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DECLASSIFED on August 29, 2016 by
Steven Zan.

Initial

REPORT ON THE STATE OF THE
CF-105 PROJECT IN JUNE, 1955

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9 August, 1955

NATIONAL AERONAUTICAL ESTABLISHMENT

Canada

FLIGHT RESEARCH SECTION

SECRET

Pages - Preface -

Text -

Figures - 11

Date: 9 August, 1955

Lab. Order:

File: BM49-7-12

For:

Reference:

Subject: Report on the state of the CF-105 project in June, 1955

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SUMMARY

This report outlines the current status of the CF-105 project as determined during a period of liaison with Avro Aircraft Ltd. in May and June, 1955.

Attention is called particularly to aircraft performance, stability and control characteristics upon which the success of the project is critically dependent.

It is noted that the weight of the aircraft has increased substantially since the publication of the most recent brochure. At the same time estimates of thrust and drag are in process of revision. It is believed that in consequence of these changes the performance to be expected is now below that specified. To definitely establish the present relationship between expected and specified performance a new and thorough analysis supported by an independent check is urgently required.

As soon as reliable figures are available it is recommended that the extent of expected performance deficiencies be communicated to the R.C.A.F.

It is anticipated that means of significantly reducing all component weights will be required. It is therefore suggested that early consideration be given by the R.C.A.F. to an extreme programme of armament and equipment weight reduction.

In the present concept of the CF-105, a system for artificially augmenting the stability is essential to the safety of the aircraft at some combinations of Mach number, altitude and load factor. It is proposed to achieve adequate reliability by providing also an emergency augmentation system.

* Combat load factor variously estimated at between 1.65 and 1.84.

The task undertaken is considerably more complex than that of merely supplementing the natural damping of the aircraft, a course of action which has been followed on many contemporary types in countering the loss of damping resulting from increasing altitude.

At least as a precaution against unexpected obstacles in the development of the proposed system, a further effort by means of wind tunnel and simulator studies specifically aimed at improving the natural stability and control characteristics of the aircraft appears to be warranted at this time and is recommended.

Some less extensive problems of design and operation requiring investigation and offering scope for further contributions to the project are also noted in this report.

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1.0 INTRODUCTION

In order to provide for continuing technical liaison between the aircraft manufacturer and Government scientific staff during a critical period in the evolution of the CF-105 interceptor design, it was agreed by the Chairman, Defence Research Board, the Director, National Aeronautical Establishment and the President, Avro Aircraft Ltd. that a representative of the N.A.E. should be attached to the project. Representation at Avro Aircraft Ltd. was established on 26 April, 1955 for an initial period of two months.

These notes constitute a preliminary report to the Director, N.A.E., on the present status of the CF-105 project as determined during this two month period.

Because in many instances component design schemes, test results and estimates are undergoing revision, the most recent information obtainable from the aircraft manufacturer is often incomplete. For this reason absolute exactness in reporting cannot be claimed.

It is intended, however, to call attention to those features of the project which at present appear to be the most critical, particularly those which may offer scope for definite contributions by the N.A.E.

2.0 DESCRIPTION OF THE CF-105 PROJECT

Studies of the requirements and design of a supersonic interceptor to replace the CF-100 in the Canadian air defence system have been in progress since 1949.

Various aspects of the problem have been examined by the D.R.B., the R.C.A.F., the N.A.E. and Avro Aircraft Ltd. and have been discussed in a number of reports published by these organizations.

In late 1951 a committee was set up by the R.C.A.F. to make recommendations on the performance requirements of an aircraft suited to the air defence system planned for the period 1957-60 and, if possible, to recommend improvements to the system. The findings of this committee were published in the "Final Report of the All-Weather Interceptor Requirements Team" dated March 1952.

Subsequently detailed specifications for the aircraft were drawn up by the R.C.A.F., the most recent being Issue II of R.C.A.F. Specification Air-7-4 dated September 1954.

2.1 Specifications

In preparing specifications the combat performance and radius of action recommended by the Interceptor Requirements Team were accepted. These recommendations called for 5 minutes sustained combat at a Mach number of 1.5 at 50,000 feet with a load factor of 2 continuously applied; combat to take place at a radius of 200 nautical miles, following a combat climb and cruise out at $M = 1.5$, or at a radius of 300 nautical miles following an economical climb and cruise out.

Recommendations of the Interceptor Requirements Team which were not incorporated into the R.C.A.F. Specification Air-7-4 were notably those calling for a crew of one man only and for installed armament and electronic equipment weights not greatly in excess of 1,500 lb. each.

Specification Air-7-4 also introduced firm requirements for the aircraft to be fitted with two engines of the Wright J67 or similar type and size and to be capable of a ferry range of 1,500 nautical miles.

Following the preparation of the specifications for the aircraft the R.C.A.F. also published Specification Air-7-5 dealing with the type of integrated electronic system required for the CF-105 two place all-weather interceptor. An upper limit of 2,000 lb. for the electronic system was written into this specification.

Supplementary details on the desired characteristics of the automatic flight control system for the aircraft were published more recently in the form of an 'Invitation to Bid' in R.C.A.F. Document Inst.-92-1, dated March 1955.

2.2 Design Proposals

The most recent of a series of design proposals for an aircraft to meet the R.C.A.F. Specification is that contained in the manufacturer's brochure "Twin engine supersonic all-weather fighter CF-105" dated July 1954. This brochure describes a large two place twin engine aircraft with a thin, low aspect ratio delta wing and no horizontal tail. It is essentially this design proposal, tendered in response to R.C.A.F. Specification Air-7-4, which has been accepted by the R.C.A.F. and for which a contract for a number of pre-production aircraft has been awarded to date.

Manufacturer's studies of smaller versions of the aircraft, including one design based on a single engine, were discontinued prior to the preparation of R.C.A.F. Specification Air-7-4 following the conclusion reached by the manufacturer and accepted by the R.C.A.F.

that such aircraft would be less likely to meet the performance requirements, involved greater risks, were less versatile and, in the case of the single engine design, suffered considerable loss in reliability and convenience of installation.

2.3 Evolution of the Design

At the present time, particularly as a result of wind tunnel and other model or component tests, many changes in details of the design of the aircraft are continuously being incorporated. Some of these changes will be discussed at greater length later in this report. For reasons of clarity in describing the project a number of major features in the evolution of the design since publication of the Avro brochure of July 1954 will be summarized here.

2.3.1 Power Plant

A comparison of the present state of development of the Wright J67 and the Pratt and Whitney J75 engines has led Avro Aircraft Ltd. to select the latter engine for installation in early pre-production versions of the CF-105 aircraft. It is proposed to fit the first aircraft with two engines of the type
A23 A25
J75[redacted] and subsequent aircraft with engines of the type J75[redacted]. Depending upon the rate of development of the Orenda PS13 engine it is proposed to fit engines of this type at some point prior to production of aircraft for squadron service.

Present estimates of the weights of these various engines with afterburners are as follows:

A23 / A25

J75[redacted] engine: 6175 lb. each
J75[redacted] engine: 6175 [redacted] lb. each
PS13 engine: 4600 lb. each

Performance calculations and detailed design at present being carried out by the aircraft manufacturer are mainly confined to the aircraft to be fitted with J75 engines.

2.3.2 Airframe

It is intended to mount and to provide for removal of both J75 and PS13 engines in a manner similar to that proposed for the J67 engines in the July 1954 brochure. Engine removal is from the rear. Fixed external intake ramps having a 12 degree ramp angle are proposed. Minimum intake area is 5.6 sq.ft. in the case of the J75 engine and 6.25 sq.ft. in the case of the PS13 engine. Fuselage boundary layer air is by-passed under the ramp, part of it being ducted through a heat exchanger in the air conditioning system and part spilling back over the fuselage aft of the intakes. It is proposed to remove ramp boundary layer air and thus alleviate any tendency for separation at the entry behind the ramp standing shock wave by applying porous suction across the ramp at this point. It is proposed to by-pass approximately 10 percent of the entering air around the engine into a cylindrical ejector nozzle at the design combat condition and at Mach numbers greater than M = 1.5.

External modifications to the airframe since publication of the July 1954 brochure include a 15 percent increase in vertical tail area, the incorporation of a 5 percent chord notch at the outboard wing transport joint and a 10 percent chord leading edge extension outboard of this point, the addition of leading edge droop, or more correctly positive leading edge camber, primarily on the outboard wing and minor changes in forebody, canopy and afterbody lines. Forebody and afterbody changes are mainly a result of area rule considerations.

2.3.3 Equipment

The armament now proposed for the CF-105 differs little from that described in the July 1954 brochure in that the primary armament consists of 4 Hughes Falcon radar seeker missiles plus 4 similar Falcon missiles with infra-red homing devices. The alternative armament proposed, however, differs from that described in this brochure and in a further Avro publication "Proposed missile installations for CF-105 aircraft" dated October 1954 in that 4 rather than 3 Sparrow II missiles are carried in the armament bay. This armament installation is described in Avro publication "Proposed installation of four internally stowed Sparrow II missiles in the CF-105 aircraft" dated February 1955.

Weight estimates for the primary armament to be carried by the CF-105 are as follows:

8 Falcon missiles at 130.3 lb. each:	1042.40	lb.
Missile pack structure:	672.79	"
Missile pack mechanism:	410.48	"
Missile pack hydraulics:	293.00	"
Missile pack air conditioning:	23.16	"
Armament provisions:	24.40	"
Total:	2466.23	"

Weight estimates for the alternative armament of 4 Sparrow II missiles are not available. The weapons themselves, however, weigh 389 lb. each so that:

4 Sparrow II missiles at 389 lb. each: 1556 lb.

The major item of equipment, apart from armament, to be carried by the CF-105 aircraft is the integrated electronic system. This consists of all the electronics required for ground and air communications, navigation and computing, AI radar and fire control equipment, including missile electronics equipment contained in the armament pack for pre-launch and launching functions, and the electronics system required to supplement the aerodynamic properties of the flying controls system and to provide automatic control of the aircraft in response to signals received from the ground or from the AI radar.

Firm contracts for all of this equipment have not yet been awarded. Weight estimates for a system proposed by the Hughes Aircraft Company in Hughes Doc. No. 0525 "An electronic system for the CF-105 interceptor" dated December 1954 quoted a value of 1940 lb. for the system excluding cables and brackets. More recent estimates by Avro Aircraft Ltd. are as follows:

Flying control electronics:	108	lb.
Radio and radar, fixed:	921	"
Radar, removable:	1260	"
Radio, removable:	276	"
Missile pack electronics:	318	"
Radar door actuation:	10	"
Probe:	15	"
Total:	2908	"

2.3.4 Weight Summary

The following recent Avro weight estimates refer to the aircraft fitted with J75A25 engines and carrying 8 Falcon missiles:

Structure:	16991.40	lb.
Undercarriage:	2754.40	"
Power plant and services:	13776.12	"
Flying controls:	1738.26	"
Fixed and removable equipment:	6661.50	"
Aircraft weight empty:	41921.68	"
Useful load (combat mission):	18360.04	"
Take off weight (combat mission):	60281.72	"
Combat weight (half combat fuel):	52006.72	"
Operational weight empty:	43731.72	"

3.0 PERFORMANCE

New performance estimates based on the aircraft fitted with J75 engines are at present in process of calculation at Avro Aircraft Ltd. At this stage a rather thorough analysis is necessary, since the effects on thrust and drag of large internal air flows must be taken into account as well as the separate contributions due to the engines and to external aerodynamics.

On completion of these estimates a similar procedure is to be followed assuming PS13 engines.

Rough calculations indicate that even with the PS13 engines installed the normal acceleration obtainable at M = 1.5 at 50,000 ft. will fall ~~well~~ short of the 2 g requirement.*

* Combat load factor variously estimated at between 1·65 and 1·84

An independent check of the analysis now being undertaken is urgently required ~~to ensure that the performance now to be expected is~~ [redacted]. It will be realized that any large reduction in performance below the 2 g requirement will have a profound effect upon the altitude capabilities of the aircraft.

3.1 Drag Estimation

In addition to the effects of internal air flows, for which it is difficult to make accurate allowances in preliminary stages of the design, the effects of modifications recently incorporated from consideration of the area rule have not been included in the aircraft performance estimates published to date. Some discussion of these two items follows.

3.1.1 Application of the Area Rule

The possibility of reducing the profile drag of the CF-105 by adjusting cross-sectional areas in accordance with the area rule has been examined by Avro Aircraft Ltd. Some notes on the method used are contained in the Avro publication "Area rule progress report" by F. A. Woodward dated February 1955. The studies carried out are confined to a Mach number of 1.5. The procedure used for calculating the zero lift wave drag is essentially that described by R. T. Jones in Reference 1 but using 100 terms in the Fourier series for the slope of the area distribution and using Mach planes at five orientations between 0 and 27 degrees.

Although modifications of varying extent have been examined by this procedure, in many cases the implications in relocating equipment and redesigning the structure were considered to be unacceptable. The modifications which have been incorporated in the design consist of relatively small changes in the lines of the forebody forward of the intakes, a reduction in cross-sectional area at the forward portion of the entry ducts by thinning the outboard lips of the intakes and an increase of cross-sectional area at the afterbody by adding a fairing or tail cone between the jet exhausts. These modifications have the effect of smoothing out to some extent undulations in the slope of the area distribution forward of the wing and of reducing the slope of the area distribution aft of the wing. The reduction in profile drag coefficient as a result of these modifications is estimated by Avro Aircraft Ltd. to be in the region of 35 to 40 percent at M = 1.5.

In applying this method for calculating zero lift wave drag several uncertainties arise. Of these the most prominent are:

(a) Uncertainties due to the presence of large internal flows

(b) Uncertainties due to fuselage cross-sectional shape and to wing location.

These uncertainties suggest a number of avenues for theoretical and experimental research. Since, however, information from wind tunnel and free flight model tests on the external drag of the CF-105 is now becoming available, uncertainties in the methods of estimation are of less importance than hitherto and therefore it is not proposed to discuss these further in this report.

3.1.2 <u>Treatment of internal flows</u>

Intake and engine ducting arrangements for the CF-105 with J75 engines are sketched in Figure 1. The properties of the proposed convergent exhaust nozzle and cylindrical ejector are shown in Figure 2.

It is understood that a similar arrangement is proposed for the PS13 engine installation.

In the case of the J75 installation a section of the by-pass duct surrounding the engine is sealed off from the ejector nozzle and a portion of the by-pass air is diverted through this region for fuel venting purposes as shown in Figure 1.

Selection by Avro Aircraft Ltd. of the type of intake, duct and by-pass system proposed was based on a number of considerations which are now summarized.

3.1.2.1 Intakes

A variable area inlet is expected to be costly in weight. At the design combat Mach number of M = 1.5, the proposed intake and by-pass combination is expected to be lighter and to result in only a small reduction in performance. Hence a fixed ramp having a 12 degree ramp angle has been chosen as the most appropriate for Mach numbers between M = 1.5 and 2.0.

By allowing fuselage boundary layer air to pass under the ramp it is hoped to avoid a reduction of pressure recovery in advance of the ramp shock system. The bleed to the heat exchanger is to be operated at just below choking mass flows at high speeds in order to reduce the possibility of shock waves moving forward and thickening the boundary layer over the ramp. Suction on the ramp itself is incorporated as a precaution against buzz resulting from separation aft of the ramp normal shock at the highest Mach numbers (M = 1.73 and above).

Avoidance of buzz is also one of the main reasons for incorporating the engine by-pass system, since at Mach numbers above M = 1.5 this allows the minimum mass flow ratio at the intake to be increased. The maximum area of the by-pass is such that the intake is just choked at M = 1.5 in the stratosphere.

3.1.2.2 Ducting

The duct from the inlet to the engine increases in area from 5.6 sq.ft. (for the J75 installation) at the intake to 7 sq.ft. at a distance downstream of 9 ft. It is then of circular section and constant diameter for the remaining 22 ft. to the compressor.

Under sea level static conditions at military rating suction in the duct is a function of intake area, decreasing quite rapidly with increase of area. The intake area was selected from structural considerations based on this case (4.28 lb. per sq.in. duct suction for an intake area of 5.6 sq.ft.). Estimates by Avro Aircraft Ltd. indicate that the total thrust losses due to ramp shocks, duct skin friction, spillage drag and momentum loss in the by-pass are insensitive to intake area over the range 5.1 to 5.7 sq.ft.

3.1.2.3 By-pass and ejector

As shown in Figure 1, by-pass flow is controlled by gills at a flush intake around the duct forward of the compressor. At Mach numbers below M = 1.5 it is intended to have the gills only partially open at a fixed setting to provide sufficient air for engine cooling. At Mach numbers above M = 1.5 the gills are to be fully open. In addition to the effect on intake conditions already noted, the by-pass is expected to improve pressure recovery at the compressor face by removing all the duct boundary layer air and to reduce intake spillage drag.

Pumping of the by-pass air is accomplished by a cylindrical ejector enclosing the convergent exhaust nozzle. Estimates of ejector performance are based on experiments carried out on various ejector configurations tested at the Lewis Laboratory of the NACA and reported, for example, in Reference 2.

The object of the ejector system is to pump the required amount of cooling or by-pass air with the minimum loss or preferably a gain in thrust. Over most of the speed range and particularly with afterburner lit, a gain in thrust is claimed. As an example, for the design combat condition of $M = 1.5$ at 50,000 ft. with afterburner on calculations by Avro Aircraft Ltd. show an increase in gross thrust amounting to 9.7 percent compared with an engine without the ejector. If this figure is accepted and allowance is made for the momentum drag of the air swallowed in the two cases (82.9 lb. per sec. through the engine and 9.2 lb. per sec. through the by-pass), an appreciable gain in net thrust is also apparent.

An additional factor to be considered in estimating the overall relationship between thrust and drag for the CF-105 is the influence of the jet on the pressure distribution and hence the drag of the afterbody. Experiments, also carried out by the NACA, on an axially symmetric body and reported in Reference 3 have shown that at supersonic Mach numbers and at high nozzle pressure ratios the effect of a jet issuing from a convergent nozzle may be favourable in appreciably reducing afterbody drag (e.g. 10 to 20 percent reduction in body drag).

The rise of pressure over the rear of the body under these circumstances, and hence the reduction in drag, is explained by pressure transmission forward within the boundary layer from the foot of the shock which forms at the base of the body. As a result of the adverse pressure gradient the boundary layer thickens and the shock, occurring where the flow around the body is forced to change direction by the presence of the exhaust jet, tends to split and fan out forward along the body. This effect, and the resulting improvement in drag, are more marked as nozzle pressure ratios are increased. Some improvement in afterbody drag was also noted at subsonic Mach numbers and high pressure ratios in the NACA experiments.

Conditions near the exhaust nozzles of the CF-105 are considerably more complicated than those of the experimental arrangement referred to above. The presence of two nozzles, each having both primary and secondary flows and separated by a fairing which is not axially symmetric, is sufficient to make estimates uncertain. Under design combat conditions, however, the values of the primary and secondary pressure ratios (7.12 and 2.85 respectively) suggest that possible gains would not be large.

To provide more specific information on interaction effects, wind tunnel tests on the CF-105 body with exhaust flows simulated are necessary.

3.2 Test Programme

Overall drag measurements at Mach numbers up to M = 1.23 have already been made during tests in the Cornell wind tunnel. Some further measurements at zero lift and at Mach numbers up to

M = 2 have been made in the N.A.E. high speed wind tunnel. In addition drag data from free flight model firings are now becoming available.

Internal flows, present during these tests, are not representative of actual conditions with engines running. A correction procedure is therefore applied by Avro Aircraft Ltd. to take account of these departures. It is interesting to note that approximately the same value of the zero lift drag at supersonic speeds, before correction for internal flows, was obtained by all three model test facilities. At M = 1.5 this uncorrected value of C_{D_0} is approximately .026 for the aircraft without leading edge droop.

Some experimental confirmation of the area method of calculating wave drag is reported by Avro Aircraft Ltd. from the results obtained by firing two "crude" free flight models. These models were used for checking telemetry techniques on the free flight range and only roughly resembled the CF-105. Agreement between calculated wave drag at M = 1.5 and that estimated from total drag measurements, corrected for skin friction and base drag is claimed to be within approximately 10 percent. It is not known in detail what corrections for internal flows were applied in this comparison.

Adequate experimental information on intake and entry duct characteristics should result from tests at present planned on a fuselage and intake model to be tested in the NACA wind tunnel at Cleveland and on a somewhat similar model now being tested in the N.A.E. 10 in. x 10 in. tunnel. It is understood also that tests of a 1/12 scale model of the ejector under static conditions are planned using a rig at Nobel.

It appears then that the major gap in experimental information to support estimates of drag (or thrust) will be confined to the characteristics of the by-pass, ejector and afterbody under flight conditions.

It is, therefore, suggested that wind-tunnel tests in which these conditions are suitably represented should be considered.

4.0 STABILITY AND CONTROL

The CF-105 is an example of a current trend in the design of high speed aircraft towards the use of wings of low aspect ratio and the concentration of the greater part of the mass close to the longitudinal axis of the fuselage.

As a result of calculations and experiments carried out by the NACA and others to study the stability of aircraft having this type of configuration, some of the difficulties likely to be encountered in providing satisfactory stability characteristics are now quite generally appreciated. Where a high degree of sweep back is also incorporated into the wing, as in the case of the CF-105, the following tendencies may be expected to appear:

(a) Unloading of the wing tips at moderate angles of attack causing pitch-up and a reduction of damping-in-roll prior to the stall.

(b) A high value of dihedral effectiveness falling off rapidly at large angles of attack as a result of tip unloading.

(c) A reduction in the effectiveness of the vertical tail at the larger angles of attack resulting in a reduction in directional stability and caused by immersion of the vertical tail in the wake of the wing and fuselage.

(d) A reduction in directional stability with increasing Mach number at supersonic speeds resulting from the decrease with Mach number of vertical tail lift curve slope.

(e) Strong inertial coupling between the lateral and longitudinal modes of motion resulting from the concentration of mass in the fuselage. This mass distribution gives rise to moments of inertia which are much lower and angular velocities which are much higher about the roll axis than about the pitch and yaw axes of the aircraft and hence necessitates the retention of all the affected coupling terms previously neglected in the dynamic equations of motion.

The effects of the first three of those tendencies are of paramount importance at subsonic speeds where the largest angles of attack are likely to be reached, but may also be significant at transonic and higher speeds where directional stability is decreasing with increase of Mach number. Inertial coupling effects are important over the entire speed range.

As noted, the above are characteristic of aircraft configurations similar to that of the CF-105 and are the prime causes for difficulty in adequately stabilizing such aircraft. The problem is complicated, however, by two further factors. The first is the effect of elastic distortions which may modify significantly the values of the aerodynamic derivatives at the high values of dynamic pressure encountered over a large part of the flight envelope. The second is the essential difficulty encountered in determining the precise influence of individual stability derivatives on the behaviour of the aircraft, particularly in manoeuvres involving both lateral and longitudinal motions. This difficulty is a consequence of the increased complexity of the dynamic equations resulting from retention of the coupling terms and excursions into a range of lifting surface angles of attack beyond the validity of linearized assumptions.

Thus, while the existence of a stability problem, such as a directional divergence, may be recognizable from the examination of derivatives determined from model tests and modifications to the aircraft favourably affecting the derivatives may be expected to produce an improvement, an assessment of the adequacy of the flying qualities of the aircraft, particularly in cases suspected of being marginal and during combined manoeuvres, requires an evaluation of the dynamic equations with all important terms retained. For this purpose electronic simulation 7
facilities are essential.

4.1 Rigid Aircraft Characteristics

Essentially all wind tunnel stability and control investigations on the CF-105 to date have been carried out at the Cornell Aeronautical Laboratory.

A summary of this test programme and an explanation of model configurations is given in Figures 3 and 4.

It will be noted that results are confined to the Mach number range between 0.5 and 1.23. The earlier tests were carried out using a model of .03 scale. Later tests have been made using a .04 scale model.

Important modifications carried out on the configuration
as ~~a result of~~ during the tests were as follows: 8

(a) Plain wing of 3 percent thickness/chord modified to incorporate 3/4 percent chord negative camber.

(b) Negatively cambered wing increased in thickness to 3½ percent chord. Ducts modified and shock ramps incorporated.

(c) Wing modified to incorporate a 5 percent chord notch at the outboard transport joint and a 10 percent chord leading edge extension outboard of this station.

(d) Vertical tail increased in area by 15 percent.

(e) Area rule modifications to the fuselage incorporated.

(f) Positive camber or droop added to the wing leading edge, primarily outboard of the notch.

In the earlier configurations it was found that a pitching moment non-linearity existed causing pitch up at moderate angles of attack at high subsonic speeds and indicating unloading at the tip. This appears to have been cured by the addition of a notch plus a wing leading edge extension. The combination chosen was regarded as the best of several tested.

Also present in the earlier tests was a directional non-linearity showing up in the yawing moment versus sideslip angle characteristics. This was most marked at transonic and subsonic speeds where very much more unfavourable values of were present at values of -3 degrees + 3 degrees than outside this range.

At the same time a tendency to buffet was suspected at some Mach numbers from inspection of pressure measurements indicating separation near the trailing edge on the outboard wing panels.

As a means of improving buffet characteristics positive camber or droop was added to the leading edge. This had the unexpected effect of removing most of the non-linearity in C_{n_β} and apparently resulted in some general improvement on the magnitude of this parameter.

~~It appears, however, that leading edge droop has caused pitch up tendencies to return although to a lesser extent than for the original plain wing.~~ Requires check. (9)

Pitching and directional characteristics before and after the various modifications to the wing are illustrated in Figure 5.

At subsonic speeds the wind tunnel results indicate some improvement in drag, excluding the component due to trim, resulting from leading edge droop and appearing as a shift of the C_D versus C_L polar to the right. It is not clear that this trend is continued at supersonic speeds. At M = 1.23, the highest test Mach number, there is very little difference in drag as a result of the modification and hence it is quite possible that the drag, still excluding control drag, is slightly higher at the combat condition of M = 1.5. (10)

Directional stability trends with angle of attack and with Mach number are illustrated in Figure 6. These curves refer to the earlier configurations so that the absolute values are now incorrect and the values of   at subsonic and transonic speeds for small angles of sideslip are much more favourable than shown. With these exceptions the trends indicated are representative.

It will be noticed that at M = 1.2 there is a very large reduction in   with increasing angle of attack. At supersonic speeds at 50,000 ft. the required angle of attack increases by very roughly 1 degree per 'g' from values of from 2 to 4 degrees in level flight. It is to be expected therefore that directional stability will decrease appreciably in turning flight at these speeds in addition to falling off at the high angles of attack required for landing.

The reduction in directional stability with Mach number at supersonic speeds is extrapolated from the test results at M = 1.23 by combining the estimated contributions of the vertical tail and of the aircraft with tail off. Estimates of the former contribution are less likely to be in error than those of the latter, since vertical tail effectiveness is primarily a function of the lift curve slope of that surface for which there is a reasonable amount of appropriate experimental and theoretical information. This is not the case for the aircraft with tail off. The contribution from this source is taken to change very little with increase of Mach number above M = 1.23. Since its magnitude is quite large, (-.0016), small errors could have a significant effect on the overall value of   for the aircraft.

Therefore, until model test information on this directional stability parameter at Mach numbers above M = 1.23 is available, quoted values of   at supersonic speeds should be regarded as tentative.

It should be noted here that there is a forward movement of the aerodynamic centre at moderately high lift coefficients at subsonic speeds coinciding with the tendency to pitch up. Available data indicate that this may be producing a negative manoeuvre margin in the landing case. This requires further investigation.

4.2 Elastic Aircraft Characteristics

Elastic corrections to the derivatives have been estimated by Avro Aircraft Ltd. by expressing the stiffness properties of the lifting surfaces (wing and vertical tail) in terms of matrices of influence coefficients, superimposing upon these similar matrices for the aerodynamic loading.

(9)

The methods used are presented in a number of Avro publications by Etkin, Woodward, McKillop and Thomann.

The method of determining air loads has also been presented in the Proceedings of the Second Canadian Symposium on Aerodynamics, February, 1954.

The magnitude of the estimated effect of elasticity on fin lift slope is illustrated by the typical results shown in Figure 7.

Values of the derivatives obtained during wind tunnel model tests corrected for aero-elastic effects and plotted as functions of Mach number, altitude and normal accelerations are contained in various Avro publications. Data in this form for the aircraft configuration with drooped leading edges are not all yet available. Some preliminary estimates for this configuration are shown in Figure 8.

It will be seen from the example given in Figure 7 that aero-elastic effects cause an appreciable reduction in fin lift slope, and hence in   , at high values of dynamic pressure. At the design combat condition this reduction amounts to 5 or 6 percent, but increases to from 15 to 20 percent at altitudes near the tropopause and to 30 percent at the maximum attainable speeds (close to $M = 1$) at sea level.

Since negative or even low positive values of   , as indicated in Figure 8, may be expected to create a severe problem in stabilization, requiring some form of augmentation, efforts to improve directional stability are clearly desirable. These might very well include an attempt to increase fin stiffness. It seems possible that the small increase in drag and weight to be expected from an increase in fin thickness to about 5 percent chord would be quite tolerable in view of the resulting increase in stiffness. Furthermore it appears possible that a greater fin rigidity could be obtained by carrying the root structure down into the central beam of the fuselage.

4.3 Augmentation of Stability

As a result of the reduction in aerodynamic damping with increase of altitude it has become necessary on many current aircraft to utilize properly phased control motions to supplement the natural damping characteristics in order to obtain satisfactory dynamic qualities. Up to the present time, however, in conventional aircraft, such systems have served the purpose of improving the combat effectiveness rather than being essential to the safety of the aircraft. In other words failure of the stability augmentation system has not compromised the safety of the aircraft.

With the CF-105 a new situation arises.

Preliminary simulator studies of the stability of the CF-105, carried out by Avro Aircraft Ltd. and by the N.A.E., indicate that under many circumstances the aircraft without any form of stability augmentation cannot be controlled by the pilot. The most serious region of difficulty is at high Mach numbers where loss of stability is likely to result in a very rapid divergence and immediate structural failure.

These studies were carried out using the earlier values of the derivatives and were of a restrictive nature since only three degrees of freedom were represented.

Some improvement in the lateral characteristics has undoubtedly resulted from recent modifications. ~~This, however, has been accompanied by the reappearance of unfavourable longitudinal tendencies.~~ (9) The present extent of the regions in which the aircraft cannot be controlled by the pilot, ~~therefore~~ [however], is not clear. A proper assessment can only be obtained by solving the equations of motion in at least five degrees of freedom with correct values of all the derivatives and inertias inserted. This has not been possible to date because:

(a) Many of the derivatives, particularly the rotary derivatives, have ~~not been~~ [yet to be] measured over the full range of Mach number and angle of attack. At the same time estimates of some of these derivatives are very uncertain. (13)

(b) Adequate electronic computing facilities for simulation studies have ~~not yet been set up~~ [been in process of preparation,].

In spite of this, the existence of regions in which the aircraft without augmentation is uncontrollable is almost certain (e.g. when passes through zero) and therefore the following alternative courses of action are possible:

(a) Leave the aircraft configuration fixed and make use of some form of stability augmentation system to ensure that there is no possibility of a rapid divergence or of structural failure and that all oscillations are adequately damped.

(b) Alter the configuration sufficiently to eliminate the possibility of a catastrophic divergence but artificially augment the natural damping.

(c) Provide satisfactory characteristics without employing a system of augmentation at all. This would undoubtedly require major changes in configuration.

The course of action at present being followed by Avro Aircraft Ltd. is the first of the above. It is felt by the firm that any configuration changes, other than those already incorporated, sufficiently effective to naturally avoid divergence would unduly penalize performance and that the investigation of such changes would result in prohibitive delays in the programme. Considerable effort is therefore being applied to the development of a suitable stability augmentation system.

A set of requirements for this system has recently been drawn up for the purpose of sub-contracting the development. These requirements are contained in an Avro internal document "Requirements for CF-105 Damping System" dated 16 May 1955.

An excerpt from these requirements, describing the function to be performed by the system, is attached as Appendix 'A' to this report.

It will be seen from the requirements that it is intended to supplement the normal augmentation system with an emergency system about the yaw axis. In the event of failure of the former system it is proposed to have the emergency yaw axis augmentation system cut in automatically. In this way it is felt that the probability of loss of control as a result of failure of the augmentation system can be made at least as small as that resulting from failure of other components, such as the hydraulic powered control system. As a further precaution it is proposed to use magnetic amplifiers in the emergency augmentation system. It should also be noted that an additional function of the augmentation system is to provide for turn coordination (i.e., to limit sideslip).

Paragraph 2 of this report refers to the specification for an integrated electronic system for the CF-105 aircraft. This specification requires that the aircraft shall be capable of performing certain functions either through manual control by the pilot or automatically. These functions are described as:

(a) Intercept
(b) Attack
(c) Return to base.

Automatic performance of these functions means that the aircraft control system is operated directly in response to signals (e.g., from A I radar or from the ground), without the intervention of the pilot. Where necessary computations on input signals are carried out by a central computer in the aircraft and are then fed to the flight control system. Suitable provision for feed back is required in order to close the control loop.

When the aircraft is flown in this manner, commands are automatically transmitted to the flying controls through a set of servos which in turn operate the main hydraulic jack valves. These servos are in parallel with a direct mechanical linkage, between the jack valves and the pilot's control column and rudder pedals and are therefore referred to as the parallel servos.

Control operations required to augment aircraft stability and damping characteristics are transmitted to the hydraulic jack valves through a separate set of servos referred to as the differential servos. It is intended to feed to these servos the necessary functions computed from the output signals from various flight sensing elements. In the normal augmentation system it is proposed to make use of the facilities provided by the central computer for this purpose. It is proposed to provide a separate computer for the emergency system.

To illustrate the relationship between the augmentation system and other control components a sketch of the elevator control system is given in Figure 9.

This diagram also shows the two modes of control ("mechanical manual" and "electrical manual") available to the pilot.

In studying the stability of the aircraft alone it is necessary to know the weight and inertias and to have a complete set of the elastic derivatives over the expected range of operating conditions. To carry out a similar study for the purpose of designing a suitable augmentation system the following additional information is required:

(a) The transfer functions relating the input and output of all sensing elements.

(b) The transfer functions for the differential servos in the system.

(c) The transfer functions relating the input to the hydraulic jack to control deflection for all controls.

If the various aerodynamic derivatives are functions of Mach number, dynamic pressure, angle of attack, etc., then these functions must be reproduced to a sufficiently close approximation so that the correct values are always applied in solving the control equations for the complete system. Where variations in speed are relatively small it may be permissible to assume that the derivatives are independent of Mach number and dynamic pressure over this small range.

At the time of writing it is understood that the transfer functions for the hydraulic jacks have been determined by Avro Aircraft Ltd. It is not known whether similar data have been obtained for the other components or whether studies are proceeding on the basis of assumed characteristics. As noted earlier simulator work to date has been necessarily restricted. However, preliminary runs have been carried out on the B.E.A.C. simulator at Malton on damping networks with the longitudinal and lateral modes uncoupled. Modification of this equipment to permit studies of augmented systems in five degrees of freedom is now in process.

It is proposed initially to simulate aircraft and component characteristics electronically, but to gradually replace the simulation of jacks and servos with the actual components. For this purpose full scale control rigs are being assembled.

The above is a brief summary of the approach adopted by Avro Aircraft Ltd. to the problem of ensuring satisfactory stability characteristics for the CF-105. The following comments are made:

(a) The design of a stability augmentation system for the CF-105 is not a straightforward task.

In addition to damping the short period oscillations about all three axes it will be necessary to provide stability by artificial means in the Dutch Roll and spiral modes for many combinations of Mach number, altitude and load factor.

In the landing case it is possible also that some augmentation of static longitudinal stability will be required. 15

(b) Provided always that the limits of control effectiveness are not approached, which does not appear to be the case at present, the development of such a system should be possible. The problems involved are, however, only partially uncovered. This is because much data, particularly on the derivatives, are still lacking and because simulator studies of the complete system in five or more degrees of freedom have not yet started. At the moment, therefore, no realistic assessment 16
of the time and effort involved in developing a satisfactory augmentation system can be made.

(c) Wind tunnel tests at present scheduled are expected to extend existing data on derivatives up to a Mach number of at least M = 2. Because uncertainty is attached to estimates of many other derivatives, particularly the rotary derivatives, the possibility of measuring these in the wind tunnel should be examined.

(d) Because the presence of non-linearities adds to the complexity of the problem of stabilization, an effort should be made during all future wind-tunnel tests to trace the source and if possible to find means of removing any persistent non-linearities.

(e) The most significant simplification of the stability problem would result from its reduction to a matter of merely augmenting the natural damping of an already positively damped oscillation and of providing turn co-ordination facilities. A continued programme with this end in view carried out in parallel with wind-tunnel and simulator studies already planned appears to be warranted at least as an insurance against unexpected delays or even failure in the development of the proposed augmentation system.

(f) In considering methods of increasing the directional stability of the aircraft it is suggested that at least the following should be considered:

(i) Means of reducing the adverse contribution of the fuselage to C_{n_β}

(ii) Increase of fin stiffness.

(iii) The addition of an end plate to the fin to increase fin lift curve slope. (Possibly accompanied by an increase of fin tip chord).

(g) Finally it should be remembered that the aircraft will be required to operate under automatic control during certain phases of the combat mission. When flown in this way and notably during the attack, quite violent manoeuvres may be commanded. The turn co-ordination facilities (minimization of sideslip), roll rate and normal acceleration limiting devices to be provided by the stability augmentation system are here essential. Problems associated with this mode of control have as yet received little attention. Operation under automatic control is also amenable to study using electronic simulator equipment as reported, for example, in Reference 4. Early initiation of such studies appears desirable once it is clear that a reasonable solution to the problem of stabilization has been found.

5.0 ELECTRONICS SYSTEM

The requirements of R.C.A.F. Specification Air-7-5 for an integrated electronic system for the CF-105 are summarized in Appendix 'B' to this report.

The closest approach to this specification tendered to date is the proposal put forward by the Hughes Aircraft Company. This proposal is based on and is very similar to the Hughes MX1179 system now under development for the U.S.A.F. for installation in the Convair F-102 single place interceptor.

A block diagram of the MX1179 system is shown in Figure 10.

The Hughes flight test programme for the MX1179 system for the F-102 aircraft is shown in Figure 11.

Major differences between the R.C.A.F. specification and the MX1179 system arise from the following:

(a) the addition of a navigator/AI operator in addition to the pilot,

(b) the requirement for true broadcast control operation,

(c) changes in certain specific components (notably in armament, radar, navigation and landing aids).

It is understood that the development of a system for the CF-105 has not yet started since differences still exist between proposals by the Hughes Aircraft Company and R.C.A.F. specifications.

6.0 ARMAMENT

Some problems arising from the proposed armament installations for the CF-105 are here described.

(a) To avoid the possibility that infra red homing missiles fired in salvo will break lock with the target and home on one another, it is proposed to launch Falcons at a small angle to one another ($2\frac{1}{2}$ degrees) and to angle them down to avoid danger of collision with the fuselage. Sparrow missiles are to be ripple fired and hence for these only downward angling is proposed.

These misalignments with the airstream in the extended position increase the loads on the launcher.

The possibility of large side loads is of particular concern in stressing the launcher. Information on these loads has therefore been sought during recent wind tunnel tests at the Cornell Aeronautical Laboratory.

(b) Launcher loads and also the weight and size of the installation are likely to be reduced if rail length can be kept short, or preferably reduced to zero. The possibility of doing this depends upon the effect of rail length on the launch trajectory and the angular and linear displacements which can be tolerated. The problem of determining the minimum rail length permissible is being studied simultaneously with that of launcher loads using data obtained from the Cornell wind-tunnel tests.

The experimental technique adopted is essentially the same as that used by the N.A.E. for the Velvet Glove launcher investigations.

(c) During the launching sequence it is proposed to open and close the missile bay doors only for the periods required to extend and retract the launchers. The doors will be closed during firing. Fluctuating door loads and other undesirable effects resulting from missile bay buffeting may occur. Door hinge moments and bay pressures have been measured during wind-tunnel tests.

(d) Sparrow II and infra-red homing Falcon missiles at present proposed require to be locked on the target prior to launch. This is likely to involve a delay in the extended position of at least 1 second and possibly 2 seconds before the missiles are fired. The effect of such delays on aircraft behaviour, particularly about the yaw and pitch axes requires investigation.

The lock-on requirement also imposes a tactical limitation on the direction of approach to the target since the long, wide fuselage nose forward of and above the missiles creates a large blind area. Interception studies are required to assess this problem.

An interesting possibility being considered by Avro Aircraft Ltd. is that of a semi-submerged missile installation. Here the missiles are merely recessed into the fuselage. A scheme is being investigated in which zero length launchers are rotated into the extended position by the thrust of the missile motor and withdrawn from the missile lugs and retracted by a return spring. A weight reduction of at least 700 or 800 lb. has been estimated for an installation of this type.

Rocket motor ignition close to the aircraft skin and missile cooling are likely to present problems with a scheme of this kind. Nevertheless the potential reduction in weight and complexity and the avoidance of large internal stowage space requirements offer powerful advantages. It is suggested that investigations of the design of an alternative armament system along these lines should be given close attention.

7.0 CONCLUSIONS AND RECOMMENDATIONS

This review of the present status of the CF-105 interceptor project leads to the following conclusions and recommendations:

(a) Incorporation into the R.C.A.F. specifications of a requirement for two particular engines of large size and a generous schedule of military equipment has necessitated a large and heavy aircraft. A gradual upward revision of many component weight estimates has resulted in a continual rise of gross weight.

This may be expected to reduce the ceiling and the available load factor at the design combat condition of M = 1.5 at 50,000 ft. Rough estimates based on recent information on drag and thrust indicate an available load factor with PS13 engines [redacted] below the 2 g requirement.

A thorough and independent check of new performance estimates currently being made by Avro Aircraft Ltd. is urgently required. It is recommended that this work should be carried out as soon as possible by the N.A.E.

(b) Estimates of some contributions to drag are uncertain. Wind-tunnel and free flight model tests already carried out or planned will provide more reliable data. Aircraft performance is, however, quite dependent upon the contributions to drag and thrust of the engine bypass, ejector nozzle and afterbody combination. Wind tunnel tests of this group of components are not at present planned. It is recommended that the possibility of carrying out such tests should be explored jointly by the N.A.E. and Avro Aircraft Ltd.

(c) In its initial configuration the stability characteristics of the aircraft were dominated by three adverse effects:

(i) Pitch up at moderate lift coefficients at subsonic speeds

(ii) Directional instability at small angles of sideslip at subsonic speeds

(iii) Directional instability at all angles of sideslip at supersonic speeds.

As a result of incorporating a wing leading edge extension and notch, adding leading edge droop or positive camber, increasing vertical tail area and modifying fuselage shape, considerable improvement has been obtained.

Non-linearity in has been largely eliminated, the magnitude of increased at all speeds and pitch up reduced.

These favourable trends, however, are not sufficient to ensure that the aircraft can be controlled by the pilot at all probable operating conditions. To avoid the possibility, particularly at high supersonic speeds and in manoeuvring flight, of a divergence resulting in structural failure, some further improvement is required. Alternatively a system for augmenting the stability must be provided which utilizes control motions to artificially adjust the values of the aerodynamic stiffness derivatives.

(d) The CF-105 is further characterized by low aerodynamic damping about all three axes. This is of less consequence to aircraft safety than to the avoidance of oscillations particularly under automatic control. Again improvement is required either by changes in configuration, which would certainly have to be large, or by utilizing control motions to artificially adjust the values of the aerodynamic damping derivatives.

(e) It is proposed by Avro Aircraft Ltd. to incorporate an augmentation system in which the objectives of both (c) and (d) are met and which in addition provides for turn co-ordination through the minimization of sideslip. By supplementing this system with an emergency system effective about the yaw axis only, utilizing magnetic amplifiers and switched in automatically in the event of failure of the normal system, a reliability as high as that of other essential components such as the hydraulic powered controls, is expected.

The problems involved in the development of such a system are only partially uncovered and therefore in the writer's opinion, no realistic assessment of the time and effort required is possible at present.

(f) In order to thoroughly study problems of stability, information on the aerodynamic derivatives should be as complete and accurate as possible. Because uncertainty is attached to estimates of many of the derivatives, particularly rotary derivatives, it is recommended that the possibility of measuring these in the wind tunnel should be examined. 18

(g) Compared with the task undertaken, the development of a system for the purpose only of augmenting damping and minimizing sideslip is relatively straightforward. Simplification of the problem to this extent, however, necessitates that in all other respects the inherent stability characteristics of the aircraft should be satisfactory. A further effort with this objective, carried out in parallel with wind-tunnel tests and simulator studies already planned, appears to be warranted at least as an insurance against unexpected delays or even failure in the development of the proposed augmentation system. 19

An investigation of this kind may not be fully compatible with the programme already in hand or planned at Avro Aircraft Ltd. In this event it is recommended that the required wind-tunnel tests of modifications and simulator studies of the effects of these modifications on the stability characteristics of the aircraft without augmentation should be undertaken by the N.A.E.

(h) The problem of adequately stabilizing the aircraft is critical and therefore of immediate importance. Related to the solution of stability problems, but of lesser urgency, is the behaviour of the aircraft under automatic control particularly during the attack phase. Early investigation of various attack manoeuvres is required, using electronic computer equipment, to determine the nature of the problems involved.

(i) Since it is most probable that Sparrow II and infra-red homing Falcon missiles must lock on before launch, the blind area created by the presence of the fuselage nose may impose a serious tactical limitation during an attack. A study of representative attack cases is required to determine whether this is so.

(j) Weight estimates for electronic equipment and armament installations for the CF-105 are now between 50 and 100 percent greater than the figures recommended in setting up the requirements for the aircraft. Effort aimed at reducing the weight of these and other components is therefore most justified. In this respect the scheme for semi external stowage of armament, being given some attention by Avro Aircraft Ltd., is promising and appears to warrant stronger consideration.

As soon as reliable figures are available it is recommended that the extent of expected performance deficiencies be communicated to the R.C.A.F.

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It is suggested that the R.C.A.F. consider the institution at an early date of an extreme programme having the following objectives:

(i) To review equipment and armament specifications for the purpose of rejecting all but the most essential items and of permitting measures which are likely to result in appreciable weight saving.

(ii) To encourage the evolution by the aircraft manufacturer of alternative and lighter schemes for the installation of equipment and armament.

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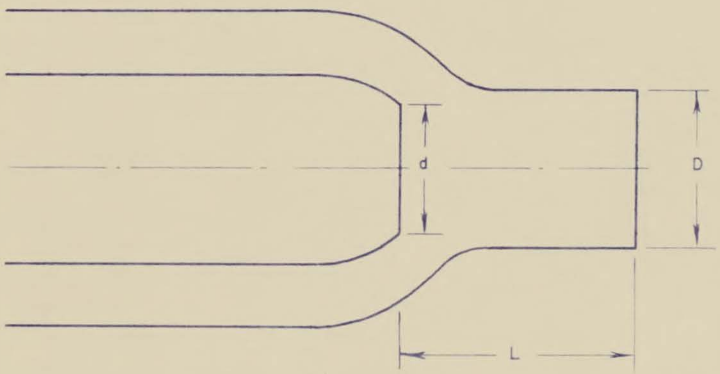
4. Mathews, C. W. — Study of the attack of an automatically controlled interceptor on a maneuvering bomber with emphasis on proper co-ordination of lift-acceleration and roll-angle commands during rolling maneuvers. NACA RM L54E27. Aug. 1954.



RATIO	AFTERBURNER	
	OFF	ON
D/d	1·43	1·13
L/d	1·738	0·58

PROPOSED EXHAUST NOZZLE AND EJECTOR

FOR J 75 INSTALLATION

FIG. 2

FIG. 3

TEST AND DATE	CORNELL REFERENCE	MACH NO. AND R.N.	CONFIGURATION	PURPOSE
SERIES I SEPT. 1953	WA 780-003 AA 891-W1	·50 - 1·23 $1{\cdot}23 - 1{\cdot}84 \times 10^6$	B_1 C_1 W_1 W_2 V_1 P_5	LONG S+C TESTS EFFECTS OF CAMBER
SERIES II APR. 1954	WA 808-003 AA 907-W1	·50 - 1·23 $1{\cdot}23 - 1{\cdot}84 \times 10^6$	B_2 C_2 W_3 V_2 R_S S_B SB_2 T	LATERAL S+C TESTS. WING PRESSURE DISTRIBUTIONS. EFFECTS OF INCREASED WING t/c. MISCELLANEOUS.
SERIES III JUNE 1954	WA 808-013 AA 907-W2	·50 - 1·23 $1{\cdot}23 - 1{\cdot}84 \times 10^6$	B_2 C_2 C_3 W_3 V_2 R_S D F_D S	EFFECTS OF MODIFICATIONS TO CANOPY, ADDITION OF DORSAL FIN AND FAIRING INTAKES ON DIRECTIONAL STAB.
SERIES IV JULY 1954	WA 808-023	·50 $1{\cdot}23$ and $6{\cdot}22 \times 10^6$	B_2 B_3 C_3 W_3 W_4 W_5 W_6 V_2 R_S T_1	LOW SPEED TESTS ON WING NOTCHES EFFECTS OF HIGH α ON S+C
SERIES V OCT. 1954	WA 808-033	·50 - 1·23 $1{\cdot}23 - 1{\cdot}84 \times 10^6$ and $5{\cdot}76 \times 10^6$	B_2 B_4 C_2 W_3 W_7 W_8 W_9 V_2 R_S T_1 NOTCHES · N_A 5, 6·5, 7·5, 8 N_B 7·5, 8, 8·5, 9	EFFECTS OF VARIOUS COMBINATIONS OF NOTCHES AND L.E. EXTENSIONS. LONGITUDINAL AND LATERAL S+C TESTS. AILERON C.P. TESTS. SHORT INVESTIGATION USING DIFFERENT PLAN FORMS
SERIES I PHASE III MAR. 1955	WA 844-003	·95 and 1·20 (·04 SCALE)	B_5 C_3 W_0 N_8 V_3 R_S PLUS FALCON AND SPARROW MISSILES	EFFECTS OF MISSILES ON AIRCRAFT CHARACTERISTICS. MISSILES EXTENDED, DOORS OPEN AND CLOSED.
SERIES I PHASE V MAR. 1955	WA 844-003	·95 and 1·20 (·04 SCALE)	B_5 C_3 W_0 N_8 V_3 R_S PLUS FALCON AND SPARROW MISSILES	FORCES AND MOMENTS ON MISSILES PRIOR TO LAUNCH. ARMAMENT BAY PRESSURES DOOR HINGE MOMENTS
SERIES II PHASE IV APR. 1955	WA 844-003	·95 and 1·20 (·04 SCALE)	B_5 C_3 W_0 N_8 V_3 R_8 PLUS FALCON AND SPARROW MISSILES	FORCES AND MOMENTS ON MISSILES FOR TRAJECTORY PURPOSES. 4 OR 5 LONGITUDINAL STATIONS, 3 VALUES OF MISSILE INCIDENCE AND 3 VALUES OF MISSILE YAW AT EACH AIRCRAFT ANGLE OF ATTACK.
JUNE 1955	NOT KNOWN	·50 - 1·23 (·04 SCALE)	B_1 V_1 W_1 E_{10} N_5 B_2 PLUS VARIOUS L.E. DROOP CONFIGURATIONS	INITIALLY TO TEST EFFECTS OF DROOP ON BUFFET TENDENCIES. LATER TO DETERMINE EFFECTS ON S+C, PARTICULARLY ON DIRECTIONAL CHARACTERISTICS.

SUMMARY OF CORNELL WIND TUNNEL RESULTS

SYMBOL	DESCRIPTION
BODY	
B_1	ORIGINAL BODY INCLUDING DUCTS
B_2	B_1 WITH MODIFIED DUCTS
B_3	B_2 WITH MODIFIED ROUNDED NOSE
B_4	B_2 WITH LONGER NOSE OF SIMILAR SHAPE
CANOPY	
C	ORIGINAL CANOPY
C_2	C_1 IN NEW POSITION
C	NEW LARGER CANOPY
WING	
W_1	3 % UNCAMBERED WING WITH CONTROLS
W_2	3 % CAMBERED WING - NO CONTROLS
W_3	$3\frac{1}{2}$ % CAMBERED WING WITH CONTROLS
W_4	W_3 PLUS $6\frac{1}{2}$ % NOTCH (A SERIES)
W_5	W_3 PLUS 8 % NOTCH (A SERIES)
W_6	W_3 PLUS 10 % NOTCH (A SERIES)
W_7	W_3 PLUS 5 % L.E. EXTENSION
W_8	W_3 PLUS 8 % L.E. EXTENSION
W_9	W_3 PLUS 10% L.E. EXTENSION

SYMBOL	DESCRIPTION
VERT. TAIL	
V_1	ORIGINAL ONE-PIECE FIN AND RUDDER
V_2	FIN WITH RUDDER + RUDDER BALANCE
MISCELLANEOUS	
P_S	SHOCK PLATES
R_S	SHOCK RAMP
T_1	FUSELAGE TANK
S_{B_1}	FUSELAGE BRAKES
S_{B_2}	FIN BRAKES
F_D	FAIRED DUCTS
S	SEALED GAPS

N.B. 1 - NOTCHES ON WINGS W_7, W_8 AND W_9 INDICATED BY N FOLLOWED BY SUBSCRIPT A OR B, DENOTING SERIES, FOLLOWED BY NOTCH DEPTH IN PERCENT.

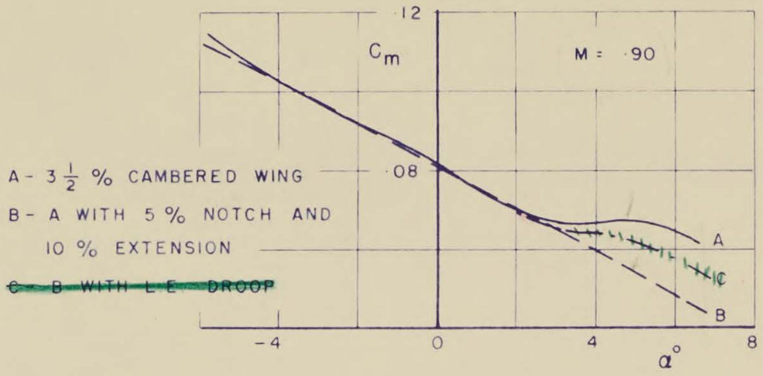
N.B. 2 - SYMBOLS APPROPRIATE TO 1955 TESTS NOT KNOWN PRECISELY BUT THE FOLLOWING DEFINITIONS ARE PROBABLE :

V_3	V_2 WITH 15 % AREA INCREASE
E_{10}	10 % L.E. EXTENSION
N_5	5 % NOTCH
B_5	B_4 WITH AREA RULE MODS.

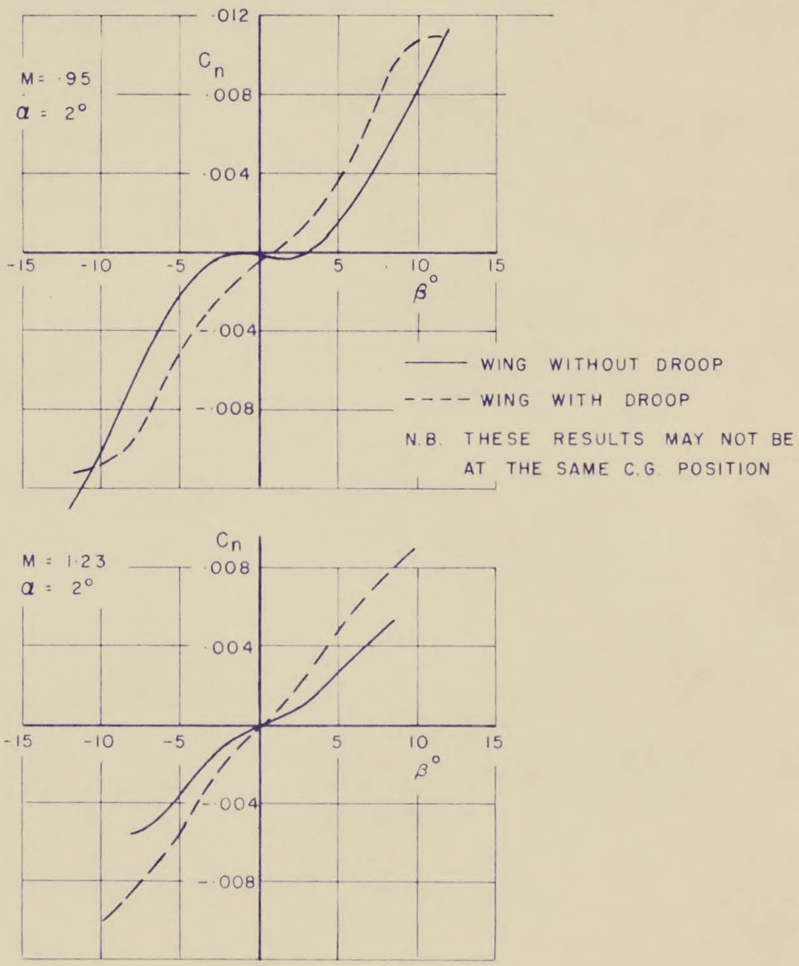
CORNELL WIND TUNNEL MODEL CONFIGURATIONS. EXPLANATION OF SYMBOLS

FIG. 4

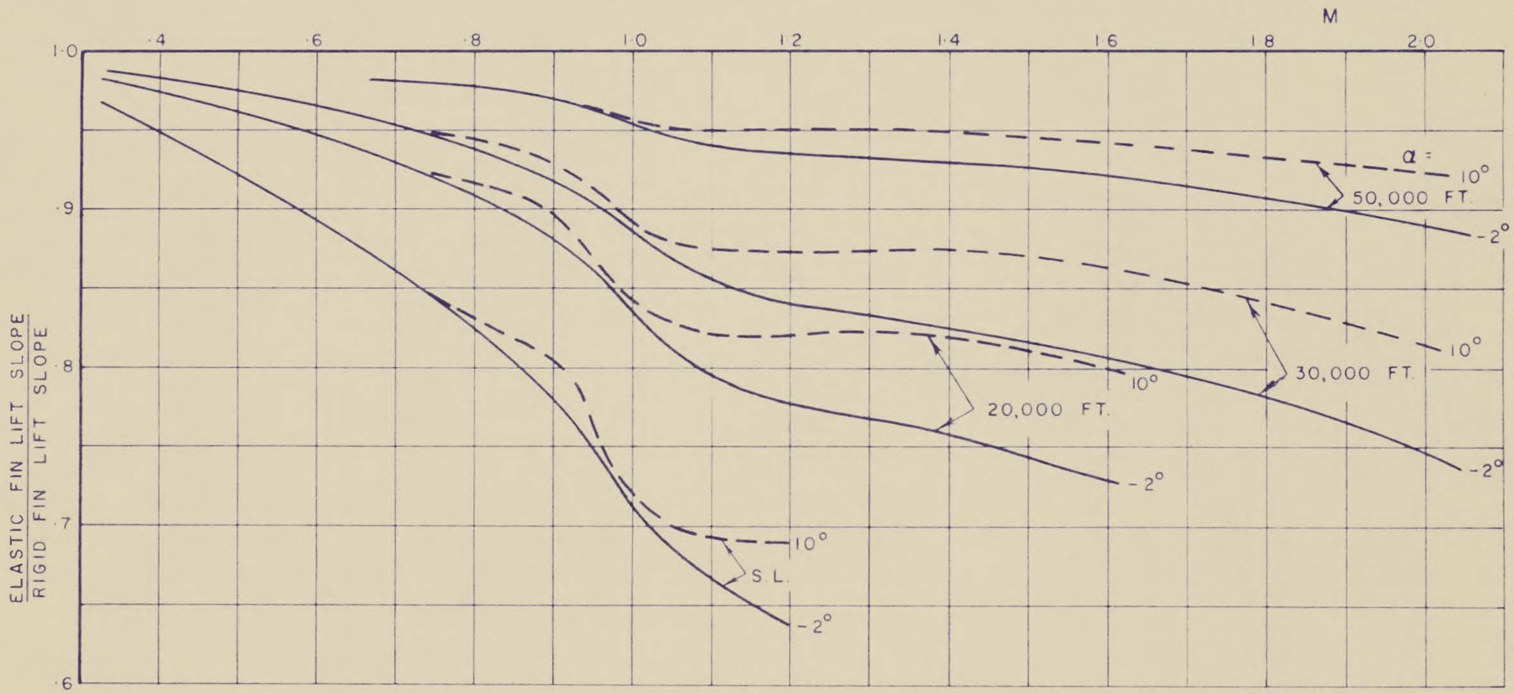
FIG. 5



a) EFFECT OF WING MODIFICATIONS ON PITCH - UP



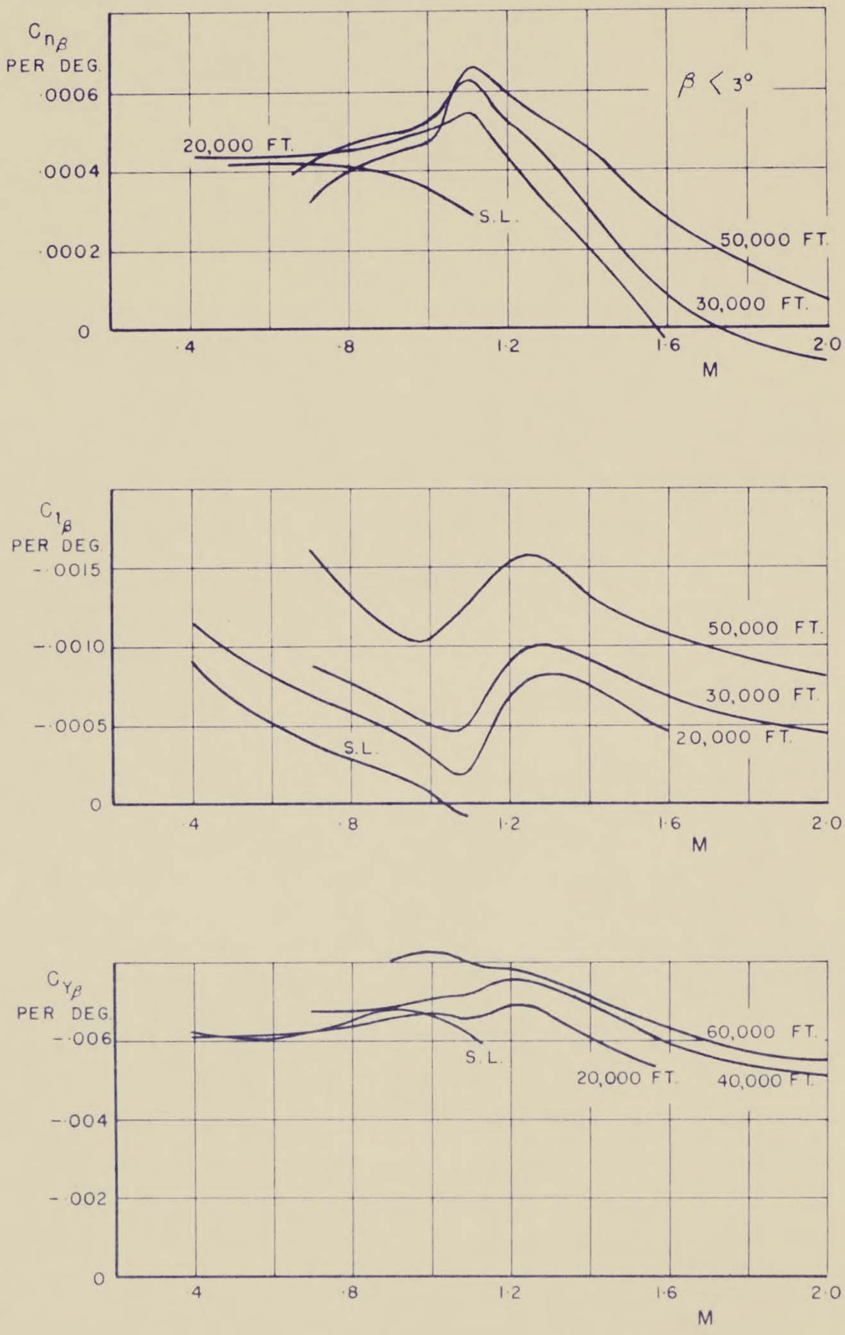
b) EFFECT OF WING MODIFICATIONS ON DIRECTIONAL STABILITY



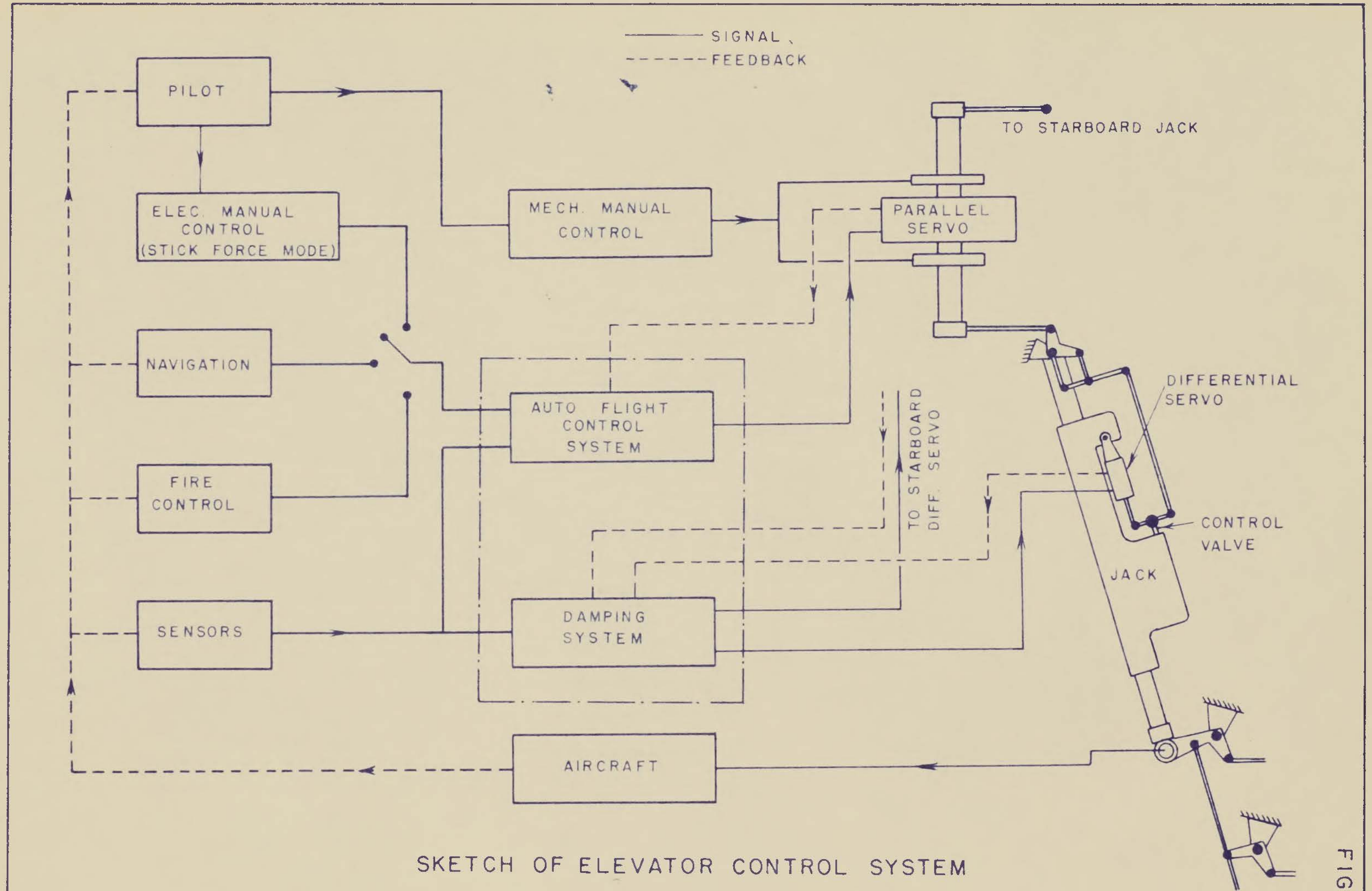
TYPICAL EFFECT OF AERO-ELASTICITY
ON FIN LIFT SLOPE
(RESULTS FOR PLAIN WING WITH EXTENDED L.E. $\beta > 3^\circ$)

FIG. 7

FIG. 8

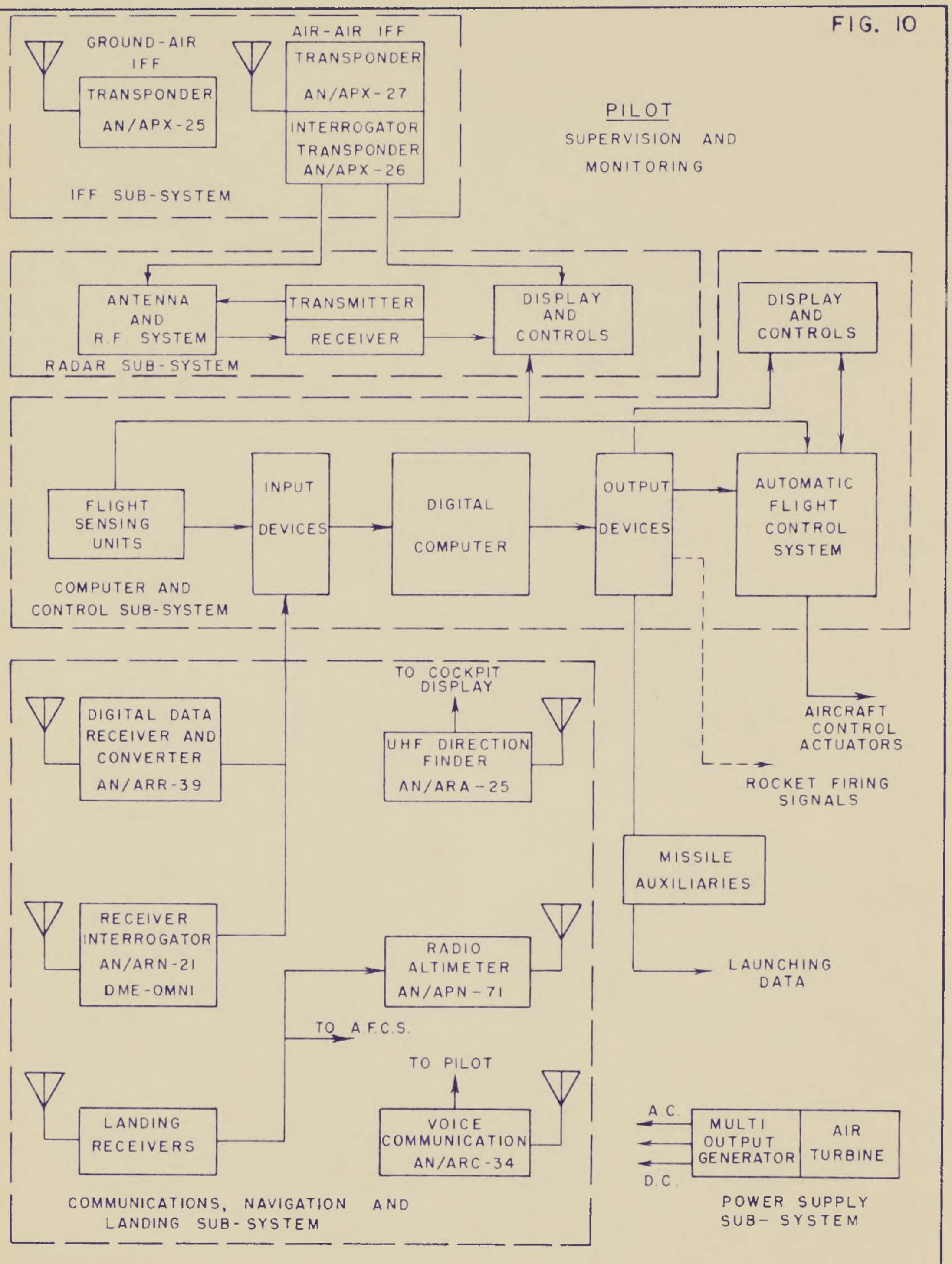


PRELIMINARY ESTIMATES OF ELASTIC DERIVATIVES OF AIRCRAFT WITH L.E. DROOP IN 1g FLIGHT (C.G. AT 0·31 M.A.C.)



SKETCH OF ELEVATOR CONTROL SYSTEM

FIG. 9



HUGHES MX 1179 INTEGRATED ELECTRONIC SYSTEM
AS PROPOSED FOR CONVAIR F-102