A Technical Note Entitled:

"The External Augmentor Concept for V/STOL Aircraft"

by

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THE EXTERNAL AUGMENTOR CONCEPT FOR V/STOL AIRCRAFT

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INTRODUCTION

The beneficial aspects of an ejector powered V/STOL concept have been well documented previously as follows:

- low temperature and low velocity of the lifting jet due to mixing which lessens the severity of ground erosion and makes handling of the aircraft easier - especially on a flight deck;
- augmentation of thrust which reduces powerplant size and weight;
- mixing of the jet within the augmentor which reduces noise;
- essential absence of rotating machinery which results in simplicity and low maintenance costs, etc.

Although these benefits are well recognized, there remains some doubt regarding the feasibility of satisfactorily incorporating an ejector system in a high performance V/STOL aircraft because the designer must solve the problems peculiar to the ejector concept as well as those generally associated with a VTOL design of any kind. In the "External Augmentor" concept, de Havilland engineers have attempted to avoid some of these major difficulties and make accommodation for others.

The concept is based on the use of chordwise ejector slots which are located adjacent to and on either side of the fuselage (Figure 1). The configuration is characterized by a marked absence of some of the classical aerodynamic interference problems which are associated with many low disc loading V/STOL configurations. Special consideration has been given to the difficulties associated with integration of the ejector system which normally occupies a very large volume within the aircraft profile. The design of the ejector itself may be considered optional; however, a particular ejector has been designed as part of a research and evaluation program for the External Augmentor concept. A relatively low level research program to study the concept has been underway since 1966 funded by de Havilland, the Canadian Department of National Defence and NASA, Ames Research Center.

SOURCES OF EXPERIMENTAL DATA

(a) Small scale tests described in Reference 1 including both wind tunnel and ejector component tests.

(b) Large scale static tests described in Reference 2. A J-85 powered model was tested in ground effect.

(c) Small and large scale ejector development tests undertaken in the de Havilland Aerodynamics Research Laboratory.

(d) Static and wind tunnel tests of a large scale model in the NASA Ames 40' x 80' wind tunnel (Figure 2). It should be noted that 80% of the thrust issues from the fuselage ejector whereas the remaining 20% issues from an augmentor flap at the trailing edge.

AERODYNAMIC INTERFERENCE IN TRANSITION FLIGHT

The general trend of jet-induced aerodynamic interference effects has been described in Reference 3. Thiere is usually a loss in lift which tends to increase with forward velocity and an increment in nose-up pitching moment which increases with speed in a similar manner. These effects are evident in the absence of a horizontal tail - addition of the tail generates further increments, especially in pitching moment. It has been suggested that these adverse characteristics occur because the lifting jets roll up beneath the wing to form a pair of strong trailing vortices. This vortex pair causes an induced twist on the wing and an induced camber over the length of the fuselage (Reference 3).

In the case of the external augmentor, the two jets which issue from beneath the fuselage, coalesce to form a single keel-like jet which does not roll up to form a vortex pattern (or, which does so only at an appreciable distance downstream). In any event, test results have shown that lift loss effects are not apparent and pitching moment increments are small.

Based on early tests described in Reference 1, it was shown that, essentially, lift characteristics could be predicted simply by adding the appropriate static jet reaction to the "power-off" aerodynamic forces. Tests in the Ames 40' x 80' wind tunnel gave similar indications as shown in Figure 3. In this case, the wing is fitted with a powerful augmentor flap which generates supercirculation round the wing. The aerodynamic lift, as represented by $C_{L_{aero}}$, is obtained by subtracting the appropriate static jet reaction of lift from the wind tunnel measurement of lift. It can be seen that values of $C_{L_{aero}}$ in excess of one were achieved at $\alpha = 0^{o}$ and that lift coefficient varies with blowing coefficient in the expected manner: by inference, it is concluded that aerodynamic interference effects are very small.

Similarly, pitching moment variations with forward velocity were small as shown in Figure 4. Normally, turning of airflow into the intake would create a large nose-up moment - as in the case of the fan-in-wing, for example. Flow visualization tests have shown that airflow to the intake of the chordwise ejector (with strake) follows a vortex pattern and enters from the side, as it were, rather than from the front (Figure 5). This may provide an explanation for the absence of large nose-up pitching moments.

Ingestion of the vortex (as depicted in Figure 5) has a beneficial effect in that both static longitudinal and lateral stability remain well ordered simply because flow over the wing is not upset by a streamwise vortex over the upper surface (which otherwise would be present). Power-on and power-off lateral characteristics are shown in Figure 6.

GROUND EFFECTS

Jet flow which strikes the ground generally adheres to it and spreads outward. Air becomes entrained into the spreading jet(s) setting up a flow field which creates a down load on the wing (a phenomenon known as suck-down). It was recognized that this effect is fundamental and little could be done to eliminate it; therefore, in the case of the "External Augmentor" it was decided to incorporate a ground cushion acting on the underside of the fuselage to offset lift loss on the wing. The magnitude of this fuselage ground cushion effect is shown in Figure 7 as measured on the J-85 powered rig.

Since there are no discreet jets, as such, it follows that the jet fountain effect is not encountered. Therefore it can be expected that hot-gas ingestion would be minimized. This has been demonstrated on the J-85 powered rig and it is expected to re-affirm this conclusion when static tests take place at Ames on the J-97 powered model.

INTEGRATION AND ACCOMMODATION OF THE EJECTOR SYSTEM

The designer is required to provide accommodation for ducting, nozzles and the diffuser passage which, taken together, occupy a large volume within the profile of the aircraft. In the de Havilland concept, the diffuser passage is situated external to the normal aircraft profile and is formed by doors, housed in the fuselage side, which are deployed to form the diffuser, (see Figure 8). By this means, the frontal area is kept to a minimum so as to reduce supersonic wave drag. With the same objective in mind, the exhaust gas pressure ratio of the engine should be about 3 to 3.5: in this way, the internal duct volume is kept reasonably low.

A general arrangement of a proposed supersonic V/STOL aircraft is shown in Figure 9.

THE EJECTOR

The ejector nozzle system for the large model is made up of a simple array of plain nozzles each having an aspect ratio of 60. Some details of the fuselage ejector are given as follows:

Chordwise length	98.0 in.
Throat width	10.5 in.
Exit width	16.8 in.
Diffuser length	34.0 in.
Number of nozzles per side	60

Performance of the fuselage ejector is shown in Figure 10 as measured on the large scale model. Thrust augmentation is defined in the following manner:

$$\text{Gross thrust augmentation, } \phi_G = \frac{\text{measured model thrust}}{\text{nozzle thrust}}$$

Performance of the system as a whole has been determined by measurement of model thrust with augmentor flap deflected to 90°. The ratio of model thrust to thrust of the bare engine is 1.52 at a pressure ratio of 3.

Figure 11 shows a comparison between cold flow tests in the DHC laboratory on an twelve nozzle segment of the augmentor and tests on the large scale model at a temperature of $700^\circ C$ (approximately). Also shown, is the duct loss between the engine and the nozzle exit plane.

Some tests have been carried out at de Havilland on a similar ejector with a nozzle aspect ratio of 100. The model is half scale relative to the large scale wind tunnel model. Some results, shown in Figure 12, indicate the variation of augmentor performance with diffuser length and with pitch spacing ratio.

CONCLUSIONS AND RECOMMENDATIONS

It is believed that the External Augmentor concept has a basic inherent simplicity together with sufficient augmentor performance potential to make feasible a high performance V/STOL aircraft based on ejectors.

More research is required in a number of areas - the next major step in the development of the concept would be to design and build an piloted hovering test bed.

REFERENCES

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   ICAS Paper 70-56, Rome 1970.

2. Whittley, D.C. Ejector-Powered Lift Systems for V/STOL Aircraft.

   CASI Journal, May 1974.

3. Marguson, R.J. Review of Propulsion-Induced Effects on Aerodynamics of Jet/STOL Aircraft.

   NASA TND-5617, February 1970.

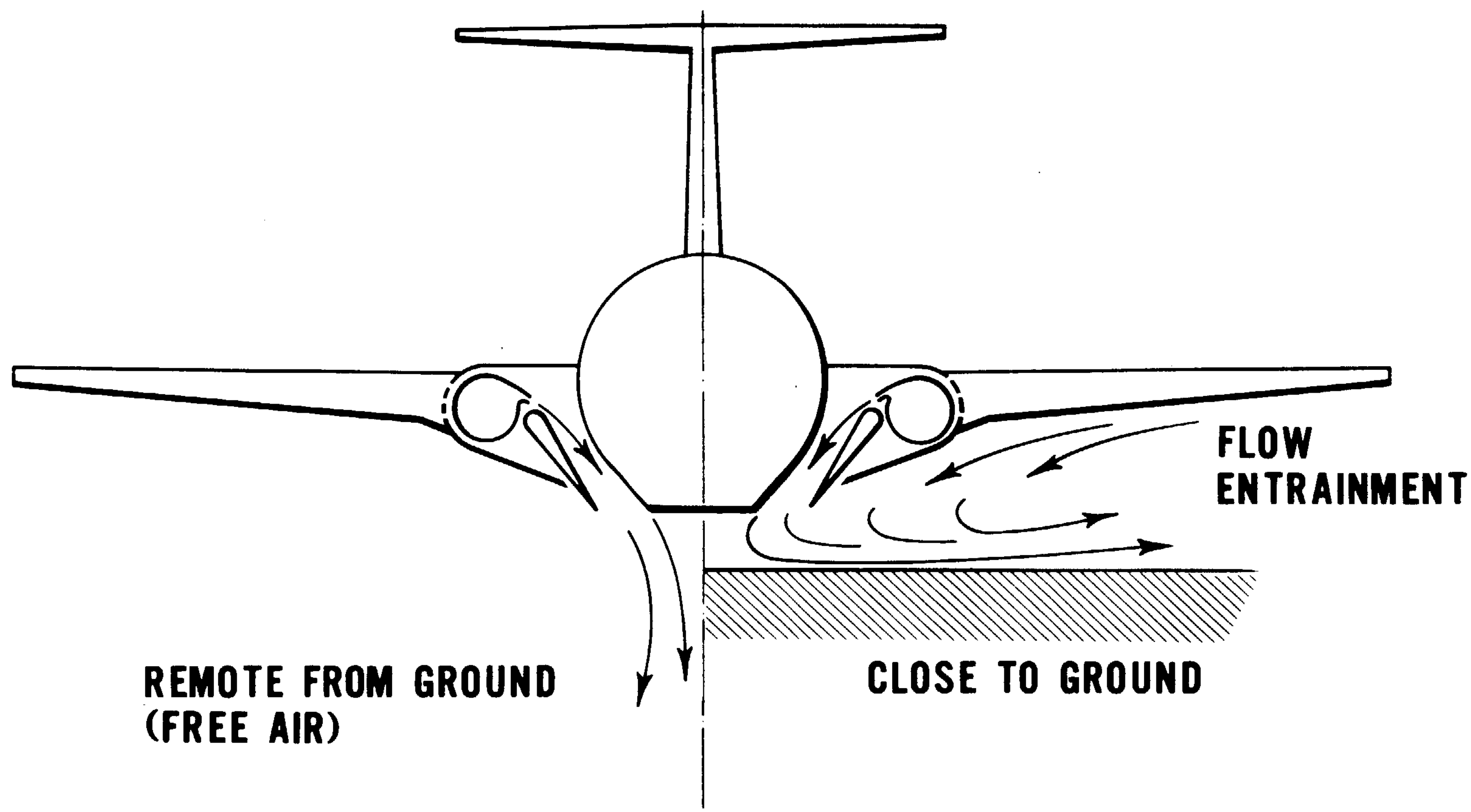

Figure 1.- External augmentor V/STOL concept flow patterns.

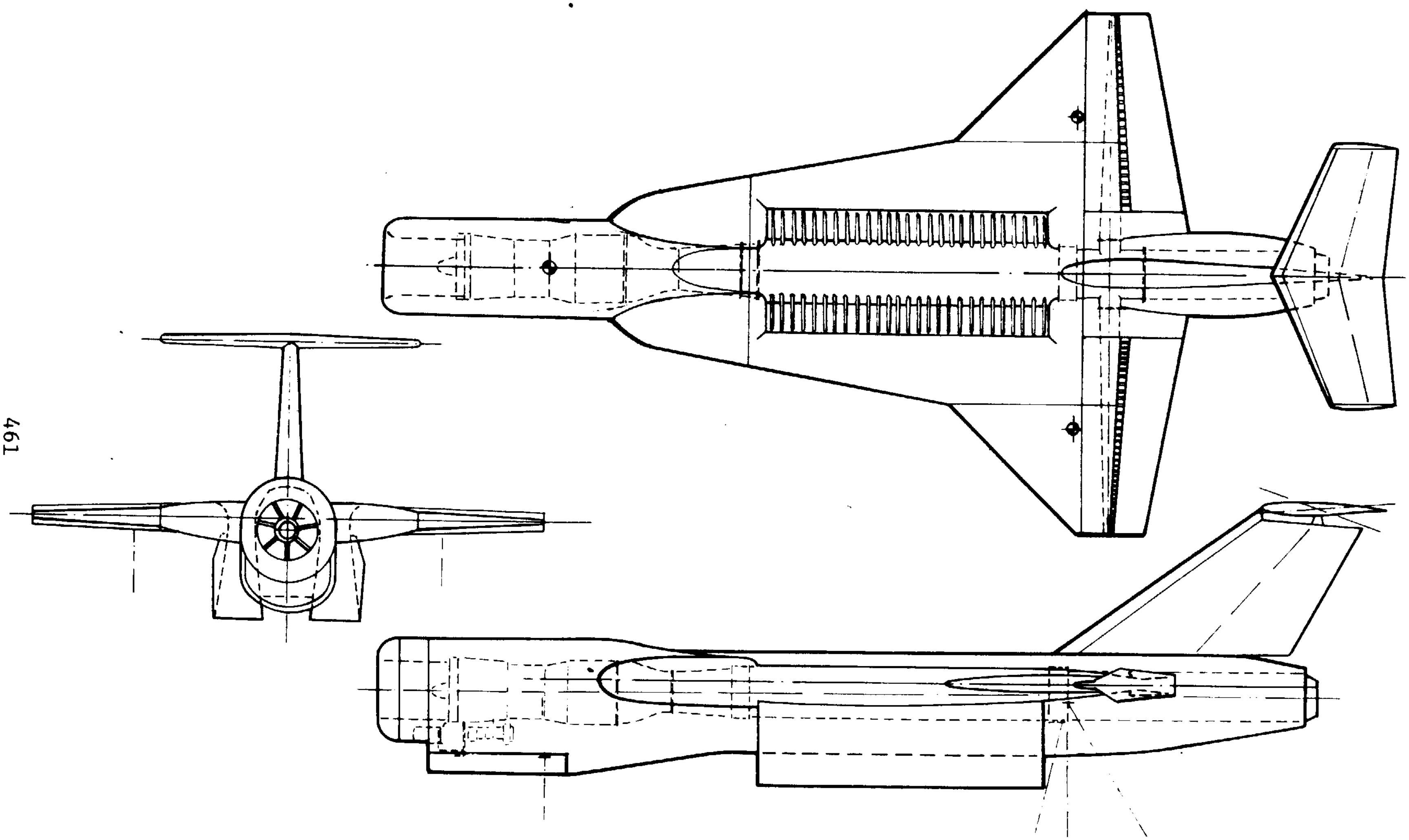

Figure 2.- DHC external augmentor V/STOL concept; G.A. of J-97 powered model.

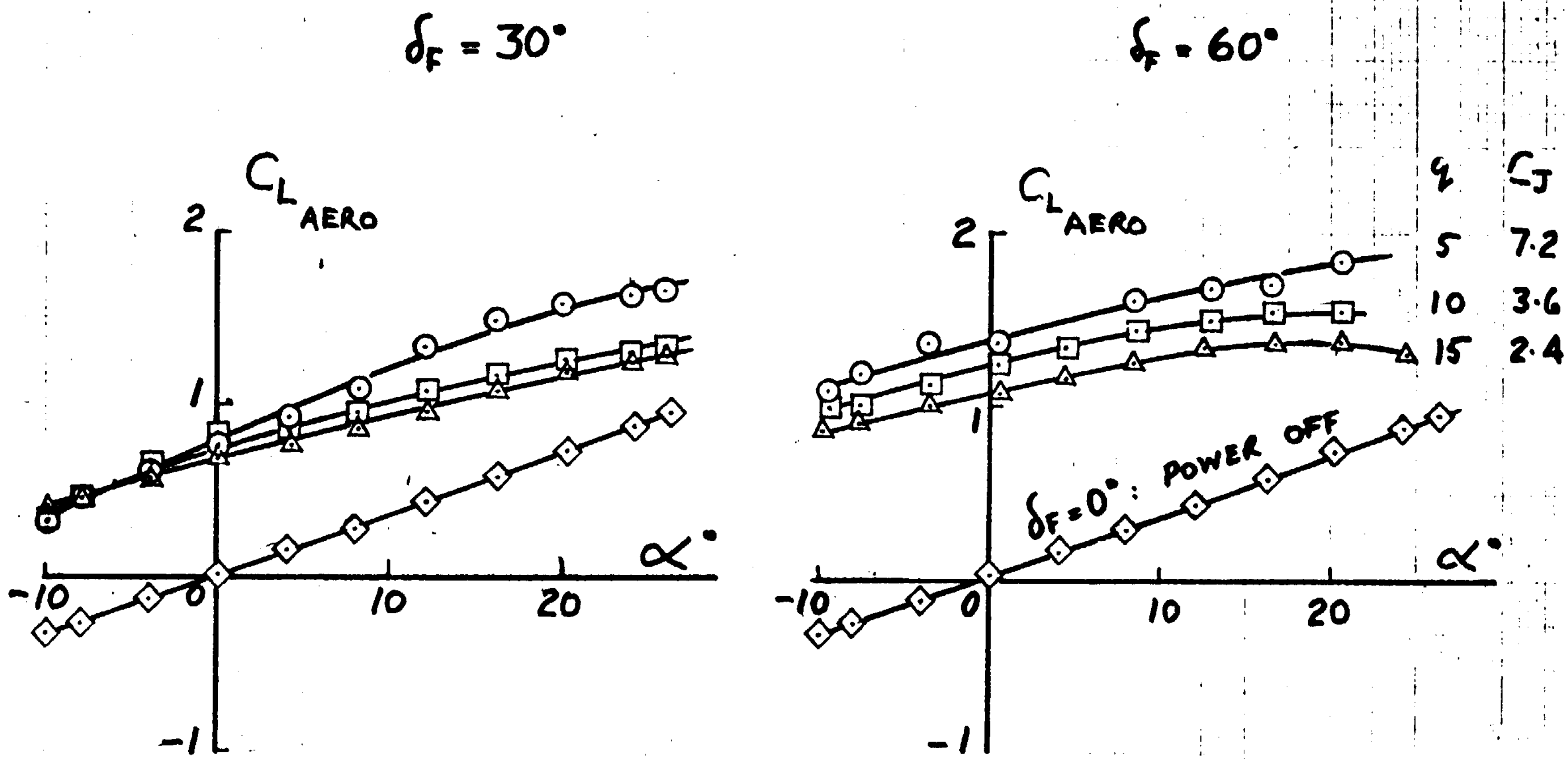

Figure 3.- Aerodynamic lift coefficient.

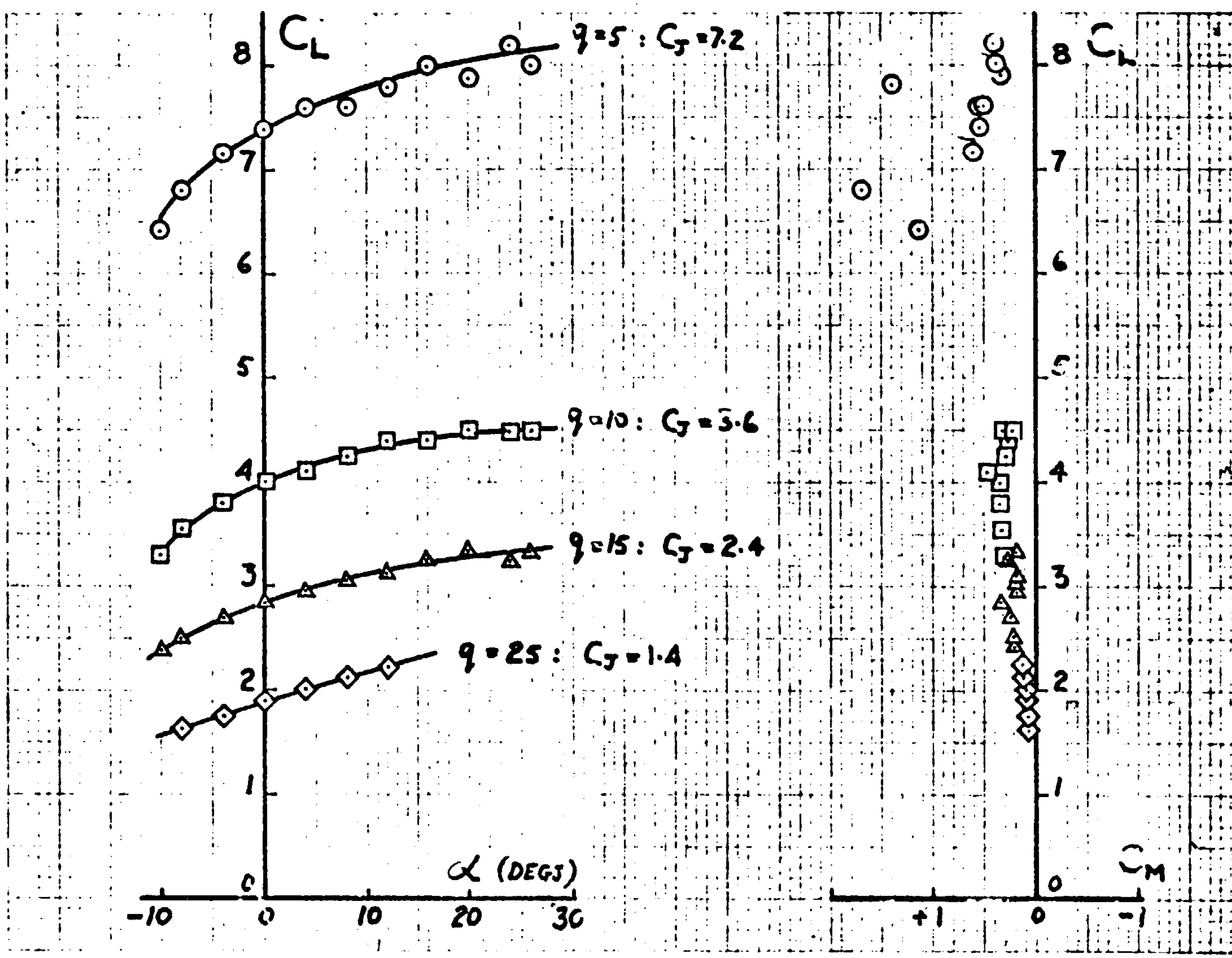

Figure 4.- Longitudinal characteristics; δ_F = 30°, NPR = 2.5.

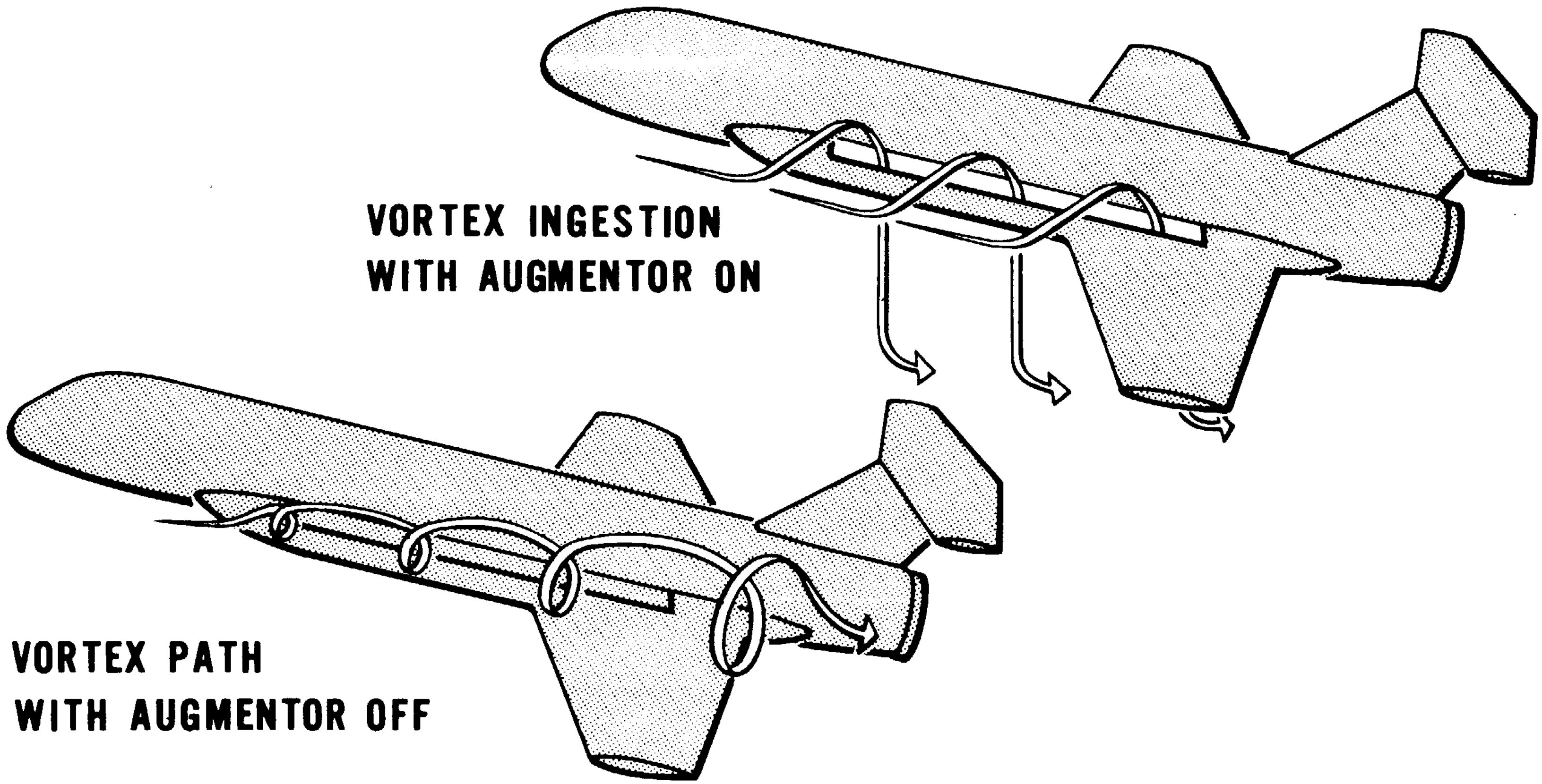

Figure 5.- Vortex behavior with augmentor.

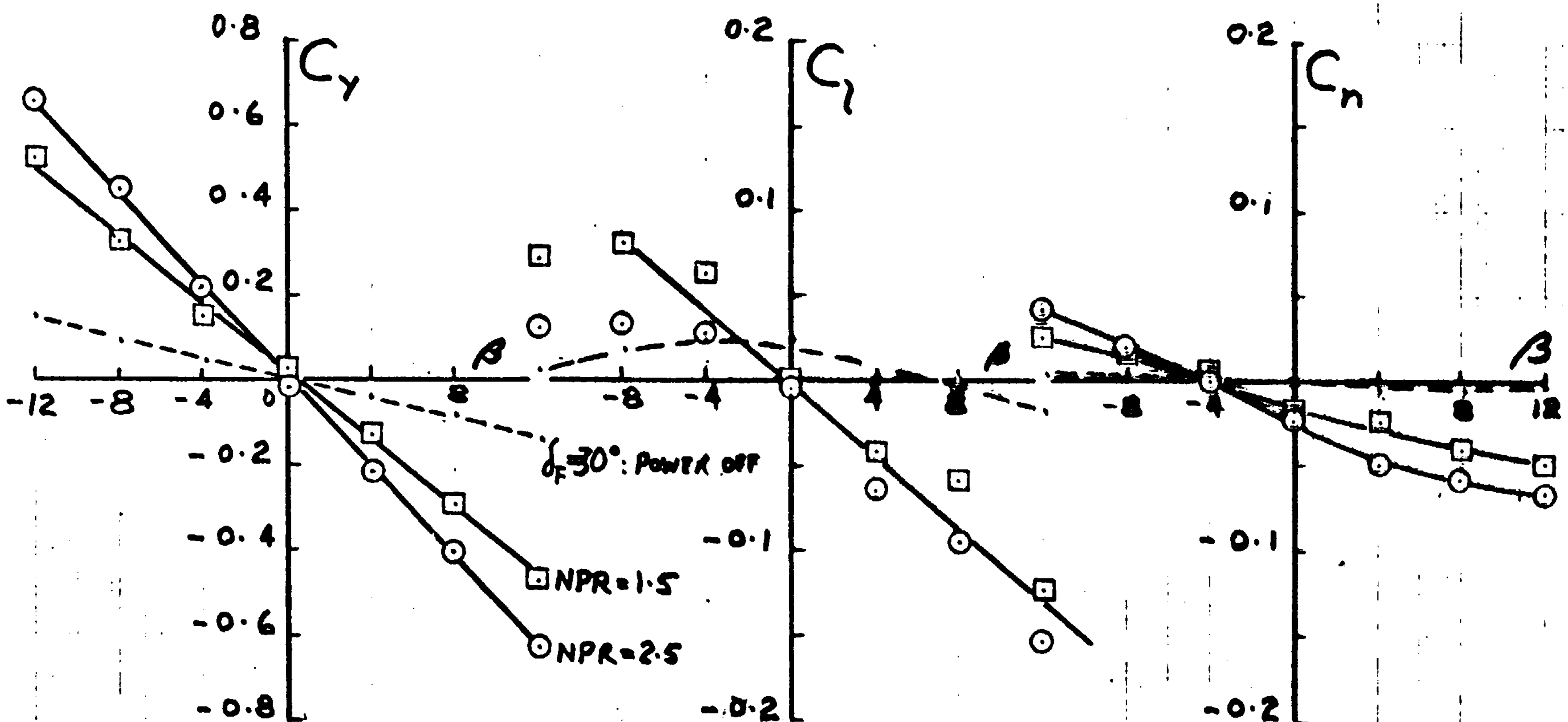

Figure 6.- Lateral directional characteristics; δ_F = 30°, q = 10 psf, α = 0°.

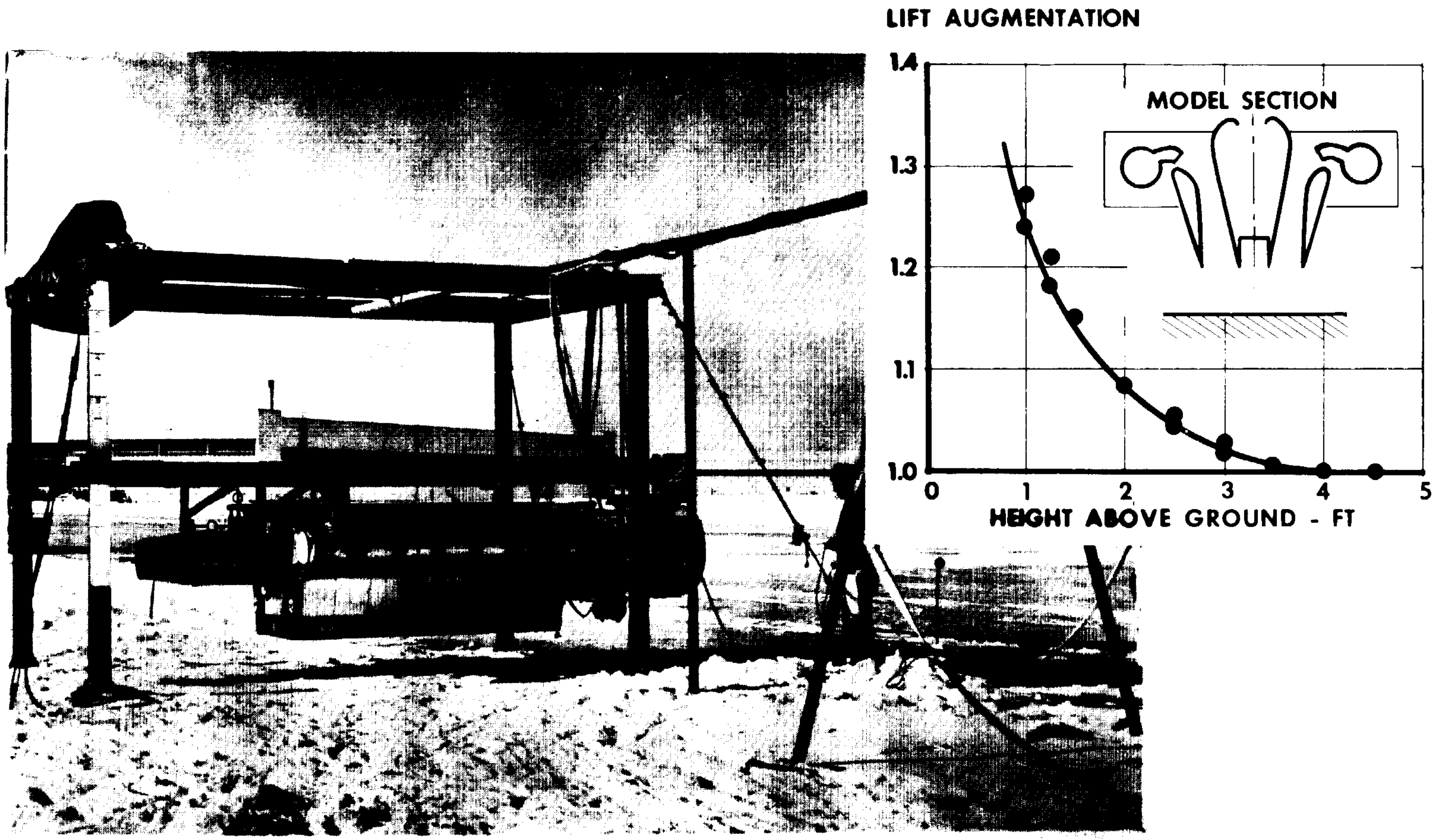

Figure 7.- Large-scale VTOL model mounted in variable height rig.

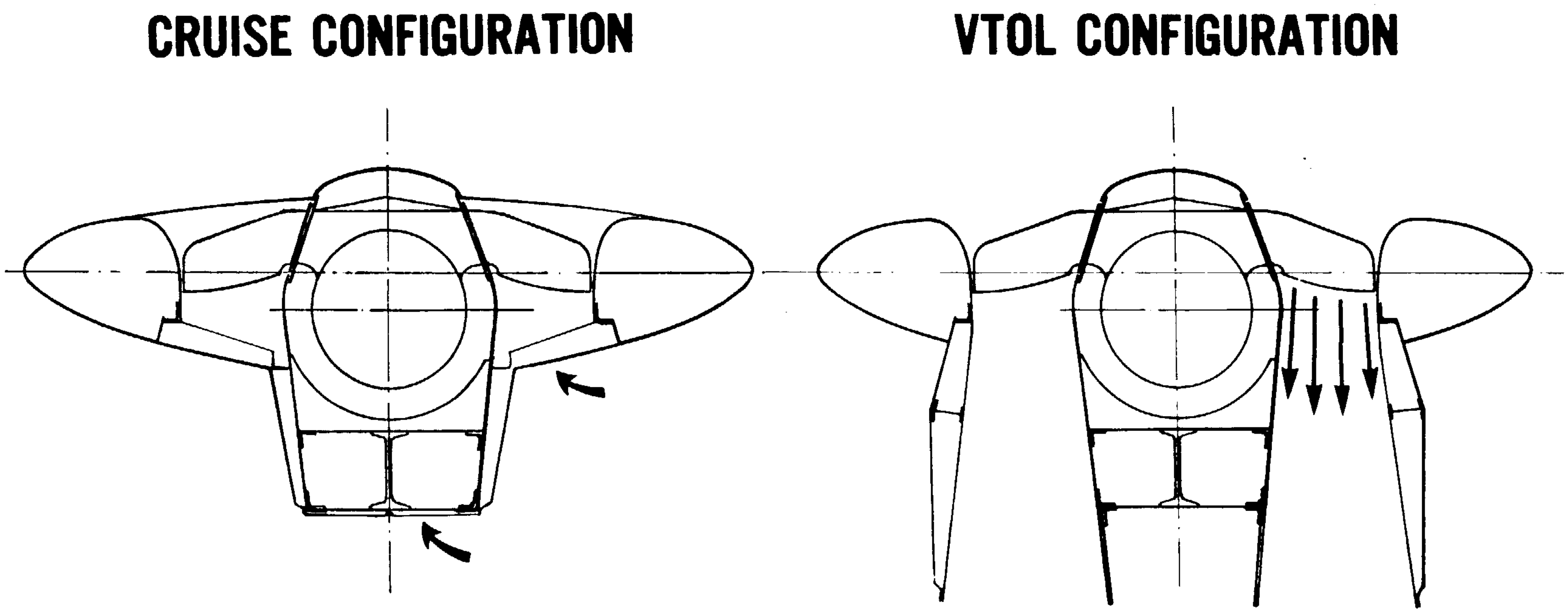

Figure 8.- DHC external augmentor; section of augmentor system.

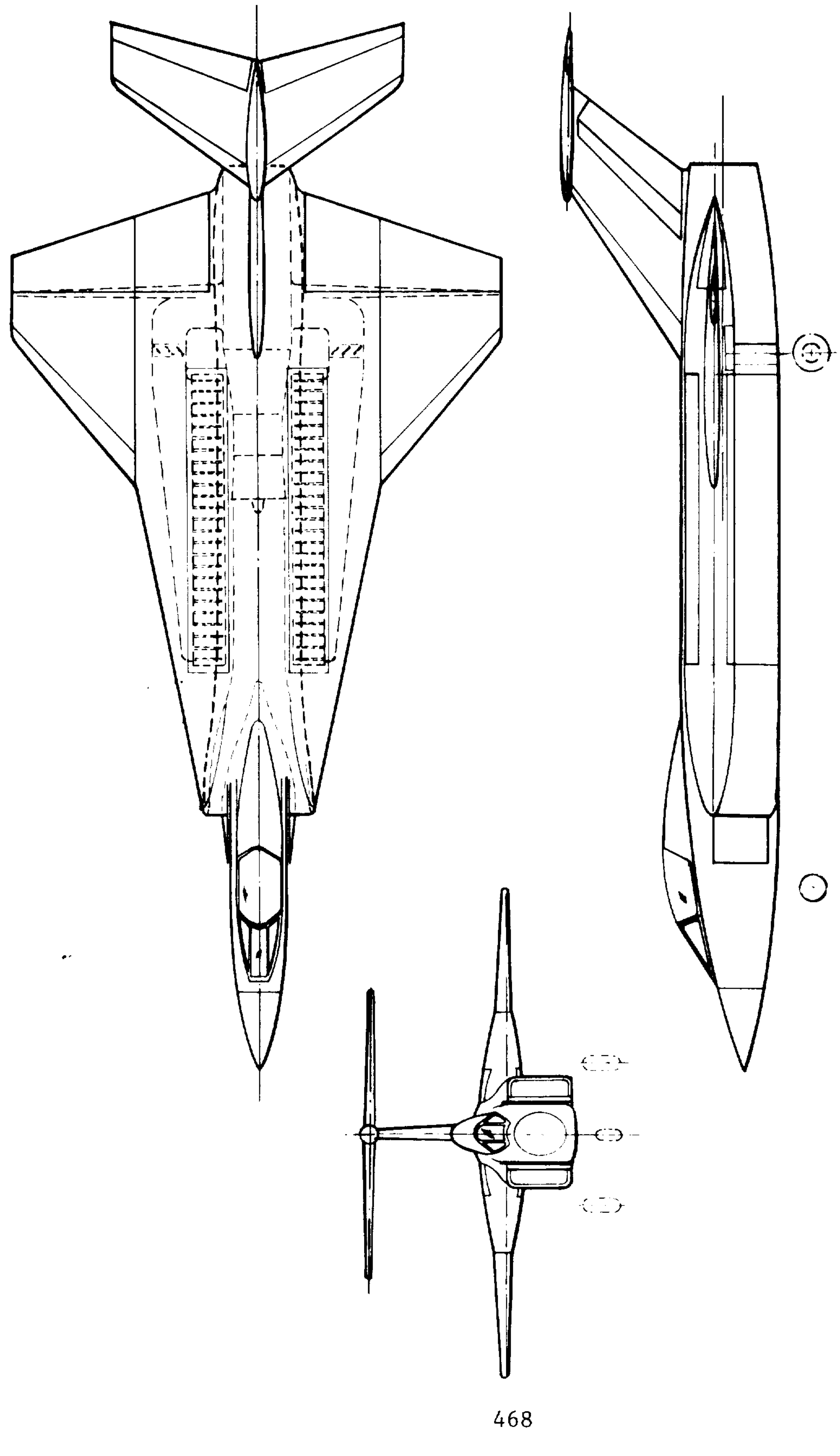

Figure 9.- DHC external augmentor V/STOL concept; "T"-tail configuration.

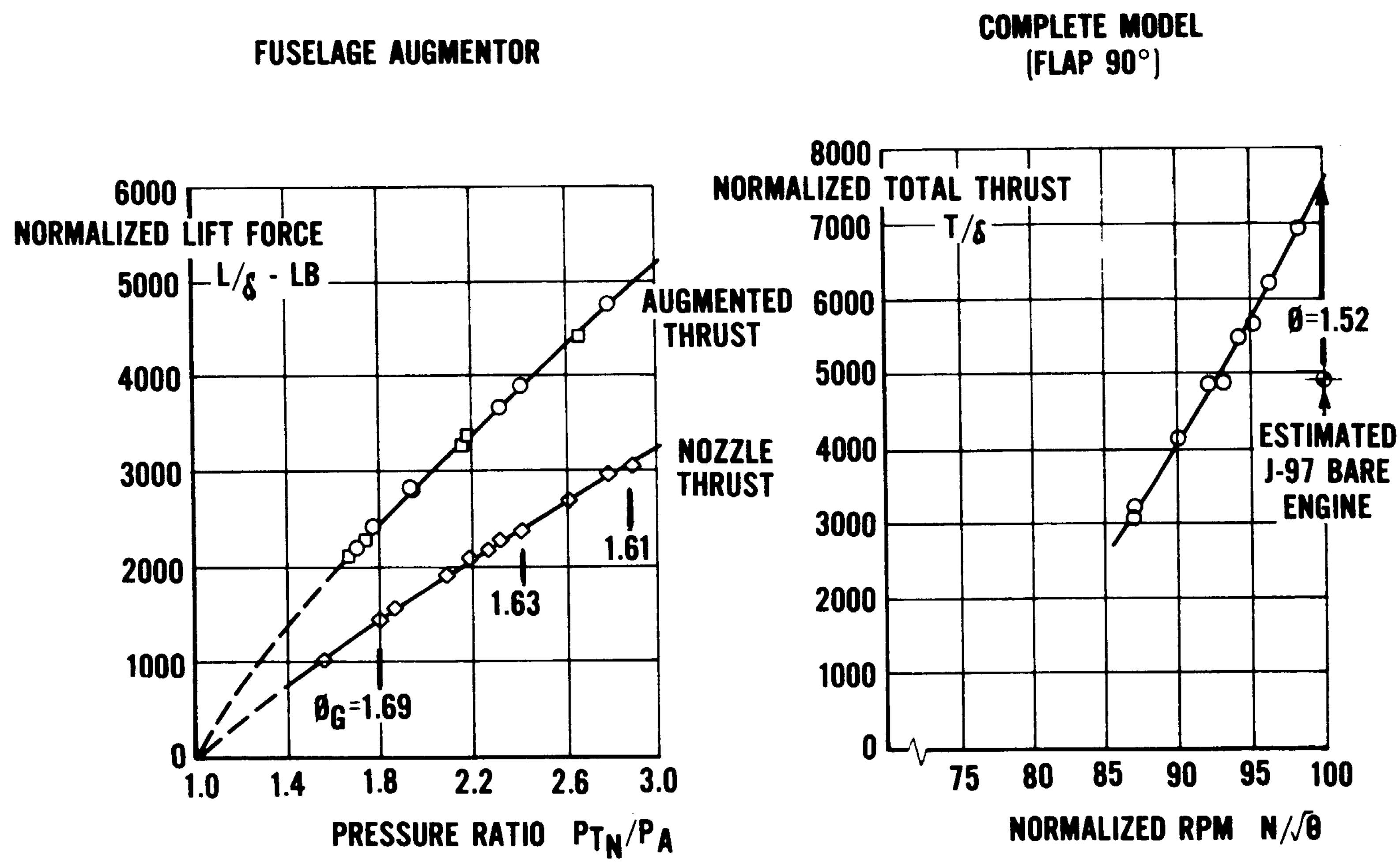

Figure 10.- Static thrust performance.

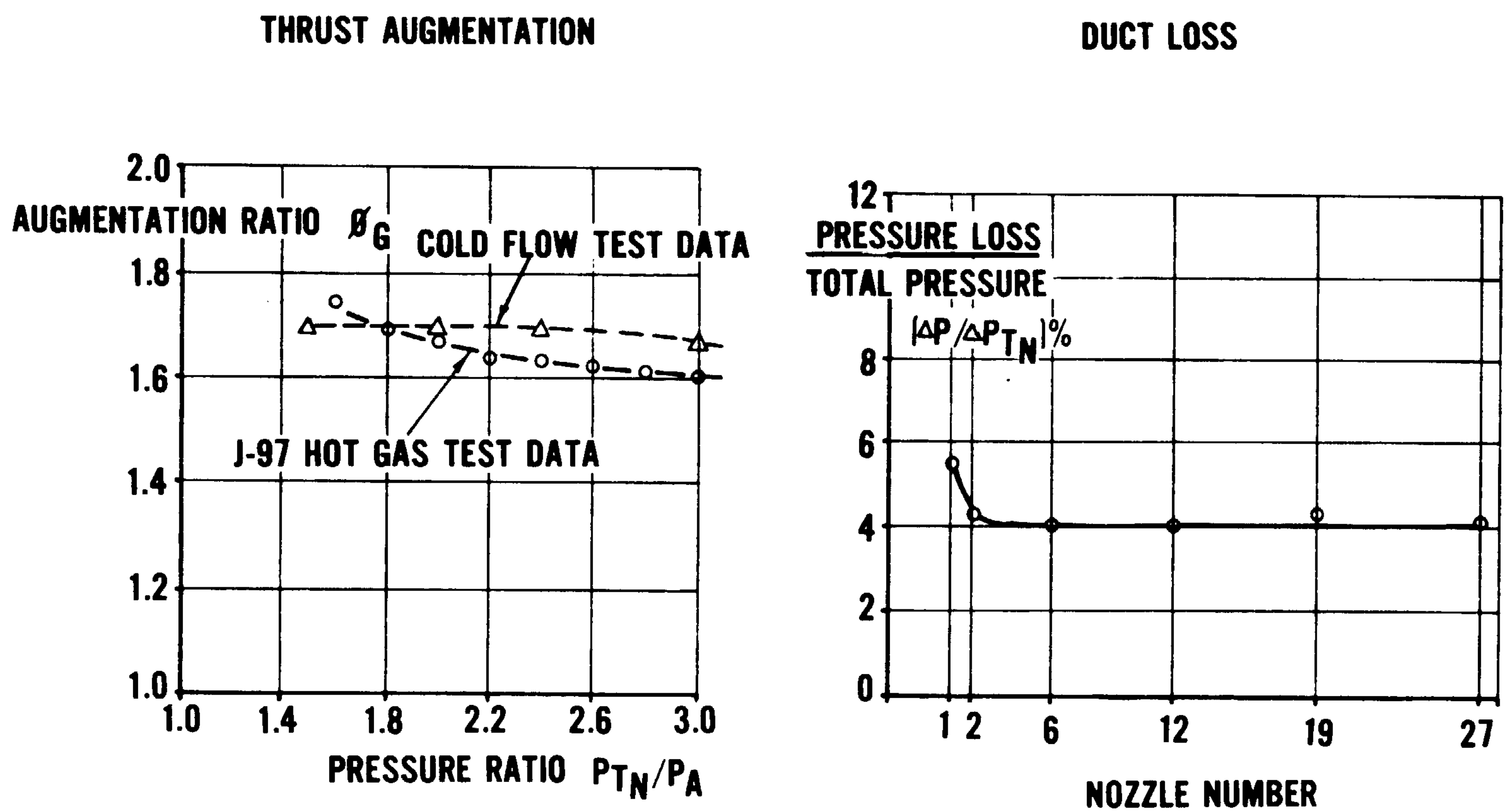

Figure 11.- External augmentor V/STOL model.

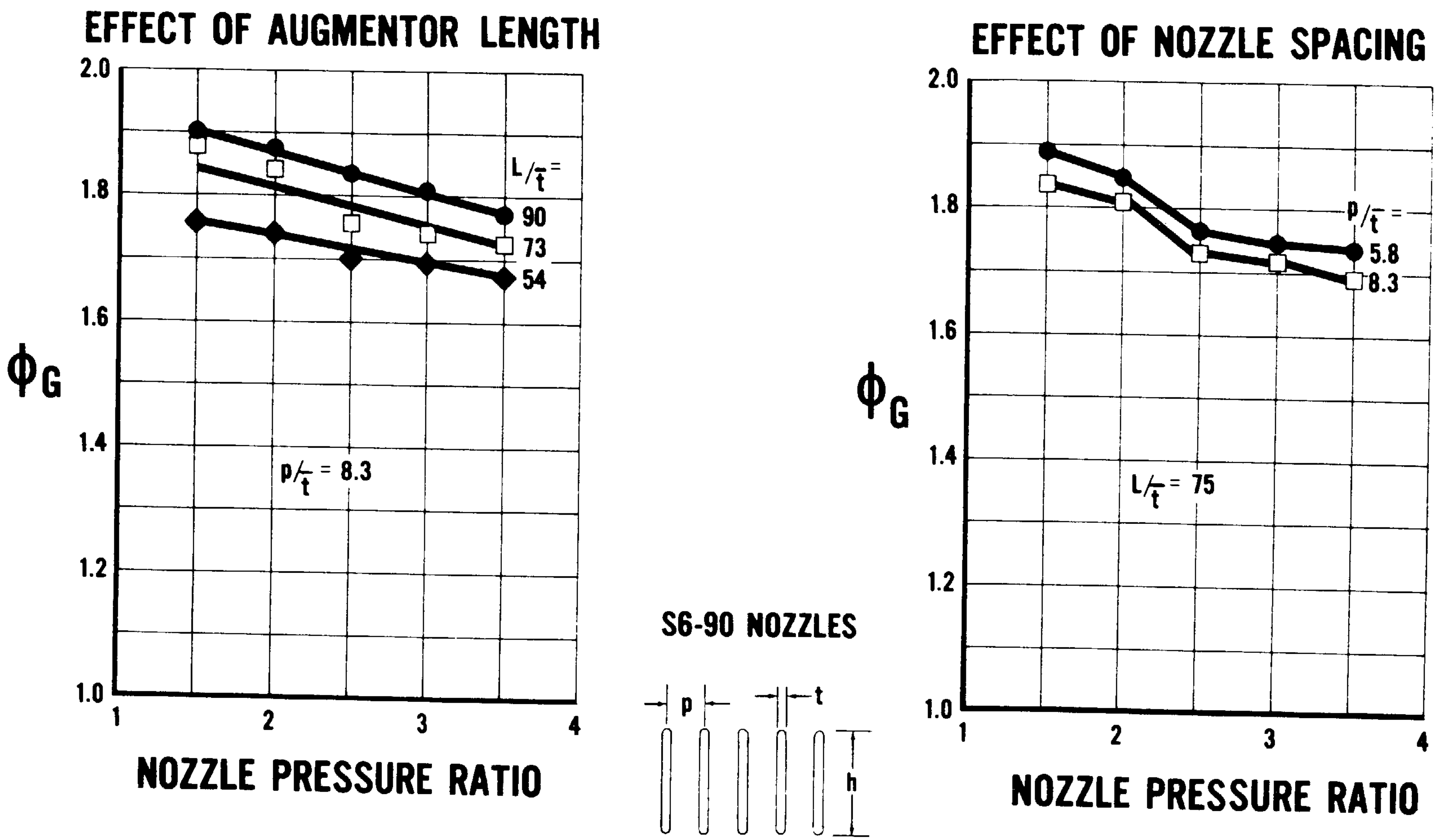

Figure 12.- Gross augmentation ratio ϕ_G; aspect ratio $h/t = 100$.