Mr. T.E. Stephenson

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JOINT REPORT ON AN RCAF-DRB-NAE VISIT TO N.A.C.A. LANGLEY LABORATORIES TO DISCUSS AERODYNAMIC PROBLEMS OF AVRO CF-105 AIRCRAFT - 19 NOVEMBER 1954.

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JOINT REPORT ON AN RCAF-DRB-NAE VISIT TO N.A.C.A. LANGLEY LABORATORIES TO DISCUSS AERODYNAMIC PROBLEMS OF AVRO CF-105 AIRCRAFT - 19 NOVEMBER 1954

SUMMARY

N.A.C.A. comments on CF-105 design problems are summarized as follows:

(a) The Company's estimate of zero lift drag at sub-sonic and supersonic speeds should be increased by 50 percent or more.

(b) Substantial reductions in drag throughout the supersonic speed range should be possible by proper application of the area rule.

(c) Present intake lip design is likely to result in prohibitive drag penalties at supersonic speeds.

(d) The high drag due to lift associated with low aspect ratio delta wings makes them poor planforms for high endurance and long range.

(e) The high drag due to lift is not improved by the negative camber proposed by the firm. Correctly designed positive camber should be used to reduce substantially both drag due to lift and trim drag.

(f) A wind tunnel programme would be required to develop the means proposed by A.V. Roe to ensure intake stability.

(g) The CF-105 wing planform is of the type which gives serious pitch-up tendencies. Cures developed in wind tunnels do not always work out in flight.

(h) The directional stability characteristics of the CF-105 are poorer than had been experienced in the United States. A wind tunnel programme should be pursued.

(i) All steps should be taken to ensure aerodynamic stability before resorting to electronic means.

(j) It is possible that the use of elevons rather than separate elevators and ailerons would result in lower trim drag and higher reversal speed.

1. INTRODUCTION

At the request of Air Vice-Marshal J.L. Plant, a visit was arranged to the N.A.C.A. Langley Laboratories for members of the staffs of the R.C.A.F., D.R.B. and N.A.E. to discuss aerodynamic problems connected with the design of the Avro CF-105 aircraft.

The members of the Canadian group were as follows:

S/L W. Armstrong, R.C.A.F./AMTS
Mr. A. Gilchrist, D.R.B.
Mr. P.J. Pocock, N.A.E.
Mr. R.J. Templin, N.A.E.

Discussions were held with the following members of the N.A.C.A. staff:

Mr. J. Stack, Assistant Director of the Langley Laboratories
Mr. Draley, Full-scale Division
Mr. Toll, Stability and Control
Mr. Whitcomb, High Speed Tunnel Section
Mr. Nicholl, Supersonic Intakes
Mr. Johnson, Flight Test
Mr. Mathews, Flight Test

2. DRAG OF CF-105 AIRCRAFT

There was general agreement that the N.A.C.A. experience with firms' drag estimates has been that they almost always estimate zero lift drag much too low, when the drag has been estimated on a piecemeal basis by adding up the drag of individual components as was done by the company for the CF-105. When shown the curve of estimated zero lift drag coefficient from the A.V. Roe brochure they agreed that they had never seen one as optimistic. After a look at the aeroplane configuration their estimate was that the subsonic value of C_{D_0} should be about 0.013 and not 0.008. Their estimate for C_{D_0} for Mach numbers greater than 1 would be 0.023 or more instead of 0.016. They indicated that the zero lift C_{D_0} for the F-102 had been 0.028 or greater before area rule modifications were carried out and approximately 0.023 after modifications.

3. DRAG DUE TO LIFT OF CF-105 AIRCRAFT

The N.A.C.A. staff and in particular Mr. Whitcomb showed great surpise at the use of negative wing camber for the reduction of trimming drag. They pointed out that one of the disadvantages of such a configuration as this was that due to the low wing aspect ratio the drag due to lift would be high in any case and that the use of negative camber would result in little or no realization of leading edge suction which could greatly reduce drag due to lift.

4. MEANS OF REDUCING DRAG

4.1 Reduction of Drag due to Lift

Mr. Draley said that it was a clear decision at the N.A.C.A. that positive camber should be used in wings of this kind in order to reduce the drag due to the lift and also to help the trim drag problem. The camber used in this method is restricted to the leading edge section near the root of the wing, the tip section being fully cambered which is equivalent to wing twist. Mr. Draley said that this camber was developed by the Ames Laboratory of the N.A.C.A. and has been found to lead to almost full realization of leading edge suction which results in large rductions in the drag due to lift of such a wing. As a case in point Mr. Draley indicated that the Convair F-102 uses this type of camber successfully. In summary, N.A.C.A. personnel agreed that the use of such positive camber decreased the drag due to lift and also decreased the trim drag. In effect they have found that the highest maximum lift drag ratios of these delta wings including the trim drag were obtained by the use of such camber.

Mr. Draley pointed out that the high drag due to lift of delta planforms such as that of the CF-105 made it a poor planform where a high endurance or a long range was required.

4.2 Reduction of Zero Lift Drag by Application of Area Rule

The N.A.C.A. staff were in general agreement that because the drag of the CF-105 was not likely to be as low as the estimate showed an attempt should be made to realize some drag reduction by application of the area rule. Their experience had shown that a misleading answer is never obtained when the area rule is intelligently applied. Langley experience has mainly been concerned with applications of the area rule to specific aircraft whereas the work at the Ames Laboratory has been directed mainly toward the mathematical developments and finer details of the area rule.

It was pointed out that at this stage in the design of the CF-105 it was probably impossible to make great changes in the area distribution of the aircraft and in particular it is probably impossible to make area reductions in any part of the fuselage. They were of the opinion, however, that intelligently applied pads or bumps could still effect substantial drag reductions on this airframe. They pointed out that the peak areas due to the intake lips and the canopy nearly coincided and that one modification might be to separate these, for example, by rearward movement of the intakes. They also pointed out that the use of added bumps perhaps on the side of the fuselage near the wing leading edge and on top of the fuselage behind the canopy would also improve the drag. Another example of where drag had been reduced by additions to the aircraft had been the use of a rearend fuselage extension and it was pointed out here that the drag reduction was much more than the thrust loss due to a longer tailpipe. Mr. Stack stated that the area rule was not so much a method of estimation as a solidly established method of design to obtain minimum drag. It was suggested that for this aircraft configuration the possible drag reduction using only added padding would be of the order of .003 to .008 at a Mach number of 1.5 and below. In any case they believed that the area rule should produce substantial drag reductions at least up to a Mach number of 2 at which speed the Mach lines begin to intersect the wing leading edge.

Further specific details relating to the application of the area rule were obtained from Mr. Whitcomb. These are not discussed here, but will be passed along to the firm.

Finally they pointed out that it would be of more benefit to discuss with the firm any specific proposal which they might make for an area rule application to the aircraft and they indicated that they would be glad to do so at any time.

5. INTAKES

The firm's proposal for avoiding intake instability due to separation of the boundary layer by the normal shock ahead of the intake was discussed with the N.A.C.A. personnel. They agreed that whereas the firm's suggested use of boundary layer suction to avoid this instability was correct in principle, they agreed that at the present time there was no experimental design data available to allow the certain design of such an intake system. They agreed that at the present time therefore wind tunnel development testing of such an arrangement would be necessary to insure its safe operation.
Mr. Nicholl said that he believed the proposal of the firm for bypassing intake air to be a good one. However, he believed that the lips of the intake were too blunt and would result in intolerable drags at Mach numbers greater than 1.

Mr. Nicholl had just finished a series of tests to determine what amount of leading edge bluntness could be accommodated without entailing excessive external drag penalties. The experiments carried out by Mr. Nicholl indicated that the leading edge radius of the intake lip should be 4½% of the intake duct radius or less if excessive drag penalties were to be avoided. Mr. Nicholl guessed that the round lips on the Avro intakes result in a drag penalty of .003 to .005 at the design Mach number of 1.5. It was pointed out that the round lips on the CF-105 intake were there in order to avoid flow separations at low forward speeds of the aircraft such as on takeoff. However, the N.A.C.A. personnel said that it was unnecessary to round the lips in this manner and that the problem could be avoided by having the roundness on the inside of the intake ducts rather than having the external roundness that this aircraft has. Mr. Nicholl said that a rough calculation of the drag due to roundness of intake lips could be made by calculating the pressure rise through a normal shock at the Mach number of interest and multiplying this pressure rise by the projected lip frontal area.

Mr. Nicholl said that the bypass boundary layer plate on the CF-105 intake would probably give rise to vortices and would hence be a problem in directional stability of the aircraft. This was also pointed out by several of the other N.A.C.A. staff members independently of Mr. Nicholl and in effect they believed that some of the directional stability problems of this aircraft which will be discussed in a following section may very well be traced to this detail of the intake. The N.A.C.A. staff members agreed that a model of this aircraft should undergo extensive flow investigation tests in a low speed tunnel in order to track down some of these problems.

6. DIRECTIONAL STABILITY OF CF-105

Typical yawing moment versus sideslip curves were shown to the N.A.C.A. personnel. The outstanding feature of these curves is the flat region or reversal of slope for small angles of yaw. All N.A.C.A. staff members expressed surprise at the instabilities. In their experience they had never seen a reversal of slope extending to low Mach numbers and low angles of attack. Mr. Toll said that in his opinion the seriousness of this could not be overemphasized inasmuch as this had been a serious source of trouble in many of their aircraft.

Mr. Toll suggested several possible causes of the directional instability. He mentioned the high wing configuration and vortex flow originating at the intakes.

He doubted that the canopy could be a cause of this effect. He suggested several possible cures or fixes. First, he thought that a small endplate at the top of the fin might help since sidewash effects were evidently small in this area. He also suggested so-called "horsals", i.e., horizontal dorsals on the sides or bottom corners of the fuselage to interrupt the fuselage crossflow. Alternatively, he thought that perhaps a sharpening of the bottom fuselage corners would produce the same effect. He thought that the one sure cure would have been an increase of fin size but if that were impossible he suggested that perhaps fins on the wing might produce some improvement. Here, however, he pointed out a difficulty which had arisen in similar tests of their own. The vortex flow on the upper surface of the wing could cause fin stalling and when the suggestion was put forward that perhaps fins below the wing might bypass this trouble he thought that this was possible.

It was pointed out that one item which should be looked into was pitching moment due to sideslip which could in some cases cause trouble in coupling longitudinal and lateral motions.

7. "PITCH-UP" TENDENCIES

It was pointed out to the N.A.C.A. staff that Avro had found pitch-up tendencies during the wind tunnel test programme in the Cornell wind tunnel. It was also pointed out that the firm had found that leading edge notches or chord extensions appeared to cure this pitch-up tendency. Mr. Toll said it was not surprising to him that this wing planform exhibited pitch-up tendencies due to the sweep and aspect ratio associated with it. The N.A.C.A. staff agreed that pitch-up tendency on fighter type aircraft was an intolerable flight characteristic. However, they agreed that experience showed that in many cases such a tendency could be cured by fixes such as those already mentioned as well as boundary layer fences. In this regard wind tunnel development programmes were necessary to arrive at an optimum configuration and/or fix. However, unfortunately, in many cases fixes that worked in wind tunnel tests were found to be ineffective at full scale and vice versa. It was claimed that the effectiveness of the fixes was dependent on many of the details of the wing geometry, for example, two fences help this problem with the F-102 having a cambered wing whereas fences were found to be ineffective with the uncambered wing on this particular aircraft. N.A.C.A. experience has shown that the spanwise position of such fixes is critical and the range falls within the region 65% to 70% semi-span.

Mr. Johnson said that such pitch-up tendencies as illustrated in the pitching moment versus lift coefficient curves for this aircraft have in some cases been found in flight to lead to pitching oscillations during turns, these pitching oscillations making it impossible to track a target aircraft.

8. ARTIFICIAL STABILITY

After considerable discussion of the question of "black box" stability it was generally agreed that in theory at least almost any aerodynamic instability could be cured by the use of artificial devices. In general there are two types of artificial stabilization, that which merely augments the stability of the aircraft and secondly that which takes commands from the pilot but which flies the aeroplane completely. An example of the first type is the now familiar yaw damper. Whereas the second type is always theoretically possible it was agreed that every attempt should be made to cure the instabilities by aerodynamic means. It was also pointed out that the U.S. forces insist on certain minimal requirements that the aeroplane should be at least flyable safely without artificial stability.

9. AIRCRAFT CONTROLS

N.A.C.A. personnel believed that aircraft trim drag could be reduced by the use of elevons rather than by the use of the system used by A.V. Roe on the CF-105. They also pointed out that the reversal speed could be increased by the use of the elevon type of control system.

Mr. Nicholl claimed that on aircraft configurations such as the CF-105, where the vertical tail extends beyond the jet exit, troubles have been experienced at transonic speeds where shock waves emanating from the overexpanded jet have blanked off part of the rudder. This might reduce the already poor directional stability and might also produce hinge moment reversal.

Mr. Mathews described some bitter experience with power control characteristics in American aircraft. Because of valve friction there has occurred a situation which can result in phase shifts in the control system and apparent instability of the aircraft. The apparent instability is due to the fact that the pilot believes he is applying correct control action, but is actually adding to the motion. Mr. Mathews said that the only sure way of checking this in the design stage was to mock up a closed loop system using the actual power control as part of the loop. A pilot operates the controls in the mock-up and the output from the power control is fed into a computer which gives the resulting aircraft motions and displays them to the pilot. He strongly recommended that this should be done for the CF-105 system.

Mr. Gilchrist discussed with the N.A.C.A. staff and in particular with Mr. Ralph Stone the problem of a rational criterion for the design of the fin. The results of this discussion will be communicated to the A.V. Roe loads group.

Mr. Toll pointed out an undesirable handling characteristic of the delta configurations at low speeds and high angles of attack. The variation of roll angle with time in response to aileron deflection may not be monotonically increasing. Basically the cause is the very high dihedral effect coupled with low directional stability. The result as far as the pilot is concerned is a poor response in roll and a high sideslip coupled with roll. Pilots refer to the phenomenon as a "very high adverse yaw".

10. NACA WIND TUNNEL TEST PHILOSOPHY

At various times during the discussions the NACA personnel pointed out the importance of low speed wind tunnel development programmes. Finally Mr. Draley emphasized that the N.A.C.A. will not consider a high speed tunnel programme until after extensive low speed tunnel development testing is complete. One reason is that often the low speed problems are simply magnified at high speeds, and they are not conveniently or economically tracked down in high speed tunnel tests; the net result may be expensive and time consuming.

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