Aircraft Structure come next in importance and all three are dealt with in separate sections of this review. We have expanded our interests in research matters dealing with military aircraft but cannot do more than refer generally to them on account of their confidential nature except in those cases where the information has already been published. We have, for instance, continued our interest in naval and civil aircraft problems, including operational research ones, for which we have Special Committees and we have kept alive an interest in helicopters and seaplanes. The Guided Weapons Advisory Board reports both to the Scientific Advisory Council and to us and we have instructed our technical committees to take an increasing interest in matters discussed by this Board.

In addition to the above, we have maintained an interest in Materials and keep in touch with the Inter-Service Metallurgical Research Council. We have welcomed the formation of a Joint Services Materials (Non-Metallic) Advisory Board. Meteorology is dealt with by the Meteorological Research Committee and our Gust Research Committee reports to that committee as well as to our own Aerodynamics Committee. We have appointed a new committee to deal with computation, a subject of increasing importance since both digital and analogue computers are a valuable aid in solving some of the new problems whose great complexity would otherwise defy solution. On the other hand, we have regarded electronics as a tool for research purposes and becoming so universal in its application that it did not need a special committee, and this view has proved satisfactory.

One major change in the operation of aircraft has taken place in the last few years which is influencing our discussions to an increasing extent. Although aerodynamics is still perhaps the most important single subject dealt with by the Council, the stability and control of aircraft are now determined not by the aerodynamic qualities alone, but by these in combination with factors which depend on the radio guidance and the mechanical properties of the automatic control. In dealing with the guidance and control of military aircraft and the navigation of both military and civil aircraft, the Council has therefore begun to call upon the assistance of radio and control mechanism experts so that all the factors affecting control and guidance, not only of piloted aircraft but also of guided weapons, can be fully taken into account. The responsibility for advising the Minister of Supply on radio and radar problems rests, as a matter of history, with the Radar and Signals Board of the Scientific Advisory Council. The application of the techniques to aircraft is, however, our responsibility. This division of responsibility, although not ideal, has so far proved a practical arrangement, and may well continue to do so. Links between the two bodies are already effected by common membership between the Radar and Signals Board and the Committees of the A.R.C. which deal with problems of guidance and control and similar links in other subjects are naturally growing.

The scope of the Council's discussions increased early in the period under review to a somewhat wider field in other subjects, especially as regards jet engines, rockets and certain engineering problems of aircraft. Work in the last field was not previously co-ordinated by any of the Council's committees and includes such subjects as de-icing, fire prevention, pressurization, improvement of plastic materials, etc. For our discussions on these matters the Council has been greatly helped by a panel of experts nominated by the Industry upon whom the Sub-Committee can call for special discussions in the subjects on which they are experts. The Council's outlook also expanded during 1949 to 1950 to the inclusion of many of those problems of guided weapons which naturally arise in the subjects already covered by the Council's Committees. During the intervening years our Committees have become thoroughly familiar with guided weapon work and better able to contribute to its advancement; we anticipate problems needing advice on a choice between the manned aircraft and the guided weapon and on the use of the guided weapon by the manned aircraft. The last three years have been a period during which an influx of new technologies has entered aeronautical engineering, needing forums for their discussion and a feeding of the results into existing technologies as far as possible; for example, the rapid development of servomechanisms is influencing both the control of aircraft and power-plants and our appropriate Committees are dealing with these matters.

A closer contact with the Aircraft Industry noted in our previous review has been maintained by pairs of members selected from nominees put forward by the Society of British Aircraft Constructors and appointed to most of the technical Committees and Sub-Committees; in a few cases additional members have been appointed. With their specialized knowledge they have...
been most helpful both in discussions at meetings and in the communication of papers.

Liaison has been well maintained with the Dominions of Canada, Australia and New Zealand and with the Union of South Africa. The Chairman and two members of the Council were Delegates both at the Second Meeting of the Commonwealth Advisory Aeronautical Research Council in Ottawa in September, 1950 and the Chairman and three members at the Third Meeting held in London in September, 1953. Reference to these matters will be found later in this review.

**Policy of the Council**

The Council has continued to act solely in an advisory capacity, sending their recommendations on research problems to the Principal Director of Scientific Research (Air) at the Ministry of Supply, who is the Council's executive officer. Our strength lies in committees whose memberships are nearly equally divided between independents and officers chosen from government departments. The latter have assisted greatly in day-to-day problems and our contacts in this way with the people responsible for, and those undertaking researches, have been very good, partly by the attendance of the research workers at meetings and partly by the visits of committees and independent members to the various government establishments. This applies not only to the Ministry of Supply but also to the Admiralty whose representatives have helped us for many years. Similar contacts have been maintained since the formation of the Council with the Air Ministry and the Ministry of Transport and Civil Aviation and, to a lesser extent, with the War Office, on various matters, affecting aeronautical research and aircraft operation.

Because the officers responsible for research are often members of our committees that discuss their work, this has made it unnecessary in many cases to make formal recommendations, because action is taken by the officer concerned following the discussions at the respective meetings.

We expressed concern in May, 1951 at the swing to development at the expense of research by which most government scientists in the aeronautical field had been switched to work having an early or immediate application, and suggested that there should be more persons directing their attention to the principles underlying progress. We have been pleased to observe changes in the desired direction and the Council itself hopes always to devote a good part of its time to the consideration of investigations not directly related to any immediate end product.

**Equipment for Research**

As long ago as 1944, the requirements for aeronautical research and development were reviewed and set out in a special Report to the Minister, and following the adoption of this Report by the Government, preliminary plans for the National Aeronautical Establishment were made in the ensuing year. Work started at Bedford in June, 1946 and, although progress was slow for some years, we are now able to express our satisfaction with what has been done in the last few years and what is immediately planned. The present position of new equipment at that Establishment is given elsewhere in this review, but we wish to record here the adoption of our recommendation for the construction of a specially long runway at the N.A.E. During the past two years we have been consulted by the Minister about the future of the N.A.E. and the Council has visited both these establishments during the past year.

We have reviewed the existing facilities for gas turbine research and development at the National Gas Turbine Establishment and we have emphasized the urgent need for more research equipment for propulsive investigations, as only in this way can the United Kingdom maintain its present pre-eminence in this field. Much has been done in the past about provision for the testing of components but the immediate need is for the erection of a high-altitude test bed. We have laid down what we consider to be the chief requirements for the proposed test plant catering for high thrust engines and we were glad to learn early in 1954 that the project had been approved by the Treasury. It is appreciated that the speeds of both civil and military aircraft will be rapidly increasing during the next two decades, but remembering that a major development in a power plant takes about ten years to design, develop and use to the stage at which it becomes obsolete, it is considered likely that the engines in use ten years hence will be similar to those which are in the minds of designers to-day. We contemplate that the requirements should be such as to meet a speed with Mach number equal to 3 at 70,000 ft. within this time.

**Equipment at firms**

The Council has been pleased to note the steady increase of useful equipment at firms and at universities for undertaking aeronautical research and considers that this can still, with advantage, be further increased. Our liaison with the universities is a close one, mainly because so many university men interested in our subjects are members of our committees. We learnt with pleasure of the setting up of the Aircraft Research Association by the Aircraft Industry, and understand that their plans to erect a large wind tunnel are now well forward. Occasional research reports are received from individual aircraft firms, and we would welcome more. The Society of British Aircraft Constructors makes us acquainted with much of the research undertaken at firms. Such contacts are valuable to us, and we endeavour to foster the excellent, and naturally more continuous relations, between official research staff and those at aircraft firms.
Research Staff

In several Reports to the Minister of Supply we have drawn attention to the importance of adequate staff for official Research Establishments and have emphasized that some of this staff must be of the highest quality. Whereas in production work, even to some extent in design and equipment work, scientific and engineering staff of average ability can, because of the nature of the work, be efficiently employed, particularly if well led, the use of too large a proportion of similar staff in the research field may easily lead to no useful results at all, or to the production of mediocre results by unnecessarily expensive methods, or even to the clouding of issues that would otherwise have been made rapidly clear. Research depends essentially on the best men in the field.

The Council welcomed the steps taken in 1950 to introduce certain higher posts in the Scientific Civil Service to be held by scientists on account of the high value of their individual work and without administrative responsibilities. Various questions about the staff to be employed at the N.A.E., Bedford and their amenities have been discussed and the Council has drawn attention to some of the factors which help in providing those conditions under which research staffs do their best work. Salaries for scientific grades and the wages for industrialists should be adequate to prevent many of them from being tempted away to the higher wages offered in industry.

The question of the supply of more good scientists is a national one. The Council has on its part pointed out the tendency for the best men to take Arts degrees in some of the universities so that the relative position of Engineering and Science compared with the Arts is decreasing, possibly due to the fact that the quality of scientific teaching in the schools is depreciating and the best boys tend to gravitate to the best teachers. Headmasters have also an important influence on the direction taken by a boy’s studies. The Council drew attention to these matters in 1952, emphasizing that technology was an essential culture of a modern kind.

Aerodynamics—Supersonic Research

We drew attention, in our last review, to the fact that experimental aircraft had flown at a speed as high as $M=1.4$. During the intervening years, experimental research aircraft have increased this speed to at least $M=2.5$. The speeds of some operational aircraft are already supersonic and a host of new problems need solution as their speeds increase still further. Much can be done by work in supersonic wind tunnels—other results are obtainable from experiments on models flown at these speeds, but the ultimate test is on the aircraft itself. For this reason the Council has emphasized the importance of having available, at an early date, aircraft flying at supersonic speeds, so that research and experiments at these speeds can go on hand-in-hand in flight and in the laboratory. We are also encouraging other experimental work at still higher Mach numbers in order to acquire fundamental knowledge for a future date. We recommended early in 1949 that supersonic research aircraft should be designed and constructed to be followed up by operational types as soon as possible.

High Speed Flight Research

The aim of most wind-tunnel research is to provide either fundamental knowledge on aerodynamics or data of use to the aircraft designer. Its value depends on checks which can best be obtained in flight. There is a danger that flight research at high speeds and high altitudes will be seriously curtailed for lack of facilities owing to rival demands on the few suitable aircraft available for such work. The newest types are required, and, consequently, there is a serious risk that the small number of prototypes which are ordered will be insufficient to meet the claims both of development and research. The Council has accordingly recommended that there should be an adequate supply of aircraft, material and personnel for flight research to proceed at a reasonably rapid rate. As an example, it was desired to get a direct comparison between swept-back and non-swept-back wings on otherwise similar aircraft. This was possible on one type at the beginning of 1950 and some preliminary measurements were made. The first reports received from both the Aeroplane and Armament Experimental Establishment and the Royal Aircraft Establishment on the stability and handling characteristics of this aircraft as a result of tests on several prototypes show that in both cases performance and handling characteristics were excellent up to $M=0.9$, but very large changes of trim and stability were encountered above this speed. The flight tests on these prototypes have yielded valuable information about the various stability and stalling boundaries in the high subsonic Mach number region. The standard of this work was ranked so highly by the Council that letters of congratulation were sent in 1950 through P.D.S.R.(Air) to the pilots at the two Establishments.

Handling Problems of High-speed Aircraft

The Stability and Control Sub-Committee has devoted several special meetings to discussions with pilots on the handling qualities at both high and low speeds of modern high-speed aircraft. Many test pilots attended by invitation from the Experimental Establishments, from Central Fighter Establishment and from aircraft firms. There was a substantial body of opinion among pilots that, at the present stage, tailless aircraft were less satisfactory for high-speed research work than the more conventional tailless designs. The two chief objections brought against tailless aircraft were: (i) a tendency to instability at high speeds due to a reduction of the damping in pitch which has not yet been explained, and (ii) the fact that trailing-edge control surfaces tend to become ineffective at high Mach numbers, so that the aircraft cannot be kept under full control.
Much consideration has recently been given to the stalling problems of thin wings in view of the tendency shown by some high-speed fighter aircraft to sudden and sometimes catastrophic wing dropping. Flight experiments carried out on one aircraft have shown that very small modifications to the wing section near the leading edge can have a profound effect on the character of the stalling of the wing. Work will be undertaken in wind tunnels with the aim of understanding this phenomenon but the difficulties of representing the modifications to the wing in tunnel experiments at an adequate Reynolds number are many. A method used at the R.A.E. for observing the development of the stall by coating the surface of the wing with a fairly thick oil and photographing the flow pattern revealed on this surface is promising.

American experience on transonic aircraft has reinforced the view of the Council that a manned supersonic aircraft is a most desirable tool for exploring certain aspects of the transonic field. We are glad to learn that a supersonic aircraft has recently become available for experiment as it will be a great aid in solving certain problems of performance and of stability and control which cannot be undertaken readily by any other means.

 Structural Fatigue

The accidents to the de Havilland Comet have drawn public attention to problems dealing with the fatigue of aircraft structures. We draw attention in the Mechanics Section of this Review to the importance attached during the last few years to research investigations on this subject.

II. AERODYNAMICS

1. TRENDS IN AERODYNAMIC RESEARCH

In 1951, the Aerodynamics Committee carried out a general review of the important trends in aerodynamic research, in order to advise on the most important fields in which effort in this country should be concentrated. The views of the Royal Aircraft Establishment, of the Aerodynamics Division, National Physical Laboratory, and of the Aircraft Industry through the Society of British Aircraft Constructors, were obtained and a study of the papers submitted by these bodies revealed a remarkable unanimity of view between the Government Establishments and the Industry.

It was recognized that the total resources in this country available for work in aerodynamics would have to provide not only the requirements for normal aircraft, but also those for supersonic aircraft and guided weapons, not to mention helicopters. In the aircraft field the most pressing problems were connected with aircraft with operational speeds near the speed of sound but the problems of supersonic aircraft were also imminent. The problems of guided weapons with their much higher supersonic speeds and their unorthodox shapes, differ largely from those of manned aircraft.

The Committee was impressed by the unanimous view of the Industry that the greatest contribution which the Government Establishments could make towards the solution of the problems facing the designer was to improve the understanding of fundamental problems. It was therefore recommended that at least half the total effort in the Establishments should be devoted to research of a systematic nature. At the same time, the indisputable need for investigations related to specific designs was recognized. In certain fields the accumulation of general knowledge can perhaps best be effected by beginning with a particular design and generalizing the experiments by progressive modifications. In others, the requisite fundamental knowledge can only be obtained by systematic experiments not immediately related to specific designs.

Some of the problems which have exercised the Aerodynamics Committee and its Sub-Committees during the period under review are discussed under separate headings below. Before proceeding to this detailed review, however, something should be said about the general methods of investigation and the progress that has been made in providing experimental equipment in this country. Fundamental to systematic advances in aeronautical knowledge is the theoretical work whose aim is to systematize the existing empirical knowledge, fill in the gaps where experimental evidence is lacking, and by extrapolation, to guide experimental investigators in the choice of problems to be explored. Turning to experimental work, the principal tool for fundamental research remains the wind tunnel and much progress has been made during the past five years in the provision of tunnels, particularly for supersonic and transonic testing. There are, however, severe limitations on the size of model which can be tested in wind tunnels at transonic speeds and this type of work must be supplemented by other methods of experiment. The technique of ground-launched rocket-propelled models is one which has already proved its value in tests covering the whole transonic range. The wing flow method by means of which models are tested by mounting them on the wings of aircraft in flight, has been used to a limited extent. Finally, many problems, particularly in relation to the handling of aircraft in the transonic region, must rely for their solution largely on tests of actual aircraft in flight. In this connection, the Aerodynamics Committee welcomed a suggestion made by the S.B.A.C. that the facilities for flight research at the firms should be more fully employed, and it is satisfactory to note that there has recently been a marked increase in the research
activities of the firms. Mention should also be made of a new and powerful technique for the study of aerodynamic problems, particularly in the fields of stability, control and oscillation: viz., the use of electronic analogue machines and digital computers.

2. EXPERIMENTAL TECHNIQUES AND FACILITIES

(a) Transonic tunnels. During the period under review, intensive effort has been devoted to the design of transonic wind tunnels, i.e., tunnels in which it is possible to test models in a wind stream flowing at speeds equal or near to the speed of sound. This has been made possible by an idea which was developed first in America, although it was mooted by Sir Geoffrey Taylor in this country before the war. If a model is tested in an ordinary wind tunnel with continuous solid walls in the working section at increasingly high subsonic speeds, a point is reached when choking occurs and no higher speed is possible. It is also possible to design supersonic tunnels in which, by suitable tunnel geometry, the air stream is accelerated through the speed of sound in front of the working section to enable models to be tested therein at supersonic speeds. Hitherto, however, there has been no means of covering the range in the immediate neighbourhood of the speed of sound. The new principle makes use of slotted or perforated walls in the working section through which the stream expands into a chamber surrounding the working section itself, thus avoiding choking and permitting continuous variation of wind speed through the speed of sound without any change in the geometry of the working section. Much research, particularly at the N.P.L. and R.A.E., has gone into the study of different shapes of slot and perforation with a view to obtaining the most nearly uniform distribution of pressure or velocity in the working section and to minimize the shocks reflected from the walls. The largest tunnel in this country which has so far been fitted with a transonic working section is the 3 ft. x 3 ft. tunnel at the National Aeronautical Establishment, Bedford. It is also planned to convert the 10 ft. x 7 ft. High Speed Tunnel at the R.A.E. for transonic running.

(b) Supersonic tunnels. The first large supersonic tunnel at the R.A.E. was built primarily for guided weapons work and has a working section 18 in. x 18 in. This has now been running for some years and has been used for general aerodynamic testing as well as for guided weapons work. At the N.A.E., Bedford, in addition to the 3 ft. x 3 ft. tunnel mentioned above, which will run supersonic up to a Mach number of 2, a much larger tunnel primarily for supersonic work with a working section of 8 ft. x 8 ft. is now in course of construction. At the N.P.L. the largest supersonic tunnel so far in operation has a working section of 18 in. x 14 in. but two larger tunnels are nearing completion. Besides those mentioned there are many smaller supersonic tunnels at the three Establishments and at various universities and firms. Most of these supersonic tunnels cover a range of speed up to about M = 1-8 or 2, although some cover a higher Mach number range and the Bedford 8 ft. x 8 ft. tunnel is designed to run up to M = 2-5. Plans have been approved for the construction of a new medium sized tunnel to cover a higher speed range. This tunnel is intended to yield experimental data at a reasonably high Reynolds number on missiles or aircraft, using the words in their most general sense, which may be expected in the future to fly at Mach numbers as great as, or greater than, M = 3-5.

(c) Hypersonic tunnels. During 1952, the Aeronautics Committee discussed at some length the problems of flow at very high Mach numbers (hypersonic flow), and at very low density (superaerodynamic flow), corresponding to conditions of flight at altitudes much higher than those of current manned aircraft, and recommended that work in this field should be undertaken in this country with a view to the extension of fundamental knowledge. Proposals were put forward at that time for hypersonic tunnels to be constructed at the R.A.E. and the N.P.L. Both received the strong support of the Council.

Three regimes of hypersonic or superaerodynamic flow have been defined, namely, (i) continuum flow in which the usual equations of gas dynamics apply, (ii) slip flow, in which there is discontinuity of velocity and of temperature at the boundary, and (iii) free-molecule flow, which can be treated only on the lines of the kinetic theory of gases. These three regimes overlap but can be approximately defined by theoretical criteria based on the ratio of the molecular mean free path to the thickness of the boundary layer around the body. Continuum flow is by far the most important of the three regimes from the point of view of practical application and the proposed tunnels at the R.A.E. and N.P.L. are designed for the study of this type of flow, with a maximum Mach number of about 8 or 10. At the same time, universities have been encouraged to give consideration to problems involving slip flow or free molecular flow, particularly flow at very low densities and also at very high temperatures. The apparatus required for work of this kind is not very expensive and might consist of (a) a small low-pressure tunnel, (b) a shock tube, or (c) an "ionic" wind tunnel in which electro-magnetic means are employed to produce a very high-speed flow of the ionized gas.

(d) Rocket model research. A valuable tool, in use for some years, for the investigation of the aerodynamic characteristics of specific aircraft or missile configurations, is the ground-launched rocket model method. The models are propelled from a launching site on the ground with the aid of rockets which eventually detach themselves from the model when the required speed has been reached. The subsequent free flight of the model is recorded by electronic, photographic and other means. This method has yielded
a large quantity of useful information on stability and
control characteristics in the transonic region where
data from other sources are often meagre. It has the
disadvantage that it is not possible to vary the con-
ditions of the experiments continuously, or to cover
a large range of values of different parameters, as can
be done in wind tunnels. On the other hand there is
no problem of interference from the tunnel walls which,
in the case of wind-tunnel experiments, require
elaborate corrections to be made to the results.

(e) Flight research. There are many vital problems
of high-speed flight which can only be investigated
on full-scale aircraft in flight and even when labora-
tory experiments on the ground can conveniently be
made, full-scale confirmation from flight tests is often
necessary. In the past, flight research has been severely
hampered because of the shortage of advanced air-
craft available for research purposes. Experience has
shown that even when a particular aircraft is originally
designed for research use it has not in fact always
become available for this purpose if it has proved to
be of interest as a military aircraft. Cases exist of
two prominent aircraft both originally ordered as
research aircraft, of each of which only two prototypes
were built in the first instance. When these aircraft
proved to be of military interest urgent problems
arose in connection with their possible development
as military aircraft, with the result that they were
not in fact available for full-scale flight research except
for short periods.

To overcome this difficulty, the Council recom-
manded to the Ministry of Supply that orders should
be placed for a sufficient number of certain advanced
types of aircraft at an early stage in the design, so
that when built, at least one of the early prototype
or pre-production aircraft could be allocated for full-time
research work.

(f) Other experimental techniques. The Council has
pressed for a more extensive development of instru-
ments, including the further application of telemetering
techniques to flight experiments on piloted aircraft, as
well as to ground-launched rocket tests and guided
missiles, on both of which they have been used with
success. An important problem is the rapid analysis
of flight data, so that results may be quickly available
as a guide to the next experiment or as an indication
of the desirability of a repeat. Efforts have been
applied to the problem of recording the readings of
aircraft instruments in a form which can immediately
be fed into a calculating machine. This process could
equally well be applied to wind-tunnel observations and
could do much to increase the effectiveness of our

Elsewhere in this Review reference is made to the
activities of the Computation Sub-Committee which
concerns itself with various types of computational
equipment including both digital and analogue com-
puters for the solution of problems in the aeronautical
field. Special mention is, however, made here of

TRIDAC, the three-dimensional analogue computer
constructed at the R.A.E. for the study and solution
of problems in the design and control of guided
weapons. Experience in the use of this machine has
shown that the operator may, with its aid, gain an
insight into the problems he is investigating which
goes far beyond the mere numerical results obtained
with the aid of the machine. It is felt that this is a
technique which might well have far-reaching applica-
tions to the design of manned aircraft as well as guided
weapons, enabling the designer to investigate the effect
of varying the parameters of the aircraft before the first
prototype is constructed.

3. AERODYNAMIC THEORY

In the Council's Review covering the years 1939–48
some account was given of the advances in supersonic
flow theory arising from solutions of the linearized
flow equation which is based on the supposition that
the disturbances introduced by a body travelling at a
supersonic speed are small in comparison with the
speed of the body itself. Since that review there
has been further development of detailed linear super-
sonic theory on this basis and experimental evidence
has shown that this theory, although only an approxi-
mation to the flow of an ideal fluid, is of great value
when the flow over a body is virtually supersonic
throughout.

A much more difficult problem is presented in
transonic aerodynamics where the flow over a body
is partly subsonic and partly supersonic and where
shock waves and their interaction with the boundary
layer play an important part. The main progress in
transonic theory has been made with the aid of small-
perturbation theory, which is limited in its applicability
to wings and bodies which are thin, to small incidences
and to inviscid flow, and which neglects the vorticity
generated by shock waves. Some wings designed for
supersonic flight will be sufficiently thin to meet the
needs of the theory. The limitation to small incidences
is a serious one and that to inviscid flow ignores the
important effects of shock-wave and boundary-layer
interaction. Despite these limitations, it is believed that
this theory, even in its present form, is of assistance in
the understanding of transonic flow and that solutions
of limited problems may be of assistance in appreciat-
ing other problems, the solutions of which are not
yet known.

In 1938 the Clarendon Press published for the
Council two volumes entitled Modern Developments in
Fluid Dynamics, the material for which had been com-
pose under the aegis of the Fluid Motion Panel, as
it was then called, and edited by Sydney Goldstein.
These volumes dealt only with incompressible flow and,
although notable advances have been made in this
field since that date, these volumes still give an
authoritative account of the main scope of knowledge
in that field. With the increasing emphasis on higher
subsonic, transonic and supersonic speeds, where the
compressibility of the atmosphere cannot be neglected,
the need was felt for a companion publication dealing with high-speed flow problems. Once more the task of overseeing the contributions was allotted to the Fluid Motion Sub-Committee, many of whose members contributed to the new publication, which was edited by Prof. L. Howarth. The two volumes, entitled *Modern Developments in Fluid Dynamics—High Speed Flow*, were published for the Council by the Clarendon Press in 1953 and have been recognized as the most comprehensive and authoritative review of the subject which has so far appeared.

During the same period a special Panel was appointed, under the Chairmanship of Prof. L. Rosenhead, to prepare a volume of tables for use in compressible flow calculations and a companion volume of graphs. These two volumes were published by the Clarendon Press in 1952 and 1954, respectively, and constitute essential working tools for calculations based on the theoretical methods discussed in the Howarth volumes.

4. SUBSONIC FLOW PROBLEMS

Despite the increased emphasis on problems of transonic and supersonic flow, there remain important and pressing problems associated with flight at subsonic speeds. Two fields in which research has been, and remains, very active are (a) drag reduction, with a view to increasing the efficiency of aircraft, particularly long-range civil and military aircraft, and (b) the low-speed problems of aircraft designed primarily for high-speed flight.

(a) Drag Reduction. Researches of Goldstein and others during the war led the way to the design of laminar-flow wings, i.e., wings designed to secure the maximum area of laminar flow over their surfaces. The drag caused by laminar flow in the boundary layer is only a fraction of that caused by turbulent flow, and the position on the surface of the wing of the transition point where laminar flow changes to turbulent has a large effect on the drag of the aircraft. Theoretically, it is now possible to design wings on which laminar flow is maintained over more than half the surface without the aid of any form of boundary-layer control. In practice, however, such results can only be achieved if the wing surface remains smooth and free from deposits of dirt, flies, etc., since any protuberance or irregularity of the surface is apt to initiate turbulence in the boundary layer. Increasingly refined techniques have been developed for studying in wind-tunnel and flight tests the conditions in the boundary layer. The evidence concerning the amount of roughness and waviness that can be tolerated without causing transition has been satisfactorily analyzed. Much has been done towards reducing surface roughness but it must be admitted that the operational problem of dealing with flies which may impinge on the wing of an aircraft especially at the lower altitudes has not yet been completely solved.

In addition to the technique of obtaining laminar flow through the use of specially designed wing sections, great progress has been made in the application of suction and other means of boundary-layer control to wings. Drag reduction is only one of several purposes for which the principle of boundary-layer control may be used, but it is probably the one which offers the greatest economic gains in the long run. The early work on the use of slot suction to reduce the drag on thick wings was brought to a halt during the period under review; this application is only feasible on aircraft with cruising speeds not higher than, say, 300 or 350 m.p.h., since at higher speeds compressibility effects would be too severe on thick wings. Owing to the fact that even for passenger aircraft the recent trend has been towards higher cruising speeds, the main emphasis on boundary-layer control for low drag has shifted to wings of normal thickness. Work on boundary-layer suction has included both suction through slots and through porous surfaces. Flight tests have been carried out on gloves fitted over portions of Vampire wings using two methods of boundary-layer suction. It will probably be necessary to suck away the whole turbulent boundary layer to obtain laminar flow when flies are deposited on a leading edge. Whether such a procedure is economical depends on how close to the leading edge the suction slot can be sited and on the development of an efficient ducting system.

Flight tests have shown that the difficulty in obtaining laminar flow on full-scale wings is greatly increased when the wing is swept-back. Visual observations of transition have been made on a number of wing and fin surfaces in flight which suggest that the nose radius of the wing section may be a dominant factor affecting the destabilizing of the laminar boundary layer near the nose of the swept-back wing. It has also been shown in wind-tunnel tests that closely spaced vortices are generated within the laminar boundary layer with their axes along the wind direction associated with unstable cross flow over the wing; as the wind speed is increased these vortices break down and cause transition to turbulent flow near the leading edge. Limited success has been achieved in maintaining laminar flow under these conditions by the application of boundary-layer suction at the nose; the tunnel results have subsequently been confirmed in flight but the suction quantities required at zero incidence to maintain laminar flow to the position of minimum pressure are of the same order as those required to maintain laminar flow over the whole chord of an unswept wing. Unfortunately there is a considerable decrease in the stability of the flow over the lower surface with increase of incidence, which makes the practical use of suction on swept wings somewhat doubtful.

(b) Low Speed Problems. As the top speeds of aircraft have increased, so the problem of obtaining a sufficiently low speed for landing has become increasingly severe. This is essentially a matter of increasing the range of usable lift coefficient before the wing stalls. Recently both theoretical and experimental work have thrown light on the nature of the stall on thin wings. Low-speed wind-tunnel tests have shown that when a
laminar boundary layer separates from the leading edge of a thin aerofoil at incidence the flow often becomes attached to the surface again some distance downstream. The region of separated flow is called a bubble and its chordwise dimension may vary from a minute fraction of the wing chord to a length comparable with the chord, depending on incidence, Reynolds number and type of aerofoil section. An analysis of tests made in this country and America indicates that the length of the bubble depends primarily on the Reynolds number based on the displacement thickness of the boundary layer at the separation point. If this Reynolds number is less than 410, a long bubble is obtained and as the incidence of the aerofoil is increased, the reattachment point moves gradually back to the trailing edge and the stall is gradual. If, on the other hand, the Reynolds number has a higher value than the above, the separated flow is unstable, quickly becomes turbulent, and the flow reattaches at a very short distance behind the separation point. With increase of incidence of an aerofoil with a short bubble of this type there is little change in the separated length until the bubble bursts, when the flow ceases to reattach itself to the surface and the stall is abrupt. Further work is in progress which shows promise of throwing light on the mechanism of the bursting of the bubble.

Much of the recent work on boundary-layer control has been directed towards increasing maximum lift. One method of doing this is to suck away the boundary layer at the nose, but there are several alternative techniques, such as the use of suction or blowing over trailing edge flaps. It may well be that this application of boundary-layer control will be the first to prove acceptable on operational aircraft. On both civil and military aircraft there is an urgent need to increase the range of usable lift coefficient at low speeds in order to keep the required runway length within bounds and to improve the handling characteristics of the aircraft in approach, landing and take-off.

Statistics of civil aircraft accidents show that a substantial proportion of fatal accidents is still associated with stalling, although in many cases the accident may primarily have been due to some other cause. The need for some kind of a stall warning device is recognized by the Air Registration Board and the view of many pilots is that, on aircraft where there is no natural stall warning, an artificial warning, preferably in the form of a stick-shaker, should be provided. On many modern aircraft, particularly jet aircraft with power-operated controls, there is no natural stall warning. Furthermore, on some recent aircraft very high rates of descent may be built up very quickly before the pilot is aware of the fact, a consequence of the much greater induced drag of wings which are thin and of small aspect ratio; it would therefore be an advantage if some form of angle-of-attack indicator were provided as well as a specific warning of the approach of the stall.

(c) Spinning. The main experimental tool for the investigation of spin and recovery characteristics of aircraft is the vertical spinning tunnel in which models built to dynamic similarity with the full-scale aircraft (apart from Reynolds number effects) are tested. After making an allowance for the difference in Reynolds number between the model and full-scale aircraft, full-scale characteristics of the spin are predicted from the model tests. A new spinning tunnel is nearing completion at the N.A.E., Bedford. In this tunnel, which has a working section of 16 ft. diameter and can be pressurized to 4 atmospheres, it is estimated that Reynolds numbers up to about one-eighth of full-scale values will be obtainable in free spinning model tests; in rolling balance tests Reynolds numbers up to about half the full-scale values will be obtainable. These Reynolds numbers represent an advance by a factor of about 15 on those obtainable in the existing R.A.E. spinning tunnel.

A new technique which may prove valuable for bridging the gap between wind-tunnel tests and full scale, consisting of free-flight tests with large radio-controlled models, has received the support of the Aerodynamics Committee. Until recently this method was impracticable owing to the fact that there was no multi-channel proportional control radio set of suitable size, weight and cost which would satisfy the conditions of the required experiments. A suitable radio control system of this type has now been developed by the Low Speed Aerodynamics Research Association at Farnborough and the Aerodynamics Committee has recommended that official support should be given to the further development of the method.

Spinning tunnel tests on new aircraft cannot be made until the design of the aircraft is almost settled and it is important that the designer should have some guide to the probable spin and recovery characteristics of the aircraft in the early stages of design. Various attempts have been made in the past to produce criteria based on the geometry of the aircraft for predicting recovery characteristics and a new criterion has recently been proposed at the R.A.E. The principal advantage which it has over its predecessors is that it includes the important parameter B/A, the ratio of the pitching and rolling moments of inertia of the aircraft, and indicates that the recovery standards will improve as this ratio increases. This is in agreement with recent full-scale experience. The new criterion does not apply to twin-boom aircraft such as the Vampire and Venom and it has other limitations, e.g., it considers only the effect of the rudder as a recovery control and sideslip does not appear explicitly in the criterion. Nevertheless, it has proved to be remarkably successful in separating both straight wing and swept-back wing aircraft into "pass", "borderline" and "fail" classes from the point of view of recovery from the spin.

When an aircraft enters a spin from straight and level flight the path of the c.g. changes from a horizontal path to a spiral about a vertical axis. During this changeover period oscillation in the angular velocities about the body axes of the aircraft are bound to
occur. In some spins these oscillations are damped out between the second and fourth turns and then the aircraft spins smoothly with the angular velocities about the body axes remaining almost constant. This is the familiar steady spin. On many present-day aircraft, however, the oscillations do not damp out but gradually increase in amplitude up to the fourth turn and in some cases the amplitude continues to increase up to at least the eighth turn. When the oscillations are of a mild type the pilot experiences no very violent changes but is aware of a continuously changing angle of wing tilt, the outer wing appearing to move from well above the horizon down to the horizon and back again, once in each turn: this type of oscillation has been called a wallowing spin. In a fully-developed oscillatory spin the oscillations in the angular velocities about the aircraft axes are quite violent, the rate of roll, for example, changing from zero to as much as 3.5 radians per second and back again in each cycle.

The oscillatory spin is not a new phenomenon but it is becoming increasingly important. To the pilot it can be an unpleasant experience in which the nose of the aircraft oscillates up and down in relation to the horizon, accompanied by marked variations in acceleration in roll and pitch. At the same time pronounced aileron snatching is apt to occur. In general, an oscillatory spin is apt to occur on aircraft with good recovery standards. It is an essential feature of the phenomenon that the wing should un-stall itself at one point of each cycle and very little action is required on the part of the pilot to effect recovery. The recommended drill is for the pilot to centralize the stick and if the aircraft does not come out of the spin by the time an altitude of 7,000 to 10,000 ft. is reached, he should bale out. As regards scale effect, flight experience shows that the oscillatory spin is more likely to occur on full scale than on model scale even though the proper scale effect allowance, based on recovery standards from the model spin, has been applied to the model results.

5. PROBLEMS OF TRANSONIC FLIGHT

As has been pointed out above, the most difficult aerodynamic problems are associated with speeds in the neighbourhood of the speed of sound, i.e., at and near \( M = 1 \). The transonic region in the broadest sense, however, may be taken to include, not merely the immediate neighbourhood of \( M = 1 \), but the whole region within which there is a mixed régime of subsonic and supersonic flow over a body. In other words, the transonic region begins where small areas of supersonic flow appear on the surface of the aircraft or missile, accompanied by shock waves marking the transition between subsonic and supersonic flow. As the speed of flow is increased, the shock waves become more pronounced and the areas of supersonic flow more extensive. Finally, the upper limit of the transonic region is reached when the flow over the whole body is entirely supersonic. Wind-tunnel observations and theoretical considerations have distinguished a number of different régimes within the transonic region as a whole, defined by the position and nature of the shock waves on the body and near its leading and trailing edges.

Shock waves have the effect of greatly increasing the drag on the body, and through their interaction on the boundary layer, they may also have adverse effects on lift, on stability and on control effectiveness. It is therefore of the greatest importance to the designer of transonic aircraft that their effects should be minimized as far as possible. One of the principal methods of doing this is to make wings as thin, and bodies as slender, as is practicable. Another is to delay the effects of compressibility, including the formation of severe shock waves, to as high a Mach number as possible by sweeping back the wings. From swept-back wings of conventional aspect ratio to delta wings of small aspect ratio is a logical step which further alleviates the effects of compressibility, and one which has been adopted by a few manufacturers in this country with considerable success.

(a) Shock-Wave Boundary-layer Interaction. It is considered that some of the major difficulties and obscurities of transonic flow are associated with effects of the interaction of shock waves with the boundary layer, particularly when separation of the boundary layer results from the interaction. The conditions under which separation occurs are now known with reasonable accuracy and many of the effects in flight are at least partially understood. On a wing or aerofoil, separation occurs at or upstream of the foot of a shock wave when the pressure rise across the shock, i.e., the shock strength, exceeds a certain value. This value is lower for a laminar boundary layer than for a turbulent boundary layer, at the Reynolds numbers obtainable in wind-tunnel tests. Separation on one surface, by arresting the rearward movement of the shock wave on that surface and reducing the rate of recovery between the shock and the trailing edge, causes the trailing edge pressure to fall rapidly and hence to diverge from the smooth and gradual variation with free-stream Mach number which would occur if separation were absent. This disturbs the equality, or near equality, of pressure on the two sides of the wake at the trailing edge, which must be satisfied for steady flow, and, to compensate for this disturbance of the trailing edge pressure, the shock waves on the two surfaces move towards the trailing-edge at different rates, with consequent changes in the pressure distribution on the aerofoil. Adverse effects which may be associated with these phenomena include loss of lift and control effectiveness, changes in trim and stability, and wing drooping, whilst it appears likely that buffeting arises from the formation of large-scale disturbances as a result of instability of the vortex sheets formed at separation.
To avoid separation, the local Mach numbers must be kept low; thin wing sections, sweep and low aspect ratio all help to do this at low incidences, but high local Mach numbers are always likely to occur for high wing incidences or control deflections. The deflection of trailing edge controls when the flow over the wing is locally supersonic leads to an abrupt increase in Mach number on the convex side of the hinge and hence an increased tendency to separation. For this reason, all-moving wing tips for tailplanes may be more satisfactory than conventional trailing edge controls for transonic flight, and other unconventional methods of control are also under consideration. Although separation effects are frequently minimized by careful choice of section shape and plan form, it is possible that application of boundary-layer control may sometimes be needed to prevent separation. Work is in progress on the application of vortex generators, fences and various forms of boundary-layer control in this connection.

(b) Drag. In the design of transonic and supersonic aircraft, one of the prime considerations is to reduce to a minimum the wave drag, i.e., the drag associated with shock waves. Something has been said about the adoption of thin and swept-back wings for this purpose but there remains a serious problem associated with the increased wave drag due to the mutual interference of the wing and the body at their junction. The design of air intakes for jet engines is an integral part of this problem.

(c) Limitations on Lift at Transonic Speeds. Aircraft designed for military operation at transonic speeds must be able to manoeuvre and this implies that the aircraft should have a reasonable range of usable lift before stalling occurs.

Apart from the stall itself, limitations on maximum lift at high Mach numbers are frequently imposed by buffeting and loss of longitudinal stability. There is need for much more fundamental understanding of these problems. Progress towards this end has come, not only from the study of shock-wave and boundary-layer interaction, but also from recent work, both theoretical and experimental, on the stalling of thin and swept-back wings. In particular, much effort has been devoted to means of countering the tendency to premature tip-stalling on swept-back wings.

(d) Stability. There remains an urgent need for more accurate knowledge of stability derivatives. Whilst the subsonic and supersonic value of stability derivatives can be predicted with reasonable accuracy, there is as yet very scanty knowledge of values in the transonic region. Continued effort, utilizing free-flight models and wing-flow techniques as well as wind-tunnel experiments, is required to extend knowledge in this field. As regards longitudinal stability, the most important problem is probably that of the variations in the damping of the short-period longitudinal oscillation, particularly in the region between \( M = 0.9 \) and \( M = 1 \), which on some aircraft amounts to a significant loss of damping. In addition, large negative static and manoeuvre margins are reported to occur on some swept-wing aircraft at lift coefficients above 0.7 in the region from \( M = 0.85 \) to \( M = 1 \). There is at present very little knowledge on lateral stability derivatives but it is possible that only their order of magnitude need be known.

(e) Control Effectiveness. Data on control effectiveness in the transonic region are being accumulated, particularly through free-flight model experiments, and the designer now has some basis on which to choose his controls. In particular, a systematized body of knowledge exists on the effects of sweepback and trailing-edge angle on the characteristics of conventional trailing-edge controls.

Certain alternative forms of control have possible advantages over the normal trailing-edge type at transonic speeds in particular respects, for example, in being less likely to cause shock-induced boundary-layer separation, but the choice of control is often a compromise between these particular advantages and disadvantages in other respects or at other speeds.

It is considered that, at any rate for some time to come, power operation of controls will be essential for transonic aircraft and that the right policy is to concentrate on making power controls reliable and not to think in terms of manual reversion. This will make the difficult problem of aerodynamic balance of controls much less severe, but it is important to ensure that deformation in the control unit is reduced to the absolute minimum by ensuring that all the effective stiffnesses are as high as possible.

6. PROBLEMS OF SUPERSONIC FLIGHT

In the supersonic field a main aim of fundamental research is to evolve a body of experimental results which will provide a basis for testing and improving the aerodynamic theories which have already been developed. Of great importance here is the bringing in to full and effective use of the large-scale supersonic tunnels referred to in an earlier paragraph, although much useful information is being obtained from tests with ground-launched rocket models.

Aircraft designed to fly at speeds up to twice the speed of sound may not have sweptback wings since the advantage of sweepback is mainly to postpone the difficulties associated with transonic flow to a higher speed of flight, and not to avoid them altogether. The first aircraft to fly at supersonic speeds in level flight, namely, the American Bell X.1, had straight wings, and so have the majority of guided weapon configurations. Many of the problems confronting the designer of a supersonic aircraft are similar to those met in the design of an aircraft required to operate at high subsonic and transonic speeds, but with increased emphasis on the body and body-wing interference contributions and on the air intake problems. It should be emphasized that, although an aircraft may be designed to have a top speed of, say, twice that of sound, it
may have to fly fairly steadily and to manoeuvre close to the speed of sound; there also remains the problem of achieving satisfactory low-speed characteristics on aircraft designed primarily to fly at transonic and supersonic speeds.

(a) Aerodynamic Heating. The aerodynamic heating of the surface of the aircraft at supersonic speeds, and the consequent effect on the structure, may be a limiting factor affecting the speed of flight of the fastest aircraft in the future. The problem is difficult to treat satisfactorily owing to the complicated effects of fine structural detail but it appears that the maximum thermal stresses on wings are likely to occur at the leading edge and at mid-chord. When the duration of flight is short, the rate at which the temperature builds up is important and this is affected by the rate of heat transfer and by the heat capacity of the material. At $M = 2$ it is assumed that it takes about half a minute for the temperature to build up and in some cases the duration of flight at this Mach number might be less than this. The acceleration at which the aircraft attains this flight speed in turn affects the initial heat transfer rates and thus the magnitude of the thermal stresses. Insulation may help to delay the effects of the build-up of temperature. An aspect of this subject which is thought to be of special importance is the effect of heat transfer on boundary-layer transition. It would seem to be established that transition is delayed when the heat flow is from the fluid to the body, so that it may be easier to maintain laminar flow over bodies at high altitude if the heat lost by radiation is high. At very high altitudes the Reynolds numbers may be relatively low and the chances of extensive laminar boundary layers are correspondingly enhanced.

(b) Guided Missiles. The advent of guided missiles has laid emphasis on certain aerodynamic problems which are not important in relation to manned aircraft, associated with such factors as (i) relatively large bodies, (ii) much higher incidences, (iii) frequent use of cruciform wing arrangements, with pitch and yaw of equal importance, and (iv) a more complex downwash problem than on most aircraft since the wings and tailplanes constitute two sets of surfaces of comparable span. A very large amount of data is required to define the aerodynamics of a missile, particularly with cruciform wings and the associated problem of mutual interference between the two sets of wings. There exists no satisfactory theory which can be applied to the problems of missiles at supersonic speeds and high incidences; the existing linear supersonic theories are of no help in this connection. Furthermore the problems of stability in flight where acceleration cannot be neglected is one which does not yield to the classical treatment in terms of linear differential equations with constant coefficients. A beginning has been made on a theory of stability in accelerated motion and valuable information on guidance and control problems is being obtained from TRIDAC, the three-dimensional simulator for guided weapons at the R.A.E., mentioned above.

III. PROPULSION

1. TEST FACILITIES FOR AIRCRAFT ENGINES

In 1951 the Council submitted, on the recommendation of its Propulsion Committee, certain proposals for equipment and facilities for propulsion research to the Ministry of Supply. This included plant for the full-scale altitude testing of engine components and an altitude test cell for complete engines, both of which were considered highly desirable. Since that time additional equipment has been provided at N.G.T.E. for testing components and a great deal has been done in the aircraft engine industry for the testing of large unit components. During 1954 the matter has again been reviewed in the light of probable engine developments during the next 10 to 15 years. No fundamental changes in the aircraft engine are foreseen at present and it has also to be borne in mind that it takes about ten years to design, develop and use an engine to the stage at which it becomes obsolete. The Propulsion Committee has expressed the opinion that an altitude test plant for complete engines should be constructed without delay in order that this country shall maintain the lead which it now holds in engine research and development.

The Committee has recommended that a test plant in the form of an altitude chamber should be capable of accepting an engine of high mass flow and reproducing conditions of temperature and pressure equivalent to flight at $M = 3.0$ at 70,000 feet. The desirability of testing engines at high speed at sea levels should also be borne in mind, and provision should be made within the above limits of mass flow, for simulating airflow around small engines. A satisfactory range of operation would be that given by the maintenance of constant indicated airspeed over the recommended range of altitude, but it is felt that consideration of such details is unnecessary at this stage. The approval of the plant in principle has been agreed by H.M. Treasury; the details of the final design have not yet been decided.

2. ENGINES FOR JET LIFT

The development of engines of low specific weight has made possible the achievement of vertical take-off and landing using jet thrust. The further development will be materially assisted by the advent of small jet engines of lighter weight. In America attention is being directed to the take-off of the aircraft from a vertical attitude from supports under a cruciform tail. In this country experiments have been made on a ‘Flying Bedstead’ in which both direct lift and controlled flight
have been achieved, based solely on the jet thrust given by Nene engines. The Council has been in touch with these developments from their commencement and has given its strongest support. It may well prove that the future of the most powerful aircraft will lie in direct lift types which do not need large areas for their take-off and landing.

3. HELICOPTER POWER PLANTS

Proposals have been put forward for the powering of large helicopters by turbo-jet engines mounted at the rotor tips. It has been estimated that a machine of between 20,000 lb and 50,000 lb all-up weight, powered by three engines of 7,500 lb thrust, would be capable of travelling at 100 m.p.h. for a distance of 500 miles with a load of 24 tons, or for 100 miles with a 54 ton load. The scaling-up to this size of the conventional shaft-driven machine appears to be impracticable due to the rapid increase in the proportionate weight of the transmission and the excessive blade weight which is required to maintain a reasonable coning angle. This latter problem is partially solved if the engines are used as blade tip weights, and it is felt that although the use of turbine engines in this way would give rise to many problems such as high bearing loading and the effect of high centrifugal force on the operation of the fuel system, such problems would not be insuperable and would be matters for development rather than research. If the construction of such engines be contemplated, they should be designed specifically for this purpose and not adapted from existing engines.

Other possible forms of helicopter power plant are tip mounted ram jets or pulse-jets, tip jets supplied by a gas-turbine driven compressor and conventional shaft-driven rotors powered by gas turbines in place of piston engines. Promising results have been obtained in America on experimental machines using the two former methods, and there would appear to be an application for ram jets and pulse-jets for use in very small helicopters. No decision can, however, be reached on the optimum power plant for helicopters or on the desirability of undertaking research on specialized turbine engines, gas generators, ram jets or pulse-jets, until definite helicopter requirements are drawn up.

4. INTAKES

Aircraft intakes have, in the past three years, been a special subject for consideration, including the performance of twin ducts at the roots of swept-back wings. This form of intake gives minimum wing flow disturbance but has the disadvantage that a part of the fuselage boundary layer is taken into the duct and the efficiency of the intake is found to be largely determined by this boundary layer air. Use of a bypass slot to remove the boundary layer increases the efficiency but it is difficult to obtain a reduction in overall drag coefficient by this method as the drag of the bypass offsets the gain in the duct. Interest has more recently been directed to supersonic intakes, consideration having been given to the problems of drag loss of centre body intakes, flow instability, the effect of intake volumetric capacity on flow oscillation, and the performance of an intake in the presence of a boundary layer. More information is required and is being obtained on the effects of variable intakes and, in fact, on the whole problem of intake arrangement.

5. COMPRESSORS

(a) General. At the N.G.T.E., emphasis is being placed on the transonic or low supersonic range of compressor, as this appears to offer something of the best of both subsonic and supersonic regimes. The transonic compressor will probably be smaller, lighter and cheaper than the conventional compressor, while its mechanical problems will be less than those of the supersonic compressor, and provided that combustion techniques follow the aerodynamic advances there appears to be a promising future for the transonic compressor engine. It is intended at N.G.T.E. to develop the transonic compressor up to a Mach number of 1-2, and a temperature rise of 50°C per stage with an acceptable efficiency.

The Propulsion Committee has agreed that the present approach to the supersonic compressor by way of development via the transonic type, and by detailed analysis of all available experimental results, is the most profitable method of attack. Direct approach to the true supersonic compressor should not however be entirely abandoned, as the ultimate development of a single-stage compressor with a pressure ratio of about 5:1 and a low diameter ratio is a most important aim. It should also be remembered that both the transonic and supersonic compressor are merely steps towards the attainment of an inexpensive lightweight engine.

Interest was taken in American work on supersonic axial compressors at the beginning of the period under review and the American results were so encouraging that work was put in hand. However, based on mass flow per unit frontal area, the supersonic unit compares unfavourably with the orthodox axial-flow compressor, a conclusion supported by some work on a supersonic compressor tested at the N.G.T.E.

(b) Aerodynamic Research. At Cambridge University, an investigation has been made into the flow about a cascade when the inlet velocity varies along the span. Good agreement has been obtained between calculated and experimental determinations of the spanwise variation of lift and circulation. The flow angles downstream from the cascade have been found to depend not only on the secondary flow in the blade passages but also on the stream displacement in the spanwise direction needed to establish radial equilibrium.

The actuator disc theory of flow in closely spaced rows of compressor blades has been developed and
compared with the results of tests on a two-stage compressor at Cambridge. Theory compares satisfactorily with experiment even in the stalled region and enables the effect of hub-tip ratio and axial spacing between the blade rows to be determined.

This compressor has recently been used to investigate the phenomenon of rotating stall, a condition which can arise when the compressor as a whole is either surged or unsurged. The rotating stall takes the form of a reduced flow through one or two blade passages, the region of stall rotating relative to the blade row in the same sense as the compressor rotation. An axial compressor may have from one to as many as seven stall cells rotating at about half compressor speed in any blade row. This phenomenon may be a cause of blade failure by vibration.

Experiments on compressor cascades of different designs have been reported from Metropolitan-Vickers Company and from the National Gas Turbine Establishment, the former including photographic studies and covering a range of Mach number and incidence, which shows the growth of shock formations in the blade passages and their interaction with and effect upon the boundary layer.

Valuable information on the growth of shock formations on turbine and compressor cascades has been given in several papers including evidence from schlieren photographs which provides some explanation of the form of the loss curve at high speeds. One paper of special interest, R. & M. 2728, shows the results obtained from a series of conventional turbine cascades, indicating a rise in loss coefficient with increase in speed above the critical value, due to a shock formation, until a single shock downstream has an effect on the pressure distribution and therefore on the boundary layer, reducing the adverse pressure gradient and therefore reducing the rate of increase of loss coefficient. This effect continues until the loss reaches a maximum and thereafter in some cases considerably decreases.

6. COMBUSTION

(a) The Process of Carbon Formation. The Combustion and Fuels Sub-Committee has devoted considerable attention to the subject of carbon formation, on which a number of papers have been communicated from the Royal Aircraft Establishment, from the Thornton Aero Engine Research Laboratory and from the Joseph Lucas Research Laboratories and some have been published externally.

Much recent experimental evidence has been accumulated by extensive studies of diffusion flames and by the application of a newly developed and promising method for the spectroscopic examination of flames. Fundamental investigations of the chemistry of the processes involved have also been undertaken. Yet, in spite of the technical importance of the subject, the fundamental processes leading to carbon formation in hydrocarbon flames are not fully understood.

There are three main theories to explain the mechanism of carbon formation. First, the polymerization theory which assumes that the hydrocarbon is first dehydrogenated and this is followed by successive processes of polymerization leading eventually to carbon particles in mist form. Second, the C₄ polymerization theory which suggests that the C₄ radicals are polymerized to form carbon complexes. The third theory, called the oxidation theory, assumes that the hydrocarbon is first dehydrogenated and that this is followed by oxygen attack, leading to peroxidized radicals which break down to form a number of simple chemical products and atomic carbon, the latter polymerizing to form carbon complexes. The observed experimental effects have been compared with the theories. The first is favoured as it agrees with the fact that the onset of carbon formation is critical to pressure. The C₄ polymerization theory has been found to be untenable. The main difficulty of the third, the oxidation theory, is that the time available for the final polymerization is very short. Some colour is lent to the significance of hydrogen atoms in the initiation of the reactions which lead to carbon formation and further experimental and theoretical work are required for its confirmation.

Much new work has been done on the fundamentals of the process of carbon formation and related subjects, and suggestions regarding the most likely mechanism have been presented. Due to the complexity of the process the exact details are not yet fully understood and further conclusions can only be presented when more experimental evidence has been obtained.

Although carbon formation is an ever-present problem during development work, there is with contemporary fully-developed designs of combustion chamber little or no practical difficulty. In certain cases there has been, however, some emphasis on the problem of carbon deposition on burners. The desirability of being able to control carbon formation in the future design of combustion chambers emphasizes the need for further fundamental investigations into the problem.

(b) Effect of Linear Scale. A theoretical investigation of the problem of the effect of linear scale was initiated at the N.G.T.E. at the request of the Propulsion Committee, the request originating from the Committee's discussions of the equipment and facilities available for propulsion research and development. The expense and difficulty of supplying air for the full-scale testing of combustion systems over a wide range of operating conditions makes it very desirable to consider how far useful results can be obtained from tests on a small scale. Fundamental knowledge of scale effect would also be of general assistance in developing combustion chambers of various sizes.

In the early stages of the study, a list of component processes was drawn up, comprising fifteen different relevant processes under the general headings of aerodynamics, heat transfer and combustion. Sufficient
information is now available to enable the relative importance of most of these to be assessed, although it is agreed that there is no clear-cut answer to the question of which of the variables will be the most important in any particular combustion chamber, and that the gaps in present knowledge are bound to throw doubt on any generalizations. It was found possible however to reduce the fifteen basic parameters to eight which were considered to be of probable primary importance, and having done this the next step was to consider how many of these could be satisfied in a model test. The conclusion was that a large number of them would be correctly simulated by a half-scale model running at the same air velocity and fuel pressure as the full-scale design, but at twice the pressure and half the mass flow.

It is felt that the N.G.T.E. study probably marks the limit to which dimensionless analysis can contribute to the solution of the problem at this stage and a considerable amount of experimental work now remains to be done. The variables are so numerous and so inter-connected that there is no simple solution to the problem of deciding on the most important parameters. Even if these can be resolved experimentally and exactly satisfied on a model scale, there still remains the question of rig power, since according to the conditions required, it is not impossible that a small-scale rig may need more power than the full-scale rig.

It is of interest to note that although the theoretical investigation at the N.G.T.E. did not cover the use of segmental models of annular chambers, the Establishment has had considerable success in the testing of a half or “D” section of a ram-jet combustion chamber.

(c) Combustion Chamber Cooling. Considerable attention has been paid by the Combustion and Fuels Sub-Committee to the subject of combustion chamber wall cooling, including external circulation of the cooling air using if necessary fins or secondary surfaces to increase the heat transfer rates, effusion cooling using porous walls, cooling by localized injection of air, and a combination of the methods of internal circulation and localized injection.

Work at the N.G.T.E., R.A.E. and elsewhere has emphasized the superior cooling efficiency of the porous wall effusion cooling method. A practical point to be considered is the blockage of the pores, but it was noted that the blockage experienced so far could be cleared by blowing air through the wall in the reverse direction. There is scope for research to find new materials of sufficient mechanical strength for use as porous walls.

Boundary-layer cooling is only directly effective against convective heat transfer, and in some cases about 50 per cent of the total heat transfer is by radiation. It is evident, therefore, that the radiation problem is of some importance, and more information is needed on the distribution of total radiation between luminous and non-luminous types, and on methods of predicting the luminous emissivity at any point of the flame with different kinds of fuel.

The general conclusion of the work to date is that the most efficient method yet considered is effusion cooling through a porous wall, although it is realized that the full advantages of this method will depend on the development of suitable porous materials. A compromise between the louvre and the porous wall types of cooling might be to use some form of gauze.

(d) Combustion at High Mach Numbers. Any significant advance in engine aerodynamics towards the achievement of low weight and low cost will have to be accompanied by an equivalent advance in combustion technique in fast air streams, considering firstly the chamber as an aerodynamic system and secondly the chemical process of combustion. The controlling factors from an aerodynamic viewpoint are length/diameter ratio, velocity and temperature ratio, while chemically the best parameters are probably residence time and the time required for ignition. Greatly improved performance could be obtained, and chambers of a much higher rating constructed, if it were possible to dispense with the requirement of idling and relighting at high altitude, and it is felt that the heavy penalty paid as a result of this requirement may not be fully realized. There does not seem to be a great deal of room for further development of combustion chambers operating at medium pressures, as efficiencies are already high. The losses associated with reheat systems for instance, considerably outweigh any possible gains in the engine combustion chamber. There will however be new problems to face if and when the supersonic compressor comes into general use.

7. TURBINES

(a) Axial-Turbines. In order to predict the performance of a turbine or to design it to a given specification, it is necessary to know the behaviour of various blade forms not only in cascade but in the turbine itself. If the performance of a sufficient number of turbines is analyzed, then rules and coefficients may be evolved to make future design more certain, and such an analysis for conventional sharp-nosed blading is attempted in a paper prepared by the N.G.T.E. This survey covers the effects of the various aerodynamic and geometric variables on loss coefficient and gas angles at both high and low Mach numbers, and also considers the effects of those losses which are in general independent of blade form. Having established the design angles and coefficients, the paper also gives data for predicting the off-design performance in terms of stalling incidence, and variation of both profile and secondary loss with incidence. A further paper gives a method of stage-by-stage performance calculation using the detailed blade performance figures previously established, together with corrections for such variables as tip clearance, blade curvature and annulus flare. With the design rules given in these papers the efficiency of
a conventional turbine can be predicted within about 2 per cent which is within the usual limits of test accuracy.

The Sub-Committee has discussed these papers fully and considers that they form a valuable addition to the information available to the turbine designer. No definite rules are however provided for the effect of boundary-layer thickness on secondary loss, and it is felt that this gap in our knowledge could be filled by work on blades in cascade, followed up by work in rotating rigs. Such work could be done by a University or the N.G.T.E., which has equipment ideally suited to the problem, and the Sub-Committee has suggested that University research students might use N.G.T.E. rigs for this purpose.

Considerable gains are possible if turbine efficiencies can be improved but insistence by designers on low weight and high work capacity makes this achievement difficult. N.G.T.E. has put forward a method of predicting performance of an axial-flow turbine (C.P.30). Research has been initiated to clear up the remaining differences between theory and experiment, in particular, the high loss coefficients of certain turbine blade cascades, where the losses measured are greatly in excess of those which would be predicted.

(b) Radial Turbines. Radial turbines have for some time been considered for particular applications, and are in fact already in use in aircraft auxiliary power units. Their rotor form is robust and they appear to be particularly suited to small-scale engine application, and both the Gas Turbine and Engine Aerodynamics Sub-Committees have discussed a number of papers which together summarize most of the available performance data. Most of the tests have been carried out on centrifugal compressors of about 8 inches diameter running backwards, a condition which approximates very closely to the optimum design for a radial-flow turbine, and peak efficiencies of 85 to 86 per cent have been measured. This is slightly inferior to the 50 per cent reaction axial turbine but is better than the low reaction axial. An efficiency of 80 per cent has also been claimed for a 4-inch diameter turbine. The torque ratio of the radial turbine is less than that of the axial machine, and its operating range is narrower, thus making the matching problem rather more difficult, but this latter problem is offset by the ease with which variable inlet nozzles can be incorporated. Mechanically, the maintenance of running seal clearances presents a considerable problem, and it is considered that stress limitations will put an upper limit on power output of about 500 h.p. In general there is a feeling that the chief merits of the radial turbine lie not so much in its promise of high efficiency, but in secondary advantages such as low runway speed and the ease with which rotor cooling and adjustable nozzles can be incorporated.

(c) Turbine Cooling. It has been accepted for some time that cooling is advantageous for all types of turbine engine except possibly the unreheated subsonic turbojet, and it is generally agreed that the major effort should be concentrated on air cooling, although work on liquid cooling should continue as this might prove to be essential for high-supersonic flight and might be usefully employed in the turbo-propeller engine and the high-temperature expendable engine. Interest has so far been centred on the turbine blades, research being directed towards the most efficient use of the cooling air supply. To this end work is needed on full-scale engine tests of blade cooling systems, on tests of complete blades on stationary and rotating rigs and on fundamental heat-transfer coefficients for the various systems.

The possibility of the use of high temperatures is of course not the only asset of the cooled turbine. An equally important advantage is the possibility of using low-alloy steels in place of expensive heat-resistant materials, the most promising arrangement of fabricated blade being that formed by a central core with machined grooves in the surface and a thin sheetmetal section welded to it. Mechanically, this construction is not entirely satisfactory but it is considered that strategically the blade is good since only the outer skin need be in oxidation resistant material. The most general objection to fabricated blades is that they frequently make use of brazing, a process which is as yet not entirely reliable, and for which a satisfactory non-destructive method of inspection has yet to be found.

Both the hollow fabricated and the solid blade with spanwise holes are cooled by the turbulent flow of air through passages in the body of the blade. With the effusion-cooled blade, the position of the transition from laminar to turbulent flow on the blade surface is particularly important because of the considerable increase in heat transfer in the turbulent region. The effusion flow required to maintain a uniform surface temperature is great near the leading edge, which is probably the most difficult position at which to maintain a high value of permeability. Experimental work on effusion cooling is in progress in this country at the N.G.T.E. and at the engine firms, and the results of this work are awaited with interest.
1. STRUCTURES

The comparatively slow straight-wing aircraft of the past have been designed mainly on a static strength basis and the stiffnesses necessary for flutter prevention and control effectiveness have been provided at little extra cost. Aircraft are now reaching speeds and flying at altitudes where it is essential that the structure should be designed with due consideration of speed and Mach number as well as normal acceleration. In aircraft of the highest speeds with very thin wings, a main problem is to provide adequate stiffness for prevention of flutter and loss of control. Two other factors assume importance: one the problem of fatigue and the other that of adequate strength to meet intense gusts which are relatively more severe for high-speed aircraft because the changes of velocity are passed through more quickly.

(a) Structural Fatigue. On account of gustiness in the atmosphere aircraft are subjected to varying loads in flight leading to fatigue of the structure. It is clear that for certain types of aircraft, particularly civil transport aircraft, the matter is one which must be given very serious attention in design, but it is also one for which the necessary fundamental data are lacking. The matter of gravest concern is that fatigue cracks may spread undetected till catastrophic failure results. In addition there is abundant evidence of maintenance troubles resulting from repeated loads: the cracking of plating and the loosening and fretting of rivets are common examples. These defects add to the running cost of aircraft and are of great concern to both operators and manufacturers.

At the beginning of the period under review we drew attention to this problem of repeated loading of aircraft structures, and pointed out that research was needed in two directions. First, accurate data were needed on the magnitudes and relative frequencies of occurrence of applied loads. The accumulation of the necessary data required the development of suitable instruments, such as the counting strain gauge and the counting accelerometer. It is now possible to record that a counting accelerometer has been produced. Secondly, much more information was needed on the way typical aircraft structures, structural elements and materials behaved under repeated loads. There was at this stage experimental evidence that for many types of loading, loads greater than about 50 per cent of the ultimate static strength occur very infrequently in normal service. This permitted the concentration of effort on obtaining data on the magnitudes and frequencies of the lower loads and on the life of structures tested in the laboratory under similar conditions.

In 1953 we drew the attention of the Ministry of Supply to the fatigue of aircraft structures following the receipt of a valuable report on this subject from our Structure Sub-Committee. This report describes many of the factors affecting fatigue strength, and also reviews briefly the present situation for civil aircraft. The outstanding impression is that progress has been made and a number of different aspects of the problem are now being explored and experimental data accumulated steadily. Even so, the problem remains most serious, and research work needs to be energetically pursued. Since no adequate theory of fatigue has yet been produced, the experimental work has an empirical basis. From the lengthy nature of the experiments required, it follows that rapid accumulation of data cannot be expected.

It is necessary to accept the principle that the structure of an aircraft wears out just as many other parts do. Subject to economic limitations, the first objective for a new design should be to provide a sufficiently long fatigue life solely by attention to the initial design. Knowledge already obtained by research and experiment should enable the life of new designs to be extended appreciably beyond that now being achieved and at no additional cost in structure weight.

A scheme has been produced by the R.A.E. to assist in the prevention of fatigue accidents to civil aircraft, which may be envisaged as proceeding in three stages. At the first stage a safe short "life" is allotted on general theoretical grounds and from past experience of other aircraft types. This arrangement enables fatigue testing of specimens to proceed while the aircraft is operating normally. The next stage produces a revised estimate based on these laboratory tests and normally gives an extension of life. This extension makes use of specific test data, but is related only to generalized knowledge of gust effects. A third stage makes use of gust measurements on the particular type and may give a further extension of life. The average life of existing types of civil aircraft is assessed in this scheme at roughly 10,000 hours (for standard European conditions of operation), and it has been suggested that for new designs this should be increased to about 30,000 hours by attention to ab initio design.

On this question of fatigue due to repeated loads, we have been kept acquainted with the important investigations that have been conducted at the R.A.E. during 1954 in connection with the accidents to the de Havilland Comet I.

(b) Strength of Structures. Despite the almost universal adoption of swept-back wings, there is still a serious lack of theoretical knowledge on the methods of stress analysis applicable to real structures. Several theoretical treatments of this subject exist but each has its practical limitations and both experimental and theoretical work are required for their elucidation. The analytical difficulties emphasize the importance of the experimental approach and existing experimental research programmes should accordingly be extended as rapidly as possible. It is essential that the test specimens used for this purpose should be built of the correct materials and to as large a scale as possible in
order to reproduce with adequate accuracy the characteristics of larger structures.

The aircraft designer has frequently to cope with the problem of load diffusion in his structure. Possibly the most common example is in the region of the undercarriage cut-out in a wing; other examples are around fuselage doors and any points of application of a concentrated load, e.g., from a fin post. In the past these problems have been solved largely by ad hoc methods and the value of each solution has been uncertain. With the development of new types of aircraft, structural efficiency has become even more important than in the past, and a better understanding of load diffusion problems is essential. Theory has yet to be extended to cover the effects of the end loads produced in the rib booms and the shear transmitted down the rib web, particularly as regards the rib at the edge of a cut-out. The end loads in the rib booms cause lateral bending of the spar boom and give some relief to the sheet. These further developments of theory should give a closer estimation of the loads in the subsidiary structure.

2. FLUTTER OF AIRCRAFT

The Society of British Aircraft Constructors, in a letter to the Controller of Aircraft, has expressed concern at the number of flutter incidents affecting aircraft during their development stage. A recent review of the situation has shown that most prototype aeroplanes have experienced flutter or allied vibration troubles. These troubles specially concern fast aeroplanes and the control surfaces of aeroplanes in general. Early in 1952 the Mechanics Committee made a number of detailed recommendations because action to remedy this situation was urgently needed. Since that time additional effort has been directed to the problem. There are three principal requirements:

(a) Increased knowledge of those aerodynamic derivatives which are essential data for calculations on flutter.
(b) Improved techniques and facilities for testing aeroplanes, both on the ground and in flight, in relation to their susceptibility to flutter.
(c) Greater effort on flutter calculation during the design stage, fully assisted by all helpful computing equipment.

The knowledge of derivatives, which is gravely lacking and most urgently required, is concerned especially with high-speed flight and with control surfaces. Such knowledge can only be provided reliably by experiments in wind tunnels and the provision of wind-tunnel facilities, especially in high-speed tunnels, for the measurement of derivatives is a matter of the greatest importance and urgency. However, the theoretical study of derivatives is also of great importance and must be prosecuted with vigour.

It must not be overlooked that, if a truly irreversible control surface were available, flutter problems involving controls would disappear and mass balance could be dispensed with. The small amount of progress that has been made in the application of irreversibility to manual or aerodynamic servo controls has not been due to a lack of suggestions for irreversible systems, but rather to certain features of the devices which are undesirable from aspects other than flutter, and which appear to be inherent to the nature of irreversibility. For instance, plain irreversibility of a direct control system is flatly contradictory to the pilot's requirement for "feel".

An attraction of powered controls is that in principle they can be made irreversible, and irreversibility has already become a reality for a few large aircraft fitted with this type of control. However, it must be emphasized that the application of powered controls does not necessarily eliminate the possibility of flutter. In practice the "irreversibility" may not be absolute because the unit is too remote from the control surface; backlash and local flexibility at the connections can, in particular, be very significant. Furthermore, the actuator is itself a source of energy and might excite oscillatory responses from the control system to which it is connected.

At the present time, an aircraft with power-operated controls which are mass-balanced is given flutter clearance, provided tests show that the mass balancing is effective and that the complete control installation is stable on the ground; in addition it must, however, pass a full flutter analysis. If the controls are not fully mass-balanced, then an investigation is made using a method based on impedance matching; this involves the measurement of the impedance of the control system and the carrying out of a normal type of flutter calculation. From the testimony of various specialists it appears that the actuator unit may go wrong in ways which are difficult to anticipate. The conclusion reached is that straightforward malfunctioning of the unit may be as great a hazard as flutter itself.

With this in mind, the Mechanics Committee has endorsed the work the R.A.E. is doing on the development of power-operated control units: special attention should be given to producing units which have a consistent performance. The Mechanics Committee has also emphasized the importance of developing reliable techniques for the vibration testing on the ground and in flight of aircraft fitted with powered controls.

New Forms of Flutter. The Mechanics Committee has also recommended that some effort should be given to the study of possible new forms of flutter. In the past, flutter incidents have opened up new fields of research which, in their turn, have produced new knowledge. The main argument is that workers in the flutter field should, through their own efforts, have some warning of possible new kinds of trouble and the measures necessary for their prevention. The outcome of this work now recommended cannot be foretold; there may be no result, but the effort is judged worth while and should include both theory and experiment.
3. NOISE

The noise of aircraft is becoming a problem of concern to all. The Council took notice of this matter in their Report in 1950 after the present position of knowledge on the source of noise and its suppression had been reviewed by some of its Sub-Committees.

Two types of noise generation of increasing interest in modern aircraft are the noise produced by the passage of the aircraft through the air, which may be thought of as chiefly originating in the boundary layer, and the noise produced by aerodynamic effects in the jet stream of the engine.

With the boundary layer noise, preliminary work indicates that the rate of emission of energy increases very approximately as the sixth power of speed. Flight measurements have shown that in a large part of the cabin the noise originates almost entirely in the aerodynamic turbulence of the boundary layer. Little is yet known of the fundamentals of this problem.

Jet Noise. The steady increase in power now being developed in jet engines is rapidly leading to the position where the aircraft powered by such engines may prove to be too noisy to be operated from aerodromes near populated areas. The biggest annoyance is caused by the ground running-up of engines, especially at night, but the noise created during take-off and landing is almost as great a nuisance. The development of external devices such as acoustic screens and portable ground muffers to alleviate the noise when running-up on the ground is proceeding and should be encouraged, but a more fundamental solution is required if the noise from aircraft in flight is to be reduced.

The overriding parameter of importance in noise reduction is the velocity of the jet. At jet speeds below about 1,000 ft. per second the aerodynamic noise of the jet is unimportant compared with combustion noise and with noise generated by the compressor blading. At higher speeds, for a given turbulence level and size, the noise energy of the jet increases approximately as the eighth power of the velocity; with overchoked conditions a power as high as the twenty-ninth has been observed. The present trend of development of jet-engine design is therefore proceeding at enormous cost in noise and it is of primary importance to reduce the jet velocity, even at the expense of some weight penalty. For this reason, the by-pass and ducted-fan types of engines are likely to be considerably less noisy than conventional jet engines. Measurements taken on the Conway engines by Messrs. Rolls-Royce have, in fact,shown that it is about 8 to 12 decibels quieter than the Avon.

There is a growing understanding of the mechanism of noise production in jets. The theoretical work of Prof. Lighthill, followed by experiments at the University of Southampton and the College of Aeronautics, has produced results which form a solid basis for further investigations on actual jet engines. Ad hoc noise suppression devices include notches and teeth projecting into the jet and sleeves, diffusers and augmenters covering the jet. Some of these devices have, in small-scale experiments, been found to reduce noise levels by up to 5 decibels in subsonic jets and by up to 20 decibels in supersonic jets. Some confirmation of the results of these model tests has already come from full-scale work by the engine firms.

The subject of noise reduction is so important and the field for research so wide that encouragement should be given to all efforts directed to a better understanding of the problem and offering possible solutions.

4. MATERIALS

(a) Transparent Materials. Considerable difficulties are being experienced with windscreens and canopies and these are likely to get worse as the operational conditions at higher speeds and greater heights become more severe. Much trouble has been encountered due to misting and frosting after rapid descent from a prolonged high-altitude flight. In addition, considerable trouble has been experienced due to a structural failure of fighter canopies and failure of the jettisoning mechanism.

It is expected that existing transparent materials will be inadequate to withstand the high temperatures reached in flight at the very high speeds which new aircraft are likely to achieve. Furthermore, at these very high speeds the shape of the canopy will become aerodynamically critical and the whole problem of vision will have to be treated in a somewhat different manner. It is expected that considerable difficulty will be experienced in giving an adequate field of view to the pilot of a supersonic fighter even by an orthodox canopy. Moreover, its drag may represent a very large proportion of the total aircraft drag and may thus be a critical factor in the design of such an aircraft. An investigation is needed into the fundamentals of pilot’s view, covering the use of indirect vision, the effect of shock waves on the accuracy of vision, and many physiological problems.

The use of transparent canopies for the cockpit raises special problems. It has been abundantly shown by experience at the increased altitude to which post-war aircraft can reach that all known transparent materials are so unsatisfactory as to be actually dangerous. The mechanical properties of glass and glass substitutes are far from ideal for the windows and cockpit hoods of present-day aircraft. Glass is heavy and its strength often unreliable. “Perspex”, the most generally used substitute, has strength and elastic properties that vary rapidly with temperature, a large coefficient of expansion, low notch sensitivity, and crazes if exposed to a solvent vapour while under tension. These difficulties are overcome at present by design ingenuity in using and mounting the transparent panels. Even so, the replacement rate of “Perspex” windows is embarrassingly high, and the replacement of defective canopies in war time would be a serious
5. AERODYNAMIC HEATING IN HIGH SPEED FLIGHT

High thermal stresses can arise in aircraft structures due to the rapid changes of temperature in flight. Two main conditions have to be considered. One is that of the unpiolated aircraft or missile with a flight duration in which steady conditions of temperature are never reached, so that thermal stresses in the structure may arise due to the temperature gradient in the materials; the other condition is that of the piloted aircraft with a relatively long flight duration in which steady temperature conditions are attained, and where the main problem will be that of obtaining materials which can function satisfactorily at as high a temperature as possible.

Between these two main conditions is the piloted aircraft with high acceleration rates accounting for boundary layer temperature increases of the order of 20°C per minute. Estimates of stabilised temperatures are reasonably accurate for long flights where the temperature has had time to become steady. For unsteady conditions, however, it has not so far been possible to check the estimated values owing to the difficulty of doing full-scale tests.

The R.A.E. is setting up a laboratory and theoretical section to investigate the effects of transient temperature gradients (thermal shock). The first indication is that there might be a strong case for the use of insulation combined with refrigeration. A small thickness (e.g. 1/8 in.) of insulation has a very great effect in relieving temperature gradients due to accelerated flight. For flight at steady speeds of relatively short duration, however, an appreciable thickness (e.g. 1 in.), is needed to slow down the flow of heat and the temperature rise. But it is clear that eventually refrigeration will be needed, because if the structure is allowed to get hot, the situation will be intolerable; at M = 1·5 the problem is not too difficult, at M = 2·0 it is difficult, but at M = 3·0 something drastic will need to be done.

6. VULNERABILITY AND ESCAPE

There is a variety of other problems associated with structures. Some of these are vulnerability of aircraft and damage to the structure by fire, and these have been subject to experimental research. Structural problems of guided weapons have been discussed in relation to the work of the Guided Weapons Advisory Board, since the problems differ appreciably from those relevant to aircraft.

Another problem is that of escape from aircraft and some progress has been made in devising means for increasing the safety of crew who wish to escape at high speeds and at great heights but much remains to be done. Parachute problems have also been before a committee of the Council, in view of the variety of their uses, including:

(1) For escape in an emergency or in troop dropping.
(2) For supply dropping.
Great assistance to the Aircraft Industry has already been provided by the large digital computing machines, such as the ACE at the National Physical Laboratory and it is expected that the new AMOS machine at Fort Halstead will also render good service.

The main fields in which analogue machines are useful is judged to be those in which exploratory work has to be done. Analogue machines are suitable for flutter investigations and some machines have already been developed and used for this purpose, including the R.A.E. flutter simulator, which was the first of this type to be constructed. In general, digital and analogue machines are considered to be complementary to each other in their applications in the field of aeronautical science and engineering; for example, an analogue machine can often be used to make a preliminary survey of the whole field so that the problem can be narrowed down to a form suitable for solution by a digital machine.

V. MISCELLANEOUS

1. CIVIL AIRCRAFT

The Civil Aircraft Research Committee has recently reviewed the research needed in connection with the design of future civil aircraft, that is to say, the generation which will succeed the Comet and its contemporaries. The Committee has also discussed topics bearing on the more strictly operational aspects of civil aviation including safety, air traffic control, meteorological forecasting and human factors, as well as such other subjects as gusts, helicopters and noise which are discussed elsewhere in this review.

(a) Approach and Landing. The increases of performance of civil aircraft in terms of cruising speed and range have been achieved largely at the expense of the low-speed end of the range. Operators have constantly stressed the need for higher lift coefficients to reduce landing speeds and give greater manoeuvrability in the approach. The air traffic control problem at busy airports would be eased by a reduction in the present variation in approach speeds which are often dictated by the characteristics of the aeroplane. Lower approach and landing speeds and improved aircraft handling characteristics would reduce the number of occasions when diversion was necessary from the airport of intended landing because of bad weather. Strong support is therefore given for work on leading-edge suction and other devices designed to improve the low-speed and landing characteristics of the aircraft. In order that designers may appreciate the control and handling qualities that should be built into aircraft to ensure a high degree of approach and landing success, the Civil Aircraft Research Committee has recommended that a theoretical and experimental study should be undertaken to determine standards for the handling and control characteristics necessary for successful approach and landing, especially in bad weather conditions.

(b) Landing Aids. During the period under review the Civil Aircraft Research Committee has taken a great interest in landing aids; in particular they have encouraged the Calvert approach lighting system developed first at the R.A.E., and later adopted by ICAO.

The Committee has twice visited the Armament and Instrument Experimental Unit (A.I.E.U.) which was formerly known as the Blind Landing Experimental Unit, and having discussed its work and programme of research, is of the opinion that considerable time and effort will be necessary before fully automatic methods of landing can be introduced into civil aviation. But a very useful first step would be to find out how to get the most out of the existing system whereby the aircraft is fed accurately and automatically into and along the line of approach and in such an attitude that, by the aid of the lighting system, a visual landing can be made manually.

In view of the contribution that FIDO is capable of making to successful landing in difficult conditions of visibility, the Committee has recommended that an experimental installation should be made for tests of recent developments in this method of fog dispersal.

(c) Air Traffic Control. On several occasions during the past few years discussions have taken place on Air Traffic Control. In order to gain first hand knowledge of some of the problems the Committee has visited the Air Traffic Control Centre at Uxbridge which controls aircraft flying in the London Control Zone, and has watched the procedures that are in use at London Airport. There has been a considerable increase in
the volume of air traffic and a significant change in its composition caused through the introduction of gas turbine aircraft.

The U.K. airways system of agreed traffic lanes covering the most important routes has been a big step forward towards the desired goal of a completely co-ordinated system, and the continuing work of a high-level Inter-departmental Committee, advised by a Development Staff, was welcomed by the Committee in the hope that further progress would be made in the development and production of a fully integrated Air Traffic Control (A.T.C.) plan for the U.K. and possibly overseas. Trials were also recommended to assess the extent of any special procedures necessary to deal with the mixing of turbo-jet, turbo-prop and piston-engined aircraft, especially in the Airport Terminal Area. These trials were made and have contributed to the successful methods at present in use.

Other aspects of A.T.C. that have been considered have included the radio navigation aids to be used, and the contribution to safety and to expediting the flow of traffic that radar can offer. Great importance is attached to the development of suitable radar equipment and to the techniques of displaying and applying information derived from such equipment.

(d) Engines for Civil Aircraft. It has often been argued that civil aircraft should have engines specially designed for civil use rather than engines primarily designed for military aircraft, and this argument is likely to carry more weight in the future. What form of engine will be best suited for airliners on different routes is, however, a question still under discussion. For the longer routes, the by-pass type of engine gives advantages in decreased fuel consumption and the development of this type of engine may lead to power plants with a lower noise level than the pure jet.

The possibility of using titanium in civil engines is one which offers a prospect of considerable economic gains. It has been estimated that, on an Avon engine, a total saving in installed engine weight of about 600 lb per engine might ultimately be achieved by this means. The Committee has recommended that adequate supplies of titanium should be made available so that the best methods of fabrication can be determined.

(e) Meteorological Forecasting. The Meteorological Office has made good progress with the evaluation and forecasting of winds and temperatures at high altitudes, a matter for which the Committee pressed some years ago. Observations of wind at the 200 mb. level are, however, sparse compared with observations of the other meteorological elements. Over the Atlantic, the effect on weather forecasting of a proposed withdrawal of the Ocean Station Vessels was carefully considered and strong recommendations were made to the appropriate authorities that the Atlantic Weather Ship network should be retained. The Committee were glad to learn that this had been done.

The airline operator finds a most serious deficiency in the accurate forecasting of the terminal conditions. To reduce fuel reserves he must be certain that the terminal will be open when the aircraft arrives. The Civil Aircraft Research Committee has emphasized the current difficulties and uneconomic consequences of operating in bad terminal conditions. Particular elements of the general problem are being considered but the Committee are not satisfied that these separate efforts are sufficient or adequately co-ordinated, nor that aircraft designers are paying enough attention to the need to reduce approach and landing speeds and to improving handling characteristics at these approach conditions. It is the Committee's considered view that the whole problem of civil aircraft in the terminal area and of their safe, regular and successful approach and landing should be studied, both in theory and in practice, by a single team of workers. Following a recommendation along these lines, a Working Party has been set up to study the problem.

(f) Human Factors. Particular attention has been paid to the problems of the efficiency of pilots and Air Traffic Control operators. Experiments have been conducted on the ability of human beings to listen to two messages simultaneously, on simultaneous visual and aural perception, and on the question of the right loading of a human being to produce efficiency. Progress has also been reported towards an international language for civil aviation.

2. NAVAL AIRCRAFT

During the period under review the Naval Aircraft Research Committee has fostered two important developments in aircraft carriers; one, a flexible deck upon which aircraft can land without an under carriage and the second the so-called "angled deck". The incentive for the former arose from the improved performance, the smaller weight and less complication in construction if an aircraft was designed without an undercarriage. Means were therefore sought for landing such an aircraft on the suitably strengthened undersurface of its fuselage. The idea was first developed by model and then by full-scale experiments at the R.A.E., to be followed by the fitting of a trial deck to H.M.S. Warrior; with the aid of this deck and an arrester gear, undercarriageless aircraft made many successful landings on the carrier.

The angled deck was originally proposed and the idea tried experimentally on a British carrier to see whether it worked. It was first fitted for operational use on the American ship U.S.S. Antietam, and later on H.M.S. Albion. On these ships aircraft land on a path inclined to the axis of the carrier. This does away with the need for a barrier to prevent the landing aircraft from overrunning into aircraft parked on the forward part of the deck, and allows pilots to land further up the deck or to take off again immediately if the pilots so wish. Other carriers are being similarly fitted with angled decks. Associated with the angled deck is the development of a mirror sight which enables pilots to approach and land along a predetermined path inclined to the axis of the carrier. This does away with the need for a barrier to prevent the landing aircraft from overrunning into aircraft parked on the forward part of the deck, and allows pilots to land further up the deck or to take off again immediately if the pilots so wish. Other carriers are being similarly fitted with angled decks. Associated with the angled deck is the development of a mirror sight which enables pilots to approach and land along a predetermined
path without the aid of a batsman; this aid is becoming necessary because the increasing speeds of approach are too fast for the successful co-operation of batsman and pilot.

**Ship Motion.** A valuable paper has been prepared by the Director of Naval Construction on ship motion at the request of and for the information of the Naval Aircraft Research Committee. It gives a very complete analysis of the motion of an aircraft carrier under a great variety of conditions of waves and wind. The paper has drawn attention to a number of interesting points: a close relationship exists between the period of pitch of a ship and the period of encounter of the ship with the waves; the null point of the flight deck is about two-thirds from the bow when the sea is dead ahead; the loss of speed in waves is an important factor for a carrier and the longer the ship the less is this effect.

From an operational point of view, the maximum wave height has been defined in the above paper as one which just broke over the bow and an interval can be chosen between maximum waves when it is possible to catapult an aircraft between them. It is much easier to judge the correct moment to launch an aircraft than to judge the cut point at the right moment when landing on. An aircraft can in fact be catapulted from a ship when it could not be expected to land safely on the deck.

To further our knowledge of the subject, a number of experiments have been made on H.M.S. *Implacable* to measure the ship motion and it is proposed to carry out additional experiments to study the effects on the aircraft of the motion of the ship. What are needed are some rough-water trials, but the desired conditions are not necessarily to be found during a given cruise.

A paper on the above subject has been read by Mr. J. L. Bartlett to the Institution of Naval Architects.

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### 3. HELICOPTERS

We drew the attention of the Minister of Supply in 1952 to the need for pressing on with helicopter research since this type of aircraft is able to undertake certain duties which other faster aircraft cannot. The steadily increasing importance of the helicopter from both the military and the civil points of view and the greater number now flying in this country, has called for an increase in the effort allocated to helicopter research to meet the needs of the aircraft designer. We have therefore pressed during the past three years for an increase in the amount of effort which has now been allotted by the Ministry.

Special attention has been drawn to the following items in the helicopter research programme as being of first urgency:

(a) **Automatic stabilization** (including maintenance of fixed position during hovering),

(b) **Flight experiments on blind flying and navigation,**

(c) **Wind-tunnel experiments on rotor and wing combinations,**

(d) **Vibration experiments on ground resonance effects.**

The above items are only a part of the research effort, which should be increased over the whole field.

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### 4. SEAPLANES

During the last five years there has been a great change in the design of flying-boat hulls. As a result of tank research and full-scale experiments, mainly in the U.S.A., the advantages of hulls of much smaller fineness ratio than was adopted in the past have become apparent. The fineness ratio, which may be defined as the ratio of hull length to beam, was about 5:1 for the very successful series of flying boats designed in this country between the two wars. This ratio was increased to 7:1 for the Saunders-Roe Princess. Much higher values, possibly as high as 15:1 might very well be adopted in a future design.

The result of this revolutionary change is to place particular emphasis on research, both on tank models and large flying models, which are necessary to investigate water behaviour. In the past the large experience of previous hulls, all of similar shape, or at any rate modified only in details, was adequate to ensure a successful design. The main difficulty was in the increase in scale as flying boats became larger and larger. Today, the design of a large flying boat would introduce a number of new problems in water performance and handling, and would need a considerable background of knowledge, built up on model research, if it is to be a success.

Valuable work on the new hull shapes has been done by a small staff at M.A.E.E. during the period under review and a large number of reports on tank tests have been published. The research work has been handicapped by the absence of a flying model, on which alone experiments on water behaviour can be made. Attempts to obtain such a model have unfortunately not been successful.

Another important new development is the use of water skis for landing aircraft both on water and on rafts. Such aircraft would generally be launched by catapult. Here again most of the work has been done in the U.S.A., but one firm in this country, Messrs. Saunders-Roe, has done some important work in their tank.

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### 5. GUSTS

During the period under review, the Council appointed a Gust Research Committee to consider what could best be done to accumulate information on the gusts that occur in the atmosphere. This Committee reports to the Aerodynamics Committee of the Council and also to the Meteorological Research Committee.

**Gust Records.** Experiments on the determination of atmospheric gusts have been continuing with some
Interruptions for a great number of years. A great deal is now known of their frequency and magnitude at the lower heights but more data needs to be collected for heights above 30,000 ft. The use of V-g recorders in aircraft to measure simultaneously the speed and acceleration of the aircraft has given results which have covered reasonably well heights up to about 15,000 ft. and this has been supplemented by information from recording accelerometers and other instruments. However, aircraft are now being produced which will operate in the future at heights of 40,000 ft. and higher and as they are designed to utilise materials of greater ultimate strength at high unit pressures structural fatigue will require closer attention than in the past. There is a need to emphasize the investigations of those gusts which can occur without warning in clear air. Other severe gusts met in cumulus or cumulo-nimbus clouds can usually be avoided by the experienced pilot and in any case will not be unexpected. A little information has been obtained at high altitudes but there does not appear to be either staff or facilities available to obtain information on gusts up to, say, 55,000 ft. within a reasonable time.

Records for many thousands of hours have been obtained at relatively low altitudes on five types of aircraft at medium altitudes from 10,000 ft. to 16,000 ft. No startling differences between the results from five types of aircraft were found. The main purpose was to check the adequacy of the present gust design specifications, and these are broadly confirmed.

The larger gusts were observed at the slower speeds and the reason for this was that the pilots slowed down when they encountered turbulence; in fact, for many years it has been a practice to reduce speed greatly on entering thundery weather. There is, however, a minimum speed now known as the “safe speed” below which it is dangerous to fly because the aircraft is liable to stall on meeting a large gust. The safe speed has been deduced from the results of the American Thunderstorm Project.

The Airworthiness Authority in this country bases its strength requirements on the accelerations which it expects aircraft will meet in flight. The estimated figures supported in the main by results given by the N.A.C.A. V-g recorder have given aircraft of adequate strength since they rarely fail in flight, but there remains a need to obtain additional information applicable to fatigue problems. This is being collected by two types of counting accelerometer: the mechanical type counts the number of times a certain acceleration is exceeded, and the electrical gives a virtually continuous curve. Work on the collection of this information continues, but the emphasis is now laid on records from flights at greater altitudes, say, above 30,000 ft.

Interpretation of Accelerometer Records. The concept of an “Equivalent sharp-edged gust” is used in the interpretation of accelerometer records obtained from one type of aircraft so that results may be applied to other types. In this it is assumed that the vertical gust velocity increases from zero to U ft./sec. in a distance of 100 ft. and then remains constant at U ft./sec. (the flat-topped gust). The equivalent sharp-edged gust is then obtained by multiplying U by an alleviation factor K. At present K is assumed to depend solely on the wing loading of the aircraft. The acceleration imparted to an aircraft by such a gust is then proportional to KUV and other simple parameters of the aircraft size and weight, where V is the forward speed of the aircraft. The alleviation factor K is intended to allow for the relieving action of the aircraft’s response to the gust, and for the fact that lift changes do not follow air flow changes instantaneously but take a finite time to grow.

Two papers communicated by the Ministry of Supply have drawn attention to the inadequacy of the present method of deriving results from accelerometer records made on particular types of aircraft for use in the design of new aircraft or in application to other types. The alleviation factor, it is shown, really depends on three parameters: the mass parameter, the gust shape measured relative to the aircraft’s size, and the wing aspect ratio. The mass parameter takes into account wing loading, altitude of flight, and size of aircraft. Gusts are of many shapes and sizes, but a single flat-topped gust gives the largest acceleration to an aircraft and therefore this concept may usefully be retained.

The Committee has therefore recommended that the alleviation factors now in use for calculating gust speeds for design purposes should be superseded by values assuming that the shape of the gust is flat-topped. Use of these new values of alleviation factor will result in a given acceleration to a modern aircraft at high altitude (say, above 40,000 ft.) being associated with a calculated gust velocity, which is considerably higher numerically than the gust velocity calculated from the present formula in A.P. 970. The Committee considers, however, that there is no reason to suspect that the present maximum gust speeds used for design purposes are too small at high altitude when translated into acceleration of the aircraft. If the new formula for gust speed is used the design gust speeds will have to be altered so that there is no change in the associated design acceleration.

A third paper communicated by the Ministry of Supply, which will be published, extends to swept-back wings the theory of gusts as developed for straight wings. For an aircraft with high wing loading and small aspect ratio the overall effect of wing sweep on gust loads is small. The Committee has recommended that the methods described in this paper should be used for the estimation of gust loads on swept-wing aircraft.

Thunderstorms. The most severe gusts are found in cumulus and cumulo-nimbus clouds. The relation between the radar echoes from cumulus and cumulo-nimbus clouds and the turbulence within those clouds is dealt with in a Meteorological Office Paper. The
turbulence encountered in flying through a cumulo-
nimbus cloud is shown to be associated with the exis-
tence within the cloud of neighbouring up and down 
currents of comparable magnitude. Measurements of 
the speed and extent of these vertical currents have 
been reported. These currents, sometimes called 
draughts, may have speeds exceeding 50 ft./sec. and 
are of the order of three-quarters of a mile across 
thus having dimensions many times greater than those 
of the gusts which cause bumps to aircraft. Up and 
down draughts of comparable speed are often in close 
proximity, being separated by a turbulent zone of the 
order of 300 yards across in which large up and down 
gusts occur. Existence of these turbulent zones can 
be inferred from the radar echo as seen in a vertical 
cross section. Turbulence was usually found near the 
edges of the vertical currents which are associated with 
the edges of the radar echoes as seen in vertical cross 
section. Accelerations of 0.5 g. or greater were found 
only in those portions of the cloud which gave an echo 
on a ground radar. The greatest acceleration expe-
rienced in these trials which were carried out by the 
Royal Aircraft Establishment and the Meteorological 
Office jointly, was 1.5 g. corresponding to an equivalent 
gust velocity of 54 ft./sec.

It is probable that in an active cloud the greatest 
turbulence is likely to be encountered within the echo 
but if this turbulence is severe there may be some sub-
stantial gusts in that part of a cloud which fails to give 
an echo. From the point of view of flying aircraft it 
is important to know at what distance from a cloud 
severe turbulence will not be found. As the worst 
turbulence may be on the edge of the radar echo it is 
likely that severe turbulence may occasionally be found 
some distance outside the echo and occasionally up to 
three miles distant from it; it is therefore preferable 
to avoid the neighbourhood of cumulo-nimbus clouds. 
A case has been reported of a pilot being guided 
through the holes between the clouds with apparatus 
used by an observer: this apparatus has now passed 
the development stage and will shortly be put on 
various aircraft.

**Avoidance of Gusts.** A final report of the trials 
of an improved cloud and collision warning radar has 
been received from the Air Ministry. Cumulo-nimbus 
clouds in Malaya were detected up to 40 miles and, in 
all, some 110 cloud penetrations were made. A lot of 
valuable data was accumulated and the maximum 
measured acceleration of 1 g. corresponded with a 
gust velocity of about 50 ft. per second.

In response to an enquiry as to how useful radar 
can be in the avoidance of gusts the Gust Research 
Committee has replied that the incidence of severe 
turbulence and icing conditions in flight can be sub-
stantially reduced by the proper use of airborne radar, 
which is better than the eye for detecting the more 
turbulent types of cloud. This is substantiated by a 
conclusion from some Singapore trials regarding tur-
bulence associated with convective cloud that prac-

tically all turbulent areas can be avoided if the radar 
response areas are passed at a distance of about one 
mile.

**Convective Storm.** The Committee has discussed the 
type of convective storm which occurs in Bengal in 
spring and early summer (the Bengal Nor-Wester) and 
also in other parts of the world notably West Africa. 
These storms derive part of their energy from the 
falling of masses of air previously very dry but cooled 
relative to their environment by the evaporation of 
rain; most other convective storms derive their energy 
from the rising of bubbles of air warmer than their 
environment. These Bengal and West African storms 
are well known to aviators as being exceptionally 
turbulent; they would show up on a radar scope.

In an analysis by the Meteorological Office of a 
large number of cases of severe turbulence above 
20,000 ft., a high percentage were associated with jet 
streams which are comparatively narrow bands of high 
velocity winds in the upper troposphere and lower 
stratosphere. Most of the observations of turbulence 
lay on the low pressure side of the jet stream. Severe 
turbulence over the British Isles is usually at heights 
not greater than 35,000 ft. but more recently informa-
tion has been received about severe turbulence over this 
country at the unusually great height of 54,000 ft.; in 
the tropics turbulence has several times been observed 
at 45,000 ft. Some of these results have been published 
in the Meteorological Magazine.

In 1951 the Gust Research Committee asked the 
Royal Air Force and the Royal Aircraft Establishment 
to arrange high-altitude flights to explore special 
weather features for turbulence. The results of these 
special flights over a period of 18 months confirm 
previous tentative conclusions regarding the association 
of turbulence with particular weather features, the most 
important being that with jet streams (see above).

The Committee was satisfied with these conclusions 
and suggested that further analyses of observations of 
turbulence in a search for associations with various 
weather types would be unprofitable except for alti-
tudes of 45,000 ft. or above. The Committee recom-
ended that further flights to investigate the region 
above 45,000 ft. for gusts were unnecessary as it con-
sidered that observations would probably accumulate 
from flights for other purposes. The Committee has 
expressed its thanks and appreciation for the results 
achieved by the R.A.F. and R.A.E. in these special 
flights.

A further paper submitted by the Meteorological 
Office (15,785) has described measurements of turbu-
lence in the high atmosphere (up to 100,000 ft.) derived 
from the behaviour of radiosonde balloons. The method 
so far used could only detect eddies of sizes greater 
than about 1,000 ft. in depth. New equipment will soon 
be in use which will permit measurements of eddies of 
smaller sizes and comparable with some of the eddies 
which cause bumps to aircraft.
6. COMMONWEALTH ADVISORY AERONAUTICAL RESEARCH COUNCIL

The Ministry of Supply has submitted to the Aeronautical Research Council for its opinion the Reports of the Second and Third Meetings of the Commonwealth Advisory Aeronautical Research Council, and the A.R.C. has recommended that the Reports should be accepted by the United Kingdom as a member country of the Commonwealth Council. The Chairman and some members of the A.R.C. represented the United Kingdom either as delegates or non-members attending at both the Second Meeting in Canada in 1950 and the Third Meeting in London in 1953. Those of us who attended these meetings welcomed and enjoyed the opportunities it gave for free discussions with the delegates from the participating countries within the Commonwealth; we appreciated both the range and depth of these discussions.

The Commonwealth Council has a scheme whereby co-ordinators are nominated by each member country in a number of subjects. Reports of each co-ordinator are sent to a chief co-ordinator in a selected country who reports yearly on the whole subject to a Central Secretariat and to the Council before each of its meetings. The A.R.C. has strongly endorsed the recommendation that the Co-ordination Scheme started in 1948 after the First Meeting in Australia should be continued and extended, and that the responsible authorities in each country should provide opportunities for meetings between members of each co-ordinating team. The Council are glad to learn that arrangements are made for such meetings.

The A.R.C. enthusiastically supported a recommendation from the Second Meeting that visits and interchanges of staff between member countries should be encouraged as much as possible and are glad to state that a good deal of co-operation has been possible in this respect between Canada, Australia and the United Kingdom.

One recommendation made at the Canadian meeting was for the continuation of flight research into boundary layer control in Australia. This flight research initiated at an earlier meeting and carried out in Australia was on a thick suction wing and led to a deeper understanding of boundary layer control and to the solution of many engineering problems, associated with the application of suction to practical aircraft. Reference is also made in the report of that meeting to flight work on distributed suction on a conventional aerofoil fitted with a porous surface tested at low Reynolds numbers at Cambridge University. The results of these investigations indicated that large reductions in the drag of conventional aerofoils can be obtained if the practical difficulties of installation and maintenance can be overcome and these investigations have been the beginning of a large development of research into boundary layer control both for drag decrease and for lift increase, the latter being also mentioned as a promising application at the Canadian meeting.

The Aeronautical Research Council appreciates the work that has been and is being done in Canada on the investigations on low temperature operation and on the protection against icing of airframes and engines which was the subject of the ninth recommendation in the Second Report.

Special attention is here drawn to three other matters contained in the Report of the Third Meeting. The first is the need felt by the Commonwealth Council for a closer co-ordination of researches concerning new materials, particularly outside this country. We have drawn the attention of the I.S.M.R.C. to this matter and have asked them to inform the other participating countries of what has been done to meet this need in the United Kingdom. The next subject relates to the human factors that are becoming of increasing importance in aeronautical engineering. We agree with the Commonwealth Council that the importance of the study of these human factors should be further stressed and that there should be closer co-operation between physiologists, psychologists and engineers directed towards the problems of conditioning aircraft to human occupation and control; we have made certain alterations to the membership of some of our own committees with a view to advancing this matter in our own work. The third subject is that of flight research, where we have endorsed the first recommendation of the Council's Report: “That it is of great importance for the progress of aeronautical science that suitable aircraft should be made available for flight research in all the member countries where such research can be undertaken and, with this end in view, aircraft might be lent by the United Kingdom.”

We have noted from the Report of the Third Meeting the valuable contributions to aeronautical research that are being made by Canada and Australia, and hope and expect that in the near future New Zealand, South Africa and India will gradually be able to add contributions of their own.

This last Report makes special reference to the recommendations of the Documentation Committee of AGARD of NATO. This Committee has recommended that aeronautical documents should conform to an international standard size (A.4) which is wider than foolscap and a good deal shorter. The stowage of international papers would be greatly facilitated by adopting this standard size, but a large amount of equipment would need to be altered if the standard size were adopted for aeronautical work in this country. We, as a Council, have expressed our general agreement with the proposed change if it be found practicable by the Ministry of Supply and H.M. Stationery Office.

7. PUBLICATION

The Council has reviewed its methods of publication of scientific papers. The number of papers issued in its original Reports and Memoranda Series has been reduced and is now restricted to papers of lasting value recording a definite advance or containing some
novelty. The decision to include a paper in this Series depends on its probable utility in five years' time. Papers of more current interest but not regarded as reaching an inferior standard are now published in a second series of papers called “Current Papers”, the first of which was put on sale by H.M. Stationery Office on 19th May, 1950. Current Papers are typewritten documents of foolscap size with a distinctive green cover bearing the title, author's name and serial number; by the end of 1954 nearly 200 had been issued in this Series of publications. They will not be collected together and issued in annual technical volumes like the Reports and Memoranda Series. In the main, the contents of a Current Paper are identical with that originally discussed by a committee of the Council plus an attached Addendum and Corrigendum sheet. A list of the serial numbers of both R. & M.s and Current Papers published during the period under review is given in Appendix V.

The Oxford University Press has published, during the past two years, four volumes, for which the Fluid Motion Sub-Committee of the Council has been responsible. Two volumes entitled “High Speed Flow” edited by Prof. L. Howarth and published in 1953 provide a sequel to Modern Developments in Fluid Dynamics edited by Prof. S. Goldstein and published in 1948.

The Compressible Flow Tables Panel, under the Chairmanship of Prof. L. Rosenhead, has been responsible for “A Selection of Tables for use in calculations of Compressible Airflow” which were published in November, 1952. A companion book of Graphs was published in September, 1954.

The Fluid Motion Sub-Committee are also arranging for a great deal of the matter in the original Goldstein volumes to be brought up to date. They will also be published by the Clarendon Press.

Mr. W. G. A. Perring

The Council wish to record the very serious loss to aeronautical science by the death of Mr. W. G. A. Perring, the Director of the R.A.E. He not only made valuable contributions himself, but was a constant source of inspiration to the staff who worked with and under him at the R.A.E. Mr. Perring was likewise a great source of strength to the Council.

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GLOSSARY OF ABBREVIATIONS

A.I.E.U. .... .... .... .... .... .... .... .... .... .... .... .... .... Armament and Instrument Experimental Unit.
A.P. .... .... .... .... .... .... .... .... .... .... .... .... .... Air Publication.
A.T.C. .... .... .... .... .... .... .... .... .... .... .... .... .... Air Traffic Control.
N.A.C.A. .... .... .... .... .... .... .... .... .... .... .... .... .... National Advisory Committee for Aeronautics.
N.A.E. .... .... .... .... .... .... .... .... .... .... .... .... .... National Aeronautical Establishment.
N.G.T.E. .... .... .... .... .... .... .... .... .... .... .... .... .... National Gas Turbine Establishment.
N.P.L. .... .... .... .... .... .... .... .... .... .... .... .... .... National Physical Laboratory.
R.A.E. .... .... .... .... .... .... .... .... .... .... .... .... .... Royal Aircraft Establishment.
R. & M. .... .... .... .... .... .... .... .... .... .... .... .... .... Reports and Memoranda.
S.B.A.C. .... .... .... .... .... .... .... .... .... .... .... .... .... Society of British Aircraft Constructors, Ltd.
APPENDIX I

Membership of the Council. December, 1954

Sir Edward Bullard, M.A., Sc.D., Ph.D., F.R.S.*
Mr. W. R. J. Cook, C.B., M.Sc.†
Sir Harry Garnet, K.B.E., C.B., M.A., F.R.Ae.S.
Dr. A. A. Griffith, C.B.E., D.Eng., F.R.S.
Sir Arnold Hall, M.A., F.R.S., F.R.Ae.S.‡
Prof. W. R. Hawthorne, M.A., Sc.D.
Mr. E. T. Jones, C.B., O.B.E., M.Eng., F.R.Ae.S.‡

Secreter: Mr. J. L. Nayler (N.P.L.).
Assistant Secretary: Mr. R. W. G. Gandy (N.P.L.).

* Representing the Department of Scientific and Industrial Research.
† Representing the Admiralty.
‡ Representing the Ministry of Supply.
§ Representing the National Physical Laboratory.

Membership of the Council, 1949–54

The following were Chairmen of the Council during the period:—

<table>
<thead>
<tr>
<th>Chairman</th>
<th>Date</th>
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<tr>
<td>Dr. S. Goldstein</td>
<td>January, 1949–March, 1949</td>
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<tr>
<td>Prof. Sir Leonard Bairstow</td>
<td>April, 1949–March, 1952</td>
</tr>
<tr>
<td>Prof. A. G. Pugsley</td>
<td>April, 1952</td>
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The following have been members during the period:—

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<thead>
<tr>
<th>Name</th>
<th>Position</th>
<th>Date</th>
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<tr>
<td>Prof. Sir Leonard Bairstow</td>
<td>(Independent)</td>
<td>January, 1949</td>
</tr>
<tr>
<td>Prof. A. R. Collar</td>
<td>(Independent)</td>
<td>April, 1949–March, 1952</td>
</tr>
<tr>
<td>Mr. H. Constant</td>
<td>(M.o.S.)</td>
<td>January, 1949–March, 1954</td>
</tr>
<tr>
<td>Mr. W. R. J. Cook</td>
<td>(Admiralty)</td>
<td>July, 1950</td>
</tr>
<tr>
<td>Prof. W. J. Duncan</td>
<td>(Independent)</td>
<td>April, 1949–March, 1951</td>
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<tr>
<td>Mr. A. Fage</td>
<td>(N.P.L.)</td>
<td>January, 1949–June, 1953</td>
</tr>
<tr>
<td>Sir Harry Garnet</td>
<td>(M.o.S.)</td>
<td>October, 1949–February, 1953</td>
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<tr>
<td>Prof. E. Giffen</td>
<td>(Independent)</td>
<td>April, 1953</td>
</tr>
<tr>
<td>Dr. S. Goldstein</td>
<td>(Independent)</td>
<td>April, 1951–March, 1954</td>
</tr>
<tr>
<td>Dr. A. A. Griffith</td>
<td>(Independent)</td>
<td>April, 1950–March, 1953</td>
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<tr>
<td>Sir Arnold Hall</td>
<td>(Independent)</td>
<td>April, 1954</td>
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<tr>
<td>Prof. W. R. Hawthorne</td>
<td>(M.o.S.)</td>
<td>August, 1951</td>
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<tr>
<td>Mr. E. T. Jones</td>
<td>(M.o.S.)</td>
<td>October, 1949</td>
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<tr>
<td>Prof. A. G. Pugsley</td>
<td>(Independent)</td>
<td>April, 1949–March, 1952</td>
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<tr>
<td>Dr. W. P. Jones</td>
<td>(N.P.L.)</td>
<td>April, 1954</td>
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<tr>
<td>Sir Ben Lockspeiser</td>
<td>(M.o.S.)</td>
<td>January, 1949–April, 1949</td>
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<tr>
<td>Mr. W. G. A. Perring</td>
<td>(M.o.S.)</td>
<td>January, 1949–April, 1951</td>
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<td>Prof. A. G. Pugsley</td>
<td>(Independent)</td>
<td>April, 1950</td>
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<tr>
<td>Mr. E. F. Relf</td>
<td>(Independent)</td>
<td>January, 1949–March, 1949</td>
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<td>Sir Harry Ricardo</td>
<td>(Independent)</td>
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<tr>
<td>Prof. E. J. Richards</td>
<td>(Independent)</td>
<td>April, 1942</td>
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<tr>
<td>Mr. W. J. Richards</td>
<td>(M.o.S.)</td>
<td>April, 1954</td>
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Prof. O. A. Saunders (Independent) . . January, 1949—March, 1950
Sir Geoffrey Taylor (Independent) . . April, 1953
Prof. G. Temple (Independent) . . . . January, 1949—March, 1951
Dr. O. H. Wansbrough-Jones (M.o.S.) . February, 1953

In the above list, leaders after a date indicate that the individual was a serving member at December, 1954, when the list was compiled.

**APPENDIX II**

Terms of Reference of the Council

1. To advise the Minister responsible on scientific problems relating to aeronautics.
2. To keep under review the progress of aeronautical research and to advise the Minister on the programme and the planning of aeronautical research carried out for the Government of the United Kingdom.
3. From time to time, to make recommendations to the Minister on research which the Council considers it desirable to initiate.
4. When requested to do so, to tender advice upon any research carried out by or on behalf of the aeronautical industry.
5. Subject to the needs of security, to make the results of British research generally available, by the publication of research reports.
6. To advise upon aeronautical education in the United Kingdom in so far as it is relevant to research.
7. To maintain contact with similar bodies or institutions in the Dominions and foreign countries.
8. To make an annual report to the Minister.

**APPENDIX III**

Membership of Committees, Sub-Committees and Panels. December, 1954

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Secretary: Mr. R. W. G. Gandy (N.P.L.).

* Representing the Meteorological Research Committee, Air Ministry.

Representation of various departments, etc., has been indicated above as follows:—

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<th>Department</th>
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<td>Ad.</td>
<td>Admiralty</td>
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<td>A.M.</td>
<td>Air Ministry</td>
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<td>D.S.I.R.</td>
<td>Department of Scientific and Industrial Research</td>
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<td>M.T.C.A.</td>
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<td>M.o.S.</td>
<td>Ministry of Supply</td>
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<td>B.E.A.</td>
<td>British European Airways</td>
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<td>B.O.A.C.</td>
<td>British Overseas Airways Corporation</td>
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<td>S.B.A.C.</td>
<td>Society of British Aircraft Constructors</td>
</tr>
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APPENDIX IV

List of Monographs and Books published between 1949 and 1954

Monographs


R. & M. 2492.. Aircraft flutter. J. Williams. (August, 1948.) Published 1st August, 1951.


R. & M. 2638.. Heat transference and pressure loss for air flowing in passages of small dimensions. J. Remfry. (June, 1947.) Published 29th April, 1954.

R. & M. 2704.. Four studies in the theory of stress concentration.
Part I. The effect of holes on the strength of materials under complex stress systems.
Part II. Stress concentration due to holes and grooves other than elliptical in form.
Part III. The effect of surface irregularities on fatigue strength.

Books

(Published by Oxford University Press)


APPENDIX V


R. & M. Nos.


Current Paper Nos.

1-179, 181 and 182.
AERODYNAMIC SYMBOLS

1. GENERAL

\( m \) Mass
\( t \) Time
\( V \) Resultant linear velocity
\( \Omega \) Resultant angular velocity
\( \rho \) Density, \( \sigma \) relative density
\( \nu \) Kinematic coefficient of viscosity
\( R \) Reynolds number, \( R = lV/\nu \) (where \( l \) is a suitable linear dimension).

Normal temperature and pressure for aeronautical work are 15° C. and 760 mm.

For air under these conditions \( \nu = 1.56 \times 10^{-4} \) ft.\(^2\)/sec.

The slug is taken to be 32.2 lb.-mass.

\( \alpha \) Angle of incidence
\( \epsilon \) Angle of downwash
\( A \) Area
\( b \) Span
\( c \) Chord
\( A \) Aspect ratio, \( A = b^2/S \)
\( L \) Lift, with coefficient \( C_L = L/\frac{1}{2} \rho V^2 S \)
\( D \) Drag, with coefficient \( C_D = D/\frac{1}{2} \rho V^2 S \)
\( \gamma \) Gliding angle, \( \tan \gamma = D/L \)
\( L \) Rolling moment, with coefficient \( C_L = L/\frac{1}{2} \rho V^2 b S \)
\( M \) Pitching moment, with coefficient \( C_m = M/\frac{1}{2} \rho V^2 c S \)
\( N \) Yawing moment, with coefficient \( C_n = N/\frac{1}{2} \rho V^2 b S \)

2. AIRSCREWS

\( n \) Revolutions per second
\( D \) Diameter
\( J \) \( V/nD \)
\( P \) Power
\( T \) Thrust, with coefficient \( k_T = T/\rho n^2 D^4 \)
\( Q \) Torque, with coefficient \( k_Q = Q/\rho n^2 D^5 \)
\( \eta \) Efficiency, \( \eta = TV/P = Jk_T/2\pi k_Q \)
### System of Axes

<table>
<thead>
<tr>
<th>Axes</th>
<th>Symbol Designation Positive direction</th>
<th>( x ) longitudinal forward</th>
<th>( y ) lateral starboard</th>
<th>( z ) normal downward</th>
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<tbody>
<tr>
<td>Force</td>
<td>Symbol</td>
<td>( X )</td>
<td>( Y )</td>
<td>( Z )</td>
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<tr>
<td>Moment</td>
<td>Symbol Designation rolling</td>
<td>( L )</td>
<td>( M )</td>
<td>( N )</td>
</tr>
<tr>
<td>Angle of Rotation</td>
<td>Symbol</td>
<td>( \phi )</td>
<td>( \theta )</td>
<td>( \psi )</td>
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<tr>
<td>Velocity</td>
<td>Linear Angular</td>
<td>( u )</td>
<td>( v )</td>
<td>( w )</td>
</tr>
<tr>
<td></td>
<td></td>
<td>( \dot{u} )</td>
<td>( \dot{v} )</td>
<td>( \dot{w} )</td>
</tr>
<tr>
<td>Moment of Inertia</td>
<td></td>
<td>( A )</td>
<td>( B )</td>
<td>( C )</td>
</tr>
</tbody>
</table>

Components of linear velocity and force are positive in the positive direction of the corresponding axis.

Components of angular velocity and moment are positive in the cyclic order \( y \) to \( z \) about the axis of \( x \), \( z \) to \( x \) about the axis of \( y \), and \( x \) to \( y \) about the axis of \( z \).

The angular movement of a control surface (elevator or rudder) is governed by the same convention, the elevator angle being positive downwards and the rudder angle positive to port. The aileron angle is positive when the starboard aileron is down and the port aileron is up. A positive control angle normally gives rise to a negative moment about the corresponding axis.

The symbols for the control angles are:—

- \( \xi \) aileron angle
- \( \eta \) elevator angle
- \( \eta_T \) tail setting angle
- \( \zeta \) rudder angle
### Publications of the Aeronautical Research Council

#### Annual Technical Reports of the Aeronautical Research Council (Bound Volumes)

<table>
<thead>
<tr>
<th>Year</th>
<th>Volume 1</th>
<th>Volume 2</th>
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<tr>
<td>1936</td>
<td>Aerodynamics, General, Performance, Airscrews, Flutter and Spinning</td>
<td>Stability and Control, Structures, Seaplanes, Engines, etc.</td>
<td>40s (41.1d)</td>
</tr>
<tr>
<td>1937</td>
<td>Aerodynamics, General, Performance, Airscrews, Flutter and Spinning</td>
<td>Stability and Control, Structures, Seaplanes, Engines, etc.</td>
<td>50s (51.1d)</td>
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<tr>
<td>1938</td>
<td>Aerodynamics, General, Performance, Airscrews</td>
<td>Stability and Control, Flutter, Structures, Seaplanes, Wind Tunnels, Materials</td>
<td>50s (51.1d)</td>
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<tr>
<td>1939</td>
<td>Aerodynamics, General, Performance, Airscrews, Engines</td>
<td>Stability and Control, Flutter and Vibration, Instruments, Structures, Seaplanes, etc</td>
<td>6s (6d)</td>
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<tr>
<td>1940</td>
<td>Aero and Hydrodynamics, Aerofoils, Airscrews, Engines, Flutter, Icing, Stability and Control, Structures, and a miscellaneous section</td>
<td></td>
<td>50s (51.1d)</td>
</tr>
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