This republication has been made possible thanks to the assistance of The Royal Aeronautical Society and Dr. James C. Floyd. This is quite a lengthy lecture and was presented in December 1958. At that time the Arrow was in phase 1 flight tests.
We hope you enjoy this piece of aviation history.
Scott McArthur. Webmaster, Arrow Recovery Canada.

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The Fourteenth British Commonwealth Lecture

The Canadian Approach to All-Weather Interceptor Development

by

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The Fourteenth British Commonwealth Lecture," The Canadian Approach to All-Weather Interceptor Development," by Mr.J. C. FLOYD, A.M.C.T., P.Eng., F.C.A.I., M.I.A.S., F.R.Ac.S. was given in the 9th October 1958 at the Royal Institution, Albemarle Street, London, W.1.
The Chair was taken by Dr. E. S. Moult, C.B.E., Ph.D., B.Sc., F.R.Ae.S., Vice-president of the Society, deputising for the President, Sir Arnold Hall, M.A., F.R.S., F.R.Ae.S., who was ill.
Dr. Moult first read a telegram from the President and then introduced the Lecturer, a distinguished Canadian engineer, for this Fourteenth Commonwealth Lecture. Mr. Floyd joined A. V. Roe and Co. Ltd., at Manchester, as an apprentice in 1929, progressing through the design and production offices to become Chief Projects Engineer in 1944. Immediately after the War he joined A. V. Roe Canada Ltd., at first as Chief Technical Officer, becoming Chief Design Engineer in 1949, Works Manager 1951, and Chief Engineer in 1952. He is now Vice-President, Engineering, Avro Aircraft Ltd. Mr. Floyd became a naturalized Canadian in 1950 and in the same year was the first non-American to receive the Wright Brothers Medal, which was awarded for his contributions to aeronautics, including his design of the Avro Jetliner. More recently, he had been known for his work on the Avro CF-100 interceptor and for the Avro Arrow, which made its first iftight in March 1958.

INTRODUCTION

In preparing this lecture I was conscious of the fact that there were many phases of the development of a modern fighter which I had not covered, and which would possibly be of greater interest to the specialists on that particular subject than those that I did include. To them I offer my apologies, however, this lecture is not intended to be a handbook or reference on the design of all-weather fighter aircraft, but was prepared more or less as a chronicle of the main events leading up to the current development flying of Canada's newest defence weapon system, the supersonic all-weather CF-105, or Avro Arrow, and its associated equipment and environment (Fig. 1).

Within the limits of security I have tried to give a broad-brush picture of some of the philosophy behind the establishment of the Weapon System, and deal also in the broad sense with many of the design and development problems encountered in a project of this magnitude. Security precludes the disclosure of actual detailed performance, either specified or achieved on the Arrow up to the present time and also prevents the quotation of some of the results of tests described in the text.

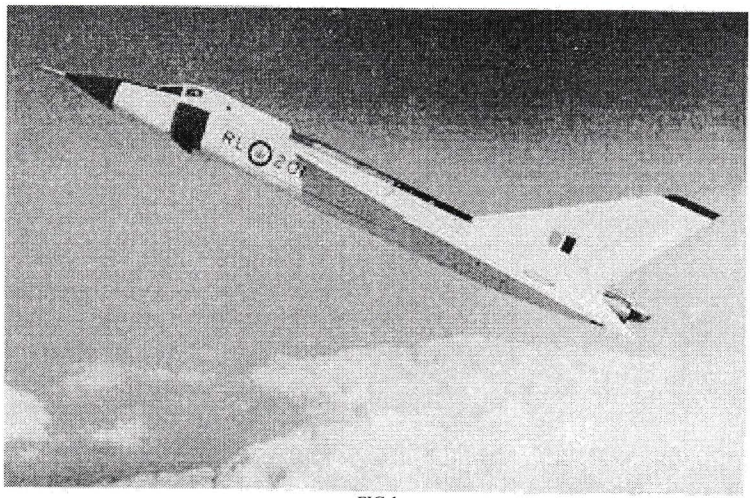


FIG.1

R.C.A.F. REQUIRMENTS

Canada's chosen role in military air power is one of defence, and Canada does not maintain any bombing or tactical Air Force.

Environmentally, while geographic proximity to the United States obviously influences the choice of systems and armament to ensure reasonable compatibility with the complex U.S.A.F. North American defence system, and the traditional association with the R.A.F. in the United Kingdom again influences the basic establishment and strength of the RCAF, there are unique requirements and conditions in maintaining an adequate air defensive system in Canada which have led the RCAF to establish the requirement for an aircraft particularly suited to these conditions.

Canada's northern frontier is a vast unpopulated expanse which, from coast to coast, is second in length only to that of Soviet Russia. Air defence bases are, of necessity, few and far between. Defensive interceptors must be capable of long range operation by day or by night, in any weather. The climate is anything but temperate, varying from near tropical conditions to sub zero temperatures, and fighters must have a very high reliability in this relatively abnormal environment.

Since Northern Canada is the first line of defence for the North American continent, our aircraft must be equipped with an automatic fire control system which will ensure the maximum probability of kill on the first pass, and the most potent airborne weapons available.

Canada learned a hard lesson in the Second World War, when she depended upon other sources for her front line aircraft. To quote the Chief of Air Staff at the time of decision to proceed with the " home brew ". In the early days of the fighting, Canadian squadrons operating overseas were low on the list for equipping with the latest types, and on one occasion, even Canadian-built Hurricanes, sorely needed by home-based squadrons to meet a Japanese threat in the Aleutians, were allocated to Russia.

In a sense. this is quite understandable, since it is like expecting a neighbour in the middle of a fire in his own house, to hand over one of his insufficient number of fire extinguishers so that you may prevent fire spreading to yours. However, it gave Canada a " loneliness complex," the cure for which I believe has turned out very well.

When, in 1946, the RCAF made the decision to re-equip its front line fighter squadrons with a two-place twin-engined day and night all-weather interceptor with a particularly long range capability, a team of RCAF officers visited aircraft factories in the United Kingdom and the United States to ascertain whether there was an aircraft on the drawing boards which was likely to fill their requirement. Apparently there was not, and they persuaded the Canadian Government to take the momentous step of financing the design and development of a suitable aircraft in Canada. The CF-100 all-weather fighter was the result.

The outcome of this joint decision must be judged on the basis that, in addition to being the standard Canadian all-weather fighter for many years, the CF-100 is now in service with the RCAF Air Division in N.A.T.O., and was recently chosen in keen competition with other available types to re-equip the Belgian Air Force. The RCAF CF-100 squadrons are also now an integral part of the North American Air Defence System under NORAD.

In the autumn of 1952, the RCAF decided that because of the increase in the threat, they would have to replace the CF-100 within a specified time by a supersonic all-weather fighter, and an evaluation team was again sent out to the countries in the Western Alliance who might have a suitable interceptor, and it was again decided that none of these countries had a project, either in design or contemplated, which fully met the Canadian requirement.

Once again, the decision was taken to design, develop, and produce in Canada. This decision was not taken on the basis that there happened to be an established aircraft industry in Canada, although this obviously had some influence on the decision. However, the Chief of the Air Staff at that time, Air Marshal Slemon, made it quite clear that Canada was not in a position to undertake the development of a new aircraft if a suitable type was being designed, developed, or produced in either the United States or the United Kingdom, and the decision to design and develop in Canada was taken entirely because of the peculiar Canadian defence requirements, the non-availability of a suitable weapon elsewhere, and the ability to meet the Canadian requirements which had already been established by the Canadian aircraft industry.

BRIEF HISTORY OF THE PROJECT

Preliminary studies on a supersonic aircraft to replace the CF-100 for the Canadian squadrons had been made at Avro during 1952 early 1953. In May 1953 RCAF Specification AIR 7-3 was issued, and this became the basis for further design studies. In July 1953 a Ministerial directive was issued from the Department of Defence Production authorizing the design study of an aircraft to meet AIR 7-3. Preliminary design on this aircraft, given the project CF-105, was completed by the summer of 1954.

The initial aircraft had two Rolls-Royce RB-106 engines with afterburners, a two-man integrated fire control system, and the armament was a mixture air-to-air missiles and 2.75 in. air-to-air rockets.

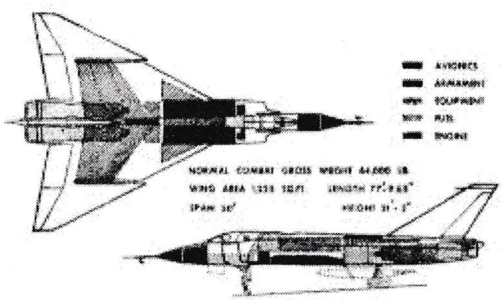
By the end of 1953 preliminary loads and sizes had been established for the complete aircraft, and certain wind tunnel work had been done to establish the dynamic parameters. The production engineers also establishing manufacturing techniques.

In early 1954 the RB-106 engine project abandoned by Rolls-Royce, and the choice of engines was therefore again in the mill. Orenda were at that time designing a large supersonic engine as a private venture, and this engine was well matched to our requirements. However, it was obvious that this would not be available for the first few aircraft. TheCurtiss-Wright J.67 engine appeared to be the most suitable engine for the earlier version, and the first few aircraft were therefore designed around the J.67. However, in 1955 it became obvious that the USAF were going to abandon the development of the J.67, and the Pratt and Whitney J.75 was substituted. The design of the aircraft had been well along on the J.67 version, and an appreciable amount of redesign had to be done to accommodate the J.75.

Aerodynamically, the CF-105 was, of necessity, a considerable advancement over contemporary aircraft. and there were few reports or tests available on which to base a firm, production type, design. Stability and control problems were probably the most difficult to assess and an extensive wind tunnel programme was instituted.

However, since the design of the aircraft had to proceed at the same time, the basic aircraft design was frozen on the basis of stability and control characteristics largely predicted from theory. By mid-1954 production drawings were going out to manufacturing.

I would like to deal briefly with some of the philosophy behind the configuration which we chose to meet the specification (Fig. 2)



NORMAL COMBAT GROSS WEIGHT 64,000 LBS.
WING AREA 1,225 SQ FT. LENGTH 77'9.65"
SPAN 50' HEIGHT 21'.3"

FIGURE 2. Data diagram.

THE CONFIGURATION

There are a number of relatively unconventional features on the Arrow and a reasonably detailed appraisal of these might easily fill a volume of 500 to 600 pages. Therefore, I intend to pick out a few of the highlights and present a broad-brush picture of the design philosophy behind them.

The RCAF had established a requirement for a two-place, twin-engined aircraft. Their preference for a crew of two was partly based on the complexity of the newer fire control systems and the fact that, while the chosen system was intended to be entirely automatic during the midcourse and terminal phases of the attack, it was the intention to press home an attack on the basis of a manual mode, in the event of the failure of the automatic mode.

The choice of two engines was based on a combination of circumstances, the advantages of two engines being obvious in reduced attrition, especially during training. One of the most important factors, however, was the fact that with the very large weapon package required as payload, and the large amount of fuel carried for the range requirements, the size of the aircraft was obviously going to be such that there was no single engine large enough to power it.

The configuration of the basic fuselage was determined almost entirely by the two-seat, two-engine arrangement and the large armament bay. I will deal more specifically with these items later.

CHOICE OF WING DESIGN

At the time we laid down the design of the CF-105, there was a somewhat emotional controversy going on in the United States on the relative merits of the delta plan form versus the straight wing for supersonic aircraft.

We tried very carefully not to become inhibited by association with either side and our choice of a tailless delta was based mainly on the compromise of attempting to achieve structural and acroelastic efficiency, with a very thin wing, and yet at the same time, achieving the large internal fuel capacity required for the specified range.

This established our delta plan form and the lack of a tail can be attributed almost entirely to our desire not to have to face the problem of putting a tail on top of an extremely thin fin out of the effects of wing downwash, or, otherwise, having to put it so low, again out of the downwash region, that our landing angles would be impossible. We felt that the problems associated with a tailless delta were more predictable and manageable.

We were also very conscious of the problems that tailed deltas were having at that time, where a large increase in downwash at the stall made the tail strongly destabilizing, so that the stalling characteristics became objectionable.

It was obvious from the outset that to give the RCAF an aircraft with flexibility of development, the aerodynamic characteristics should be such that they would not limit the speed to less than the structural limitations. The aluminum alloy structure which we favoured was good for speeds greater than a Mach number of 2, and we therefore felt that our aerodyna- mics should be at least as good as this.

To achieve this we had to go to the thinnest possible t/c ratio, and started out with a 3 per cent t/c wing throughout the span, but aileron reversal forced us to go to a thicker and stiffer wing section, and we compromised at 3.5 per cent at the wing root, and 3.8 per cent at the tip. The structural advantages of the delta made the achievement of a thin wing section possible without a large weight penalty.

So for us, the tailless delta had distinct virtues, with the added advantage that Avro Manchester had, by that time, done considerable flying with the 707 delta research aircraft, prior to the design of the Vulcan tailless delta bomber, and this information was, of course, available to us.

However, the delta, like everything else, also had its vices. For instance, aeroelasties were obviously to play a very big part in our design, due to the extremely thin wing and fin sections and, in calculating the aeroelastic and flutter characteristics of a delta wing the standard semi-empirical methods of analysis would have produced a prohibitively heavy structure if we had used them indiscriminately. We had to examine all types of aeroelastic and flutter problems from first principles, and we repeated these as the design progressed. The establishment of the structural matrix was a very laborious process, most of which had to be done on our digital computers.

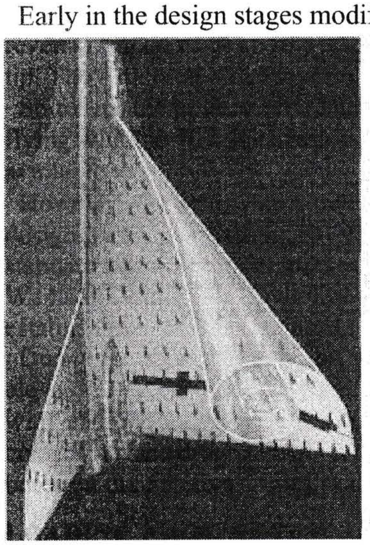
Due to the short elevator arm we were in trouble with trim drag. The high elevator angles required to trim at high altitude increase the elevator drag considerably. We investigated means of reducing this and the most promising appeared to be the introduction of negative wing camber. Camber has the effect of building in some elevator angle without the excessive control surface drag. The amount of camber chosen, which was 3/4 per cent negative, was that which would give a good compromise between the positive angles to trim at low altitude, and the negative angles required at high altitude.

LEADING EDGE NOTCH AND EXTENSION

Early in the design stages modifications were made to the original clean wing. These were the addition of leading edge droop, and the semi-span notch with outer wing chord extension.

These modifications were made as a result of wind tunnel tests at Comell Laboratories in Buffalo on a 3 per cent complete model, sting mounted. The approximate Reynolds number used during the tests was between one and two million. These tests showed that we were getting a pitch-up or non-linearity in the Cm-a curve at moderate angles of attack. This phenomenon is not peculiar to deltas, being common to all swept wing aircraft. In flight it could cause a tightening in the turn.

Crudely, the condition appears to be caused by vortices which start at the tip and move to the apex of the swept wing. Low pressure air is collected from the fuselage and causes a breakaway outboard of the area covered by the vortex, which is mainly at the trailing edge (Figs. 3&4). This causes the effective



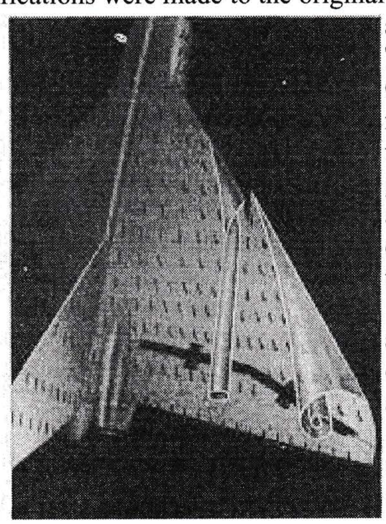


FIGURE 3. Vortex pattx plain wing.FIGURE 4. Vortex p of wing with notch and ext leading edge.

aerodynamic centre to shift forward, giving a "pitch-up" or an abrupt

[redacted] change in moment curve.
While the pitch-up appeared on test to be of small magnitude, since very moderate amounts of pitch-up can be embarrassing to the pilot, attempts were made eliminate it.
We were aware of the work that had been done by N.A.C.A. and the R.A.E. and the fact that a number of other aircraft which had exhibited this tendency used either notches in the leading edge at about semi span, or extensions of the wing leading edge outboard, in an attempt to prevent the flow separation. The notch had been used, for instance, on the English Electric F-23, and the leading edge extension had been installed on a Grumman F9F9, and a Chance Vought aircraft. The notch has a somewhat similar effect to a fence causes the disturbing vortices to move away from apex of the swept wing toward the notch, which is at semi-span, and reduces the area of disturbed flow over the wing. The notch, however, produces these effects by air flow rather than as a physical barrier. It was our opinion that the effects of the notch are present over the whole speed range, whereas a fence is usually only effective over smaller speed ranges, and the notch was expected to increase the drag by a lesser amount than a fence.
We did find, however, in our tests that with the notch alone the test results were not repeatable; in other words, the same results could not be got in subsequent tests. When the leading edge extension was installed in addition to the notch the results were far more repeatable. Eight different notches and three extended leading edges were tried in various combinations. The depth of the notch appeared to be the most critical parameter, and here again we had to bear in mind that we could not have too deep a notch because of structural problems.
Figure 5 shows the effect of the 5 per cent notch, 10 per cent extension of the local chord on the outer wing, which was finally adopted, against the unmodified 31/2 per cent wing at M=0.9, and at an elevator angle of - 20deg.

DROOPING OF LEADING EDGE

During the time that the tests were being made on the notch and leading edge extension for pitch-up we were following very closely the work being done on the F.102 with regard to a reduction in induced drag by drooping the wing leading edge, and also the work that was going on at Avro Manchester on the Vulcan. They were drooping the leading edge to increase the buffet boundary by preventing leading edge breakaway at high angles of attack.
This also influenced us in choosing the 10 per cent increase in leading edge outboard, to cure pitch-up, since we realised that, if after investigation we found that it would be advantageous to droop the leading edge, the extension would increase the amount of effective droop.
Droop was installed on the wind tunnel model, 8deg inboard and approximately 4deg outboard. This increased the buffet boundary considerably. For instance, at M=0.925, which is the normal subsonic cruise Mach number, the CL at which we estimate the onset of buffet is increased from 0.26 with the extension alone, to 0.41 with the extension plus droop. The buffet, or flow separation, was indicated by pressure plots on the ailerons in the Cornell Laboratory tunnel tests. The supersonic drag did not appear to be increased appreciably.
We were also cognisant at this time of the work on Vortex Generators which Avro Manchester were doing for alleviating the shock-induced rear separation, but from the evidence we had from N.A.C.A., and also from the Manchester reports, it was felt that for a t/c ratio of under 5 per cent this would not be a problem, and Vortex Generators would not be required for this reason on the CF-105.

ANHEDRAL

Another peculiarity of the CF-105 wing is the 4deg anhedral. This was established entirely to reduce the length of the undercarriage, and has no appreciable aerodynamic effect or significance.

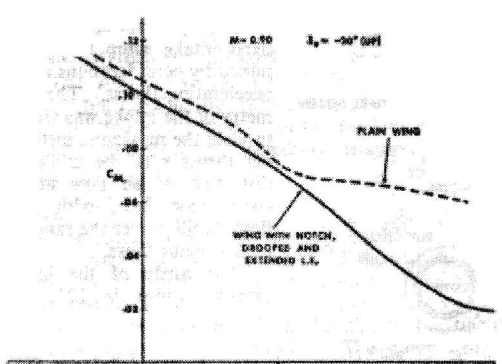


FIGURE 5. Effect of wing modification on $C_M - \alpha$.

HIGH WING

A high wing arrangement was adopted because of the greater flexibility with this layout. For example, it allowed a relatively simple engine installation and any changes in engines and armament can be made without affecting the basic wing structure, which is not always the case with an integrated wing-fuselage structure.

It also allowed us to carry the wing structure straight through without a break at the fuselage and simplified the wing to fin attachment, since there was no necessity to carry the fin structure down through the engines. The fin is 4 per cent t/c.

AREA RULE

A great deal of theoretical work was done on the application of Area Rule to the CF-105 and during the early design stages certain changes were incorporated in the aircraft to take advantage of the results of our area rule work.

Eleven plastic models were made at 1/30th scale and cuts were taken on these to represent various Mach numbers. The cuts were then checked on a planimeter, the results fed into a digital computer, and plots were made around the aircraft at 0deg., 45deg., 90deg., 135deg. and 180deg.. Most of the results were obtained around a Mach number of 1.5 and, as a result of this extensive investigation, we sharpened the radar nose, thinned down the intake lips, reduced the cross-section area of the fuselage below the canopy, and added an extension fairing at the rear, to smooth out the bumps in the area rule curve (Fig. 6).

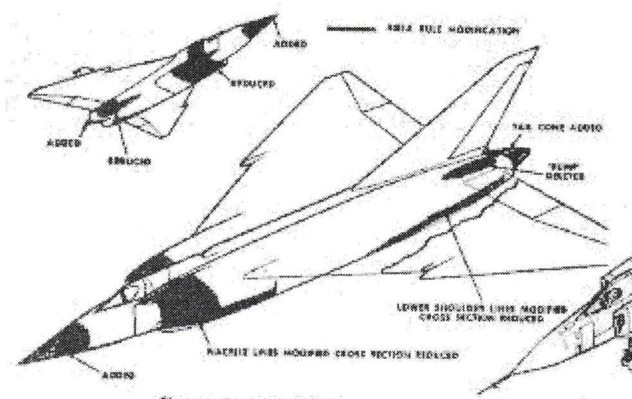


Figure 6. Area ruling.

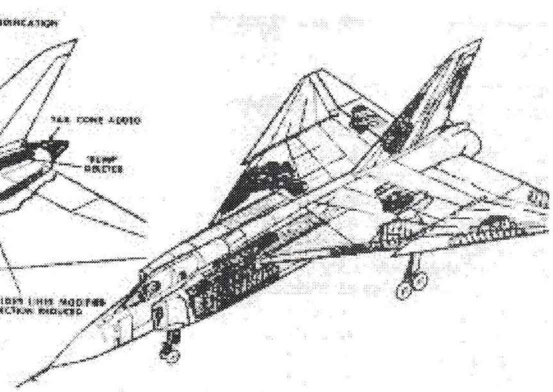


Figure 9. Arrow structure cutaway.

ENGINE AND INTAKES

The CF-105 is undoubtedly the most " re-engined" of any aircraft at this stage of development since, one by one the engines slated for the project fell by the wayside. However, I will not attempt to go into the history of the " thousand and one " installations but will deal mainly with the final (?) installation on the production Mark 2. The first five aircraft are fitted with Pratt and Whitney J.75 engines, and the sixth aircraft is the first Mark 2 with Orenda Iroquois engines.

The Iroquois power unit is an axial flow gas turbine of twin spool configuration. The compressor is designed for a high air mass flow, and a pressure ratio of 8 to 1 at sea level static. Compressor delivery air bleed is used for driving the air turbine centrifugal fuel pumps, and is also available for aircraft services.

The engine incorporates an afterburner which is built as an integral part of the basic engine. The afterburner operation is fully automatic, the engine having a modulated final nozzle to produce the desired thrust to temperature relationship at the selected power lever setting.

Figure 7 shows the engine cooling system at speeds greaterthanM=0-5.

The intake gills immediately adjacent to the compressor inlet open up at M= 0. 5 and allow air to by-pass around the engine for cooling purposes, and to alleviate spillage at high Mach number. By this means, it is possible to achieve near optimum performance with this fixed geometry intake, in the subsonic. transonic, and supersonic speed ranges. At very high Mach numbers, if the air which could not be swallowed by the engines were allowed to spill from the intake lips, there would be a high drag penalty, bad pressure recovery characteristics within the intake itself, and possible de-stabilising effects from the components of spillage.

The technique of by-passing air over the engine between the engine and compartment sidewalls not only takes care of the spillage and cools the engine but, by acting as a beat exchanger, collects heat from the afterburner casing and passes it into the ejector exit annulus, providing a small percentage of additional thrust.

For fire protection, the critical compartments containing the fuel system, and so on, are enclosed by titanium shrouds and stainless steel insulated blankets.

The gills are automatic, and when the aircraft has reached a forward speed high enough to create a static pressure higher than ambient within the intake duct, the by-pass gills open due to ram intake pressure, and allow the air to by-pass over the engine.

With the twin-engine configuration on the Arrow, there has been no requirement for either bifurcated intakes or nozzles, and the flow is relatively clean.

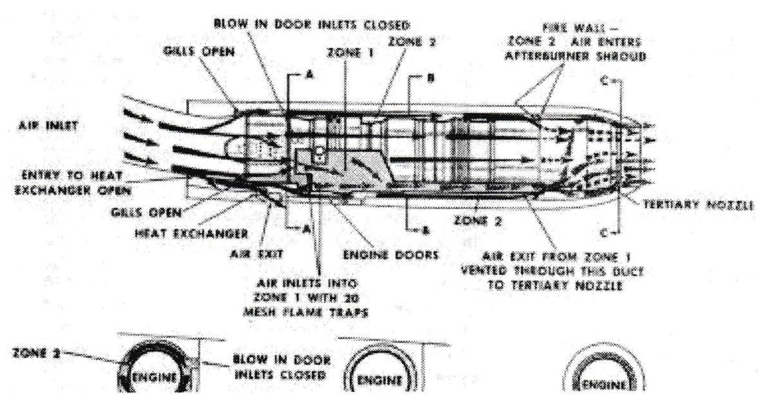


FIGURE 7. Engine cooling. Flight case M=0.50 and upwards.

AIR INTAKE

The arrangement of the intakes is shown in Fig. 8, and consists basically of the following.

(a) a boundary layer bleed, which diverts two-thirds of the air in the boundary layer over the top and bottom of the wing, the middle third being taken into the heat exchangers in the air conditioning system,

(b) the intake ramp, which is used to create an oblique shock wave at supersonic speeds to allow optimum pressure recovery characteristics inside the intake, and which, combined with the normal standing shock, prevents turbulent conditions in the intake over most of the Mach number range.

The optimum angle for the fixed intake ramp was determined by considerations of net accelerating thrust. The geometry of the intake was chosen to yield the maximum installed net thrust with the minimum distortion of air flow at the compressor face, with inlet flow stability over the range of engine mass flows.

The angle of the intake external ramp is 12deg., and the intake contraction and profile from the face of the intake lips to the throat was determined by 1/6th scale models, tested to give the required total pressure recovery and acceptable distortion levels at low subsonic Mach numbers, without conviction with supersonic flow requirements.

A number of modifications were made to the ramps as a result of these tests. One of the problems encountered was an interaction between the inlet shock and the boundary layer from the ramp, which caused fluctuating conditions inside the intake similar to the commonly known " intake buzz." Perforations were installed on the face of the ramp, and the boundary layer air from the ramp was sucked through these per- forations by an extractor, seen below the intake, which has a series of cascades.

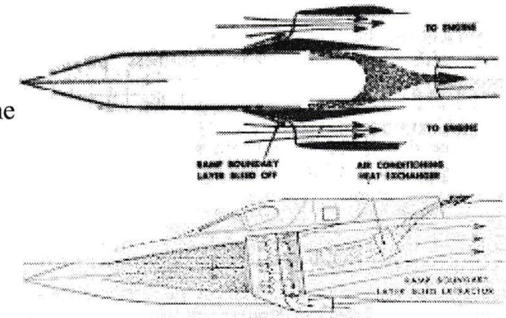


FIGURE 8. Intake geometry.

The 1/6th scale model, tested in the N.A.C.A. 8 ft. x 6 ft. Lewis tunnel, represented the full scale aircraft configuration as far rearward as the engine compressor, face. It included the canopy, fuselage inlet ducts, and bleed, to determine the interaction of the fuselage and canopy surfaces with the air flowing through the intake.

Continuous-view schlieren high speed cameras. as well as flow pressure and temperature instrumentation, were used to determine the flow patterns in the intake. Thirty-seven configurations were checked, involving 1,283 data points. They were all tested within one month, with the wind tunnel time running to something over 100 hours.

BASIC STRUCTURAL DESIGN

T'he structure of the CF-105 is relatively conventional. but the thin low aspect ratio delta configuration and the two engines buried in the fuselage have introduced a number of interesting structural problems (Fig. 9).

WING

The outer wing consists of a multi-spar, highly swept, box beam, with heavy 75ST6 tapered skins and ribs running normal to the main spars. The trailing edge consists of a control box housing the aileron control linkage system, to which the aileron is attached by a continuous piano hinge. The outer wing is attached to the inner wing, by a peripheral bolted joint, covered by a fairing.

The inner wing consists of a main torsion box containing four 75ST6 spars, ribs running parallel to the centre line of the aircraft, and 75ST6 machined skins with integral stiffeners connected by posts. This box is also an integral fuel tank, pressurised to 19 p.s.i. The inner wings are joined at the centre line of the aircraft.

Over the fuselage, and behind the main box, is a rear box extending aft, to which the fin is attached. The fin consists of a multi-spar box beam with heavy 75ST6 tapered skins and ribs normal to the spars.

FUSELAGE

The fuselage has been basically designed around the two engines and their intake system, with the crew cockpit nesting in between the intake ducts. The engines are suspended from the inner wing and they are enclosed by fuselage at the sides and bottom. Underneath the inner wing spars, heavy formers attach the fuselage to the wing. The fuselage sides are attached to the wing chordwise by a continuous piano hinge.

The removable armament pack lies underneath the intakes at the centre section.

UNDERCARRIAGE

One of the most difficult structural problems has been the stowage of the undercarriage gear, which is relatively long, in view of the high wing arrangement and the large angles of attack at takeoff and landing.

It was found to be impossible to stow the undercarriage system in the thin wing without shortening and twisting it as it retracted.

ANALYSIS

With the low aspect ratio delta wing arrangement it was not possible to consider the wing acting as a beam attached to a rigid fuselage.

The wing deflects chordwise under the inertial, lift and elevator loads, and this in turn affects fuselage bending, and the whole structure was analysed as a fuselage-wing combination, with the wing considered to act as a plate.

Matrices were established relating energy of deformation to stress at selected points, and by a series of approximations, new matrices were obtained as the deflections were established, which related stress and deflection with unit loads.

Another difficult structural problem was the internal air pressures in the intake. The air intake system, the shrouds surrounding the engines, the fuel tanks, and the cockpit are all subject to positive and negative pressures. The whole structure had to be considered as a pressure vessel under internal and external pressure.

The air intakes are circular over most of their length, but change to rectangular section at the intake ramps. They are made from 24ST aluminium alloy and, in addition to the internal-external pressure tests, 50 calibre bullets have been fired through a duct pressurised to limit pressure to establish whether explosive decompression would take place. It did not.

FATIGUE

We felt it was important that the structure had a relatively uniform fatigue life, and that there should be no point where the stress concentration factors exceeded the average value by any great amount. A great deal of attention was paid to obtaining the best possible fatigue life without too much of a weight penalty, by careful detail design and detailed stress analysis.

An extensive programme of fatigue testing of joints was carried out, and this also applied to systems testing. In the 4,000 p.s.i. hydraulic system, for instance, extensive fatigue testing of pipes and components was done, especially on those items attached to components on which there were high transient loads, such as the control actuators.

Thermal stresses were also a problem. Elevated temperatures not only have the effect of reducing the allowable stresses and elasticity of the materials, but transient conditions where the outer skin may be relatively hot due to friction, while the inner portion of the structure or skin may not have had time to warm up, produce differential stresses in the structure.

ACOUSTIC ANALYSIS

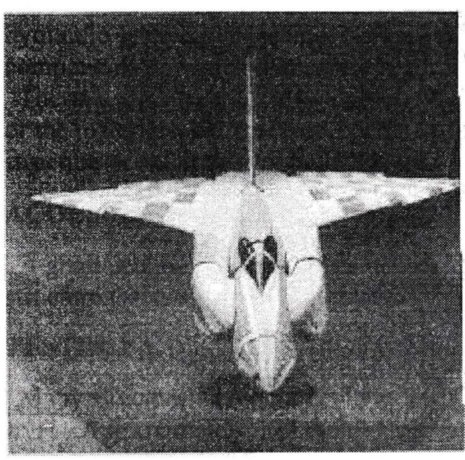
A great deal of *ad hoc* and basic research testing was conducted on representative structures in a sound chamber, since much of the structure is exposed to the high acoustic potential damage from afterburner operation.

TESTING

Many structural components have been tested, ranging from complete tests of the whole aircraft, down to very minor tests such as rivets. Approximately 120 major structural tests have been carried out, some consisting of tests of 30 to 40 specimens to get a representative figure.

The results of many of these tests have already been incorporated into the structural design.

FLUTTER STUDY



Studies on flutter included extensive investigation of wing modes, fin and rudder modes, and control surface buzz (Fig. 10(a)).

FIGURE 10(a). Flutter model.

WING

The wing was treated as a plate, because of the low aspect ratio, and the modes were calculated for the complete aircraft, since it was obvious that it would be impossible to separate the wing and fuselage in a structure of this type. Cantilever modes were also calculated, as a check. Calculations involving the complete aircraft in the symmetrical case involved 6 degrees of freedom, plus control effects.

Vibration modes were calculated by a matrix iteration method from a 60-point matrix. The frequencies were found to be quite low, and it was later decided to include all wing modes up to the anticipated control surface frequencies. A number of methods of calculating flutter were tried, and we came to the conclusion that a conventional strip theory analysis using two-dimensional derivatives was inadequate for highly swept wings, and that a form of lifting surface theory was required. The aircraft's flutter speed appeared dependent on the fuselage bending and torsional stiffness, with the wing torsional stiffness playing a secondary role.

FIN AND RUDDER

Three degrees of fin freedom were included in the analysis, together with the rudder fundamental mode. A wide range of rudder frequencies was covered to establish the stiffness required of the control circuit for flutter prevention.

The results showed that flutter should be no problem on the fin, providing the rudder frequency was kept to twice the fundamental bending frequency. A stream wise strip method was used for the supersonic analysis and no flutter speeds were encountered.

The low speed model programme demonstrated except for very low rudder frequencies, the calculations were conservative. A very high margin was obtained and the flutter point agreed well with N.A.C.A. data on similar plan forms. In view of the high margin it was considered worthwhile to proceed with a transonic model programme.

CONTROL SURFACE BUZZ

Three types of control surface buzz were considered, the first being the shock wave boundary layer interaction problem which occurs at a speed slightly higher than the wing or fin critical Mach number. An oscillatory condition arises when the shock waves move rapidly back and forth across the control surface hinge line, influenced by the trailing edge shape of the control surface, and the particular flight manoeuvre being made.

Another type arises from the interaction between the structure and the integrated electronic system and auto-pilot. The accelerometers in the auto-pilot sense airframe vibrations, as well as primary motion, control surface movement results. Work was done to arrange sensor location to minimise these false signals. T'he third type of buzz is associated with a one degree of freedom flutter due to the theoretical loss of damping at low supersonic Mach numbers.

GROUND RESONANCE

Ground resonance was an important factor, since with an aircraft the size and weight of the Arrow, the complete dynamic structural characteristics had to be completely investigated on the three-point under-carriage suspension. The tests showed that the aircraft, fuselage, and the wing were better than calculated. However, the fin appeared to be less easily predictable, since there was considerable rudder torsion coupling. Further fin flutter tests have been made to check the predictions.

FLIGHT FLUTTER TESTING

The modes of interest are easily excited by the controls in flight, and we have done considerable stick tapping in an attempt to obtain records throughout the speed envelope. From this, by telemetry, the time and magnitude of damping are checked. Fig. 10(b) shows the excellent damping recorded from these tests.

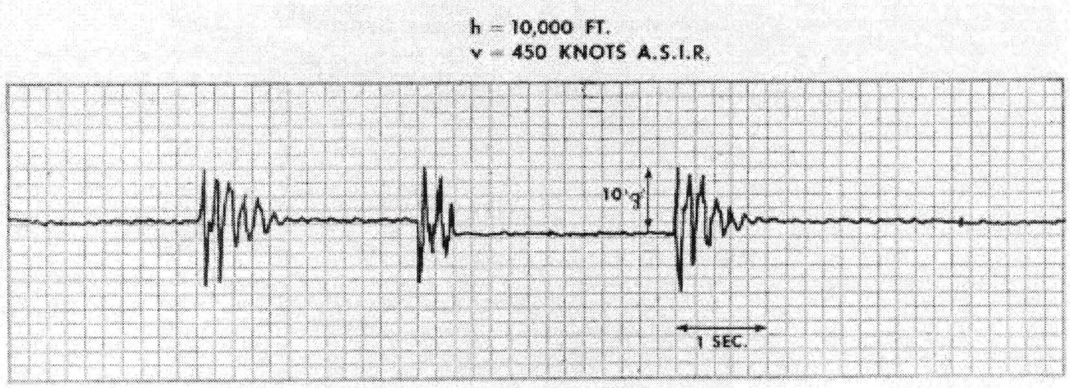


FIGURE 10(b). Damping trace produced by stick tapping during flight test (aileron mounted accelerometers).

MATERIALS

To eliminate time delays, due to development of unfamiliar production processes, we did not go in for extensive use of the newer techniques, such as steel honeycomb, and used titanium only where its high temperature properties were required, rather than from a strength consideration. However, a number of the newer materials were used.

The inner wing skins are machined out of a solid billet, using a 75ST aluminium alloy. This was stretched a nominal 2 per cent immediately after solution treatment and before artificial ageing, to produce an essentially stress-free condition. We felt that fully heat-treated alloy would contain residual stresses which would be relieved during machining and result in distortion.
The stress relieved plate is also much less susceptible to stress corrosion.

For, components machined from hand forgings, we used a new aluminium alloy 7079, which has a chemical composition and heat treatment which is guaranteed to have a minimum transverse elongation of 4 per cent, and which can be heat-treated to achieve its maximum mechanical properties with almost negligible stress, even on sections up to 6 in. in thickness.

On certain of the external surfaces we had a need for magnesium alloy sheet, which was determined by the necessity of achieving the required degree of stiffness, as well as maintaining the highest possible strength to weight ratio. The standard magnesium alloys of the aluminium zinc type were found to lose much of their strength at the temperature corresponding to a Mach number of 2, i.e. approximately 250'F, and they failed to recover their original properties on return to room temperature.

The specification finally used was ZE41H24, and we had little difficulty with it after establishing the proper techniques of hot forming.

ZH62, a new casting alloy, was used on the windshield and canopy castings, which are complex and difficult to cast in any magnesium alloy. Strength is maintained quite satisfactorily in this alloy to over 300'F, with almost complete recovery. The alloy is weldable, which makes possible the salvaging of complicated castings which might be scrapped if they happened to be unacceptable through minor surface defects, such as miss-runs or local surface porosity.

On the undercarriage, which had to be relatively slim to go into the thin wing section, the manufacturers of this component went to 280,000 p.s.i. high strength steel. Extensive investigations had been made on several steels to determine the best compromise between high tensile strength and an inevitable reduction in ductility and impact strength, which results from the use of high tensile strength. Great care had to be taken to reduce the hydrogen content, since hydrogen embrittlement has a marked effect on the fatigue strength and impact properties.

Titanium was used in sheet form extensively in the shrouds and portions of the structure adjacent to the jet pipe, where the low weight and high strength at temperatures up to 800'F are required. This is mainly commercially pure titanium.

Extensive investigations were made into the possible use of titanium as a structural material, but although at that time some of the titanium alloys appeared to be promising as a replacement of high strength aluminium alloys in the structure, the manufacturers were unable to obtain uniformity of the product to ensure that the higher strength was in fact available.

Titanium is being used as a replacement for steel in some joints and fastenings, since there is a distinct weight saving from this.

FLYING CONTROL SYSTEM

The basic flying control system of the CF-105 is fully powered. The surfaces are operated by dual hydraulic jacks, each side of which is supplied by an independent hydraulic system, so that in the event of an engine failure, or the failure of one hydraulic power supply, full control can be maintained.

There are three modes of control., manual, automatic, and emergency. The manual and automatic modes are shown in Figs. 11(a) and 11(b). The pilot's effort is converted into an electric signal by a stick force transducer at the top of the control column. This signal is fed to the command servo through a magnetic amplifier circuit. The command servo is an electro- hydraulic mechanism which converts the amplified signal into movement of the linkage leading to the control valves on the elevator jacks. The stick is mechanically connected to the command servo output.

To provide some feel for the pilot on pulling " g," which has to be artifically created with a fully powered system, a suitable signal is channelled into the command servo from the aircraft performance sensors, the signal being picked up electrically by the sensors and fed into an electronic network.

In the automatic mode the command servos are operated by signals from the electronic black boxes of the integrated fire control and combat system. Displacement of the stick takes place under these conditions, but can be over-ridden if the pilot applies sufficient force.

Artificial stability augmentation is fed into the system in the following manner. Unstable tendencies are picked up by sensors and adjustments are made to the control system deflections by an independent servo, without reaction by the command servo, so that the pilot is unaware of this correction.

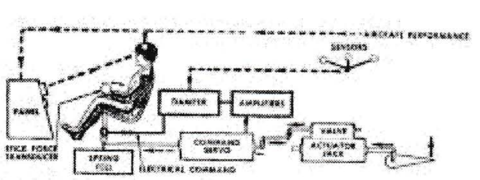


FIGURE 11(a). Flying control system—manual mode (elevator).

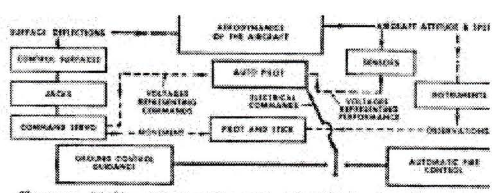


FIGURE 11(b). Block diagram of flying control system automatic mode.

DAMPING SYSTEM

The problem of obtaining adequate natural aerodynamic stability for an aircraft with the altitude and speed range of the CF-105 was extremely difficult especially in view of the low aspect ratio, and direction stability in particular was a problem.

With the very thin fin required with a supersonic aircraft there is a large reduction in fin effectiveness high indicated air speed, and the fin lift falls off considerably, due to the lift slope curve decreasing with Mach number.

To achieve adequate directional stability over the complete flight envelope we resorted to a synthetic "damping " system.

Longitudinal dynamic stability is satisfactory at low altitude, but deteriorates with altitude in the normal way, and above 40,000 ft. the natural damping required augmentation to make the aircraft an effective weapon launching platform. The periods of oscillation are too short at high speeds for the pilot to be able to control adequately the response to a gust.

We were left then with a necessity to augment longitudinal dynamic stability at high altitudes for weapon launching, and to augment lateral static and dynamic stability at a combination of high altitude and high speed to obtain adequate controllability. We did consider very carefully ways and means to produce better natural directional stability by, say, increasing the fin area some 50 to 60 per cent or putting underslung dorsal fins, i.e. dorsal fins, under the fuselage, but the performance penalties of doing this were considered to be unacceptable. For instance, if we increased the size the fin, it would geometrically reduce the fin arm. It would also increase the fin weight and move the c.g. aft, which again reduces the directional stability, and so we would be getting into an area of diminishing returns.

It was therefore decided to obtain the required stability on all axes by artificial means, and since failure of the artificial damping system could be a problem in some areas of the flight envelope, it was also decided that the system must be made with either the same or better reliability than a standard power-operated system.

The highest possible degree of reliability and safety has been built in to the damping system. For instantance on the yaw axis, which is the most critical, there is complete duplication, including sensors, computers, and hydraulic servos. The duplicate yaw axis system called the " emergency damping system." The switch over from " normal " to " emergency " in case of a detected malfunction is automatic. The main sensing element is an accelerometer and, at low speed, a side-slip vane. It is therefore necessary for a double failure to occur before the pilot is left without damping.

The damping system has proved to be quite a development problem, and much of our flight testing so far has been concerned with sorting out the system. However, we were quite aware at the outset that this would be the case and, on the other side of the ledger, the flight testing has shown that our directional stability is better than expected.

The system is designed to operate in conjunction with the automatic flight control system, which in turn is integrated with, and is an essential part of, the integrated interceptor electronic system. The main function of the damping system is to dampen the short period oscillations about all three axes, and to dampen the longitudinal long period oscillations.

The system provides turn co-ordination and side-slip minimisation in operational manoeuvres up to 6g positive in pull-outs, and 4g positive in turns. This protects the fin structure from excessive loading. The damping system also provides for uncoordinated manoeuvres at the option of the pilot, which is carried out by a cut-off switch on the rudder bar, and provides a means of manual control.

The emergency damping system, which is on the yaw axis only, provides stability and damping of the Dutch Roll mode, and limits the side-slip to well within the structural integrity limit on the fin, in pull-outs or 2g turn manoeuvres.

FIRE CONTROL SYSTEM

While it is not possible, for security reasons, to describe the integrated electronic system which is the brain and nerve centre of the Arrow weapon system, I can say that it is a very sophisticated system and provides automatic flight control, airborne radar, telecommunications and navigation, and special instrumentation and pilot displays, and can operate in either fully automatic, semiautomatic, or manual environment.

The system is carried mainly in the radar nose, with missile auxiliaries housed in the armament bay.

WEAPON PACK

A number of different kinds of missile armament can be carried in the large armament bay. The missiles are housed in a removable pack below the fuselage, attached at four points, and re-arming is very fast, the pack being lifted into place by a mobile rig which also serves as a transport dolly (Fig. 12).

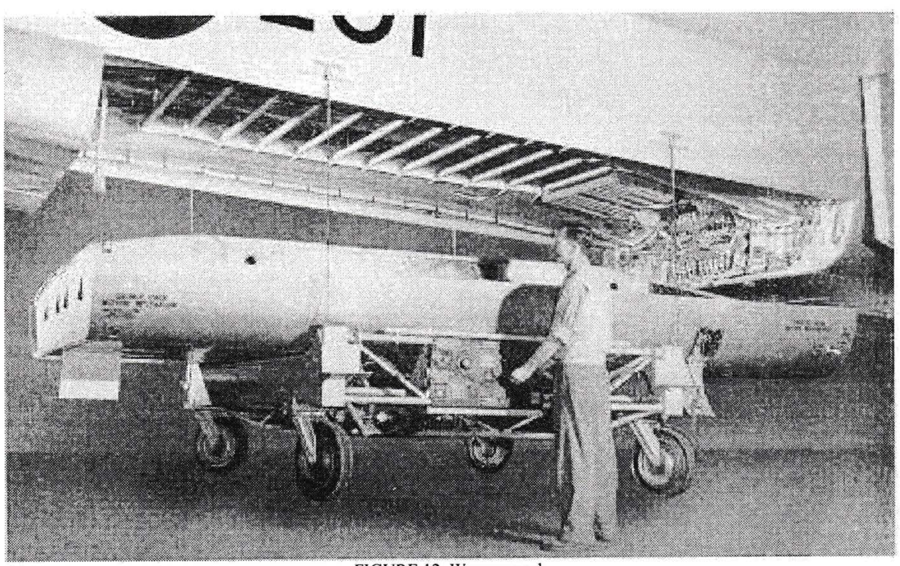


FIGURE 12. Weapon pack.

FREE FLIGHT MODELS

During the early phases of preliminary design, we decided that a great deal of data could be accumulated from free flight model firing, especially on dynamic stability and control, and also that free flight models would give a better means of establishing the aircraft drag than wind tunnel models, since the effect of the data boom on the relatively low Reynolds numbers of the wind tunnel tests, and the difficulty of making an accurate strain gauge drag balance, free from the interaction of other components, made it dificult to establish the drag by tunnel tests.

We estimated that 1/8th scale models, fired to the correct Mach number at low altitude would give approximately full scale Reynolds

numbers, due to the higher air density closer to sea level.
The first model was fired in December 1954 to evaluate the techniques for launch, separation, telemetering, and tracking (Fig. 13). Four crude models had been made with an approximate representation of the CF-105 configuration to check general problems associated with firing. These were followed by seven considerably more sophisticated and representative models, having up to 16 channels of telemetry. Of the last seven models, three were drag models, two lateral stability models, and two longitudinal stability models.
The models were all launched from a zero length launcher, and boosted to a Mach number of 1.7 by a JATO booster, having 50,000 lb. of thrust for a period of three seconds.
The telemetry package radioed back to a ground recording station, position, pressures, acceleration data and so on.
Separation was achieved by means of drag; the greater drag to weight ratio of the boosters when power is exhausted, slows the booster more rapidly than model, and the two separate.
Most of the firings were done at the Canadian Armament Research and Development Establishment at Picton, on the shores of Lake Ontario, which has a range telemetry ground station. Our own telemetry mobile trailer receiver was also used as a check.

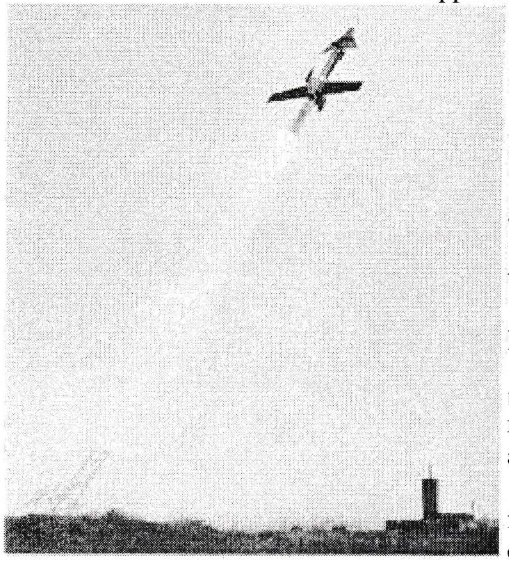


FIGURE 13. Free flight model launching

Additional range instrumentation consisted of kine-theodolites taking pictures at five frames a second, complete with azimuth and elevation scales. All the shutters of the cameras were synchronised. Doppler veloci-meter radar was utilised to obtain correct velocity information, with an 8 ft. diameter transmitting and receiving dish.
There was also a tracking radar, operating 600 pulses per second on "S" band.Quick-look data was obtained from a plotting board.
Two models were fired at the N.A.C.A. Range Wallops Island. One of these models had the fuselage, contoured for what we called, " super" area ruling, to ascertain what decrease in supersonic drag might expected as we optimised the shape to achieve minimum drag at a given speed. The gains were shown to be quite small.
For the lateral stability models, lateral accelerations were excited by means of a yaw impulse system mounted in the nose of the model in the form of a motor-driven Geneva cross mechanism, containing five cartridges of 10 lb. second impulse, and firing alternately port and starboard, through a hole in each side of the nose at intervals of 1 1/2 seconds.
On the longitudinal stability models, the elevators were actuated by a mechanism contained completely inside the model using a hydraulic oil-air accumulator.
In all, these tests were remarkably successful, the three drag models provided the data to evaluate supersonic airframe drag and also served as a qualitative assessment of the CF-105 dynamic stability. We had no aborted firings, even on the crude models, and the reliability of the telemetry transmission was over 95 per cent. On one occasion, for instance, a model fired over Lake Ontario hit the water after the test and then skipped out again over the surface, and continued to send back information to a group of surprised technicians at " point zero"!

DATA ACQUISION AND HANDLING

With an aircraft of the complexity of the Arrow, an extremely large number of individual readings of several hundred parameters are necessary during a test flight, if reliable dynamic characteristics of both aircraft and systems are to be obtained.
With the possible data points per flight running into several million, it is obvious that manual handling of this data would be impractical. The only way that such a mass of data can be handled quickly is by means of an automatic system.
This data handling system requires that the information be presented in an electrical form, and magnetic tape is used to store the large masses of information received.
It was felt that " in flight " monitoring would be necessary during the Arrow flight testing to enable the maximum data to be obtained from each flight, and to monitor against possible troubles in flight. The means of accomplishing this was already present in the company in the form of a mobile telemetry unit which had been initially constructed for the free flight model firings.
The Arrow data acquisition and handling system is composed of an airborne multi-channel recorder system, an airborne radio telemetry link, a mobile telemetry receiving station, and a mobile data reduction unit capable of reducing data obtained by either airborne system (Fig. 14).

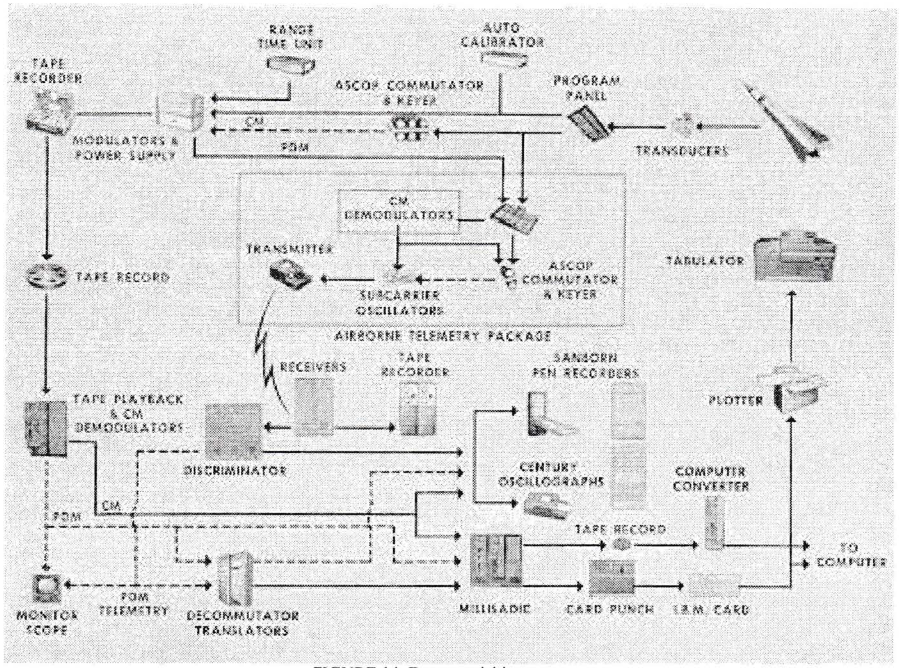


FIGURE 14. Data acquisitison system.

With the large armament bay required on the Arrow, in the form of a removable self-contained unit, it has been relatively easy to house all of our telemetry transmitting instrumentation and oscillographs, and so on, in the weapon pack (Fig. 15).

For visual monitoring of flight conditions a special "operations" room was prepared, containing recording oscillographs giving instantaneous visual records of data in analogue form during actual flight. Personnel in this room are in radio contact with the pilot by means of the conventional radio links, so that instructions and comments may be exchanged at any time during the flight.

On the first series of flights, we were plagued with a number of minor problems, mainly due to the literally thousands of wires and connections running to the instrument pack. A central " patch board " has since been included to allow any circuit changes to be made at one location.

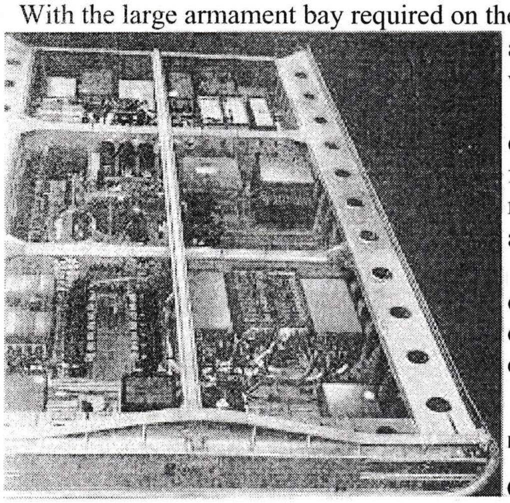


FIGURE 15. Instrument pack.

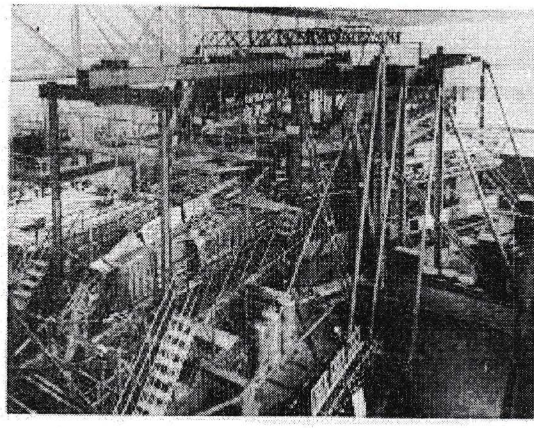
GROUND TEST PROGRAMME

The philosophy of proceeding immediately with, production type build which we adopted on the CF-105, and which I will discuss later, obviously involves greater technical risks than the prototype/pre-production/production technique and, to protect as much of our engineering investment as possible, the decision was made early in the programme to carry out what was considered at the time to be an extraordinary amount of structural and systems testing.

A large proportion of this testing was used for development purposes, for instance, the basic development of the control system and damping system was done on the control system rig.

Many of the major structural tests, however, could not be considered in the development category, since production components were required from Manufacturing, and these components were not, in many cases, ready until the first aircraft was about to fly. In these cases, the test became more of a check on the completed design.

A large number of critical components were checked prior to flight. This included the checking of fatigue of typical joints and structures, elevated temperature testing, panel and torsion box testing, and so on.



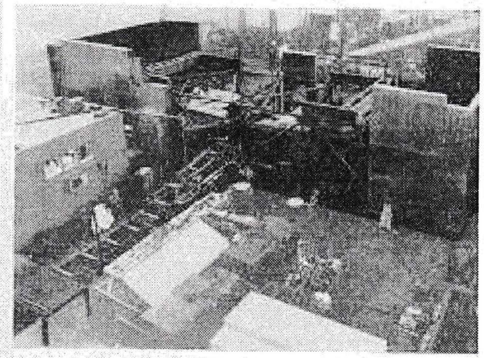


Figure 17. Flying control systems test rig during construc

FIGURE 16. Structural static test rig.

The next step in the structural programme was to test the complete aircraft in the large static test rig (Fig. 16). These tests began in early 1958, the objective being to confirm the calculated internal load distribution in the complete aircraft structure from the applied ,external loads, and to confirm the calculated stiffness and deflections of the structure under load, in addition to establishing the overall structural strength of the airframe under limit load conditions for various flight and landing cases.

In the major cases, up to 30 hydraulic systems are used to apply the loads, via a multiple beam system, to some 1,100 points on the aircraft. This has led to the use of an automatic load control system which allows control to be maintained by a single operator through regulating valves.

The load in each hydraulic jack is sensed by a strain gauge system to ensure that the overall load is compatible with the percentage of limit load to be applied. More than 3,000 strain gauge recording stations are used on the structure, and 300 deflection gauge stations. The central strain gauge recording unit is capable of reading out close to 800 stations in 25 minutes. The results are simultaneously typewritten and punched on to IBM cards for ease of processing by the Technical Office.

TRANSIENT HEATING TESTS

Transient heating tests were made on representative sections of the fuselage and wing using radiant heat lamps powered by a variable voltage supply controlled by a simple analogue computer.

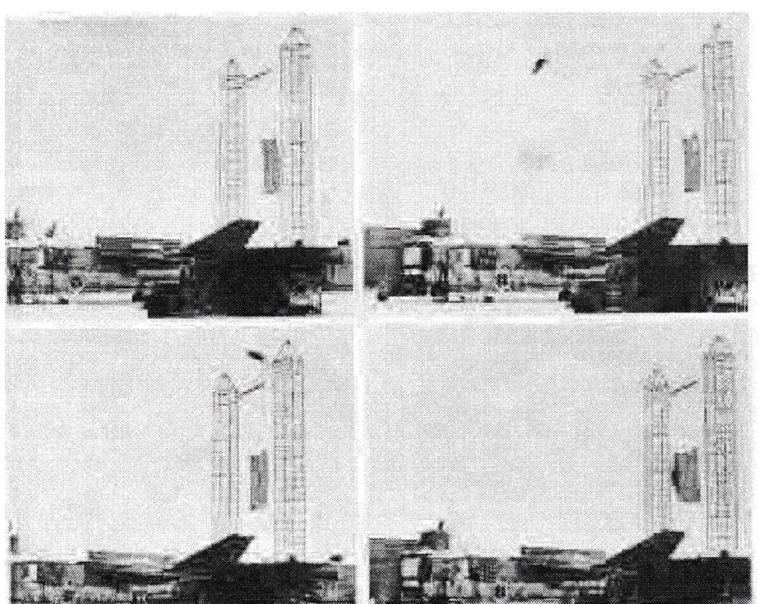


FIGURE 20. Static testing of crew escape system.

SYSTEMS TESTING

Flying Control System Rig

Since this rig was used for basic development of the flying control system, it was a fairly sophisticated rig, containing a dummy cockpit, a complete control system, closely controlled electric motor drives to simulate various engine conditions, all control surfaces and adjacent structure, and the synthetic stability system. (Fig. 17).

For the aerodynamic response tests, surface loading was provided by large leaf springs attached to the surfaces, and the tests simulated correct inertial conditions at the same time maintaining structural stiffness.

A large amount of instrumentation was provided to record motions of the actuators, valves, servos, and so on, together with hydraulic system pressure at critical points in the system. On this rig we were able to make complete evaluation of the flying control system from the cockpit to the control surfaces. The rig was also used during simulation tests on the complete aircraft. This particular rig is tied in with a co-axial cable to the Analogue Computer Room, some distance away. Output from potentiometers mounted at the control surfaces were transmitted to the computers, which in turn fed in derivatives obtained from wind tunnel testing. Landing, take-off and manoeuvring under gust conditions were simulated to give the pilot some feel of aircraft problems, including break-out forces.

A flight simulator was set up with visual representation of aircraft attitude, rate of climb, stability, and so on, and included engine noise inputs. A considerable amount of " flying" was done on this rig by the test pilots, before actual flight.

Fuel System Rig

A full scale rig representing half the complete aircraft fuel system was built and mounted on a special gantry on which the specimen is pitched and rolled to simulate all attitudes of the aircraft in flight. All components of the fuel system were installed so that their function would be similar to that experienced in flight. Vacuum pumps were available on the rig to simulate altitude conditions. Tank pressurisation was provided, and a large heater to elevate the fuel temperature, to check flows under hot fuel conditions. This rig was also used for qualification testing of the various items in the fuel system (Fig. 18).

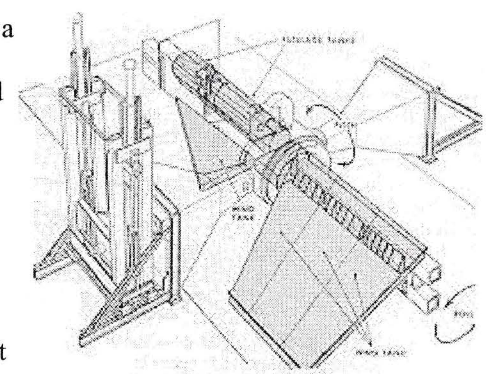
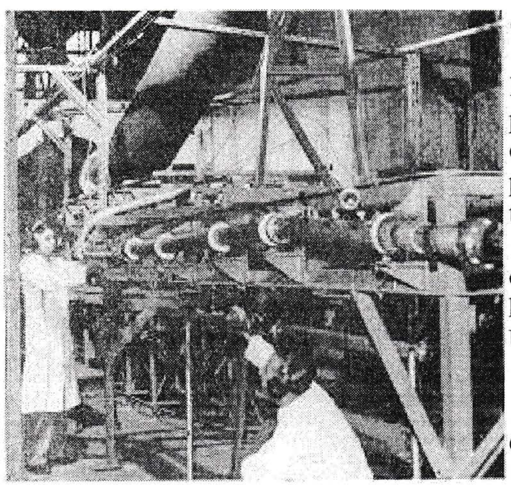


FIGURE 18. Fuel system test rig.

Air Conditioning System Rig

This rig was provided to check systems functioning and the mass flow distribution throughout the system. The rig represents the complete air conditioning system, the cockpit being represented by an air tank of equivalent volume.

The rig had to be totally enclosed because of the high noise level. Air temperatures at 30 locations in the rig were recorded by thermocouples, and the air turbine speed was obtained from a magnetic pick-up, which in turn was recorded on special instrumentation. Fig. 19 shows the rig before completion.



Other Tests

A number of other tests involving the complete aircraft electrical system, the complete landing gear, the utility hydraulic system, and so on, were made. A system of insulating panels can be placed around most of the test rigs, and air is supplied through heat exchangers to raise the temperature to 250'F., or reduce it down to -65', by reversing the process. It was possible by this method to test the control system, structure, and so on, at the temperature conditions which apply throughout the flight envelope.

The complete aircraft armament has also been the subject of an intensive test and development programme, and has involved considerable flight time on the CF-100's, which have been used as test vehicles for the Sparrow weapon programme at Malton, and at the U.S. Naval missile test centre at Point Mugu, California.

Crew Escape System

A considerable amount of development was carried out on the crew escape system, especially in view of the two-man crew requirement. We have estimated from simulated escape sequences that the completion of escape takes an average of approximately 8 seconds, from the time the pilot begins to order the observer to escape, to the point at which both men are clear of the aircraft.

Crew escape time checks and tests were made on one of the Arrow mockups, and full scale ejections were made from the cockpit of the static test aircraft, using a dummy (Fig. 20). Film records indicated that the dummy's legs fouled the instrument panel during ejection, but it was considered that the behaviour of the dummy had not been entirely representative of that of a live occupant, and additional tests were made at the R.A.E. by the Martin Baker Company, with satisfactory results.

Ejection from the Arrow is completely automatic. The pilot pulls the seat blind, this first triggers the canopy mechanism and, when the clamshell canopy has reached its full travel, the seat automatically ejects, and the pilot is later ejected automatically from the scat.

To improve the time of ejection, we are now considering a linked escape system, with the pilot ejecting both the observer and himself from one control, which we estimate would cut down the escape time to 2.5 seconds.

It is also proposed to carry out ejections from a supersonic rocket sled to demonstrate as fully as possible that the emergency canopy opening and crew ejection mechanisms function correctly, and that crew members can be safely ejected clear of the structure over the full flight envelope.

Wind Tunnel Tests

It would be impossible in a relatively short paper to deal adequately with our wind tunnel programme, which involved some 4,000 runs and 4,000 hours of tunnel time at various facilities in Canada and the United States, including the Ottawa tunnels of the National Aeronautical Establishment, the Cornell Laboratories at Buffalo, the N.A.C.A. Langley Field and Cleveland tunnels, and the supersonic tunnel at the Massachusetts Institute of Technology. Fig. 21 lists the major tests made up to the present time. The amount of data collected, especially on basic aircraft stability, was enormous.

MODEL	PURPOSE	FACILITY
	(a) WIND TUNNEL	
3/100 COMPLETE MODEL	STABILITY & CONTROL (SUB & SUPERSONIC)	CORNELL 3' x 4' AND 10' x 12'
4/100 COMPLETE MODEL	STABILITY & CONTROL ARMAMENT FORCES (SUB & SUPERSONIC)	CORNELL 3' x 4'
1/10 & 1/8 REFLECTION PLANE	ICING CONDITIONS (LOW SPEED)	N.A.E. 10' x 5.7'
7/100 COMPLETE MODEL	CANOPY & MISSILES JETTISON GROUND EFFECTS (LOW SPEED)	N.A.E. 10' x 5.7'
1/80 COMPLETE MODEL	STABILITY & CONTROL (SUPERSONIC)	N.A.E. 16" x 30"
1/40 FUSELAGE INTAKE	INTAKE FLOW (SUPERSONIC)	N.A.E. 10" x 10"
1/50 REFLECTION PLANE	STABILITY & CONTROL (SUPERSONIC)	N.A.E. 16" x 30"
1/24 COMPLETE MODEL	SPIN CHARACTERISTICS (SUBSONIC)	N.A.E. SPINNING TUNNEL
1/6 FUSELAGE INTAKE	INTAKE STUDY (SUB & SUPERSONIC)	NACA CLEVELAND 8' x 6'
3/100 COMPLETE MODEL	DIRECTIONAL STABILITY (SUPERSONIC)	NACA LANGLEY 4' x 4'
1/30 CANOPY MODEL	RAKE SURVEY (SUBSONIC)	N.A.E. 10" x 10"
1/10 COMPLETE MODEL	FLUTTER (LOW SPEED)	N.A.E. 10' x 5.7'
1/40 REFLECTION PLANE	FLUTTER (TRANSONIC)	M.I.T. 22" DIA.

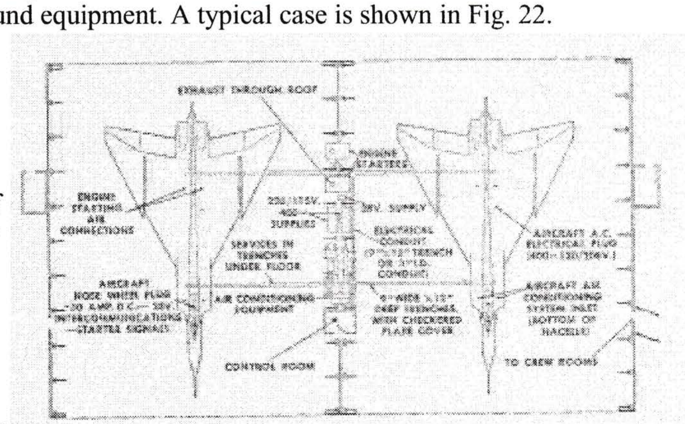
MODEL	PURPOSE	FACILITY
	(a) WIND TUNNEL (CONT'D)	
4/100 FIN MODEL	RUDDER BUZZ (SUPERSONIC)	N.A.E. 16" x 30"
4/100 COMPLETE MODEL	MISSILE TRAJECTORIES, CANOPY HINGE MOMENTS AND STABILITY EFFECTS (TRANSONIC)	CORNELL
α - β VANE FULL SIZE	FUNCTIONAL TESTS (SUPERSONIC)	N.A.E. 16" x 30"
	(b) WATER TUNNEL	
3/100 CANOPY MODEL	VISUAL FLOW CHECKS (LOW SPEED)	N.A.E. 9.84" x 13.11" WATER TUNNEL
	(c) ENGINE DUCT MODEL	
6/10 DUCT MODEL	FLOW EFFICIENCY AND AIR BLEED TESTS	ORENDA TEST CELL
	(d) FREE FLIGHT MODELS	
1/8 SCALE FREE FLIGHT (11 MODELS)	DRAG & STABILITY (SUPERSONIC)	C.A.R.D.E. RANGE ONTARIO AND LANGLEY FIELD RANGE
	(e) ANTENNA RESEARCH	
1/48, 1/18, 1/8, 1/10 OF, AND FULL SCALE MODELS	ANTENNA & ANTENNA PATTERN RESEARCH	SINCLAIR RADIO LABS. LTD.

Figure 21. Model testing programme

Ground Support Equipment

In the early stages of preliminary design, it was decided by the R.C.A.F. that the ground support equipment should be designed concurrently with the basic aircraft, to allow the squadrons to be trained and equipped well ahead of the receipt of operational aircraft. It was also realised that with an aircraft of the complexity of the Arrow this equipment would, in any case, be required when the first few aircraft started their flight test programmes.

A ground support design group was set up over three years ago within the Engineering Division to design those items required for satisfactory operation of the aircraft, and R.C.A.F. personnel joined this group to form a team which would evaluate and resolve the equipment received for the service readiness hangars and general turn-around equipment. A typical case is shown in Fig. 22.



Studies were made on maintenance facilities and, as the design progressed, a number of conferences were held on the engineering mockups to establish the times of replacement and inspection of every equipment item on the aircraft. This group also prepared a proposal outlining a method for providing the personnel and skills required to maintain the complete Arrow weapons system, including the organising of maintenance personnel and recommendations for training programmes for ground crews.

Policy of Manufacture

Our programme of building on the CF-100 had been carried out by the conventional method of building two prototype aircraft with minimum tooling, then building 10 pre-production aircraft on harder tools and, on the

13th aircraft, going into full scale production on relatively sophisticated tooling. Our timing, from the start of design in 1946 to delivering the first production aircraft was approximately six years.

On the CF-105, it was obvious from the outset that, based on its greater complexity, even the first aircraft could not be built by hand methods and a certain amount of fairly hard tooling would be required. In addition, our schedule was to be very tight, from the time of initial design, to delivery to R.C.A.F. squadrons.

In considering the method to be followed, we were also aware of the change in philosophy which was taking place in the United States on the basis of the Cook-Craigie recommendations, which provided for elimination of prototypes and experimental drawing and tooling, the first aircraft being built from production type tooling, and from production drawings.

However, the manufacturers who had followed this philosophy at that time had previously had either research aircraft of the general configuration of their production vehicle, or had, in fact, built prototypes before going ahead with a production article. For instance, in thecase of the F.102, considerable development work had been done on the XF-92 research vehicle, and two prototypes had been built before going into full production on the F.102, whereas we had a completely new and complex aircraft, without the benefit of a research vehicle, and the engineering gamble which had to be taken, due to the gaps in our knowledge, was formidable.

On the other hand, there did not appear to be time to build prototypes, develop them, and then re-issue production drawings incorporating the changes found from development.

The decision was made, therefore, jointly between the Company, the R.C.A.F., and the Canadian government to proceed with a number of development aircraft on the basis of a production type drawing release from the outset. In other words, it was decided to take the technical risks involved to save time on the programme.

Production personnel worked along with the Design Office to check and advise on produceability as the design went along. Detailed layouts, part prints and material specifications were all issued on a full production basis. Drawings were made full scale on glass cloth or vinyl transparencies to assist checking and allow these drawings to become masters for tooling templates, and so on. Full scale plastic templates were made up from the initial lines lofts, to be used as references and tool patterns by Manufacturing. Permanent type tools were made up throughout the build of assembly jigs, sub-assembly jigs, and detail tools. Fig. 23 (a) shows the main assembly jig and Fig. 23(b) shows one of the large milling machines purchased to mill the inner wing skins.

A full scale metal mockup was made from the detail tools as they became available, and this mockup acted not only as a tool proving device, but was also used to train the production crews who were to build the first flying aircraft, and was used by Engineering as a check, and later, as a development tool. Where the correct material was not available, many parts of the mock-up were made from soft material, and some parts were made by hand to bring it up to a state of completion a little earlier than would have been the case if we had waited for permanent tooling. While every attempt was made to keep this mockup up to date with all changes, this happy state was never achieved, since the first aircraft was coming along fairly quickly behind the metal mockup.

I will not pretend that this philosophy of production type build from the outset did not cause us a lot of problems in Engineering. However, it did achieve its objective, and has provided us with more development airframes on which to do development flying and checking.

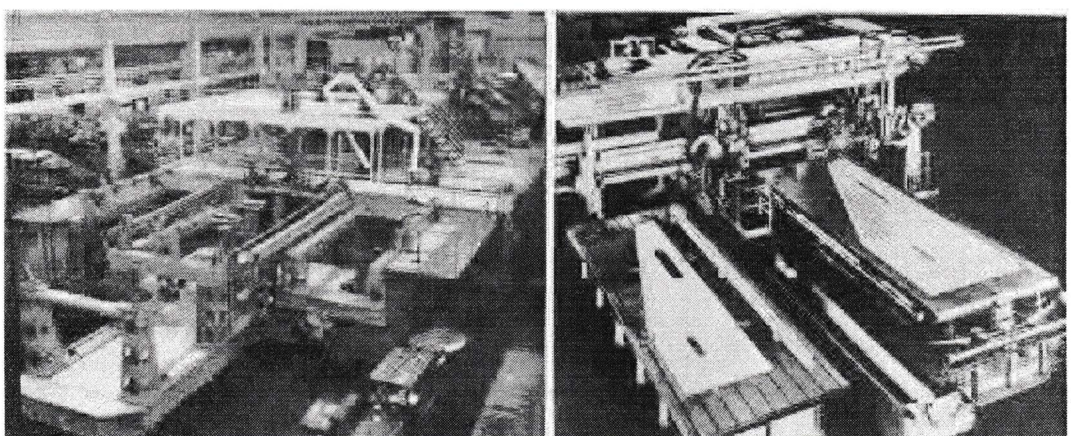


FIGURE 23(a). Arrow main assembly jig. FIGURF, 23(b). Machining Arrow wing skins.

In examining the number of aircraft to be used in the test programme, we were again very conscious of the time element, and it was obvious that we would need a relatively large number of aircraft to obtain the development flying necessary on the airframe, engine, fire control system, and armament.

The Air Force examined the programmes which had been carried out in the United States, to ascertain the approximate number of flying hours required in a contemporary development programme. However, on examination, it was obvious that Canada could not afford to go for such an extensive programme, with up to 50 development aircraft, and a compromise was made with 15 aircraft being established as straight development vehicles for the various components, with an additional 21 aircraft for the R.C.A.F.'s evaluation programme, before these aircraft went into operational service. The portions of the programme for which these aircraft will be used is shown in Fig. 24.

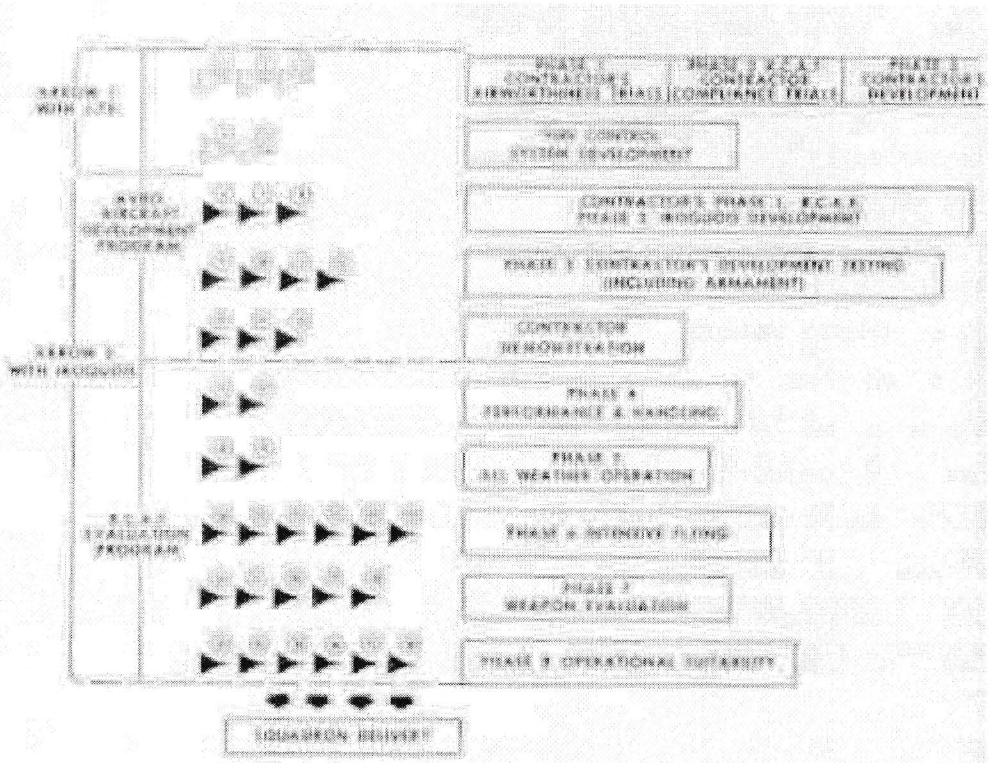


Figure 24. Development allocation.

Flight Test Programme

The first engine running in the aircraft took place on 4th December 1957, taxi trials were started on Christmas Eve, 1957, and the first flight was made on 25th March 1958.

Stage One of the flight test programme on the first aircraft covered the period from first flight until the 23rd April 1958, i.e. the first 29 days of flying, during which nine flights were made.

The first two flights were for pilot familiarisation, the aircraft flew super- sonic on the third flight and, on the seventh flight, reached a speed well over 1,000 miles per hour at an altitude of 50,000 ft. in a climb while still accelerating.

Most of the early flying was done by Jan Zurakowski, Avro Chief Development Pilot. The aircraft was also flown by F/Lt. J. Woodman, R.C.A.F. Evaluation Pilot, and "Spud" Potocki, Avro development pilot

Most of these flights, beyond the third, were at supersonic speeds, but the aircraft was not flown to it's, maximum speed capability at any time during these early flights.

Practically all of the flights have been made at weight considerably in excess of the mission weigh estimated for the Mark 2 operational aircraft, since the installed weight of the J.75 engines is higher than the installed weight of the Iroquois, and ballast is also required in the nose to balance this extra weight Average take-off weight has been around 67,000 lb., and landing weights have been in the order of 54,000 lb.

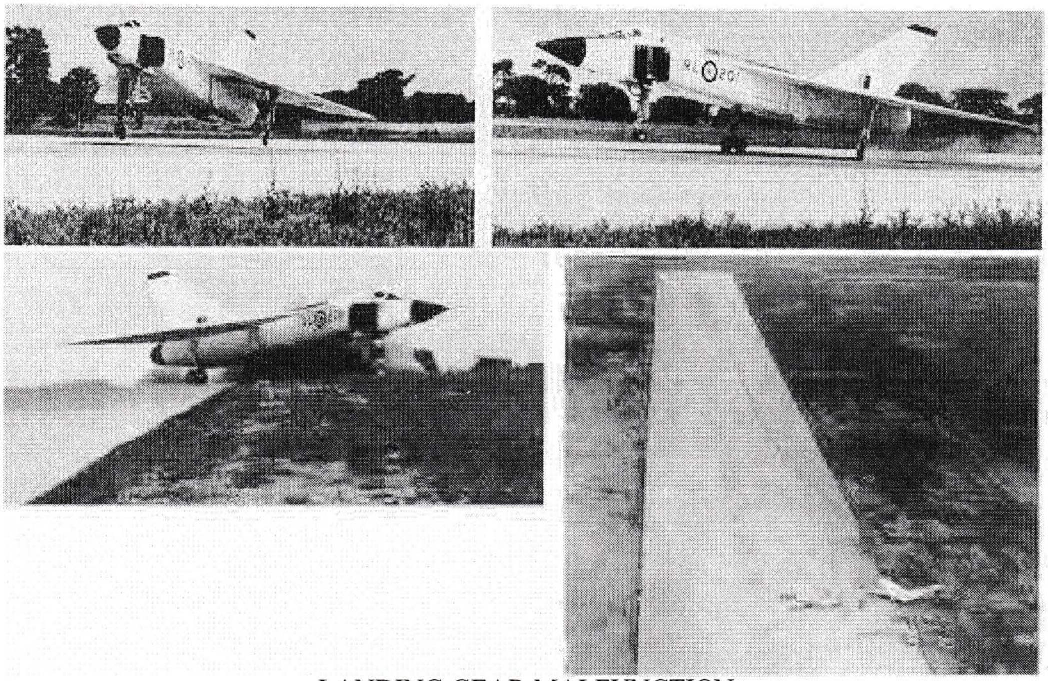
Basically, this first series of tests were to evaluate the general handling qualities of the aircraft over as much of the flight envelope as possible, to evaluate the flying control system and damping system, to check instrumentation and telemetry techniques, and to check safety under adverse conditions, such as one engine throttled back, induced oscillations, and so on.

The following comments were extracted from the pilots' reports:-

- The nosewheel can be lifted off by very gentle movement of stick at just over 120 knots.
- Unstick speed is about 170 knots A.S.l., with an aircraft attitude of about 11deg.
- Acceleration is rapid, with negligible correction required, and no tendency to swing.
- Typical touchdown speed is a little over 165 knots (the normal landing procedure is to stream the drag chute on touchdown when the nosewheel has settled).
- There was no indication of stalling at the maximum angle of attack at 15deg.
- Stability steadily improved with speed.

- Change of trim was negligible except in the transonic region, where small changes of trim were required.
- No attention was required by the pilot to prevent over-controlling.
- In turns, stick force was moderate to light, but always positive with no tendency to pitch up or tighten.
- In sideslip, the aircraft was a little touchy with-out the damper, but excellent with damper switched on.

To quote the pilots, " In general, the handling characteristics and performance of the aircraft agreed well with estimates."
This series of flights provided an excellent start to, our flight test programme. After the Stage One flying, the first aircraft was given a thorough inspection and was flying again on 7th June on Stage Two Testing. On the 11th flight on 11th June, we had an unfortunate accident due to a failure of the undercarriage, which put the aircraft out of commission for several months.
Because of the excellent photographic coverage which we obtained of the accident, we were able to assess the cause very quickly. The aircraft had touched down with the port leg twisted, and was in this condition during the whole of the 4,000 ft. run. I have included some of these photographs as a matter of interest.



LANDING GEAR MALFUNCTION
FIGURE 25 (top left). Before touch-down.
FIGURE 26 (top right). At touch-down.
FIGURE 27 (above). Arrow veering off runway following release of brake parachute.
FIGURE 28 (right). Aerial view of aircraft ground run and final attitude.

Figure 25 shows the aircraft just before touch-down, indicating the port leg. in a twisted condition; Fig. 26 shows the aircraft just on touch-down with the leg being dragged sideways and the tyres just beginning to smoke. Fig. 27 shows the aircraft just as it ran off the runway into the soft earth, snapping off the undercarriage; and Fig. 28 shows the path taken on landing.
Aircraft Nos. 2 and 3 have now taken over the bulk of the current flight test programme and, in proving the flight envelope, have flown at speeds considerably in excess of those achieved on the first aircraft.

EVALUATION

It is interesting to note that in Canada the flight evaluation set-up is a little different to that in the United Kingdom, where the government establishments at Farnborough and Boscombe Down are available for, extensive development flying, and similarly, at Wright Field, Eglin Field, and others in the United States.
In Canada, the prime contractor takes on the job of all the initial development flying and evaluation, with R.C.A.F. crews assigned to work alongside. The final performance evaluation is made at the R.C.A.F. Central Experimental and Proving Establishment at Rockcliffe.
Later armament evaluation will be carried out at the R.C.A.F. Air Armament Evaluation Detachment at Cold Lake, Alberta, and all-weather evaluation at the Climatic Detachment, located near Edmonton, Alberta. The Cold Lake airfield site covers 10 square miles, and the 4,000 square miles range is large enough for unrestricted missile and rocket firing. Electronic optical theodolites are used for tracking and photographing aircraft and missiles. High speed cameras, spotting scopes and telemetry systems are also used in tracking missiles. This facility is probably one of the largest overland ranges in the world.
With regard to our own flight testing, we have had the added problems of operating from a busy commercial airport adjacent to the

plant and have to tie our flight testing in with scheduled commercial flights. However, with as many as 30 flights a day on the CF-100, we have had little problem with this, due to the excellent co-operation of the Department of Transport controllers.

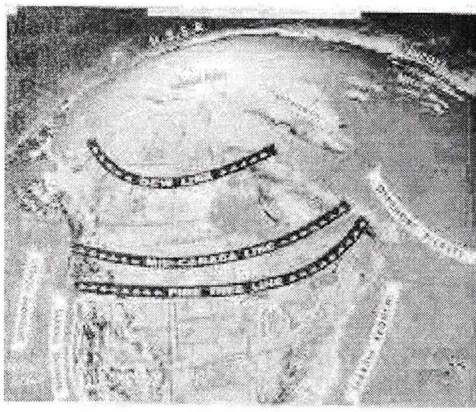
Before operating the Arrow from Malton, the question of noise was raised, since the installed thrust of. the Arrow is well over twice that of the, CF-100. A considerable number of noise frequency and pressure levels were analysed before flight. However, so far, it has been obvious that the actual noise levels encountered during all conditions of taxi, take-off, landing, engine run-up, and so on, present no greater problem on the Arrow than they did on the CF-100 and, in fact, are considered to be less than at least one of the commercial aircraft operating from the same facility.

Defence Environment

The overall defence system for the North American Continent is now generally well known. The D.E.W., or Distant Early Warning Line is the first line of defence and runs from Baffin Island to Alaska, over the far North of Canada. The second line is the Mid-Canada Line, provided by Canada, and the third line is the Pine Tree Line, which was jointly financed by the United States and Canada.

These three lines are supplemented at the ends by inshore and offshore pickets (Fig. 29). In addition, there exists an airborne network of early warning aircraft fitted with powerful radar. Practically the whole of this warning network lies in Canadian territory.

A Semi-Automatic Ground Environment System (S.A.G.E.) developed in the Lincoln Laboratories in Boston, is now being set up to provide a complete surveillance and weapons control system. All information in a particular area can be presented on a master scope and the S.A.G.E. system is capable of transmitting the data to the interceptor electronically to provide an auto- matic intercept (Fig. 30).



Since North American Air Defence (N.O.R.A.D.) now controls the complete Air Defence system of the North American Continent in an emergency, the Arrow weapon system will be operating within this environment (Fig. 31).

Weapon System Concept

The ultimate responsibility for the Arrow "Weapon System" including the aircraft, the ground support equipment, and the base facilities, rests with the Royal Canadian Air Force and the Department of National Defence, who created the operational requirement and will eventually operate the weapon system.

In the interest of better control and co-ordination of the development and production of the Weapon Systen a group was formed within the R.C.A.F. under the direction of an Assistant for Arrow Weapon System (A/AWS), reporting to the Chief of Aeronautical Engineering, R.C.A.F., who has been delegated " Technical Authority " for the programme. The group is larger made up of R.C.A.F. engineering officers drawn from the various specialist engineering directorates.

A portion of the management responsibility of the A/AWS is sub-contracted to the aircraft supplier, Avro, who, as " Co-ordinating Contractor." undertakes much of the detail co-ordination of the whole programme, subject to monitoring by A/AWS.

The Arrow programme is a colossal undertaking for Canada, and up to the present time it has required the co-operation and integration of all the responsible agencies within our country, and I would like to emphasise the " national " nature of the project. There are some 650 individual companies engaged in the programme, mostly on sub-contract work for Avro.

Significant contributions to the programme have been made by the Canadian Defence Research Board and the National Aeronautical Establishment in Ottawa where most of the low and medium speed wind tunnel work was carried out. We have also received valuable assistance from the N.A.C.A. in the United States, and the R.A.E. in the United Kingdom in the use of their facilities where these have not been available in Canada.

Postscript

On re-reading my manuscript I was conscious of the fact that while it contained most of the important facets of the Arrow programme that could be covered inside the security limits, it did not even begin to convey the human side of the endeavour.

There were many periods of frustration and in the early stages of the programme the project was ON and OFF about every three months, while Government and the Service wrestled with the problems involved in managing and financing such a large project.

When the programme finally got under way, and the engines scheduled for the project fell by the wayside one by one, we had to re-design our fuselage three or four times, and while the aircraft had been designed from the outset with the flexibility to make re-engining as simple as possible, it appeared to us that every engine manufacturer had gone out of his way to make things different! Some engines had three-point mounts, some four, and pressure ratios differed, which meant an almost complete re-design of the air conditioning system, since this is dependent on the engine for its prime inputs.

The R.C.A.F. naturally wanted the best and latest integrated electronic system and weapon in the aircraft, and finally chose these, after a considerable portion of the aircraft had been designed around an earlier system.

This is, of course, normal to some extent in our business. However, since this is the major military project in Canada and involves almost all the aircraft and associated industries, the whole Arrow programme is in the " shop window " so to speak, and every set- back becomes almost a national calamity!

This can be quite embarrassing from an engineering point of view, especially super imposed upon the added pressures of attempting to meet what was probably the most advanced contemporary interceptor requirement.

However, we have survived so far, and from the results of our flying up to the present, there is every reason to believe that Canada's biggest military venture will emerge from a state of national discussion to become a sourceof national pride and security, if such there can be in our peculiar but exciting time. To those of us in Canada who have been actively engaged in this project, this will be sufficient.

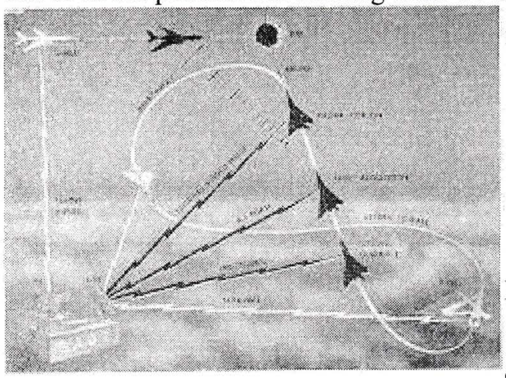
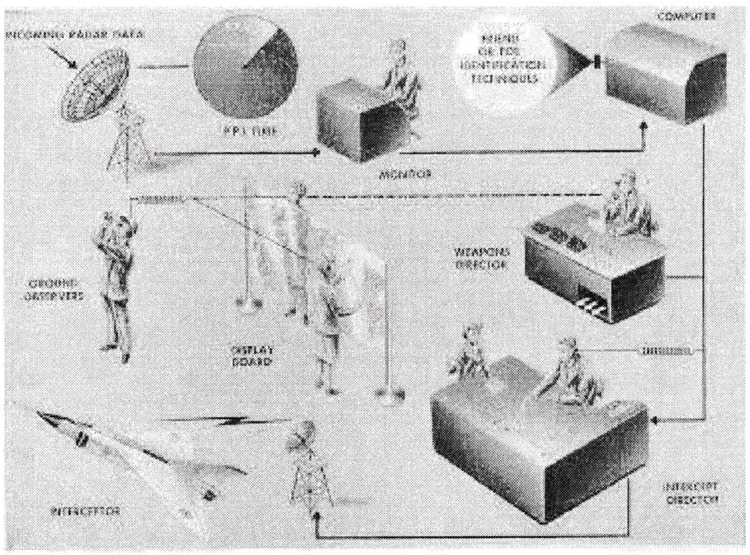


FIGURE 31. Arrow environment.

NOTE

The opinions which I have expressed in this lecture do not necessarily coincide with those of the R.C.A.F., the Canadian Government, or Avro.

I wish to thank my colleagues in the Engineering Division at Avro for their kind assistance in the preparation of some of the material for the lecture and, particularly, Mr. R. F. Marshall who struggled with the art work and diagrams, to finish them in almost zero time, and my secretary, Mrs. Salter, for her patience in sorting out a readable manuscript from a collection of almost illegible scribbled notes and garbled records.



VOTE OF THANKS

DR. MOULT: The lecture had been a most interesting one in the best traditions of the Commonwealth Lectures. The Avro Arrow was an impressive aircraft; it was a complex piece of machinery, like most aircraft nowadays, and it had been a success because of thoroughness, attention to detail and excellant planning from the beginning. Great credit was due to Mr. Floyd, to his Company and to Canada for their achievement.

It was not the custom to have a discussion after the Commonwealth Lecture, and he would ask Mr. N. E. Rowe, C.B.E., B.Sc., F.C.G.I., M.I.Mech.E., F.R.Ae.S., Technical Director of Blackburn and General Aircraft Ltd., and a Past President of the Society, to propose the vote of thanks.

MR. ROWE: They had heard an account of a great enterprise, courageous in its conception, in its execution and distinguished by the resolute pursuit of an extraordinary variety of problems, all done in parallel with a very difficult programme of production " from the board." He congratulated the lecturer, not only on his lecture, but on being the leader of such an enterprise.

There was no doubt that Canada had an extreme awareness of the importance of aeronautics for peace; that had been made evident by the lecturer., they knew it also from the tremendous Canadian activity in the civil field and from the contributions from Canada to this particular series of lectures.

In 1948 Mr. James T. Bain had lectured on " Aircraft and the Airlines-A Canadian View "., in November 1949 they had had " Inter-City Transport Development on the Commonwealth Routes" by Mr. H. Aitken; in 1955 " The growth of Aeronautical Research in Canada, During the Post-War Decade" by Dr. J.J. Green; now there was Mr. Floyd's lecture, and to complete the picture they had had in this same series a most stimulating lecture by Mr. B.S. Shenstone " Why Airlines are Hard to Please."

Obviously Canada was interested in the widest range of aeronautics and had the clearest idea of it's importance for war and for peace; if one were prepared for war then one could ensure peace, so Canada was supporting the whole field of aeronautics in a most complete

way.
The nature of a modern, complex aircraft involved a tremendous weight of effort and he was not surprised to hear that 650 firms in Canada had been engaged on the Arrow project and that it was the major item in the whole Canadian aircraft industry. Such an effort required co-ordination of a high order and a vast system of pre-flight testing to ensure success. The wisdom displayed in this aspect of the work and the engineering that went into the project was proved by the successful first flight which they had seen on the film which had been most impressive.
The last time he had spoken at a Commonwealth Lecture, had been when he was President and introduced Dr. Green, who also gave a classic lecture. On that occasion he had commented that the lecture was originally devised to form a focus for the aeronautical problems of the Commonwealth and thought that the series had achieved this. To judge from his remarks, that opinion was shared by Mr. Floyd who would like the focus to be brought to practical reality by a meeting of Commonwealth Aeronautical Engineers, something which probably all engineers in the audience would be only delighted to see.
Mr. Floyd's lecture was a stimulus to all in the Commonwealth, showing vision in concept with resolution and skill in attack on most difficult problems; not only had they tackled and solved the most difficult problems in aircraft design but also, those of the most advanced jet engine practice.
Such lectures as these strengthened the position of aeronautics throughout the Commonwealth and added greatly to the prestige of the Society; in this sense especially they offered their warmest thanks to Mr. Floyd.

Following the Lecture a Dinner was given at 4 Hamilton Place at which the following were present-

Dr. A. M. Ballantyne, T.D., B.Sc., PH.D., Hon.F.C.A.I., A.F.I.A.S., F.R.Ae.S., Secretary, Royal Aeronautical Society. Air Commodore F. R. Banks, C.B.. O.B.E., Hon.F.I.A.S..M.I.Mech.E., F.R.Ae.S., Director Bristol Aeroplane Co. Ltd.; Member of Council and Vice-President. ' A. D. Baxter, M.Eng., M.I.Mech.E., F.R.Ae.S., Chief Executive, Rockets and Nuclear Energy, de Havilland Engine Co. Ltd.; Member of Council. Marshal of the Royal Air Force, Sir Dermot Boyle, G.C.B., K.C.V.O., K.B.E., A.F.C., Chief of the Air Staff. Major G.P. Bulman, C.B.E.. B.Sc., F.R.Ae.S., Honorary Treasurer; Member of Council and Past President. A. F. Burke. O.B.E., President, Society of British Aircraft Constructors Ltd. W. G. F.
Burns, A.F.R.Ae.S., Civil Aviation Adviser to the High Commissioner for Australia.
Sir Sydney Camm, C.B.E.. F.R.Ae.S., Chief Designer and Director, Hawker Aircraft; Member of Council and Past President. J. R. Cownic, B.Sc.(Eng.), Grad.R.Ae.S., Chairman of the Graduates' and Students' Section and Member of Council. Sir George Cribbett. K.B.E., C.M.G., Deputy Chairman, British Overseas Airways Corporation; 1950 British Commonwealth Lecturer.
M. A. S. Dalal, M.A.(Cantab.). LL.B., Regional Manager, Air-India International Corporation. Handel Dayies, M.Sc., A.F.I.A.S., F.R.Ae.S.. Deputy Director General, Future Systems, Ministry of Supply; Member of Council. W. Dirkse-van-Schalkywk, Acting High Commissioner for the Union of South Africa. Lord Douglas of Kirtleside, G.C.B., M.C., D.F.C., Chairman, British European Airways.
Sir George Dowty, Hon.F.C.A.I., F.I.A.S., M.I.Mech.E., F.R.Ae.S., Chairman and Managing Director, Dowty Group; Past President.
Sir George Edwards, C.B.E., B.Sc., F.R.Ae.S., Managing-Director, Vickers-Armstrongs (Aircraft) Ltd.; Member of Council; Immediate Past President.
Sir William Farren, C.B., M.B.E., M.A., F.R.S.. M.I.Mech.E., Hon.F.I.A.S., F.R.Ae.S., Technical Director. A. V. Roe and Co. Ltd.; Member of Council; Past President. J. C. Floyd, F.C.A.I., M.I.A.S., F.R.Ae.S., Vice-President, Engineering, Avro Aircraft Ltd.; 14th British Commonwealth Lecturer.
Dr. G. W. H. Gardner. C.B.. C.B.E.. F.R.Ae.S.. Director, Royal Aircraft Establishment: Member of Council. H. H. Gardner, B.Sc., F.R.Ae.S., Director and Chief Engineer (Military Aircraft), Vickers-Armstroungs (Aircraft) Member of Council.
R. E. Mardingharn, C.M.G., O.B.E., F.R.Ae.S., Secretary andChief Executive, Air Registration Board; 1952 British Commonwealth Lecturer. E. T. Jones, C.B., O.B.E., M.Eng., F.R.Ae.S.. Deputy Controller of Overseas Affairs, Ministry of Supply: Member of Council and Past President. M. B. Morgan, C.B., M.A., F.R.Ae.S., Deputy Director. Royal Aircraft Establishment. Member of Council. Dr. E. S. Moult, C.B.E., B.Sc., F.R.Ae.S , Director and Chief Engineer, de Havilland Engine Co. Ltd.; Member of Council and Vice-President. Sir Cyril Musgrave, K.C.B., Permanent Secretary, Ministry of Supply.
John Nash, A.F.R.Ae.S.. Astra Aircraft Corporation; Member of Council of Southern Africa Division of the Society.
J. H. Parkin, C.B.E.. Hon.F.I.A.S., F.R.Ae.S., Consultant to Division of Mechanical Engineering. National Research Council of Canada.
Colonel R. L. Preston, C.B.E., A.F.R.Ae.S., Secretary-General, The Royal Aero Club, Captain J. L. Pritchard, C.B.E., Hon.F.R.Ae.S., Secretary, Royal Aeronautical Society 1925-51.
Squadron Leader R. C. G. T. Rogers. D.C.Ae., A.F.R.Ae.S., R.A.F., Directorate of R.A.F. Fighter Aircraft, Research and Development, Ministry of Supply; Member of Council. J. A. Ross, A.R.Ae.S.. Trans-Canada lines. N. E. Rowe, C.B.E.. B.Sc., F.C.G.I., F.I.A.S., F.R.Ae.S., Technical Director, Blackburn and General Aircraft Ltd.; Member of Council and Past President. Major-General G. N. Russell, C.B.E., C.B.. President, The Institute of Transport.
W. Tye, O.B.E., B.Sc., F.R.Ae.S., Chief Technical Officer, Air Registration Board; Member of Council.
Sir Hubert Walker, C.B.E.. 1953 British Commonwealth Lecturer. L.A. Wingfield, M.C., D.F.C., A.R.Ae.S., Solicitor to the Royal Aeronautical Society.