C. P. No. 679

C. P. No. 679

MINISTRY OF AVIATION

AERONAUTICAL RESEARCH COUNCIL

CURRENT PAPERS

A Roll-Balance Free-Flight Test Vehicle for the Measurement of Aileron Rolling Power and Roll Damping at M = 0.8 to 2.5

By

K. J. Turner

LONDON HER MAJESTY'S STATIONERY OFFICE

1965

FOUR SHILLINGS NET

U.D.C. No. 533.6.011.35/5 : 533.6.013.413 : 533.694.511 : 533.6.055

C.P. No. 679

March, 1958.

A ROLL-BALANCE FREE-FLIGHT TEST VEHICLE FOR THE MEASUREMENT OF AILERON ROLLING POWER AND ROLL DAMPING ~~AT M = 0.8 TO 2.5~~

by

K. J. Turner

SUMMARY

The existing roll-balance technique for measuring roll damping has been extended for use at higher Mach numbers and also adapted for the direct measurement of aileron rolling-moment. Two test vehicles have been flown successfully, each carrying a model of a proposed aircraft design; one was used to obtain ℓ_p and the other ℓ_ξ. Results were obtained over the speed range M = 0.8 to 2.2.

LIST OF CONTENTS

LIST OF TABLES

LIST OF ILLUSTRATIONS

1 INTRODUCTION

The roll-balance technique[1,2] has become a simple and well established free-flight method for obtaining roll damping at transonic speeds. The need has arisen, however, to extend the technique to cover Mach numbers of 2.0 and above and concurrently to measure aileron rolling moment at these speeds. Earlier free-flight work on ailerons has been mainly concentrated on the investigation of aileron effectiveness (ℓ_ξ/ℓ_p) at zero lift; this is very easily done by flying non-separating test vehicles fitted with three wings, each having a fixed, pre-set aileron[3]. This technique, however, would be rather cumbersome at Mach numbers above 2.0 since either larger rockets or multi-staging would be necessary

A solution to this problem has been found by adapting the roll-balance type of test vehicle to measure the aileron rolling moment.

This note describes the development of the test vehicle and discusses the results from the first two successful models which were intended to be roughly representative of a canard supersonic aircraft design.

2 THE DEVELOPMENT OF THE TEST VEHICLE

The design was based on a solid fuel boost motor which was capable of accelerating the vehicle to about M = 3.0 although the present vehicles were ballasted to restrict their maximum velocity to M = 2.3.

The principle of the experimental method is to measure the rolling moment reaction between the test vehicle and a sting-mounted model (Fig.1). If the vehicle does not pitch or yaw, the measured rolling torque is given by

$$T = I_x \dot{p} + L_p p + L_\xi \xi .$$

For the measurement of roll damping no aileron angle is applied and the model is forced to roll by fixed controls on the rear of the vehicle. Then the damping derivative can be obtained from measurements of T, p and $\dot{p}$. The aileron rolling moment derivative is obtained from a second test vehicle on which the model ailerons are set to the required angle. If the rate of roll of this vehicle can be kept near zero then the aileron rolling moment follows directly from the torque on the sting.

For the roll-damping experiment one of the first problems to solve was that of getting the test vehicle to roll at the correct rate throughout the whole speed range from M = 2.3 down to 0.8. Two requirements had to be met:

(1) The change in rate of roll through the transonic region must not be too sudden; otherwise accuracy is lost because of large inertia correction and difficulty in determining the rate of roll precisely.

(2) The rate of roll should increase gradually as the vehicle decelerates in such a way that the rolling moment on the roll balance is kept fairly constant. If this is not done the subsonic measurements will be so low that they will inevitably lose their accuracy.

Three preliminary rough test vehicles were flown to investigate these rolling characteristics. They were not fitted with models or roll-balance units but each carried four aluminium-alloy fins of the type shown in Fig.1. The sets of fins were of different stiffnesses to obtain data on the aero-elastic effects, since by the correct choice of fin stiffness the second requirement can be met. The best rolling characteristics were achieved with light alloy fins 0.38 inches thick. With thinner fins the rate of roll at the higher Mach numbers was too low. The most flexible fins - made in 0.193 inch light alloy - experienced aileron reversal at about M = 2.8 during the boosting phase (Fig.13).

One unexpected problem that arose was the difficulty in obtaining good roll records from the instrumentation at Aberporth. The roll position, and hence rate of roll, is measured by detecting the minimum signal-strength points when the plane-polarised signal from the test vehicle is orthogonal to the rotating plane-polarised receiver aerial on the ground. This system, however, works properly only when the vehicle axis lies along the axis of the receiver aerial dish. As it strays away from this line a "Hooke's joint" error is introduced and the signal strength falls rapidly. Further errors were suspected from the strong sea-mirror effect reflecting the signal from the vehicle to the receiver by a secondary path. The three preliminary vehicles were flown along a low trajectory (launcher elevation 25°; maximum height 5000 ft) but on later vehicles better roll records were obtained by elevating the launcher to 40° and firing the models up to about 18,000 ft.

Before the present models were flown three attempts were made to measure the roll damping on a typical guided missile design. The vehicles were boosted up to a maximum velocity of M = 2.7, but in each case the model broke away from the sting just before the maximum velocity was reached. Careful examination of the high-speed ciné films showed the vehicles performed a slight barrel roll towards the end of the boost phase which probably initiated the failure of the sting by a combination of aerodynamic and centrifugal forces on the model. In order to prevent this on the present models the maximum velocity was limited to M = 2.3 by the addition of a [illegible] ballast weight, the sting diameter was increased from 0.785 inches to 1.25 inches and great care was taken on the rolling vehicle to ensure that the rocket venturi was accurately aligned with the vehicle axis. These modifications were successful in eliminating the barrel roll and it is hoped that the velocity restriction need not be applied on later test vehicles.

3 DESCRIPTION OF THE TEST VEHICLES

The complete test vehicle is illustrated in Figs.1 and 2 and the major data are listed in Table 1. It is built around a non-separating solid fuel boost motor which carries four stabilising fins at its rear end. For roll-damping experiments each of the fins has its tip bent to form a 45 degree delta aileron but for the aileron rolling-moment experiments the fins are left flat. The ballast weight and roll-balance unit are screwed to the front of the rocket. A diagram of the roll-balance is given in Fig.3; it is similar, in principle, to that described in Ref.1 but has been re-designed to withstand the extra loads experienced at the higher Mach numbers. The sensitive element is a torsion bar which is supported in 3 ball-race bearings and anchored at the rear; the model is screwed and pinned to the forward end. The angle of twist of the torsion bar is detected by an inductance transducer which amplitude modulates the carrier wave of the 465 Mc/s telemetry set over the frequency range 130 to 160 Kc/s. The whole range of the instrument is covered by 0.35 degrees twist and the stiffness can be easily adjusted by suitable choice of the torsion bar diameter. Shortly before flight the roll-balance unit is calibrated by applying a range of rolling moments to the model and noting the output frequency. This test is repeated with side forces of 50 lb applied to the model, to check that the balance is insensitive to such forces as will arise in flight from centrifugal loading if the vehicle barrel rolls.

Two spike aerials are mounted at the rear of the telemetry housing, and each has a reflector aerial mounted 11 cm in front of it to improve the radiation strength rearwards.

Two flares are fitted to the fin assembly to assist visual tracking.

4 DESCRIPTION OF THE MODELS

The models are illustrated in Figs.4 and 5 and major data are listed in Table 2. They were representative of a possible design for a supersonic aircraft but were simplified by making all the aerofoil surfaces of trapezoidal section and mounting the wing on the body centre-line at zero incidence. The structure was kept as light as possible to minimise the bending moment exerted on the sting by centrifugal forces. The bodies were machined from hollow magnesium alloy castings, the wings and fin were of aluminium alloy but the foreplane had to be of steel to prevent leading-edge tip divergence. The nacelles were made of aluminium alloy tube spun over at the leading edge to produce the correct lip angle and entry area associated with the centrebody used.

Model 1, for measuring ℓ_p, had the ailerons set to zero and was mounted on its sting at a roll angle of 30° relative to the boost fins to ensure that they were not in the wake of the model wings (Fig.1). Any small asymmetry in flow over the boost fins could initiate a small barrel roll; this must be avoided at all costs.

Model 2, for measuring ℓ_ξ, had the tip-ailerons set at 5° to produce a rolling moment to port. On this vehicle the intention was to keep the rate of roll as near zero as possible so the model was mounted on its sting with the wings in line with two of the boost fins; in order that the downwash acting on the fins would produce a rolling moment to starboard tending to cancel the rolling moment produced by the model.

5 ANALYSIS OF RESULTS

5.1 Trajectory data

Both models were fired at an elevation of 40° and were tracked by kinetheodolites for the whole of the flight. The trajectories are plotted in Fig.6. Velocity (Fig.7) was obtained by radio-reflection Doppler corrected for flight path curvature and wind component. The slightly higher velocity and trajectory achieved by model 2, compared with model 1, arises from its lower drag, since no energy is expended in producing a high rate of roll. The roll data (Figs.8 and 9) were obtained from a combination of spinsonde records and high-speed camera records of the flares as viewed from the rear. The roll-receiver aerials were set up at 40 degrees elevation which enabled the roll record to be read for the first 19 seconds of flight. Beyond this point (corresponding to about M = 1) the trajectory curved over rapidly and the roll record became unreadable. The mean flight path elevation for the first 10 seconds of flight was about 32 degrees; some further improvement in the roll telemetry reception might therefore be obtained by raising the launcher elevation to 45 degrees to bring the flight path more closely in line with the roll-receiver axis.

The results have been completely analysed for the first 30 seconds of the flight only (M = 2.3 to 0.8).

5.2 Roll damping (model 1)

The equation for the single-degree-of-freedom rolling motion of model 1 is,

$$I_{xx}\dot{p} + L_p p = T$$

where T is the rolling moment reacted by the model onto the boost rocket and is measured by the roll balance. The inertia term, however, is so small compared with T (less than 0.5%) that it can be neglected. Then,

$$\ell_p = \frac{T}{\frac{1}{4}\rho V b^2 S p} .$$

Atmospheric data are obtained from a radiosonde balloon shortly before firing.

The roll-damping derivative is plotted in Fig.11 and the corresponding tip helix angle in Fig.10.

5.3 Aileron rolling moment (model 2)

The rolling equation for model 2 is

$$I_{xx}\dot{p} + L_p p + L_\xi \xi = T .$$

Again the inertia term can be neglected and, for this particular vehicle, the damping term also; since the rate of roll was so low (Fig.9) that L_p p was less than 0.4% T in the worst case.

Then,

$$\ell_\xi = \frac{T}{\frac{1}{2}\rho V^2 S b \xi} .$$

This derivative is plotted in Fig.[illegible]

If the rate of roll, and hence the damping term, had not been negligible it could, of course, have been allowed for using the damping data obtained from model 1. In this case the correction would have been negative since the vehicle was rolling in the direction opposed to the aileron deflection.

6 DISCUSSION OF RESULTS

6.1 Flight behaviour

For the roll-damping experiment it is essential that the vehicle rolls accurately about its axis. If it does not, the model describes a barrel roll which introduces errors from the yawing component of the motion and the centrifugal forces exerted on the sting may be large enough to break it. Our experience on these and earlier damping test vehicles indicate that, to achieve the required accuracy of rolling, the following rules must be observed:

(a) The longitudinal pitching frequency of the test vehicle must be kept well below the rolling frequency at all Mach numbers.

(b) There must be no 'bow' in the boost motor.

(c) The venturi axis must be accurately aligned with the axis of the boost, typically to within $\pm\frac{1}{4}$ degree.

(d) The boost fins must be aligned within ±2 minutes relative to the vehicle axis and the tip aileron angles must not differ more than ±5 minutes relative to each other.

Close examination of the high-speed camera records of model 1 disclosed no measurable barrel rolling at all. The rate of roll of model 2 was extremely low; the model made only one revolution in the first 15 seconds of flight. For such a vehicle the roll-damping moment on the wings may be neglected and the aileron rolling moment can be obtained directly from the firing of one test vehicle only. This may be very desirable for some types of test where various roll-producing devices are being investigated since it is the damping experiment with its requirement of a high rate of roll which is the difficult one to do.

6.2 Roll damping results

The experiment was, of course, done at zero incidence and the result has been compared in Fig.11 with estimates based on linearised theory for the damping at subsonic speeds and at M = 2.5. While there is fair agreement at M = 2.5, the subsonic measurement appears to be about 40% below the estimated value. The sudden drop in ℓ_p on decelerating through M = 1.0 is believed to be a genuine result as the balance unit has a very rapid response and the drop is clearly shown on the telemetry record. The magnitude of the rolling moment being measured in this test varied between 1.5 and 5.0 ft lb and the tip helix angle (Fig.10) between 0.5 and 1.5 degrees.

6.3 Aileron rolling moment results

The experimental result (Fig.12) agrees very closely with a theoretical estimate except, again, at subsonic speeds. This probably indicates that there is some subsonic flow separation from the sharp leading-edge of the very thin wing section.

This type of aileron, incorporating a fairly large all-moving tip, does succeed in maintaining a high effectiveness in the supersonic region and should therefore provide adequate lateral control at the top end of the speed range. It is, perhaps, worth noting that the parting line between the wing and the aileron horn was sealed by a small fence. This was done to give some support to the aileron leading edge which otherwise might have failed through divergence.

The rolling moments measured varied between 3.0 and 12.0 ft lb.

6.4 Accuracy

Since the main object of these experiments was to prove the technique, only rough models were used and no claim is made concerning the accuracy of the final ℓ_p and ℓ_ξ curves with regard to an aircraft of this particular configuration. It is possible, however, to say something about the possible accuracy of the technique for future tests.

The measurements of velocity and atmospheric data follow well-established range practice and can yield Mach number to about ±0.5%. The rate of roll can be obtained within ±2%.

The limiting factor on the roll balance unit is hysteresis, which on the present vehicles was reduced to within 1% of the full scale deflection. Thus it should be possible to measure the ℓ_p and ℓ_ξ derivatives on a given model to within ±4%. The major factor is, however, the accuracy of the model and particularly the absence of wing twist on the damping model since the tip helix angle is so small. If we assume a typical mean helix angle of 1 degree it is obvious that very high standards of accuracy will be required to eliminate any spurious moments arising from wing setting errors.

7 CONCLUSIONS

A fairly simple and straightforward free-flight technique for the measurement of roll-damping and aileron rolling-moment has been developed. Some care has to be taken in the accurate assembly of the test vehicles but practical workshop tolerances have been established as a guide.

The vehicles should be fired on a high trajectory with a launcher angle of about 45 degrees and the roll receiver aerial must be closely aligned with the expected flight path.

The results from one pair of models indicate that accurate measurements of roll-damping and aileron power can be obtained from M = 0.8 to 2.2 and that the maximum velocity can probably be increased to M = 3.

LIST OF SYMBOLS

b	model span
I_{xx}	inertia of model about its rolling axis
L_p	rolling moment due to rate of roll
ℓ_p	non-dimensional roll damping derivative
L_ξ	rolling moment due to aileron angle
ℓ_ξ	non-dimensional aileron rolling moment derivative
p	rate of roll
R_a	Reynolds number based on standard mean chord
S	model gross wing area
T	torque reaction between test vehicle and model
V	true flight path velocity
ξ	aileron angle
ρ	local air density

LIST OF REFERENCES

No.	Author	Title, etc.
1	Turner, K.J. and Herbert, P.J.	Development of a Transonic Research Technique using ground-launched rocket-boosted models. Part III. Measurement of roll damping. ARC.19060 June, 1956.
2	Bland, W.M. and Sandall, C.A.	A technique utilising rocket-propelled test vehicles for the measurement of the damping-in-roll of sting mounted models and some initial results for delta and unswept tapered wings. NACA Tech. Note 3314. May, 195[illegible]
3	Lawrence, T.F.C. and Swan, J.	Development of a transonic research technique using ground-launched rocket-boosted models. Part I. Control effectiveness measurements. ARC.13740 July, 1950.

TABLE 1

Test vehicle data

Overall length - (without model)	150 ins
Span	33.8 ins
Inertia in pitch	221 slug ft^2
Flares - two 30 second magnesium	

TABLE 2

Model data

Weight	3.7 lb
Inertia in roll	0.0025 slug ft^2
Span	10.93 ins
Wing area (gross)	58.2 sq ins
Aspect ratio	2.0
Length	26 ins
Aileron angle (model 2)	5 degrees
Aerofoil section - trapezoidal 3% $^t/_c$	

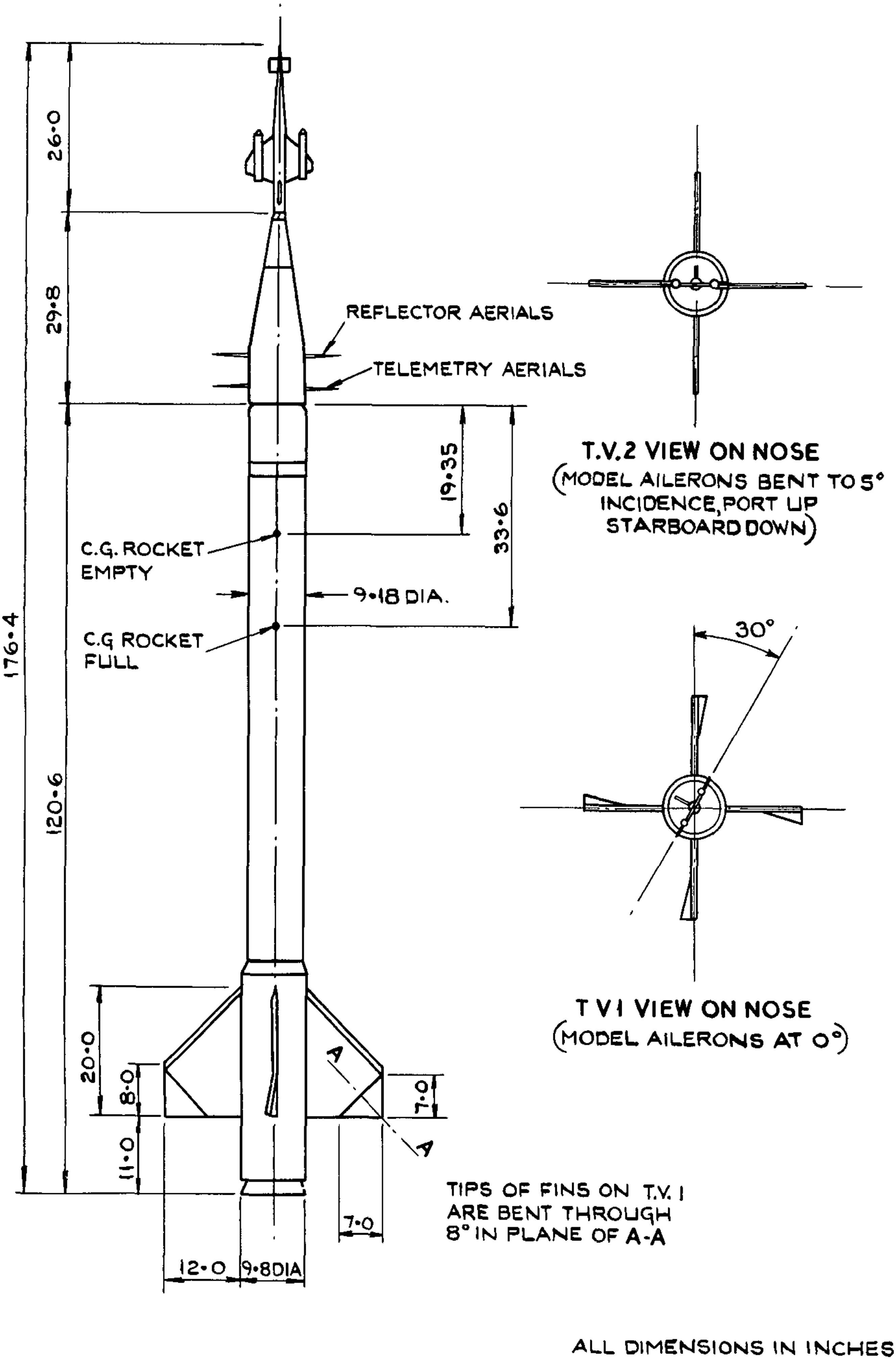


FIG. I. GENERAL ARRANGEMENT OF TEST VEHICLES I & 2.

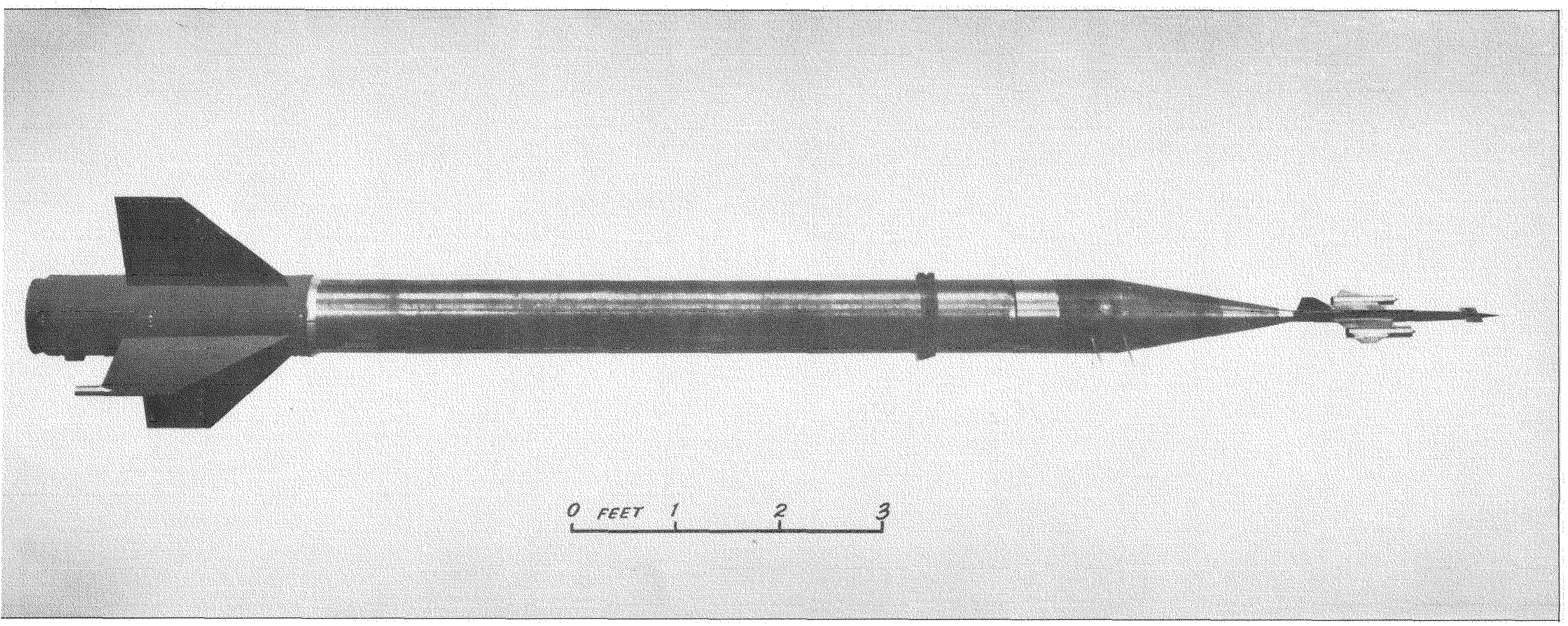


FIG.2. TEST VEHICLE 2 (FOR MEASUREMENT OF ℓ_ξ)

NOTE:- TEST VEHICLE 1 (FOR MEASUREMENT OF ℓ_p) IS IDENTICAL, APART FROM HAVING TIP AILERONS ON THE FOUR BOOST FINS

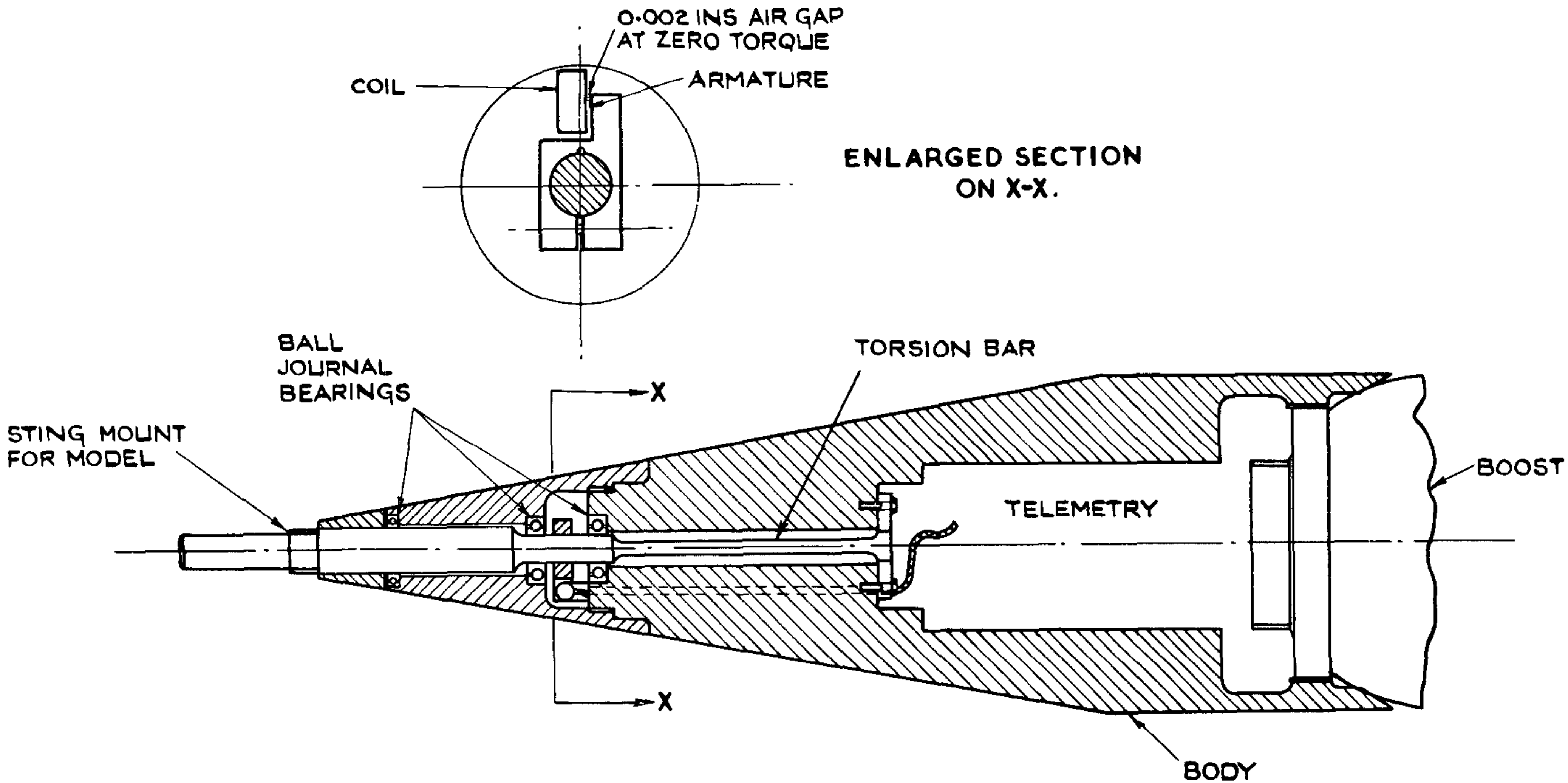


FIG. 3. DIAGRAM OF ROLL- BALANCE MECHANISM.

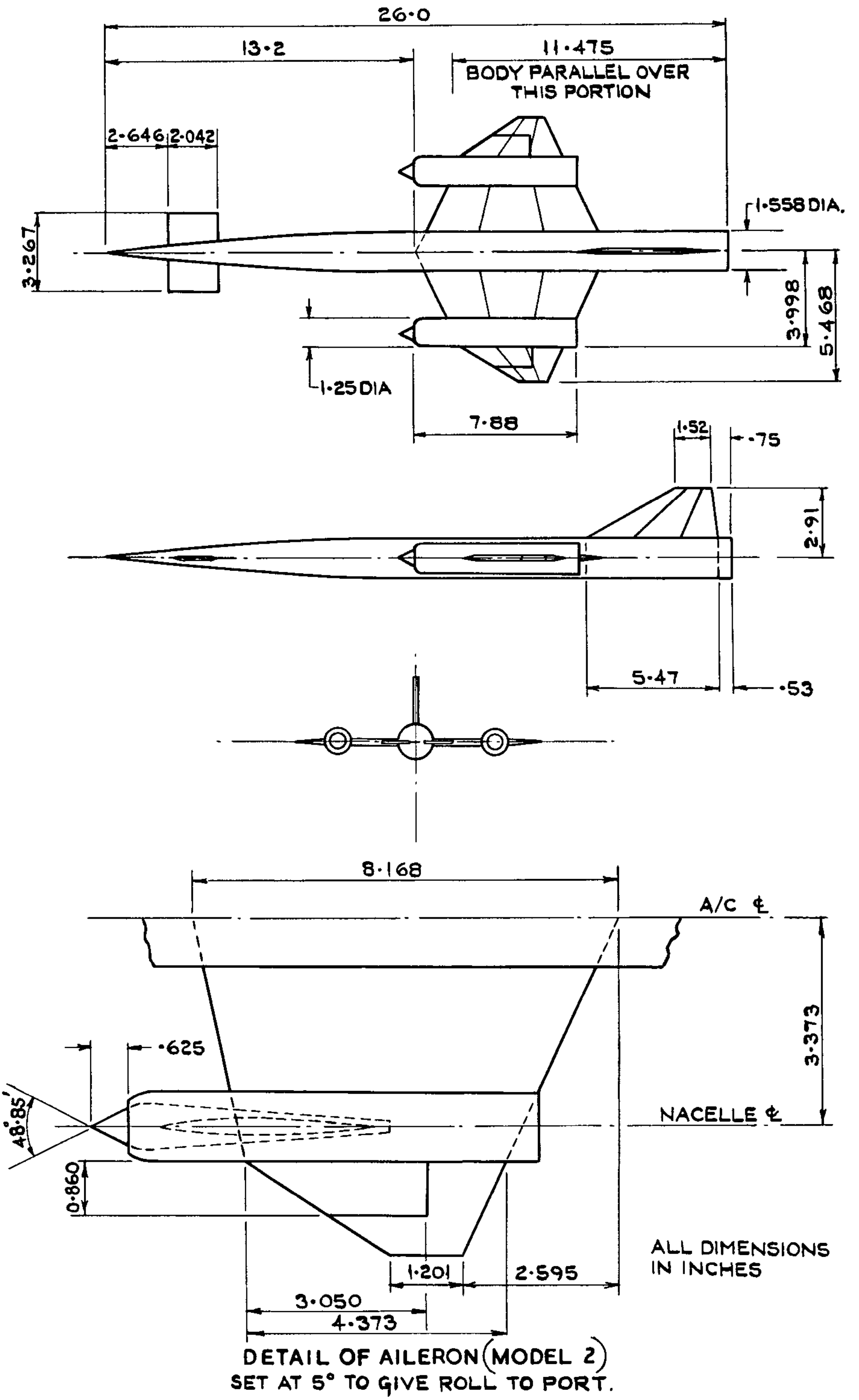
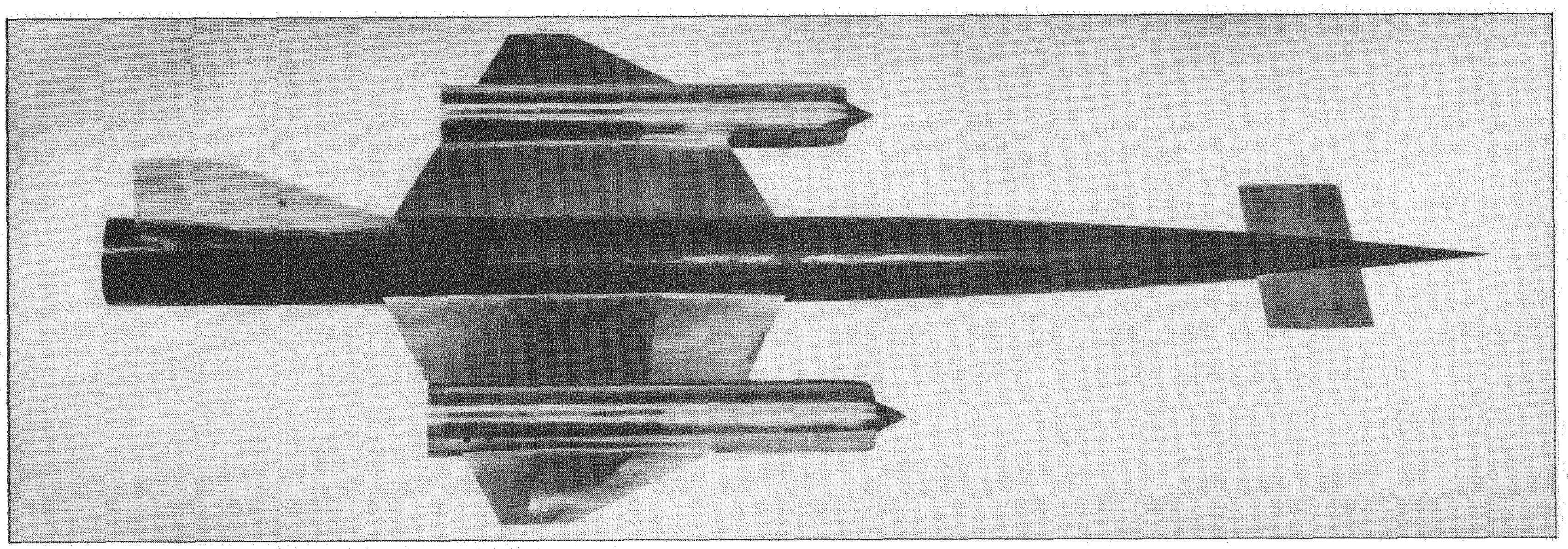
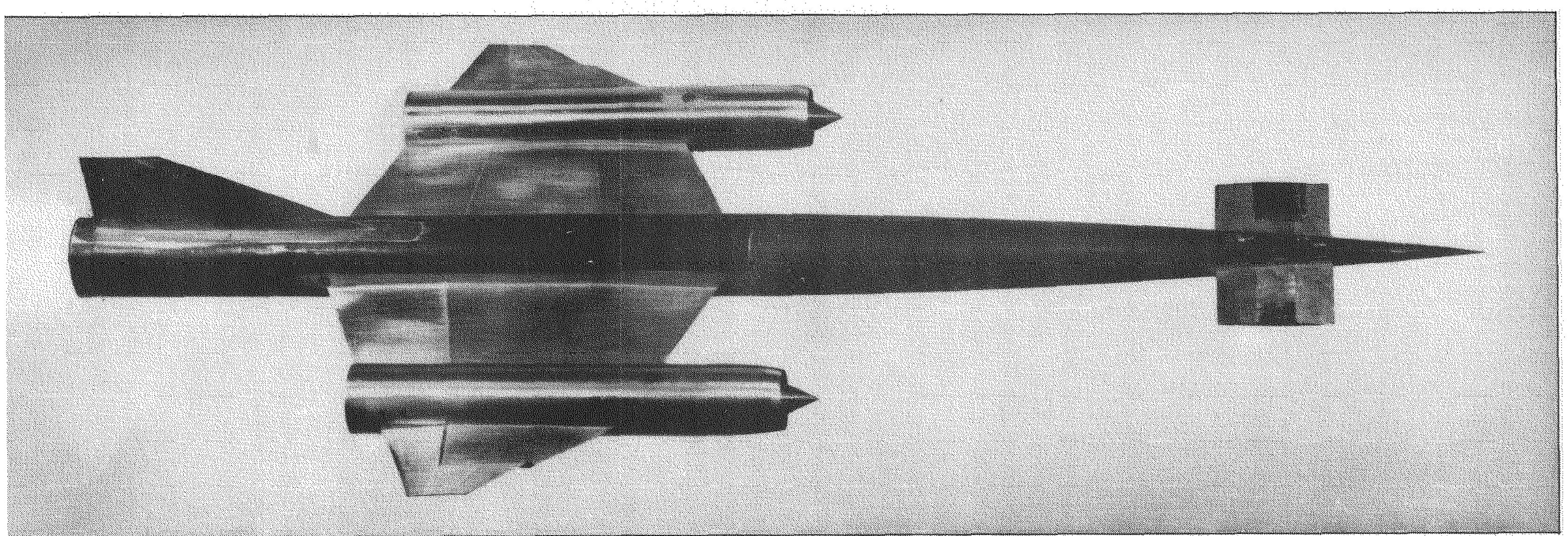


FIG. 4. GENERAL ARRANGEMENT OF MODELS 1 & 2.



a. ROLL DAMPING MODEL (MODEL 1)



b. AILERON ROLLING MOMENT MODEL (MODEL 2)

FIG.5a & b. MODELS 1 & 2

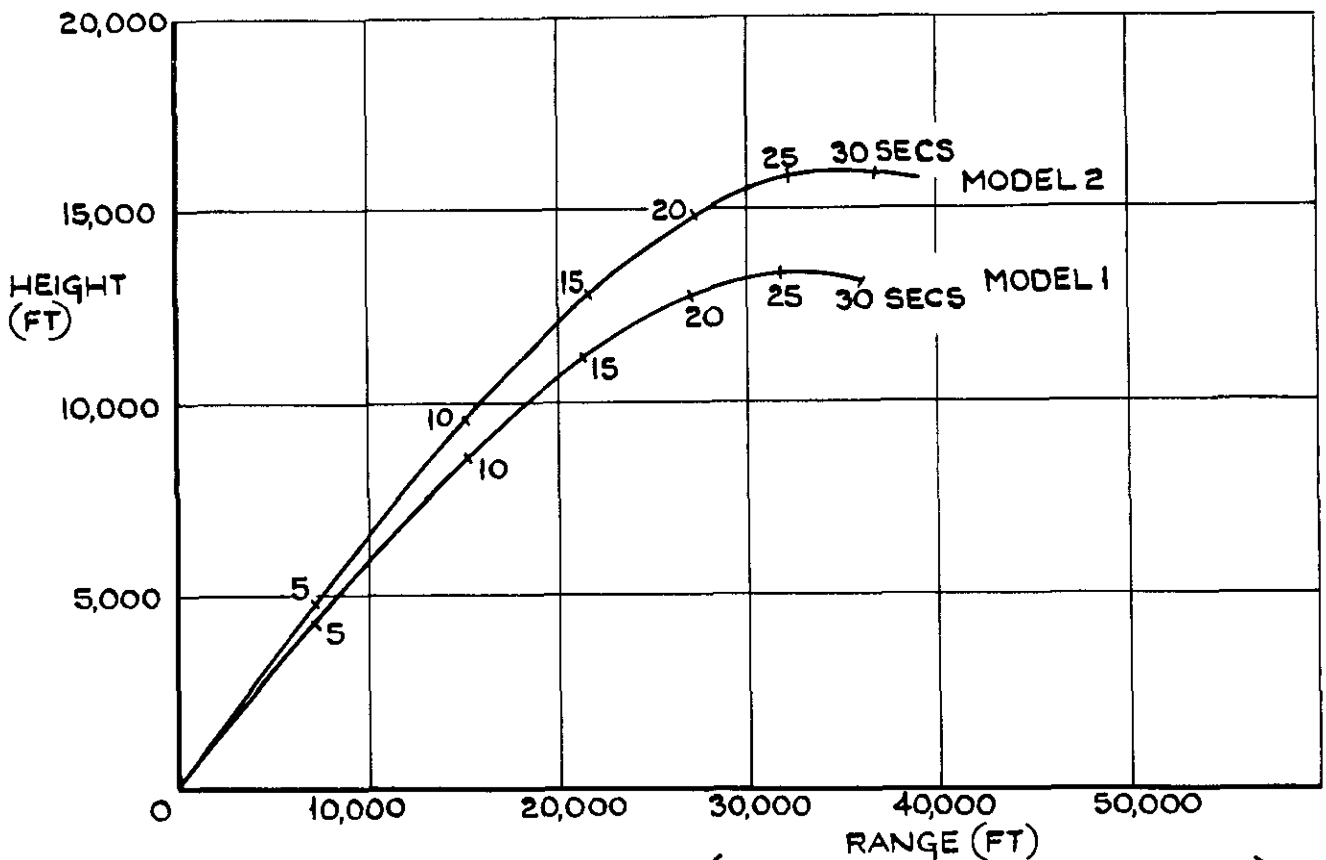


FIG. 6. TRAJECTORY (40° LAUNCHER ELEVATION)

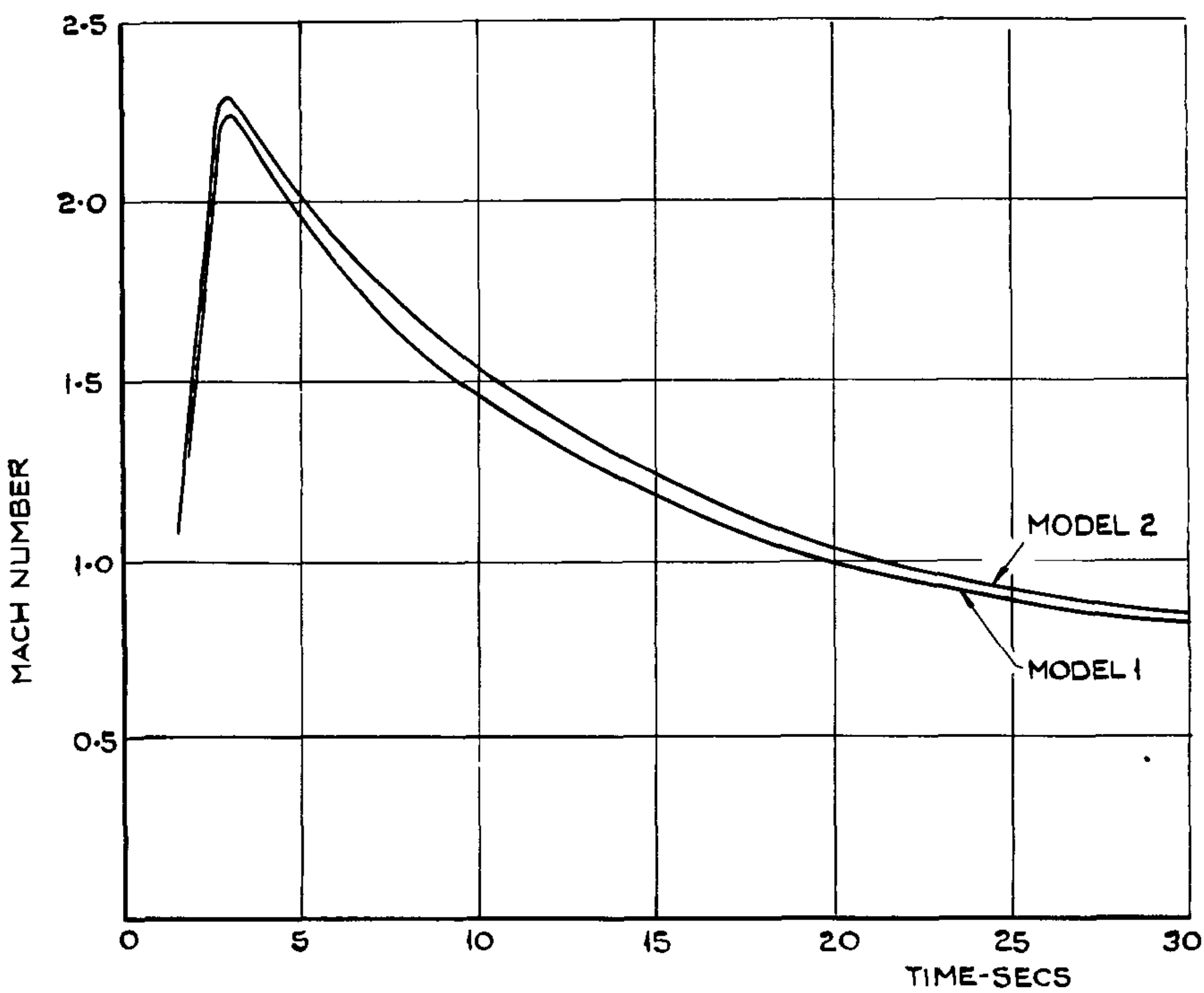


FIG. 7. MACH NUMBER.

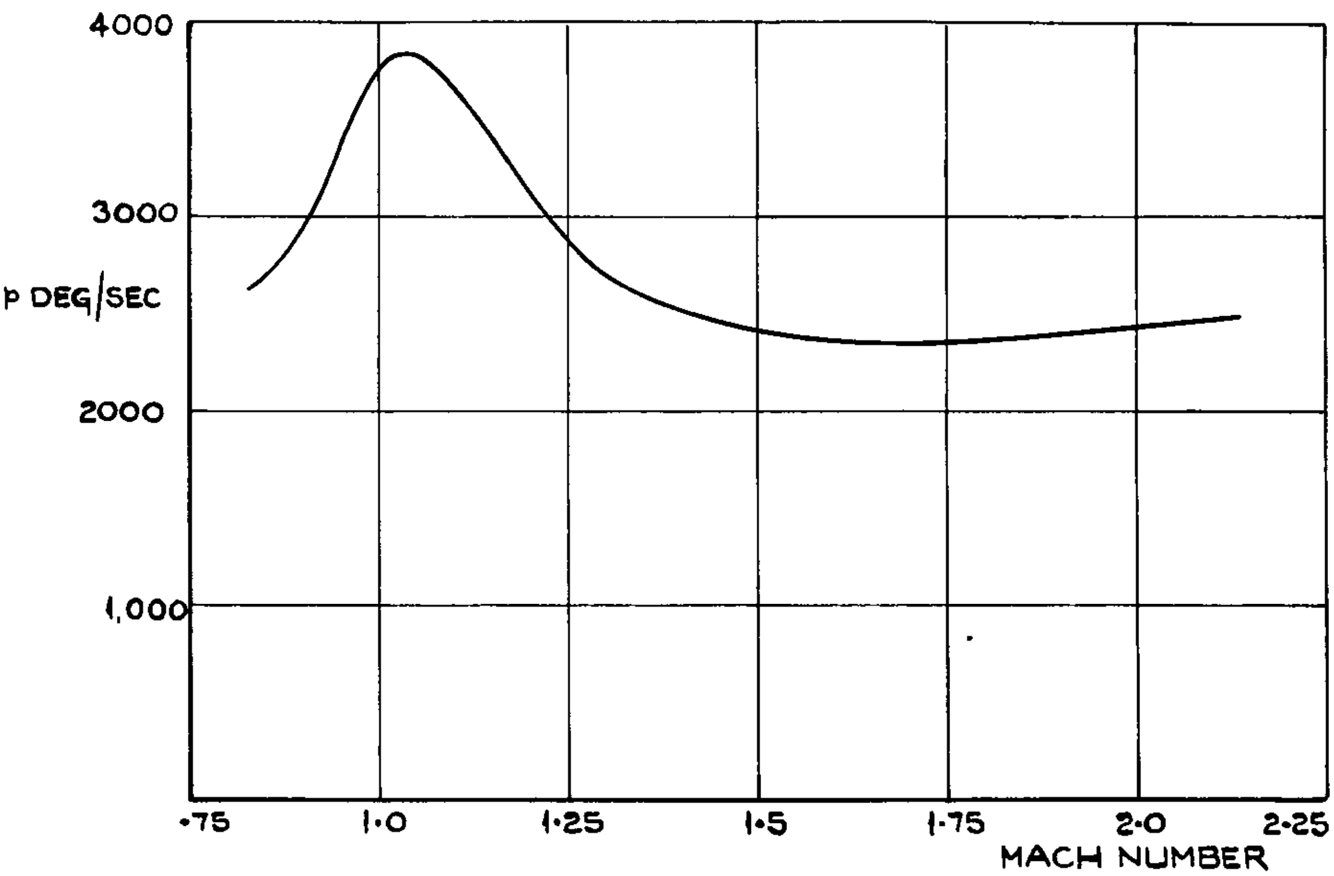


FIG. 8. RATE OF ROLL (MODEL. 1.)

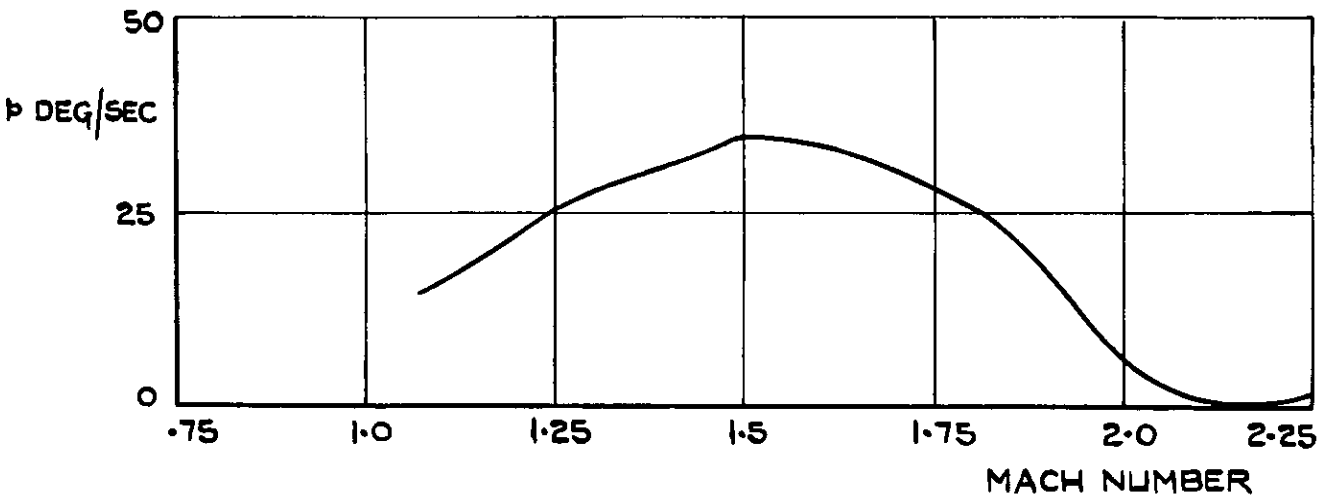


FIG. 9. RATE OF ROLL (MODEL 2)

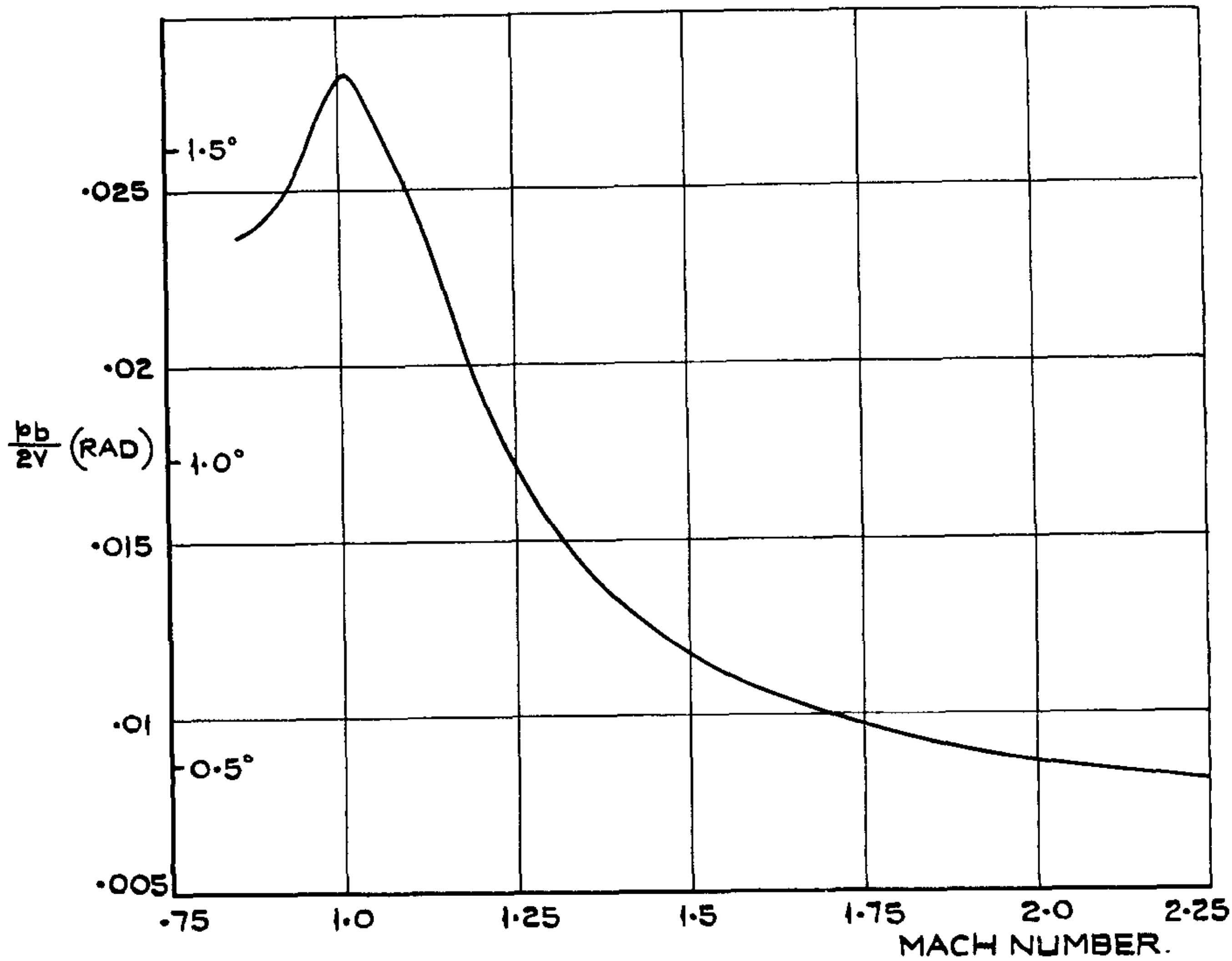


FIG.10. TIP HELIX ANGLE (MODEL.1.)

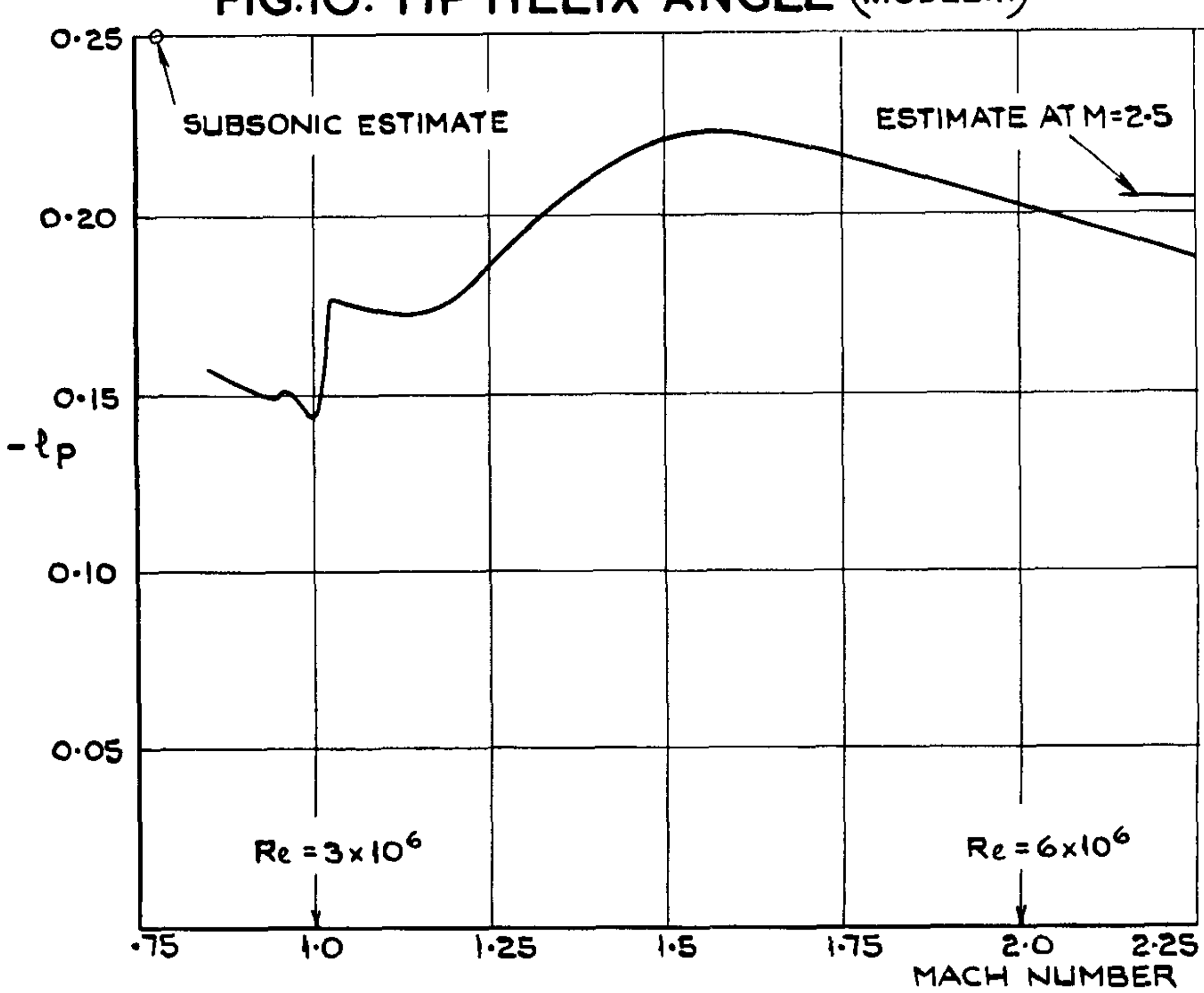


FIG. 11. ROLL DAMPING (MODEL.1)

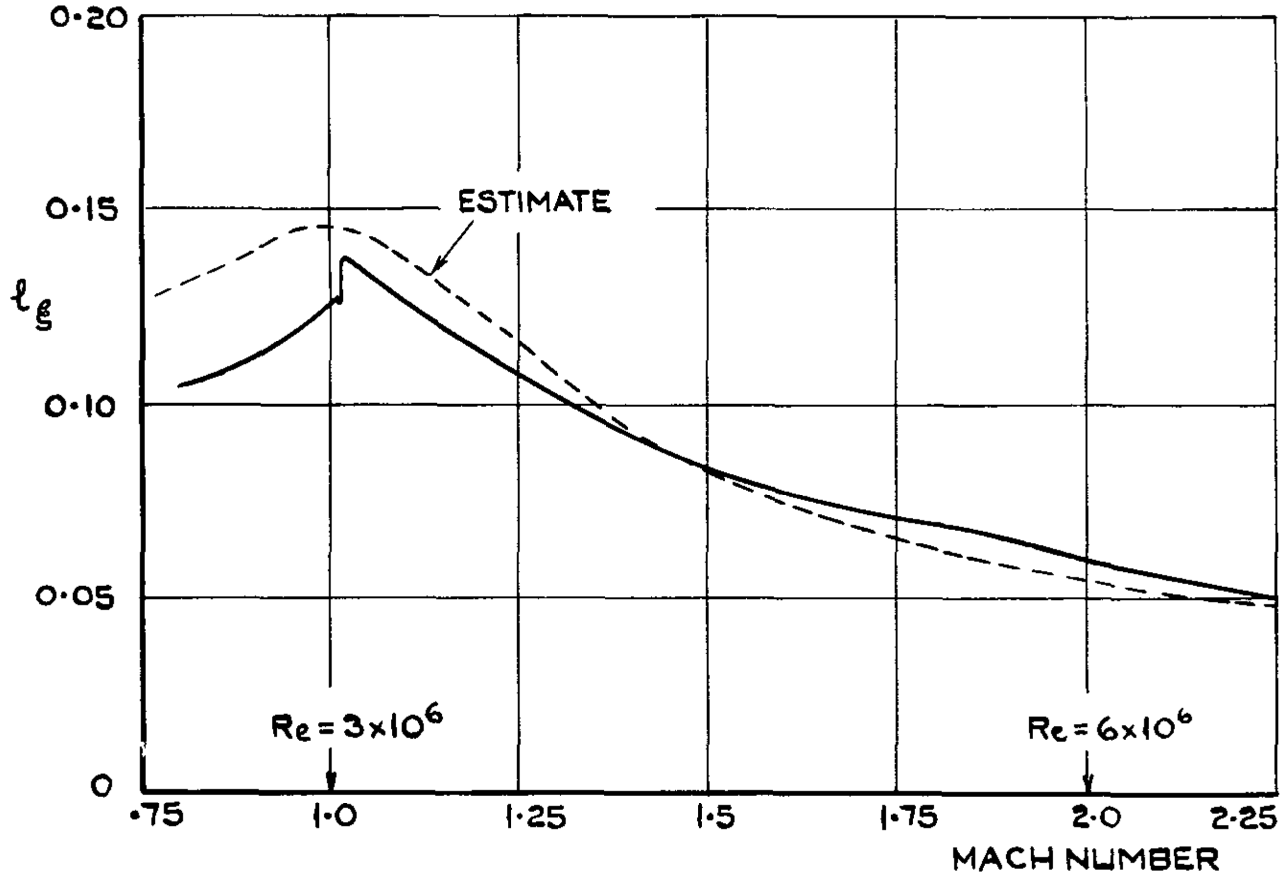


FIG. 12. AILERON ROLLING MOMENT (MODEL 2)

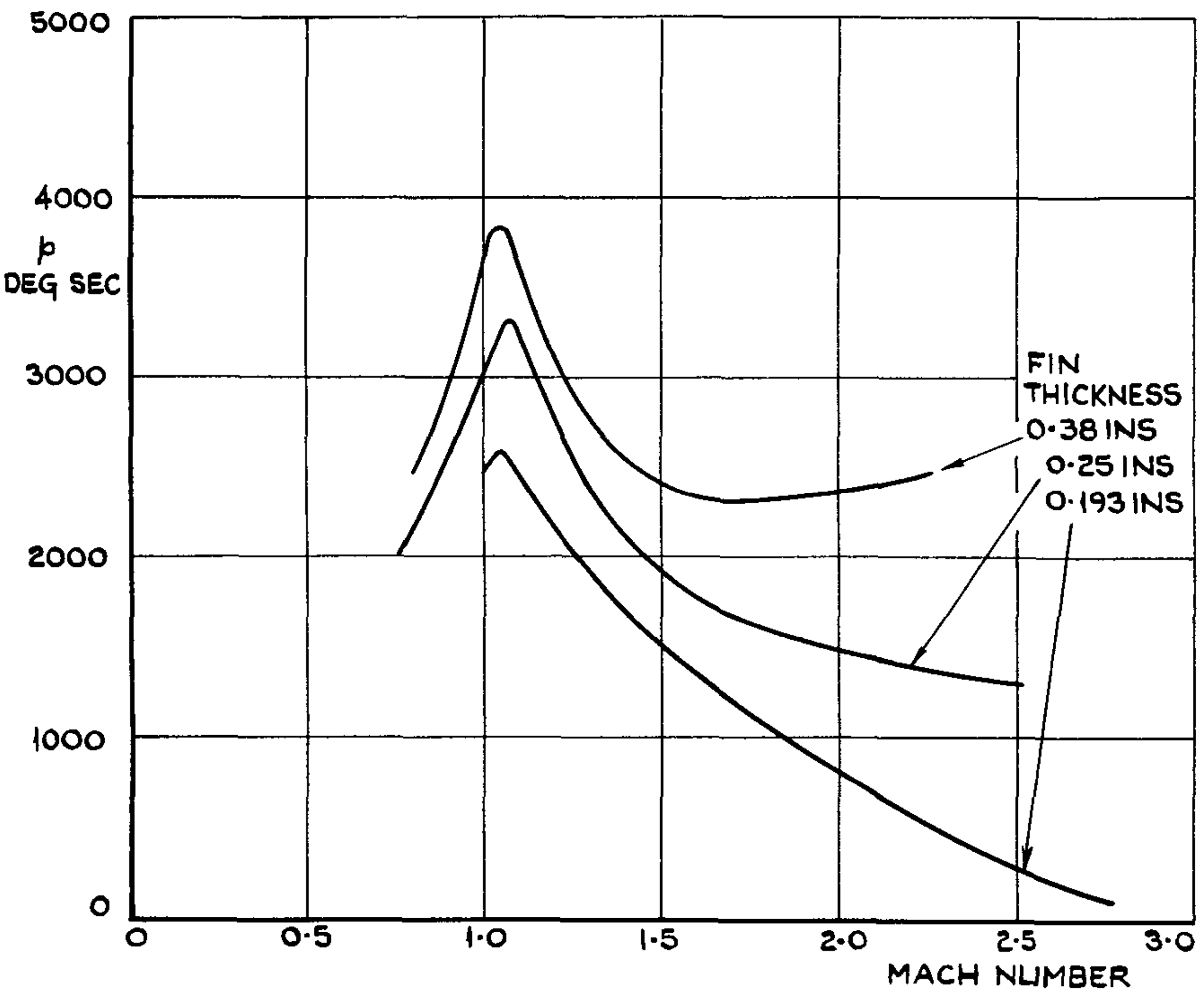


FIG. 13. RATE OF ROLL OF PRELIMINARY TEST VEHICLES.

A.R.C. C.P. No. 679

533.6.011.35/5
533.6.013.413
533.694.511:
533.6.055

THE MEASUREMENT OF AILERON ROLLING POWER AND ROLL DAMPING BY FREE-FLIGHT MODELS AT MACH NUMBERS UP TO 2.5
Turner, K.J. March, 1958.

The existing roll-balance technique for measuring roll damping has been extended for use at higher Mach numbers and also adapted for the direct measurement of aileron rolling-moment. Two test vehicles have been flown successfully, each carrying a model of a proposed aircraft design; one was used to obtain ℓ_p and the other ℓ_ξ. Results were obtained over the speed range M = 0.8 to 2.2.

A.R.C. C.P. No. 679

533.6.011.35/5:
533.6.013.413.
533.694.511:
533.6.055

THE MEASUREMENT OF AILERON ROLLING POWER AND ROLL DAMPING BY FREE-FLIGHT MODELS AT MACH NUMBERS UP TO 2.5
Turner, K.J. March, 1958.

The existing roll-balance technique for measuring roll damping has been extended for use at higher Mach numbers and also adapted for the direct measurement of aileron rolling-moment. Two test vehicles have been flown successfully, each carrying a model of a proposed aircraft design; one was used to obtain ℓ_p and the other ℓ_ξ. Results were obtained over the speed range M = 0.8 to 2.2.

A.R.C. C.P. No. 679

533.6.011.35/5:
533.6.013.413:
533.694.511:
533.6.055

THE MEASUREMENT OF AILERON ROLLING POWER AND ROLL DAMPING BY FREE-FLIGHT MODELS AT MACH NUMBERS UP TO 2.5
Turner. K.J. March, 1958.

The existing roll-balance technique for measuring roll damping has been extended for use at higher Mach numbers and also adapted for the direct measurement of aileron rolling-moment. Two test vehicles have been flown successfully, each carrying a model of a proposed aircraft design; one was used to obtain ℓ_p and the other ℓ_ξ. Results were obtained over the speed range M = 0.8 to 2.2.

C.P. No. 679

Published by
HER MAJESTY'S STATIONERY OFFICE
To be purchased from
York House, Kingsway, London, W.C.2
423 Oxford Street, London, W.1
13A Castle Street, Edinburgh 2
109 St. Mary Street, Cardiff
39 King Street, Manchester 2
50 Fairfax Street, Bristol 1
35 Smallbrook, Ringway, Birmingham 5
80 Chichester Street, Belfast 1
or through any bookseller

C.P. No. 679

S.O. Code No. 23-9013-79