



MINISTRY OF TECHNOLOGY

AERONAUTICAL RESEARCH COUNCIL

CURRENT PAPERS

An Investigation into a Technique
for Measuring Jet Interference
Effects using Free-flight Models

by

G. H. Greenwood

LONDON: HER MAJESTY'S STATIONERY OFFICE

1967

PRICE FOUR SHILLINGS NET

U.D.C. No. 533.695.7 : 533.696.5 : 533.6.055 :
533.6.013.12 : 621.455-846

C.P. No. 969*
November 1966

AN INVESTIGATION INTO A TECHNIQUE FOR MEASURING JET
INTERFERENCE EFFECTS USING FREE-FLIGHT MODELS

by

G. H. Greenwood

SUMMARY

A free-flight model investigation is described, the major object of which was to gain design and operational experience in the field of jet interference studies. Measurements were made of the effect of a propulsive jet on the external drag of a boattailed body of revolution but because of uncertainties in the jet performance these measurements are of significance only in illustrating the experimental technique. A solid-fuel rocket motor was used as the primary source of the jet flow.

* Replaces R.A.E. Technical Report No. 66364 - A.R.C. 29039.

CONTENTS

	<u>Page</u>
1 INTRODUCTION	3
2 DESCRIPTION OF THE MODELS	3
3 METHOD OF TEST	4
3.1 Boosting	4
3.2 Data acquisition	4
3.3 Data reduction	5
4 TEST CONDITIONS	5
5 RESULTS AND DISCUSSION	5
5.1 Preflight	5
5.2 Inflight	5
5.2.1 Nozzle static pressure	5
5.2.2 Jet thrust	6
5.2.3 Drag	6
6 CONCLUSIONS	6
Symbols	7
References	8
Illustrations	Figures 1-11
Detachable abstract cards	-

1 INTRODUCTION

Interaction between the external flow and the boundary of a propulsive jet may cause pressure changes on adjacent structures leading to a modified external drag and possibly to trim changes on an aircraft or missile, especially when the Mach number of the external flow is in the transonic and supersonic range and if the nozzle is underexpanded.

In the experimental study of such interference effects extensive use has been made of wind tunnel facilities but so far the use of rocket-boosted free-flight models has been confined to American tests.

The aim of the present test was therefore to gain some practical design and operational experience within the R.A.E. in the use of free-flight models in the field of jet-interference studies. This aim was achieved by measuring the total drag and base pressure on two models of identical external shape one with and one without a propulsive jet issuing from the base; a quantitative reference frame for the results was provided by using an external shape identical to that used in the N.A.S.A. test of Ref.1.

The primary source of the jet flow was a modified solid-fuel rocket motor*.

Model tests over a Mach number range of 1.17 to 1.42 were made at free-stream Reynolds numbers from 8 to 10 millions per foot.

2 DESCRIPTION OF THE MODELS

Two models were used in the test their external shape being identical to that used in Ref.1 and as illustrated in the photograph of Fig.1 and general arrangement drawing of Fig.3.

The models are designated models 1 and 2 and are described as follows:-

Model 1 This model was flight tested without a jet efflux and its primary purpose was to provide total drag and base pressure measurements relevant to the "jet-off" condition.

Model 2 The purpose of this model was to provide total drag and base pressure measurements relevant to the "jet-on" condition. A propulsive jet was provided by igniting a plastic composite propellant^φ contained in a 5-inch diameter rocket-motor tube inside the model. The propellant gases were then exhausted through a double-nozzle assembly incorporating a plenum chamber to dissipate

*Development of the rocket motor and its associated nozzle assembly was carried out by Dr. H. Crook of R.P.E. Westcott.

^φR.P.E. Westcott, specification RD.2307.

the high combustion pressures to an acceptable level of jet exit total pressure. Typical design procedures relevant to such a nozzle assembly and to the simulation of full-scale jet flow parameters at model scale are described fully in Ref.2.

It was in fact hoped that by using the design principles of Ref.2 jet exit flow parameters comparable with those of Ref.1 would be achieved but it became apparent that in practice the required nozzle geometry would have to be evolved through a protracted series of static test firings. Since the major object of the present test was an exercise in operational technique the precise character of the jet flow was considered of no real importance and the test firings were therefore terminated as soon as a repeatable exit flow had been established.

Fig.2 illustrates the base region of model 2 and shows the position of the nozzle static pressure orifice (see section 5.1) and of the base pressure orifices; the position of the latter being identical for both models. Fig.3 shows the internal arrangement of model 2 together with details of the nozzle assembly.

In Fig.4 a device is illustrated which was used to delay ignition of the jet motor until the model had separated completely from its external rocket booster. This device was basically a 6.0 volt electrical ignition circuit interrupted by inertia-type switches which allowed ignition to occur only after the model had been subject to the following sequence of accelerations. When an acceleration of at least +10g was attained during the initial boosting phase one half of the ignition circuit was electrically complete and ignition occurred when the circuit was finally complete at one second in time after the model acceleration had fallen to +3g.

3 METHOD OF TEST

3.1 Boosting

Each model was launched to its required test velocity using a twin 5-inch diameter rocket motor booster as illustrated in Fig.5. At the motor all-burnt condition the models separated from their boosters under the existing drag and inertia forces and went into free flight.

3.2 Data acquisition

Each model was tracked by kinetheodolite cameras sited along the range boundary thus providing a record of space co-ordinates from which trajectory

and velocity data were obtained. Velocity was also obtained by integrating the response of model-borne longitudinal accelerometers.

A 465 Mc/s multi-channel R.A.E. sub-miniature telemeter was used in conjunction with variable-inductance type transducers to obtain the required inflight pressure and force measurements.

Atmospheric pressure, temperature and wind velocity at the appropriate flight altitudes were obtained using the standard range procedures.

3.3 Data reduction

The methods used to reduce the recorded telemetered data to variations of drag coefficient, jet nozzle and base pressure with flight Mach number were basically as described in Ref.3.

4 TEST CONDITIONS

The variation with flight time of free-stream Mach number, altitude and Reynolds number is shown in Figs.6 and 7 for models 1 and 2 respectively.

5 RESULTS AND DISCUSSION

5.1 Preflight

The performance of the jet motor and nozzle assembly was established prior to flight by ground tests in which the static pressure measured at a point inside the convergent exit section of the nozzle was correlated with the simultaneously measured thrust. This static pressure point (see Fig.3) was located as near the jet exit plane as model space would allow.

Fig.8 shows the static pressure/thrust relationship obtained from the pre-flight tests.

5.2 Inflight

5.2.1 Nozzle static pressure

Inflight values of the nozzle static pressure measured at the same point as in the preflight tests (5.1) are presented in Fig.9. It will be seen that the maximum measured inflight static pressure was only about 50 lbf/in^2 compared with 63 lbf/in^2 measured during the preflight tests (Fig.8). This indicates that either the full jet performance was not attained in flight or the flight pressure measurements were themselves in error due perhaps to a fault in the pressure transducer. Although the latter is thought unlikely there is nevertheless some uncertainty in the nozzle pressure measurements and hence in the deduced inflight performance of the jet motor.

5.2.2 Jet thrust

In Fig.10 values of inflight thrust are presented. These were deduced from the pressure/thrust relationship of Fig.8 and the flight measurements of nozzle static pressure of Fig.9 but because of the anomaly associated with the flight measurements of nozzle pressure (5.2.1) the possibility of some uncertainty must not be discounted.

5.2.3 Drag

Fig.11 shows the variation with Mach number of the total and base drag coefficients for both models.

The total drag coefficients for the "jet-off" condition are seen to differ by only about 4 per cent between models 1 and 2 - an amount easily accountable as experimental uncertainty. Excellent agreement has been obtained between the "jet-off" total drag of model 2 and that from Ref.1.

The "jet-on" total drag coefficients were computed from the equation:-

$$C_{D(\text{jet-on})} = T_j - W(a/g + \sin \theta)/q_0 S ;$$

the inclusion of the inflight thrust term, T_j , thus introduces the possibility of some uncertainty in the "jet-on" total drag coefficients (5.2.1). This uncertainty coupled with the fact that the jet thrust and hence probably the jet pressure ratio was varying throughout the test precludes a direct comparison with the "jet-on" total drag coefficients from Ref.1 which were obtained for a constant jet pressure ratio, p_j/p_0 , of 3.75. Unfortunately the uncertainty in the flight performance of the jet motor did not allow reliable values of jet pressure ratio to be computed for the present test.

The presence of the jet efflux induced positive pressures on the base annulus resulting in negative values of "jet-on" base drag coefficients comparable in magnitude to those of Ref.1.

6 CONCLUSIONS

An investigation has been described in which measurements of the external drag of a boattailed body of revolution were made in free flight with and without a simulated propulsive jet issuing from the base. Despite some uncertainty about the jet performance the investigation has established the validity of the free-flight model technique in the field of jet interference studies.

SYMBOLS

a	longitudinal acceleration	ft/sec ²
Aa	area of base annulus = 0.019	ft ²
Ab	area of base = 0.0645	ft ²
C _D _{total} (jet on)	$T_J - W(a/g + \sin \theta)/q_o S$	
C _D _{total} (jet off)	Drag (lbf)/q _o S	
C _D _{base} (jet on)	$(p_b - p_o)Aa/q_o S$	
C _D _{base} (jet off)	$(p_b - p_o)Ab/q_o S$	
g	acceleration due to gravity	ft/sec ²
p _b	base pressure	lbf/ft ²
p _o	free-stream static pressure	lbf/ft ²
p _J	jet exit static pressure	lbf/ft ²
q _o	free-stream dynamic pressure	lbf/ft ²
S	reference area = maximum body cross-sectional area = 0.23	ft ²
T _J	jet thrust	lbf
W	instantaneous model weight	lb
θ	flight-path angle	degrees

REFERENCES

- | <u>No.</u> | <u>Author</u> | <u>Title, etc.</u> |
|------------|-------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 1 | R. A. Falanga | A free-flight investigation of the effects of simulated sonic turbojet exhaust on the drag of a boattail body with various jet sizes from Mach number 0.87 to 1.50.
NACA RM L55F09a; August 1955 |
| 2 | C. A. de Moraes
W. K. Hagginbotham, Jr.
R. A. Falanga | Design and evaluation of a turbojet exhaust simulator, utilizing a solid-propellant rocket motor, for use in free-flight aerodynamic research models.
NACA RM L54I15, December 1954 |
| 3 | J. A. Hamilton
P. A. Hufton | Free-flight techniques for high-speed aerodynamic research.
Journal of the Royal Aeronautical Society,
Vol. LX, pp. 151-185, March 1956 |

Telemetry aerial

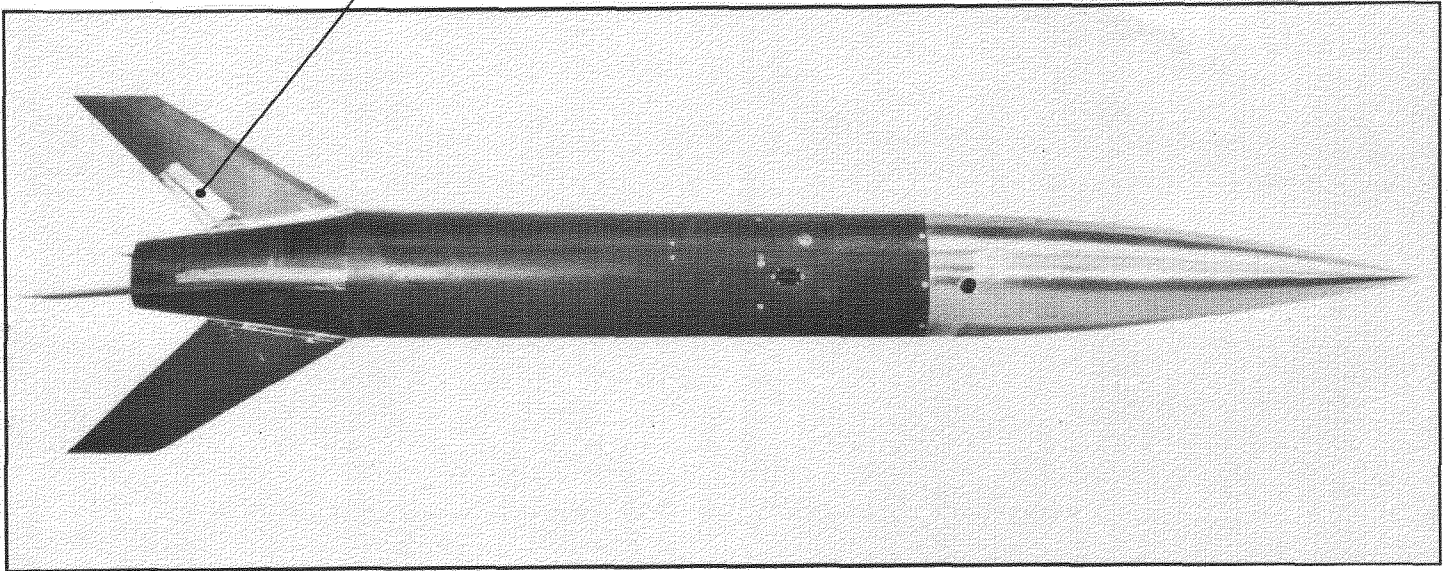
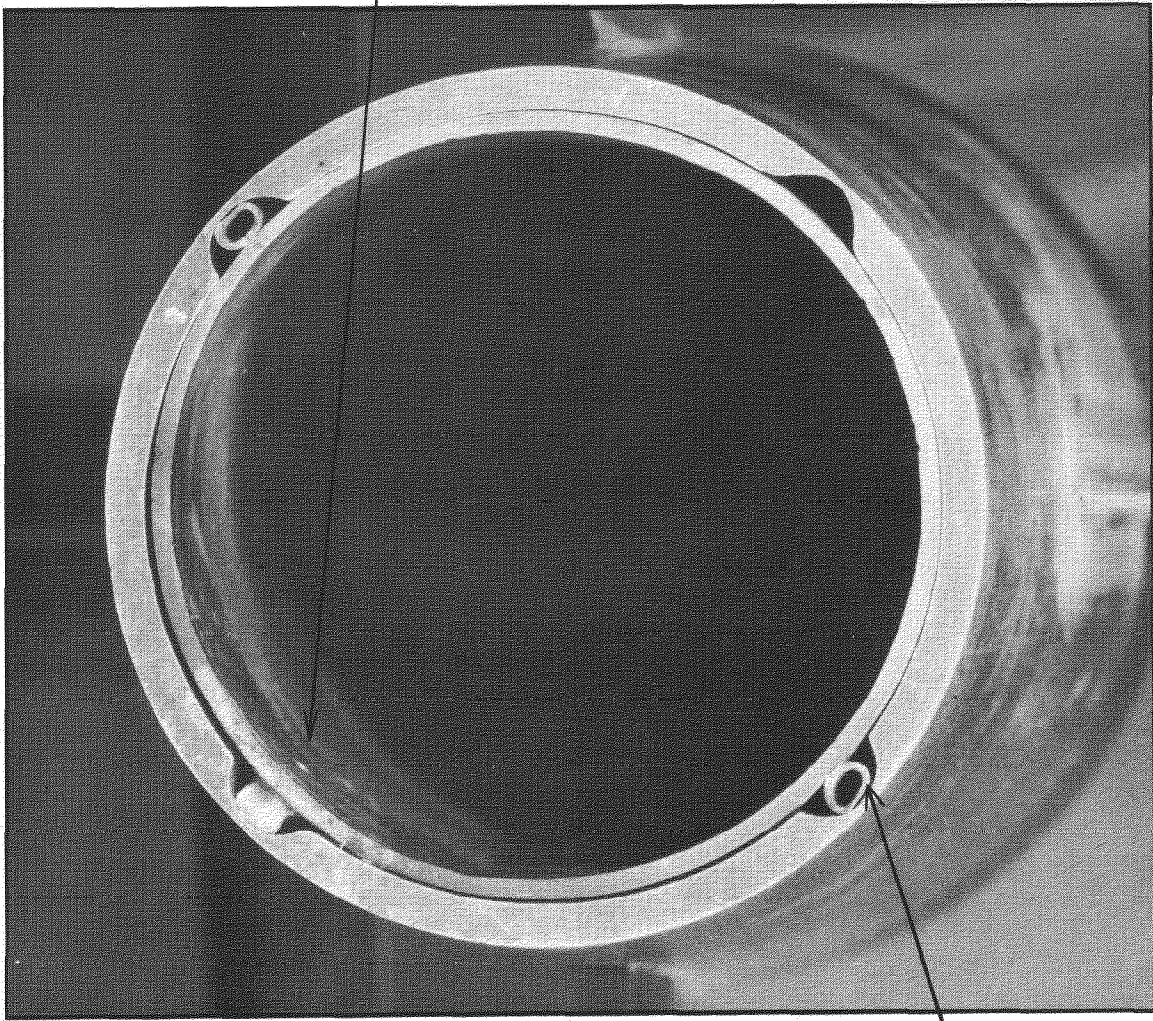


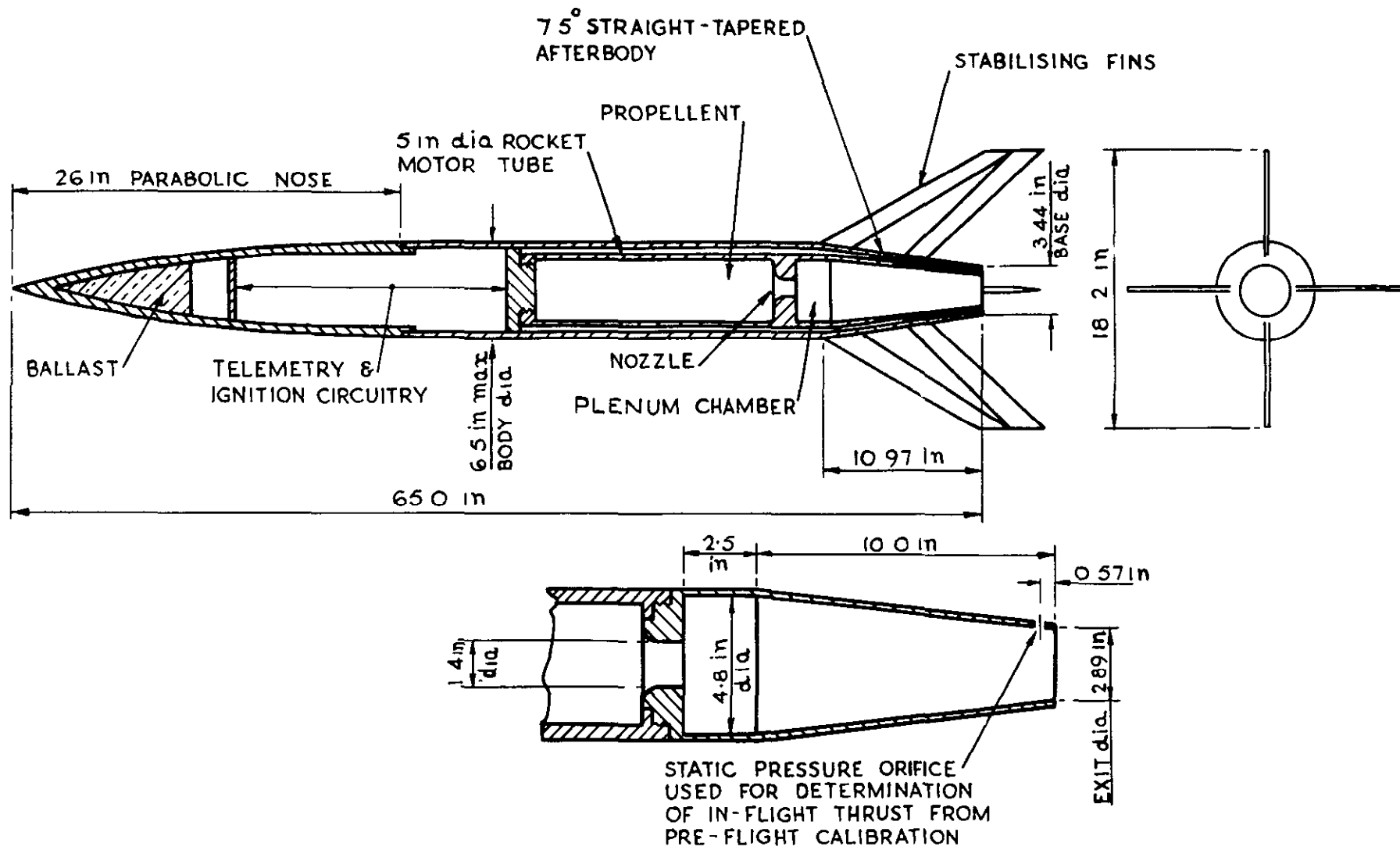
Fig.1. External shape of models

Nozzle static pressure orifice (model 2 only)



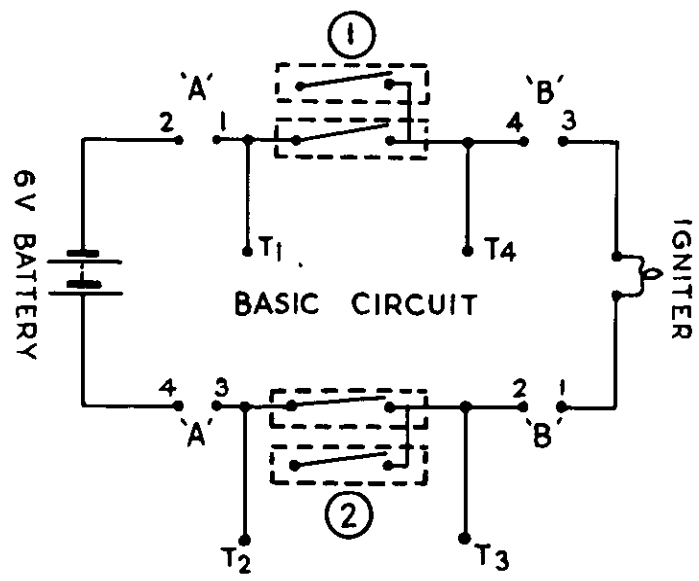
Base pressure orifice

Fig.2. Base annulus and nozzle showing pressure orifices

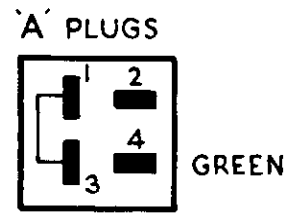
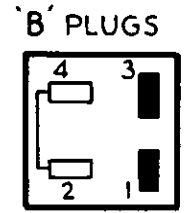
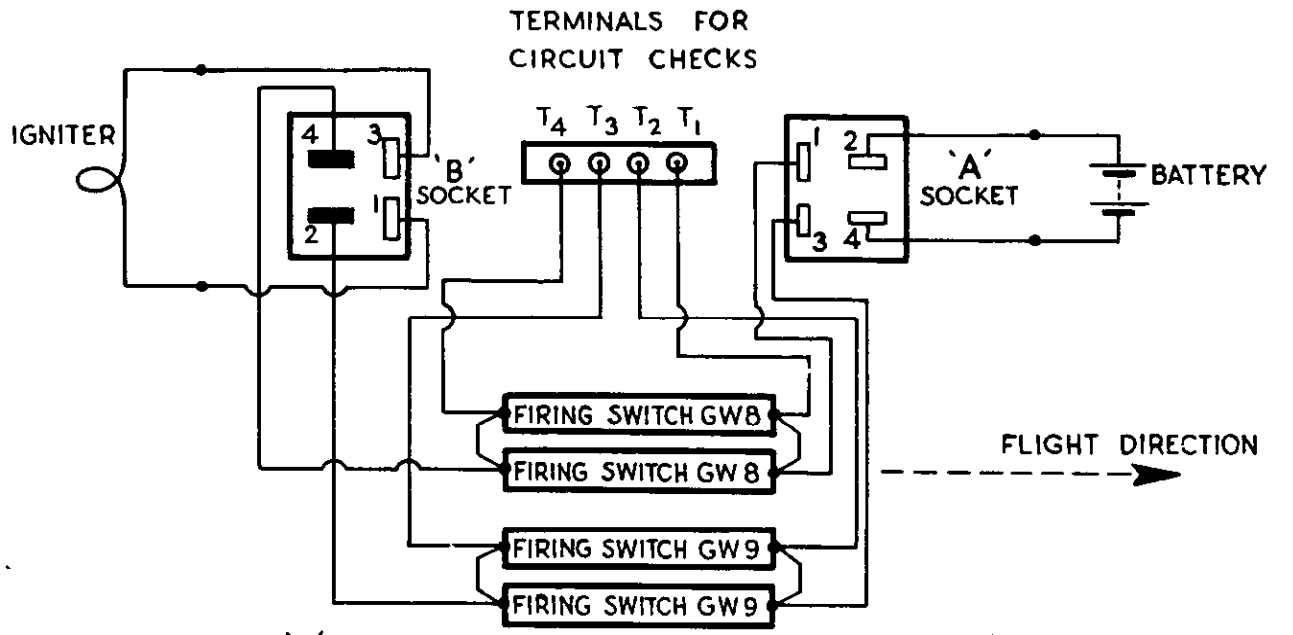


DETAIL OF NOZZLE ASSEMBLY.

FIG 3 GENERAL ARRANGEMENT OF MODEL 2

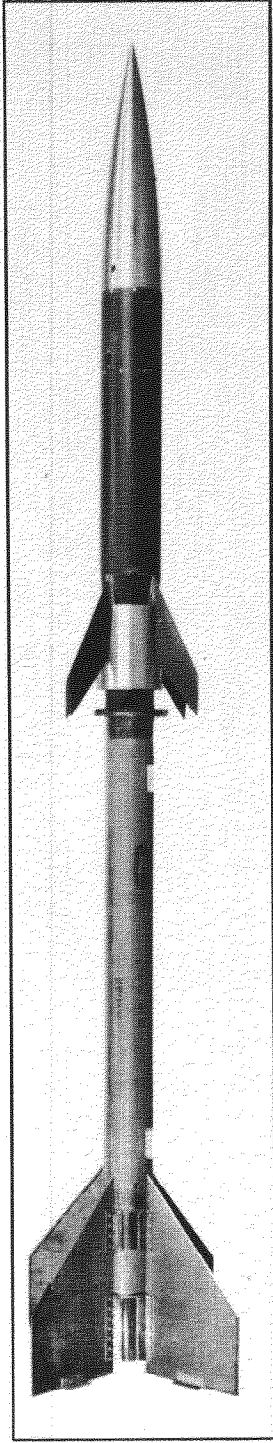


- ① FIRING SWITCHES
PARTIALLY CLOSED AT +8G
FULLY CLOSED (FIRING) ONE
SECOND AFTER ACCELERATION
FALLS TO +3G
- ② ARMING SWITCHES
FULLY CLOSED AT +10G

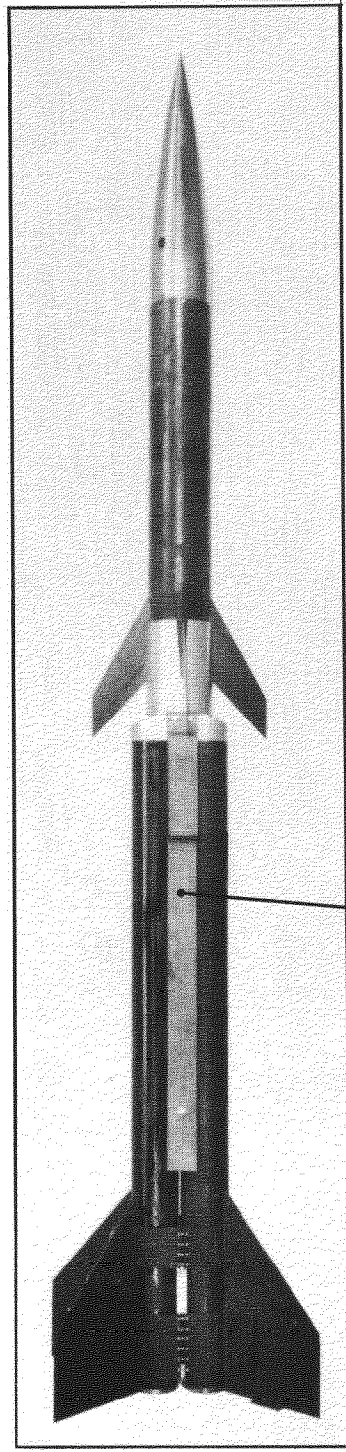


GREEN = ISOLATING OR SAFETY PLUGS
RED = ARMING PLUGS

FIG 4 JET MOTOR IGNITION CIRCUIT (MODEL 2)



Model 1 - twin 5" dia. rocket motors



Ballast

Model 2 - twin 5" dia. rocket motors plus ballast to restrict maximum velocity

Fig.5. Boosting arrangements

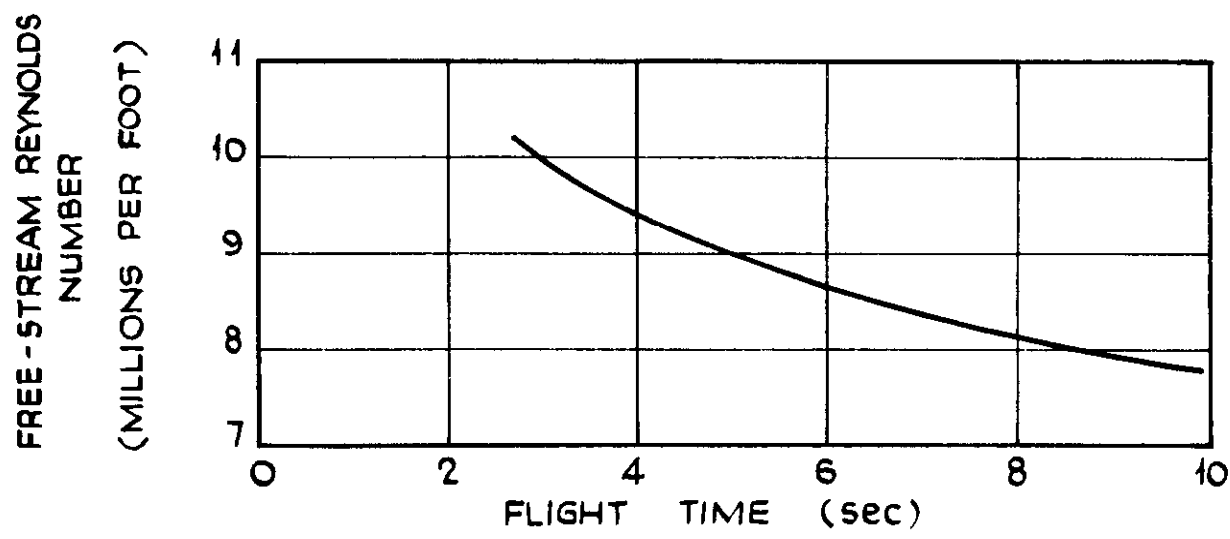
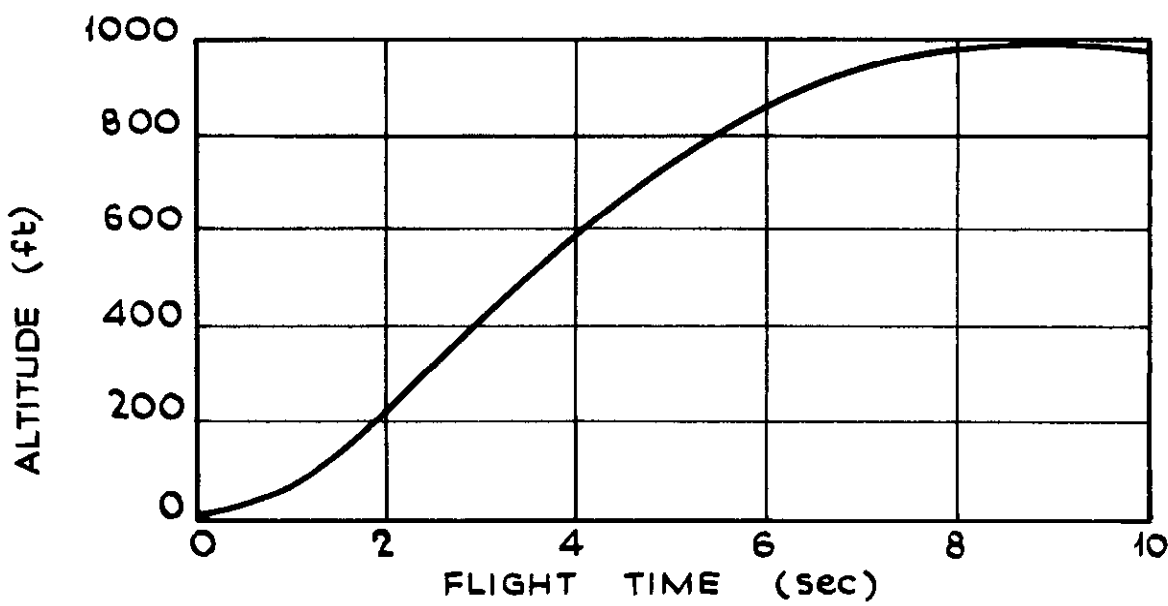
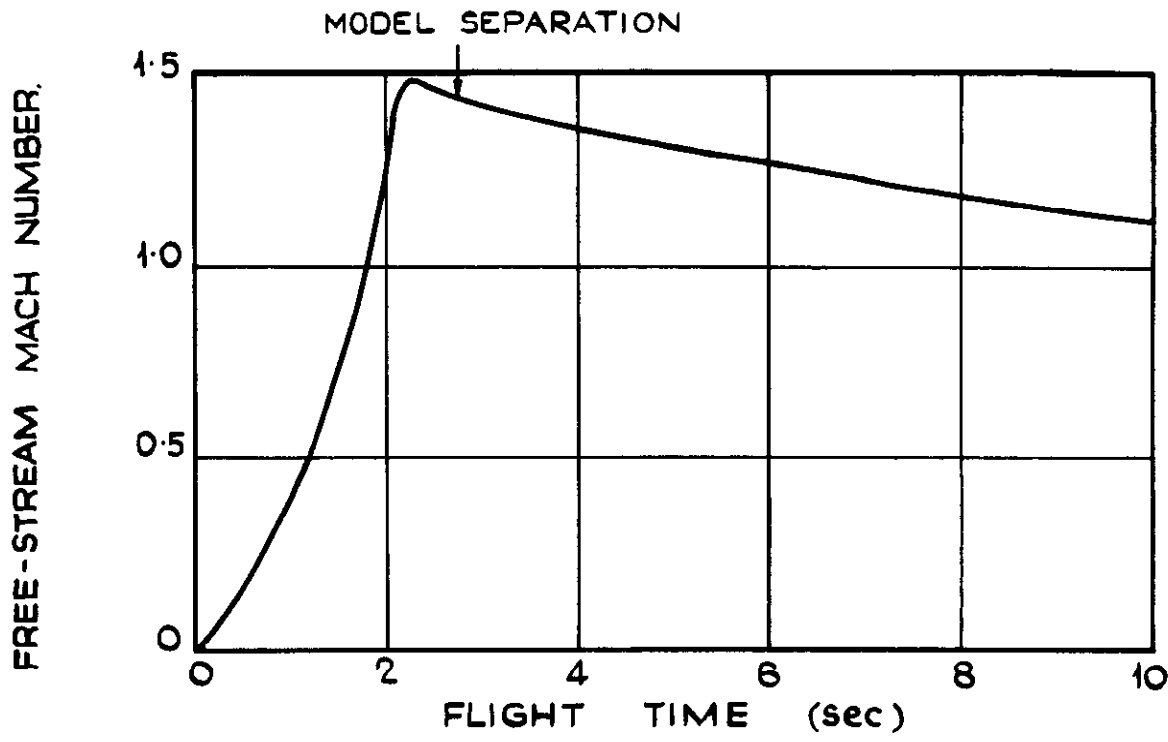


FIG. 6 TEST CONDITIONS - MODEL 1

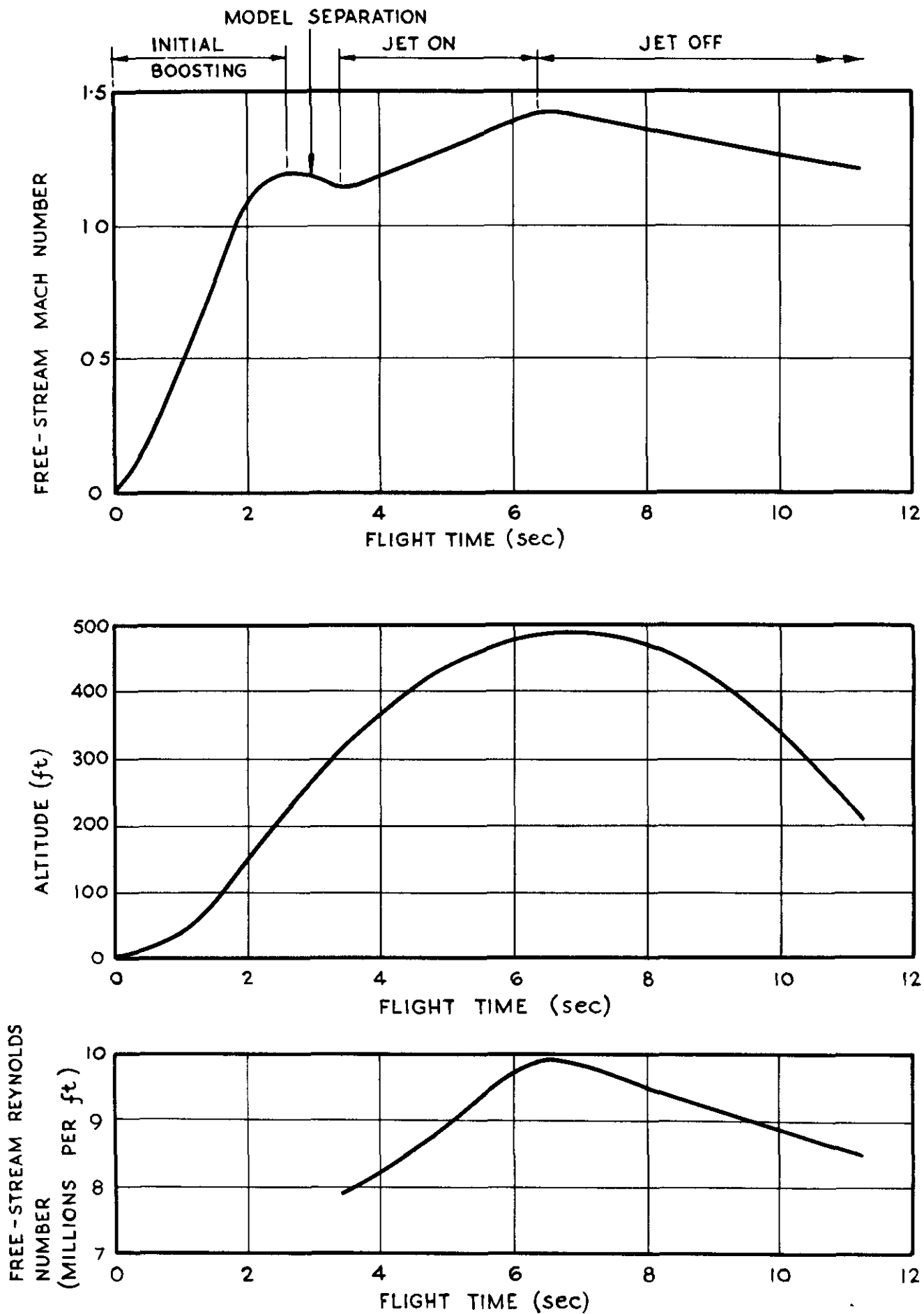


FIG.7 TEST CONDITIONS — MODEL 2

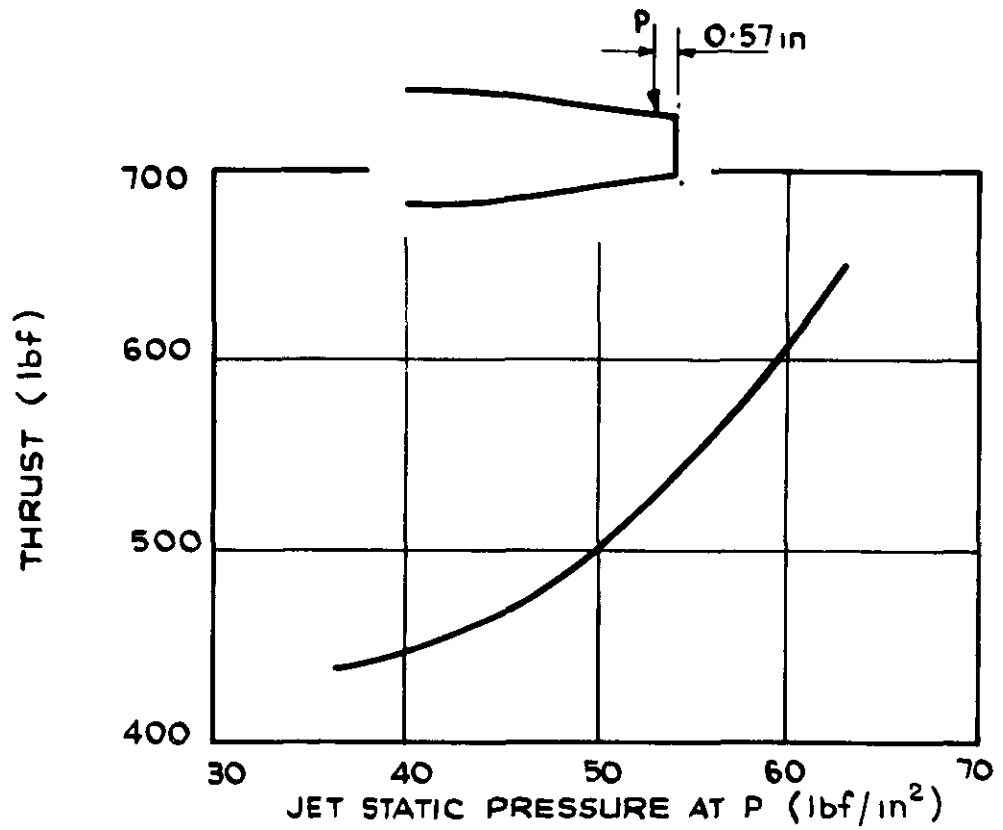


FIG. 8 PRE-FLIGHT CALIBRATION OF THRUST V JET PRESSURE

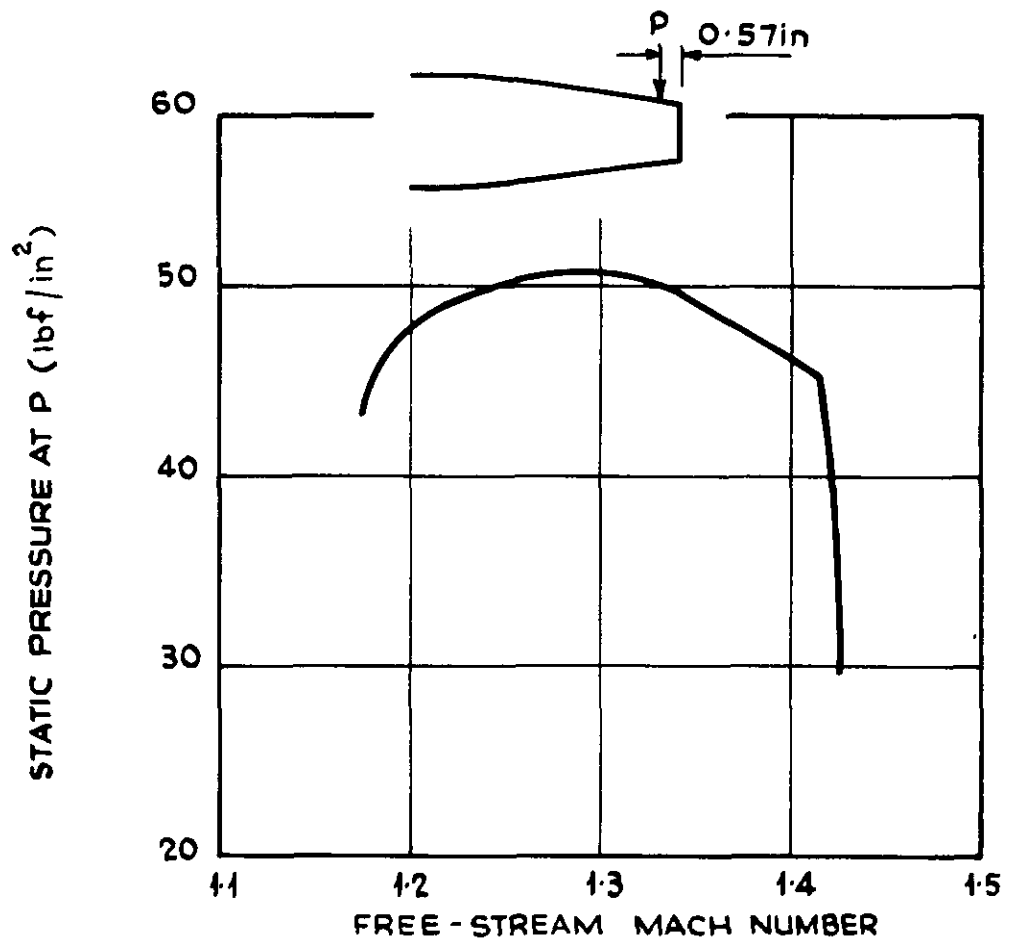


FIG. 9 IN-FLIGHT JET STATIC PRESSURE (MODEL 2)

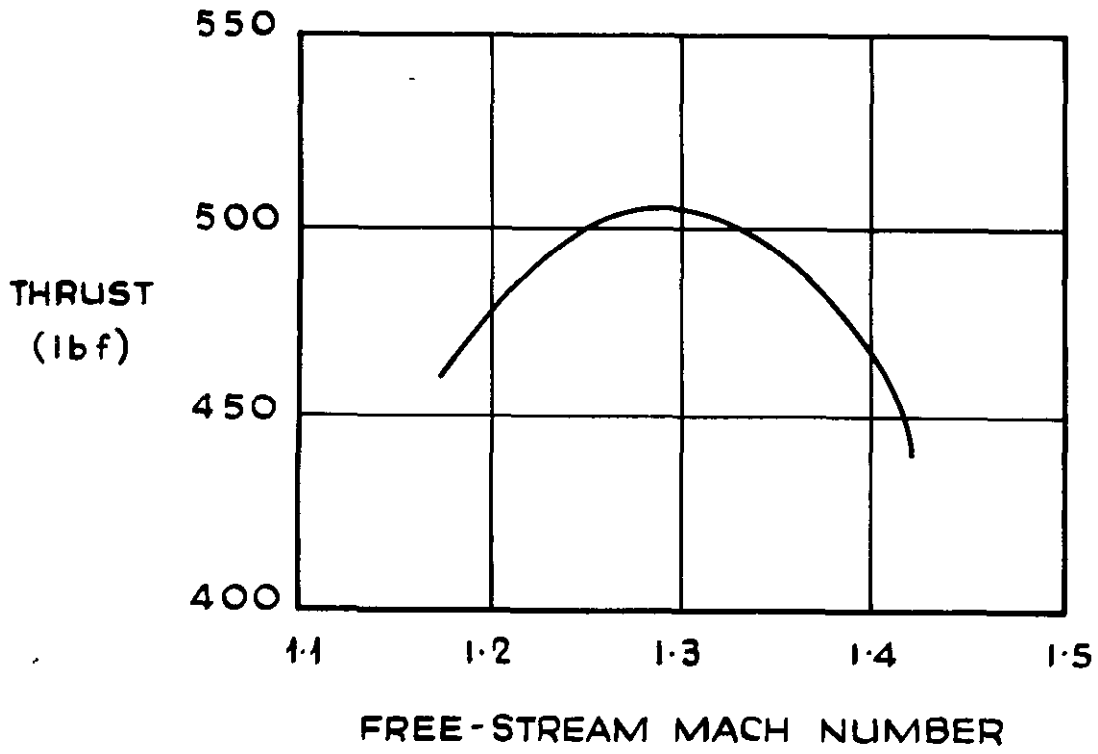


FIG. 10 INFLIGHT THRUST (MODEL 2)

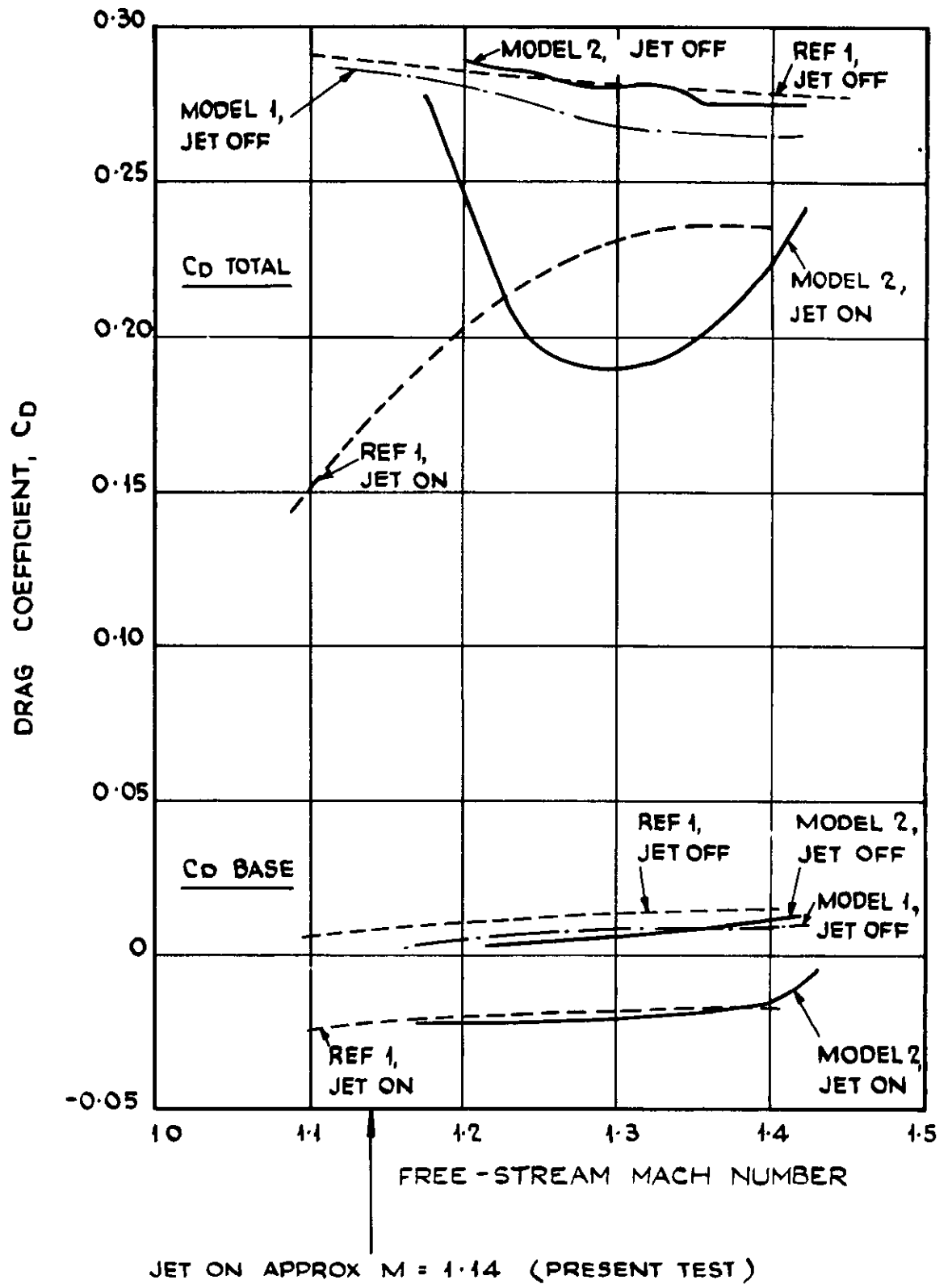


FIG. II TOTAL AND BASE DRAG COEFFICIENTS

A.R.C. C.P. No. 969
 November 1966
 Greenwood, G.H.
 AN INVESTIGATION INTO A TECHNIQUE FOR MEASURING JET
 INTERFERENCE EFFECTS USING FREE-FLIGHT MODELS

533.695.7 :
 533.696.5 :
 533.6.055 :
 533.6.013.12 :
 621.455-846

A free-flight model investigation is described, the major object of which was to gain design and operational experience in the field of jet interference studies. Measurements were made of the effect of a propulsive jet on the external drag of a boattailed body of revolution but because of uncertainties in the jet performance these measurements are of significance only in illustrating the experimental technique. A solid-fuel rocket motor was used as the primary source of the jet flow.

A.R.C. C.P. No. 969
 November 1966
 Greenwood, G.H.
 AN INVESTIGATION INTO A TECHNIQUE FOR MEASURING JET
 INTERFERENCE EFFECTS USING FREE-FLIGHT MODELS

533.695.7 :
 533.696.5 :
 533.6.055 :
 533.6.013.12 :
 621.455-846

A free-flight model investigation is described, the major object of which was to gain design and operational experience in the field of jet interference studies. Measurements were made of the effect of a propulsive jet on the external drag of a boattailed body of revolution but because of uncertainties in the jet performance these measurements are of significance only in illustrating the experimental technique. A solid-fuel rocket motor was used as the primary source of the jet flow.

A.R.C. C.P. No. 969
 November 1966
 Greenwood, G.H.
 AN INVESTIGATION INTO A TECHNIQUE FOR MEASURING JET
 INTERFERENCE EFFECTS USING FREE-FLIGHT MODELS

533.695.7 :
 533.696.5 :
 533.6.055 :
 533.6.013.12 :
 621.455-846

A free-flight model investigation is described, the major object of which was to gain design and operational experience in the field of jet interference studies. Measurements were made of the effect of a propulsive jet on the external drag of a boattailed body of revolution but because of uncertainties in the jet performance these measurements are of significance only in illustrating the experimental technique. A solid-fuel rocket motor was used as the primary source of the jet flow.

© *Crown Copyright 1967*

Published by
HER MAJESTY'S STATIONERY OFFICE

To be purchased from
49 High Holborn, London W.C. 1
423 Oxford Street, London W. 1
13A Castle Street, Edinburgh 2
109 St Mary Street, Cardiff
Brazennose Street, Manchester 2
50 Fairfax Street, Bristol 1
35 Smallbrook, Ringway, Birmingham 5
7-11 Linenhall Street, Belfast 2
or through any bookseller