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REPORT BIBLIOGRAPHY ON ZERO LAUNCH UNCLASSIFIED
Recd. from Astia July 29, 1958

AD-107-828
Continental Army
Command Board # 4

Test of zero length launcher for OQ-19 target drones
31 July 1956 33 p. incl. illustrations

"A description is presented of evaluations on a zero launcher for OQ-19 target drones and of procedures for aligning the jato bottle onto the drone. The launcher is of a simple steel framework construction which can be trained in the vertical plane to various preset angles. The 2½ x 7 foot launcher can be mounted on a trailer truck or a fixed foundation. The jato carrier consists of 2 circular supports and a cup to house the jato bottle and two support arms which are attached to fittings installed on the drone sides. The jato bottle is positioned at the aft end of the drone as an extension of the centreline axis of the fuselage. Fifteen zero-length launchings of OQ-19 target drones proved the feasibility of the launcher for use by RCAT detachments. The elimination of the time consuming jato alignment procedure was considered possible by the redesign of the carrier components along with marking the location for the installation of components during production of the target drone. The zero-length launcher system when modified could be considered as a supplement to the RL-2 rotary launcher and as a replacement for the cumbersome A-7 catapult."

AD-92-609
Sperry Gyroscope Co.
~~CONFIDENTIAL~~ UNCLASSIFIED

Design and manufacture of air launching racks for Sparrow I and rework of existing racks for the evaluation program.

"The first launching rack was a narrow pylon-type structure which supported the missile at three points by hook-like devices which were inserted into recesses on the body of the missile. When the missile was modified its centre of gravity was in front of the forward recesses and the first launcher design was abandoned. Ten new launchers of zero-length were designed and built which employed 2 short-pronged forks to engage 2 retractable spring-loaded buttons on the missile. The second design restricted missile launching conditions and a launcher of finite length, designated Aero X1A, was conceived. Eleven Aero X1A launchers were designed and built. Prior to completion of the Aero X1A launchers it was decided to rework the 10 zero-length launchers into a design resembling the Aero X1A. In both configurations the missile is fastened to a sled which rides in a long rail on the bottom of the launcher; on firing, the missile and sled move forward three feet, when the sled is snubbed to a stop and the missile continues forward. In the reworked launchers the dynamic impact loads on the sled were in excess of its strength. The Aero X1A launcher rack is narrow, stressed skin structure approximately 3.5" wide by 6" high by 101" long. It weighs about 58 lbs. Major component assemblies of the launcher are:1.structure assembly, 2. sled assembly, 3. buffer assembly, 4. detent assembly, 5. umbilical plug and lifting mechanism, 6. jettison assembly, 7. landing lock assembly, 8. sway brace assembly, 9. cable assembly and 10. indicator switch assembly. Functions and design details of the components are described."

AD-41 041
Northrop Aircraft Inc.
CONFIDENTIAL
UNCLASSIFIED

Clearance study of N-69 C, D, and E missiles with zero-length and short rail launchers (using reduced thrust boosters) F.G. England Nov. 53. Illus.

AD-26 037
Northrop Aircraft Inc.
CONFIDENTIAL
UNCLASSIFIED

XB-62 preliminary analysis of a zero length launching with jetavator control. L.E. Hamilton & R.A. Branker. 13 Jan. 54

"Launching of the XB-62 missile is accomplished by a zero-length launching system which uses a rotating arm or a short rail type launching platform with 2 jatos attached directly to the fuselage. A preliminary analysis was conducted to determine the relative merits of an auxiliary control for the present system. This control is a ring type jet reflector (jetavator) which is mounted on the jato nozzles. Analysis indicated that the sidewind tolerance is increased from 6 to 20 knots by using the jetavator. For a 20 knot tail-wind tolerance, the allowable alignment error in pitch is increased from 0.38 deg. to 0.55 deg. A headwind produces no adverse effects on the launching. The wind tolerances and allowable alignment errors can occur simultaneously or in any combination that does not exceed any of these tolerances separately. A more effective jetavator is under study."

AD-18 367
Northrop Aircraft Inc.
CONFIDENTIAL
UNCLASSIFIED

Design test of snubbing system and instrumentation on N-73 zero launcher. F.Q. Banker, R.D. Glascock & H.F. Kale 2 Feb. 53 47 p. Incl. Illus.

"This test was conducted to establish the pressures required in the snubbing system and the suitability of design of the launcher instrumentation. A secondary test of Northrop relief valve shear pin 2114796 was conducted to establish shear data required in the design of the snubbing system relief valve. The test specimen consisted of Northrop Zero Launcher 3508 including 5001162 launcher assembly, 5111022 mechanical installation, 5111578 potentiometer installation and 5111577 camera installation. The test setup and procedure are outlined. Five free-fall tests were conducted as a functional check of the snubbing cylinders and the pressure relief valve mechanisms. The fifth free-fall with a precharge pressure of 15 ps and an effective rod length of 2.44" actuated the relief valves Accelerated fall tests were also conducted. Part of these tests were constructed to produce a tangential velocity of 31 fps with a minimum mechanical rebound. The remaining tests were performed to cover a tangential-velocity range. The test conditions, the resulting tangential velocity and the mechanical rebound of the accelerated falls are given. Precharge pressures greater than those indicated by the safe-operation range may result in non-operation of the snubbing system. Precharge pressures less than those indicated by the safe -operation range may cause excessive mechanical rebound. Tolerances in the system do not permit consistent operation at pressures low enough to give rebounds of less than 6 deg. A memorandum report on zero launcher 3507 is included."

AD-38 587
Naval Personnel
Research Unit,
San Diego, Calif.
UNCLASSIFIED
~~CONFIDENTIAL~~

Basic occupational data on guided missiles.III Regulus-XSSM-N-8 (Revised) Paul W. Athan & Robert P. Green
Sep. 53 Illus.

"A compilation is given of information on the Regulus missile obtained from several sources with the use of various data-gathering techniques. The Regulus is a surface to surface guided missile whose general configuration is similar to a small jet aircraft. The missile which is capable of carrying a 3000 lb payload 500 naut. mi. has a 21 ft. wing spread and an overall length of 34 ft. The missile will exist as a tactical and assault weapon, a drone pilotless aircraft and a flight-test vehicle. The major components of the missile are summarized and the tasks involved in the operation of these components are described. Charts are given which present the overall Regulus missile program. The catalog also includes a general overview of the missile program and a discussion of the general considerations involved in performing research during the test and evaluation phase; a series of charts which discuss the overlap of related duties performed by existing ratings and the duties required by Regulus missile personnel; a chart which traces the flow of the missile from the time it leaves the manufacturer until it is launched; a glossary of guided missile terms as well as all terms encountered in the Regulus study; and a bibliography of technical materials."

AD-6177
Naval Air Missile
Test Center, Point Mugu

Tests of Regulus short-length launching configuration.
Donald E. Power 16 Feb. 53 Illus.

"A rail-type launcher designed and built by the Naval Aircraft factory at Philadelphia provides a guided travel of 12 ft, is fixed in azimuth and elevates to 30 deg. for missile launching. The weight of the launcher is 18,650 lb. The operation of the launcher, using dummy missiles, was satisfactory during tests. The flight paths of the missiles were satisfactory in both azimuth and elevation. The jato units separated cleanly from the first two missiles, but did not separate from the third missile. Newly developed igniters with low ignition-schock characteristics were used in the jato boosters."

AD-19 633
Chance Vought Aircraft
UNCLASSIFIED
~~CONFIDENTIAL~~

XSSM-N-8 Regulus. Tech. progress report No. 5 1 Jan - 30 June 53 124 p. Illus.

"The Regulus program for 1 Jan. 53 through 30 June 1953 is reviewed. The Regulus is a transonic, turbojet powered surface-to-surface guided missile. Tactical Regulus can be launched from a short-rail launcher located aboard a submarine, a cruiser, an aircraft carrier or a mobile platform at any desired point. The flight-test version of Regulus can be launched in the same manner and, in addition is equipped with a landing gear for conventional runway take-off and recovery. As of 30 June 1953 a total of 53 flights were attempted, 43 of which were considered successful. Thirty seven of the Regulus flights ended with recovery of the vehicle tested, and six of the flights were intentional dive-to-impact missions."

AD-4840
Chance Vought Aircraft
CONFIDENTIAL
UNCLASSIFIED

XSSM-N-8 Regulus Prog. Rept. No. 2 1 July - 31 Dec. 51
158 p. Illus.

"Regulus is transonic, turbojet-powered, surface-to-surface guided missile designed to carry a special-type 3000 lb war head to major targets at ranges up to 500 naut. mi. Tactical Regulus can be launched from a short-range launcher located aboard a submarine, a cruiser, an aircraft carrier, or a mobile platform at any desired point.The flight-test version of Regulus can be launched in the same manner and is equipped with a landing gear for conventional runway take-offs and recovery. A total of 15 flights were attempted, 14 of which were considered highly successful and 13 of which ended with complete recovery of the vehicle."

AD-48 512
Air Proving Ground Command
CONFIDENTIAL
UNCLASSIFIED

Operational suitability test of the B-61A weapon system.
Flash Rept. No. 1 12 July 54 Illus.

"Tests were conducted to evaluate the B-61A zero-length launcher blast shields and the RATO booster ejector head. With and without the blast shields on the launcher, damage occured to the external power and fire control cables and to the warhead winch cover. It was concluded that the blast shields which are a part of the B-61A tactical launcher and the ejector head which separates the expended Rato booster from the Airborne B-61A can be eliminated. Recommendations were made that, 1. the blast shields and the ejector head be eliminated and 2. the modifications described be incorporated in future B-61A launchers."

AD-142 434
Northrop Aircraft Inc.
SECRET
UNCLASSIFIED

XSM-62 missile AF53-8184 (N-3321) Unclassified title by D.J. Deering Flight Test Rept. 23 Aug. 57 Illus.

A flight test was proposed for the AF53-8176 missile to determine the integrated missile systems operating characteristics. The missile was successfully launched from a short rail mobile launcher, remained in flight 3.4 sec. and impacted about 680 ft. downrange from the launcher. Data were obtained to partially evaluate the operation of the Mk. I guidance system in an N-69E series missile. All major subsystems functioned satisfactorily except the flight-control system. A reorientation of the pitch-rate gyro between the D and E series missile with neither a wiring or a check-out procedure modification resulted in a reversed polarity of the pitch rate signal; this caused divergent control response of the jetavators and elevons which resulted in the loss of the missile. The loss of 115-v, 400-c power to the afterbody telemetry system resulted in the loss of all commutated data at 1.15 sec."

AD-49 413
Air Force Missile
Test Centre
Patrick A.F. Base
CONFIDENTIAL
UNCLASSIFIED

Modified B-61A flight test results -Aug. 53 - April 54 (Unclassified title) R.M. Gray, and David W. Jones Summary rept. Aug. 54 70 p. Illus.

"Flight test data were obtained from 40 launchings of the modified B-61A weapon system in an evaluation of the in-flight reliability and accuracy of the B-61A system (excluding the warhead). The airborne portion of the system consists of pilotless aircraft utilizing a turbojet engine for cruise and a solid booster rocket for takeoff from a zero-length launcher. Of 27 flights covered, 13 were successful; 6 of these fell within 3175 ft. and 7 within 3500 ft. of the mean point of impact. On the basis of these flights, the minimum in-flight reliability of the system accuracy is that 50% of the successful missiles launched can be expected to strike within 3400 ft. of the target if the target is the mean center of impact. The inflight reliability and accuracy of the B-61A weapon system are considered to limit its combat effectiveness. The missile control and guidance systems appear to be the predominant contributors to the system unreliability, and the guidance error and the terminal dive error are major contributors to the system miss-distance. The major cause of the guidance error came from the MSQ guidance system's inability to determine aircraft location in space during flight."

AD-23 360
Northrop Aircraft Inc.
SECRET
UNCLASSIFIED

Clearance study of N-69 C,D and E missiles with zero-length and short rail launchers (using reduced thrust boosters) F.G. England Nov. 53 72 p. Illus.

A study was made of the conditions that must be met at ambient temperatures of -10 deg. F to permit the missile to clear the launcher satisfactorily. The X226A1 boosters are used on the Northrop N69C missile to launch it from a zero-length launcher. The X226A3 boosters are used on the Northrop N69D and N69E missiles to launch them from a short-rail launcher. Equations were derived for the motion of the N69C missile and the motion was plotted as a funtion of booster forces at -10deg F. The basic geometry showing the relationship between the boosters and the missile was determined."

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AVRO AIRCRAFT LIMITED
MALTON – ONTARIO
TECHNICAL DEPARTMENT

AIRCRAFT: ARROW 2A		REPORT NO. 72/STAB/45	
		SHEET NO. 1	
		PREPARED BY	DATE
		D.L. Martin	Sept '58
		CHECKED BY	DATE

ARROW 2A ZERO LENGTH LAUNCH

1. Introduction

This is a preliminary investigation of the dynamics of the Arrow 2A, zero length launch. The trajectory and time histories of the incidence, pitch angle, velocity, etc., have been determined for the standard launch and for launches on hot and cold days. The effects of misalignment of the booster thrust axes and of movements of the aircraft centre of gravity have also been determined.

The effects of control by the pilot or by the flying control damping system have not been considered.

It must be emphasised that changes in geometry in launching altitude, in c.g. position, weight and inertia will probably occur as the design becomes finalised and in this case the responses presented here will become less accurate. The purpose of the analysis was to estimate the allowable tolerences for the rocket booster thrust alignment and for the combined centre of gravity position, in order that the flight during the boost phase should be acceptable. This purpose has been fulfilled.

2. Contents

Fig. 4 (Cont'd)

4.5 Variation of Flight Path Angle with Time
4.6 Variation of Rate of Pitch with Time
4.7 Variation of Normal Acceleration with Time
4.8 Variation of Longitudinal Acceleration with Time

Fig. 5 Effect of Temperature

5.1 Trajectory
5.2 Variation of Airspeed with Time
5.3 Variation of Angle of Pitch with Time
5.4 Variation of Angle of Incidence with Time
5.5 Variation of Flight Path Angle
5.6 Variation of Pitch Rate with Time
5.7 Variation of Normal Acceleration with Time
5.8 Variation of Longitudinal Acceleration with Time

Fig. 6 Response to Misalignments causing Maximum Yawing Moment

6.1 Trajectory
6.2 Yaw Angle
6.3 Sideslip Angle
6.4 Roll Angle
6.5 Rate of Yaw
6.6 Rate of Roll
6.7 Lateral Acceleration

Fig. 7 Response to Misalignments causing Maximum Rolling Moment

7.1 Trajectory
7.2 Yaw Angle
7.3 Sideslip Angle
7.4 Roll Angle
7.5 Rate of Yaw
7.6 Rate of Roll
7.7 Lateral Acceleration

3. References

P/WT/98 N.A.E. Low Speed Wind Tunnel Tests
72/POWER/2 PS-13 Engine Performance
P/AD/96 Elastic Longitudinal Derivatives
P/AD/97 Elastic Lateral Stability Derivatives
70/AD/1 Effects of Open Canopies, Ramp Bleeds, etc.

4. Weight, Inertia, Geometry, Etc.

4.1 Approximate Estimation of Moments of Inertia

Information given in Weights Report Number 7-0400-07-9 for the Arrow 1 at an all-up-weight of 60,000 lb was used as a starting point. This information was:

$$K_x^2 = 42.81 \text{ ft}^2$$

$$K_y^2 = 210.9 \text{ ft}^2$$

$$K_z^2 = 244.3 \text{ ft}^2$$

The radii of gyration of the rockets and installation about the combined centre of gravity position are:

$$k_x = 85'' = 7.08 \text{ ft}$$

$$k_y = 105.3'' = 8.78 \text{ ft} \qquad \text{(see Fig. 1)}$$

$$k_z = 135'' = 11.28 \text{ ft}$$

Weight of the fully loaded aircraft without boosters = 76,855 lb (2385 slug)
Weight of one booster and cradle = 5,500 lb (342 slug)

It was assumed that the additional mass of the Arrow 2A, without the rockets, did not alter the values of the radii of gyration.

Rearward movement of the c.g. due to addition of rockets = 15.07" = 1.255'

Thus the moments of inertia of the aircraft with rockets are:

$$\text{Rolling M of I, } A = 2385 \times 42.81 + 342 \times 7.08^2 = 102{,}100 + 17{,}150 = \underline{119250 \text{ slug ft}^2}$$

$$\text{Pitching M of I, } B = 2385 \times (210.9 + 1.6) + 342 \times 8.78^2 = 507000 + 26380 = \underline{533380 \text{ slug ft}^2}$$

$$\text{Yawing M of I, } C = 2385 \times (244.3 + 1.6) + 342 \times 11.28^2 = 586000 + 43500 = \underline{629500 \text{ slug ft}^2}$$

4.2 Variation in Mass and Moments of Inertia with Time

It was assumed that the weight of rocket fuel was 9,300 lb.

The rate at which this fuel is burnt is dependent upon the temperature as indicated in the table below.

If $\mathring{m}$ is the burning rate in slugs / sec., then-

Depreciation in roll inertia, $\Delta A = \mathring{m} \times 7.08^2$
Depreciation in Pitch inertia, $\Delta B = \mathring{m} \times 8.78^2$
Depreciation in Yaw inertia, $\Delta C = \mathring{m} \times 11.28^2$

These are tabulated below:

Temp °F	Burning Time sec	Rate of Burning lb/sec	Rate of Burning slug/sec	ΔA/sec slug ft²	ΔB/sec slug ft²	ΔC/sec slug ft²
-65	4.55	2045	63.5	3180	4900	8080
+77	3.71	2510	77.6	3900	6000	9860
+120	3.45	2700	83.8	4200	6460	10650

4.3 Centre of Gravity Position as a fraction of M.A.C.

Leading edge of M.A.C. is at station 435.82 inch
Combined c.g. is at station 545.67 inch
Mean aerodynamic chord length = 362.6 inches.
Centre of gravity is at $.303\bar{c}$

4.4 Pitching Moment due to Engine Thrust

The notation and method suggested in report 70/AD/1 (section 6) was employed.

For PS-13 Engines:

$k_1 = 19.485 - h\bar{c} = 19.485 + .303 \times 30.218 = 28.64$ ft.

$k_1 + k_2 = 53.71$ $k_2 = 25.07$ ft.

$f_2 = k_2 \sin \gamma + (h_v - h_j) \cos \gamma$

4.4 (Cont'd)

= 25.07 x .0451 + (9.79 - 8.64) x 1/12 x .9990 = 1.130 + .096 = <u>1.226 ft.</u>

The static thrust of the engines has been obtained from 72/POWER/2

Temp	Thrust
120°F	40000 lb
77°F	44000 lb
-65°F	45600 lb

Therefore on a standard day (77°F) the pitching moment due to the engine thrust = 44000 x 1226 = 53,944 lb. ft.

4.5 <u>Offset of Booster Thrust Line</u>

In order to balance the pitching moment from the aircraft engines at the instant of firing, the rocket booster thrust line will be offset from the combined centre of gravity position. Let the required perpendicular offset be f_3 feet.

Then for balance of moments
$2T_R \cos 28\ f_3 = T_{gross}\ f_2$

Where T_R is the thrust of one booster rocket and T_{gross} is the gross thrust of both engines.

The rocket thrust, T_R, varies with temperature as shown in the table:

Temp	T_R
120°F	143,500 lb
77°F	130,000 lb
-65°F	101,500 lb

4.5 (Cont'd)

Thus for balance at 77°F, $f_3 = \dfrac{53,944}{2 \times 130000 \times .8830} = .2449$ Ft.

5. Longitudinal Response

5.1 Equations of Motion

A step by step analysis which is based upon the following equations has been employed:

$$\mathring{u} = \frac{X - m\,q\,w}{m} \qquad (1$$

$$\mathring{w} = \frac{Z + m\,q\,u}{m} \qquad (2$$

$$\mathring{q} = \frac{M}{B} \qquad (3$$

Where the notation is given in figure (2)

$$X = T_{gross}\cos\gamma - D_{Eng}\cos 1.2\alpha + 2T_R\cos 28^\circ\cos 6^\circ - W\sin\theta + L\sin\alpha - D\cos\alpha \qquad (4$$

$$Z = T_{gross}\sin\gamma - D_{Eng}\sin 1.2\alpha - 2T_R\cos 28^\circ\sin 6^\circ + W\cos\theta - L\cos\alpha - D\sin\alpha \qquad (5$$

$$M = q\,S\,\bar{c}\;Cm_{cg} + D_{Eng}f_1 + T_{gross}f_2 + 2T_R\cos 28^\circ f_3 + \Delta M \qquad (6$$

Where T_R is the thrust of one booster rocket
ΔM is an additional moment due to errors in alignment, etc.

$D_{Eng} = 0$, when $V = 0$, and it has been assumed to be zero at all speeds.

The offset of the rocket booster thrust axes from the c.g., f_3, is such that $-2T_R\cos 28^\circ f_3 = T_{gross} f_2$

5.1 (Cont'd)

$$Cm_{cg} = Cm + cm_q \frac{qc}{2v}$$

Values of the coefficients C_L , C_D and Cm were obtained from P/WT/96 , sheets 1.1c , 2.5 and 8.1 respectively.

The value of Cm_q was obtained from sheet 1.8.1 of report P/AD/98.

Equations (1, (2, and (3 were used to determine u, w, and θ. These gave values for V and α.

$$\alpha = \tan^{-1}\left(\frac{w}{u}\right) \qquad (7$$

$$V = \sqrt{w^2 + u^2} \qquad (8$$

The trajectory was obtained by using the equations

$$\mathring{s} = V \cos(\theta - \alpha) \qquad (9$$

$$\mathring{h} = V \sin(\theta - \alpha) \qquad (10$$

6. Lateral Response

6.1 Equations of Motion

A step by step analysis which is based on the following equations has been employed:

$$\mathring{v} = \frac{Y + mpw - mru}{m} \qquad (11$$

$$\mathring{p} = \frac{L + E\mathring{r}}{A} \qquad (12$$

$$\mathring{r} = \frac{N + E\mathring{p}}{C} \qquad (13$$

The notation is standard and refers to datum line body axes. The terms $E\mathring{r}$ and $E\mathring{p}$ have been assumed to be negligible.

$$Y = mg\ (\phi \cos\theta + \psi \sin\theta) + qS\left(Cy_\beta \beta + Cy_p \frac{pb}{2v} + Cy_r \frac{rb}{2v}\right) + \Delta N \qquad (14$$

6.1 (Cont'd)

$$L = qSb\left(Cl_\beta \beta + Cl_p \frac{pb}{2V} \pm Cl_r \frac{rb}{2V}\right) + \Delta L \qquad (15$$

$$N = qSb\left(Cn_\beta \beta + Cn_p \frac{pb}{2V} + Cn_r \frac{rb}{2V}\right) + \Delta N \qquad (16$$

The terms mg ψ sinθ and $qS\left(C_{y_p} \frac{pb}{2V} + C_{y_r} \frac{rb}{2V}\right)$ have been assumed to be negligible.

The variation of the longitudinal terms with time has been assumed to be that obtained for the trimmed case.

The lateral derivatives have all been taken from P/AD/97, and no allowance was made for the undercarriage.

Equations (11, (12, and (13 giving the acceleration in v, p, and r were used to determine the responses in v, β, ϕ, and ψ.

The equations giving the lateral coordinates of the centre of gravity in space are:

$$\dot{X}' = u \cos\theta \cos\psi + v(\sin\phi \sin\theta \cos\psi - \cos\phi \sin\psi) + w(\cos\phi \sin\theta \cos\psi - \sin\phi \sin\psi) \qquad (17$$

$$\dot{Y}' = u \cos\theta \sin\psi + v(\sin\phi \sin\theta \sin\psi + \cos\phi \cos\psi) + w(\cos\phi \sin\theta \sin\psi - \sin\phi \cos\psi) \qquad (18$$

These are simplified to:

$$\dot{X}' = u \cos\theta \cos\psi \qquad (19$$

$$\dot{Y}' = u \cos\theta \sin\psi + v \cos\phi \cos\psi \qquad (20$$

to give the trajectory in plan view

7. Misalignments in Longitudinal Plane (Standard Day, 77°F)

Variations in the directions of the booster rocket, thrust axes, and movement of the aircraft centre of gravity' allow pitching moments to be produced which cause the trajectory to vary from the optimum path.

7.1 Misalignment of the rocket thrust axes by fifteen minutes of arc and a vertical displacement of the c.g. of 1 inch

Displacement of the thrust axis from the nominal c.g. position is

$$\Delta f_3 = \pm \frac{15}{60} \times \frac{200}{57.3} = \pm .872 \text{ inch}$$

$$\text{Pitching Moment} = \pm 2T_R\ (1 + \Delta f_3)\ \cos 28^\circ\ \cos 6^\circ$$
$$= \pm 2 \times 130000 \times \frac{1.872}{12} \times .8830 \times 9945 = \pm 16{,}600 \text{ lb ft.}$$

8. Misalignments in Lateral Plane (Standard Day 77°F)

8.1 Misalignments of rocket booster thrust axes by 0°15' to give a yawing moment; + 5% variation of rocket thrusts and c.g. offset in Y direction to give additive yawing moment

The care considered is illustrated in figure 3.

a = .872 inch
$b = 1.872 \cos 28^\circ = 1.654$ inch

$$\Delta Y = - .95 \times 2T_R \cos 28^\circ \sin 0^\circ 15' - .05 \times 2T_R \sin 28^\circ$$

$$= -950 - 3050 = \underline{-4000 \text{ lb}}$$

$$\Delta N = .95 \times 2T_R\ \frac{1+a}{12} \cos 28^\circ \cos 6^\circ + .05 \times 2T_R \times \frac{b}{12} \cos 6^\circ$$
$$+ T_{gross} \times \frac{1}{12} = 33800 + 1782 + 3665 = \underline{39{,}247 \text{ lb. ft.}}$$

$$\Delta L = .95 \times 2T_R\ \frac{1+a}{12} \cos 28^\circ \sin 6^\circ + .05 \times 2T_R\ \frac{b}{12} \sin 6^\circ$$
$$+ T_{gross} \cos\gamma \times \frac{1}{12} = 3550 + 190 - 165 = \underline{3575 \text{ lb. ft.}}$$

8.2 Misalignment of rocket booster thrust axes by 0°15' to give a rolling moment; 5% increase in rocket thrusts and c.g. offset in Y direction to give additive rolling moment

It is assumed that the booster rocket, thrust axes are deflected 0°15' in opposite directions in the Z,X plane to give a positive rolling moment.

8.2 (Cont'd)

$$\Delta Y = 0$$

$$\Delta L = 1.05 \times 2T_R\ R\ \sin 0^\circ 15' \cos 6^\circ + 1.05 \times 2T_R \times \frac{1}{12} \cos 28^\circ \sin 6^\circ$$

$$= 2,100 + 8,480 = \underline{10,580 \text{ lb. ft.}}$$

$$\Delta N = 1.05 \times 2T_R \times \frac{1}{12} \cos 28^\circ \cos 6^\circ = \underline{20,000 \text{ lb. ft.}}$$

Where R is distance between booster rocket nozzle and aircraft datum, measured in the Y direction.

9. Conclusions

The initial 5 seconds of flight of the zero length launch has been investigated under standard conditions, with various misalignments, and at extreme temperature conditions. The results indicate that the maximum acceptable tolerences of c.g. positions and rocket motor thrust misalignment should be as follows:

Aircraft c.g.	Longitudinal	± .5% M.A.C.
	Lateral	± 1 inch
	Vertical	± 1 inch

Rocket nozzle misalignment: 15 minutes of arc.

Assuming that no corrective action is initiated by the pilot prior to t = 3 secs (approx V = 160 knots) then, at standard temperature conditions, the above tolerences will produce the following flight envelope : at t = 3 secs :

Height above ground	$53 \text{ ft} < h < 120 \text{ ft}$
Angle of pitch	$+8^\circ < \theta < +38^\circ$
Angle of incidence	$+2^\circ < \alpha < +16^\circ$
Flight path angle	$+5^\circ < \gamma < +23^\circ$
Pitch rate	$q < \pm 10^\circ/\text{sec}$ ✓.
Normal acceleration	$+.3 < \eta < 1.4$
Longitudinal acceleration	$0 < \eta_x < 3.2$
Sideslip angle	$\beta < \pm 7^\circ$
Bank angle	$\phi < \pm 19^\circ$
Roll rate	$p < \pm 15^\circ/\text{sec}$ ✓.
Yaw rate	$r < \pm 10^\circ/\text{sec}$
Lateral acceleration	$\eta_y < \pm .8$

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AVRO AIRCRAFT LIMITED MALTON – ONTARIO TECHNICAL DEPARTMENT		REPORT NO. 72/STAB/45 SHEET NO. 11	
AIRCRAFT:		PREPARED BY	DATE
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		CHECKED BY	DATE

9. (Cont'd)

No allowance has been made for the effect of the damper system.

The responses calculated for the no-misalignment case on hot (120°F) and cold (-65°F) days have been used to estimate the following envelope which allows for temperature variation as well as c.g. movement and thrust misalignment. This has been obtained by simple addition of two individual responses, but will be fairly accurate.

At $t = 3$ secs:

Height above ground	$+18 \text{ ft.} < h < +124 \text{ ft}$
Angle of pitch	$+4^\circ < \theta < +44^\circ$
Angle of incidence	$0^\circ < \alpha < +19.5^\circ$
Flight path angle	$-4^\circ < \gamma < +23^\circ$
Pitch rate	$q < \pm 12^\circ/\text{sec}$
Normal acceleration	$+.2 < \eta < +1.5$
Longitudinal acceleration	$0 < \eta_x < +3.6$

The lateral responses on hot and cold days have not been calculated and so the overall envelope for these cases cannot be estimated.

The thrust line tolerence will be extremely difficult to meet. A slight improvement can be obtained by very accurate control of c.g., by limiting the launchings to one fixed configuration (fuel, equipment), where c.g. position is known to within ± .25 inch in every direction. For the pitching responses, and for the lateral responses where the thrust misalignments produced a yawing moment, the thrust misalignment of 0°15' is equivalent to a c.g. movement of .8 inch. Therefore, reduction of the tolerence on c.g. movement to ± .25 inch will allow the nozzle misalignment to be approximately 0°30'.

For the lateral responses where the thrust misalignment produced a rolling moment, the reduction of the tolerence of the c.g. position to ± .25 inch causes a marked reduction in the out of balance moments, making this an unimportant case.

The calcualations do not include effects of structural deformations due to application of the high rocket thrust. These effects will have to be evaluated accurately and then compensated for by geometrical lay-out of the booster rockets. It has also been assumed that the geometry is such that the thrust from the rocket motors balances the engine thrust on a standard temperature day.

9. (Cont'd)

When allowance is made for temperature variation, the envelope has two critical points, (1), the height gained after 3 seconds may be as low as 18 feet, and (2), the incidence may reach as high as 19.5 degrees (C_L = .88). It follows that the tolerences laid down for c.g. position and thrust misalignment cannot be increased.

Aerodynamic pitching moment, lift and drag are insignificant for the first two seconds of flight and therefore use of the damper system during the launch will only offer very small improvements at 3 seconds.

No allowance has been made for wind velocity, crosswind, or velocity gradient.

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PREPARED BY	D.L. MARTIN
DATE	SEPT 58
CHECKED BY	
DATE	

FIG 1 BASIC GEOMETRY OF BOOSTER ROCKETS

(NOT TO SCALE)

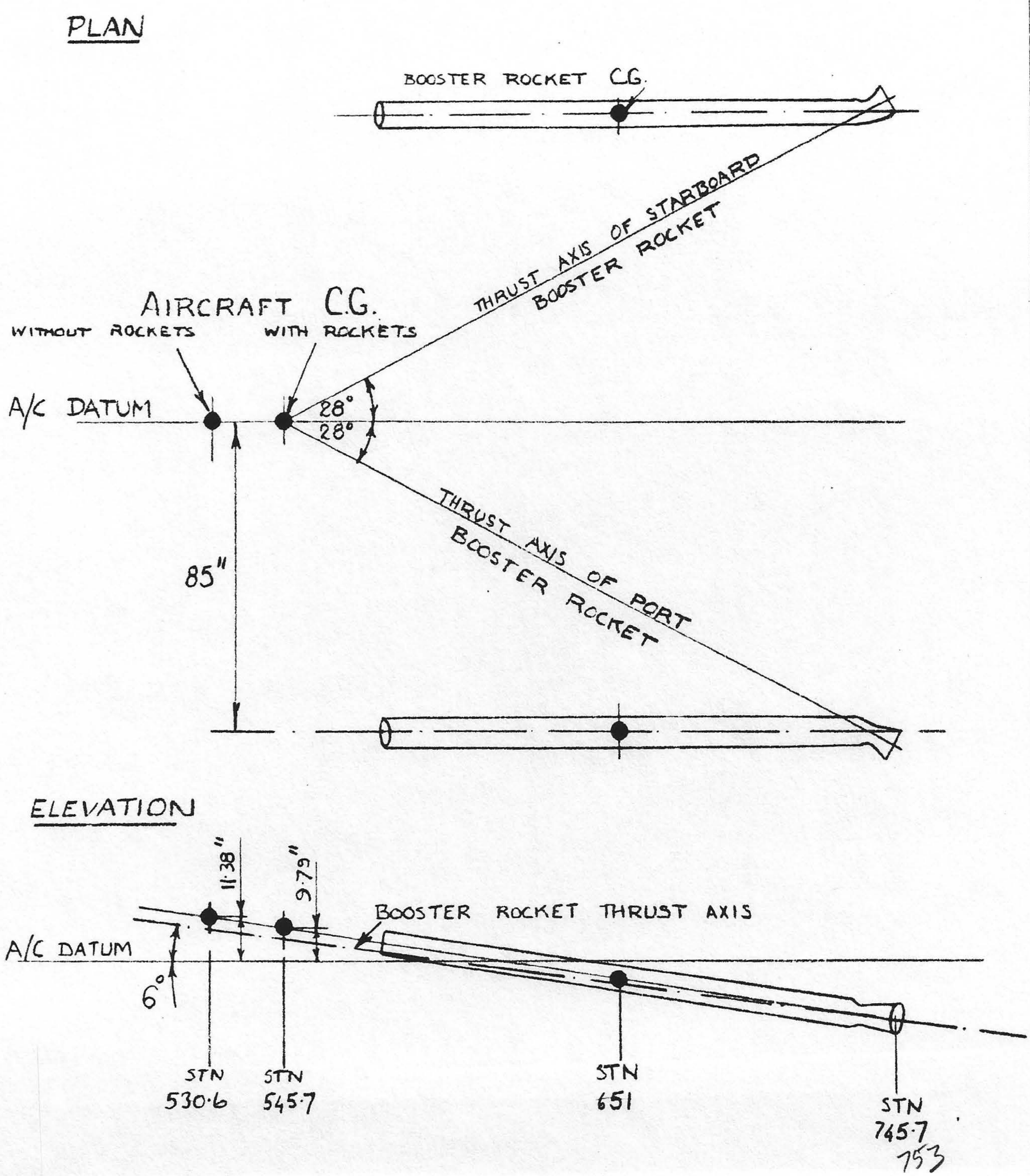
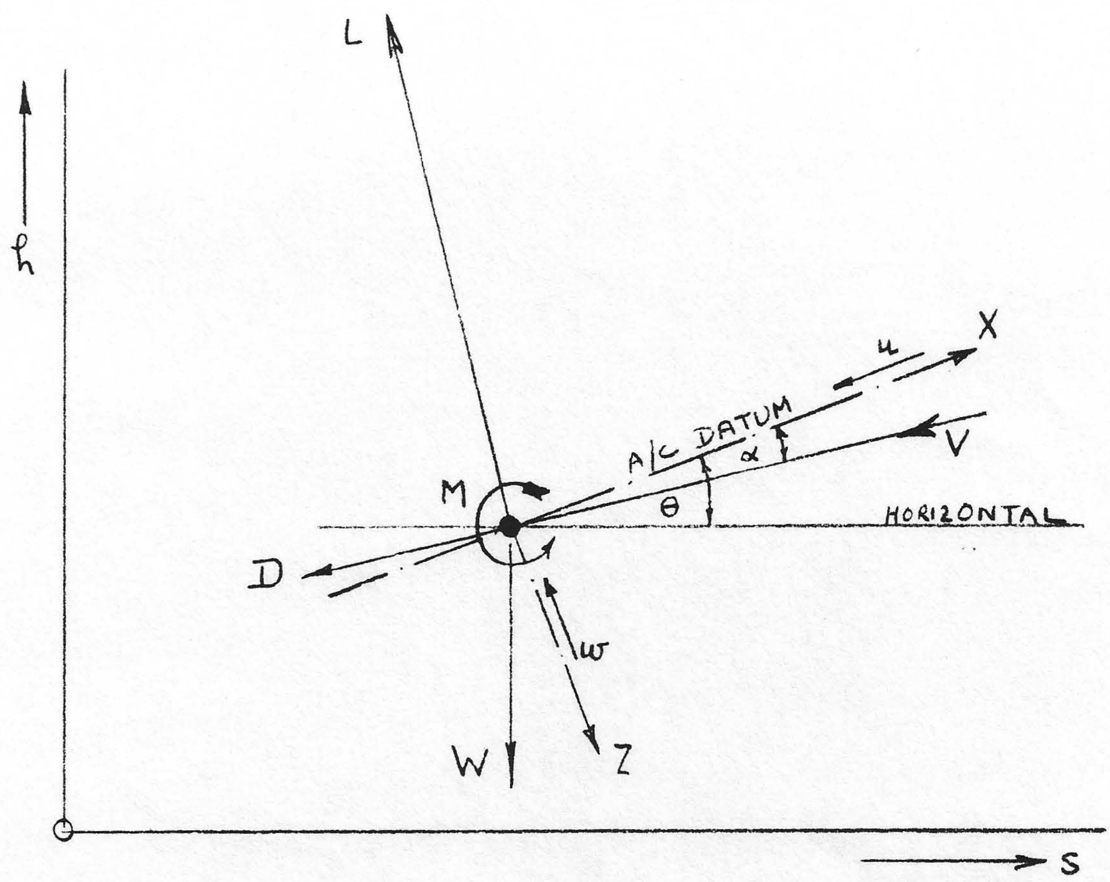


FIG 2

LONGITUDINAL AXIS



L = LIFT

D = DRAG

V = VELOCITY

W = WEIGHT

X = FORCE ALONG A/C DATUM.

Z = FORCE PERP^R TO A/C DATUM

u = VELOCITY ALONG A/C DATUM

w = VELOCITY PERP^R TO A/C DATUM

M = PITCHING MOMENT

S = HORIZONTAL DISTANCE TRAVELLED BY C.G.

h = VERTICAL DISTANCE TRAVELLED BY C.G.

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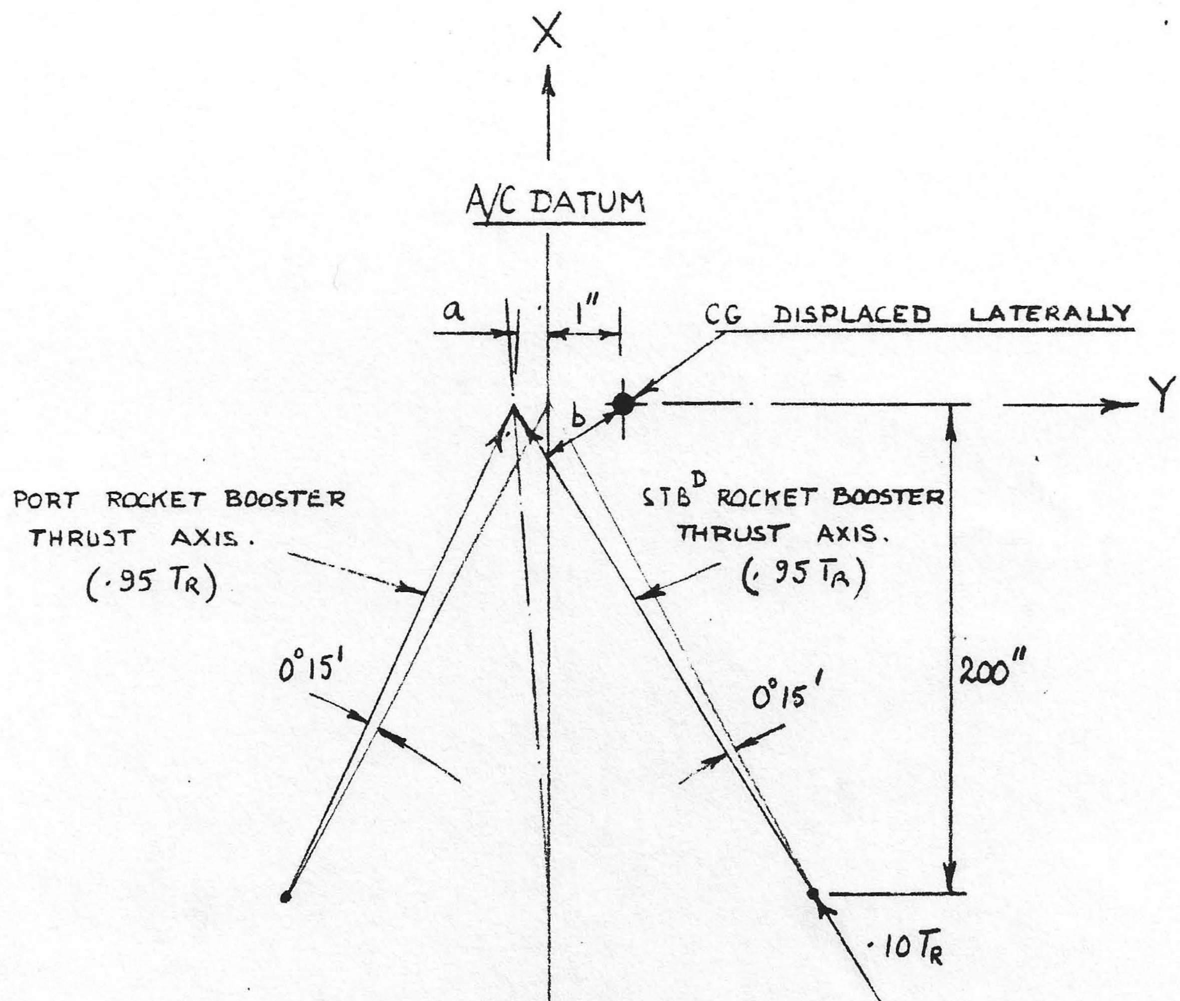
		PREPARED BY	DATE
		D.L. MARTIN	SEPT 58
		CHECKED BY	DATE

FIG 3



MISALIGNMENT GEOMETRY FOR YAWING RESPONSE.

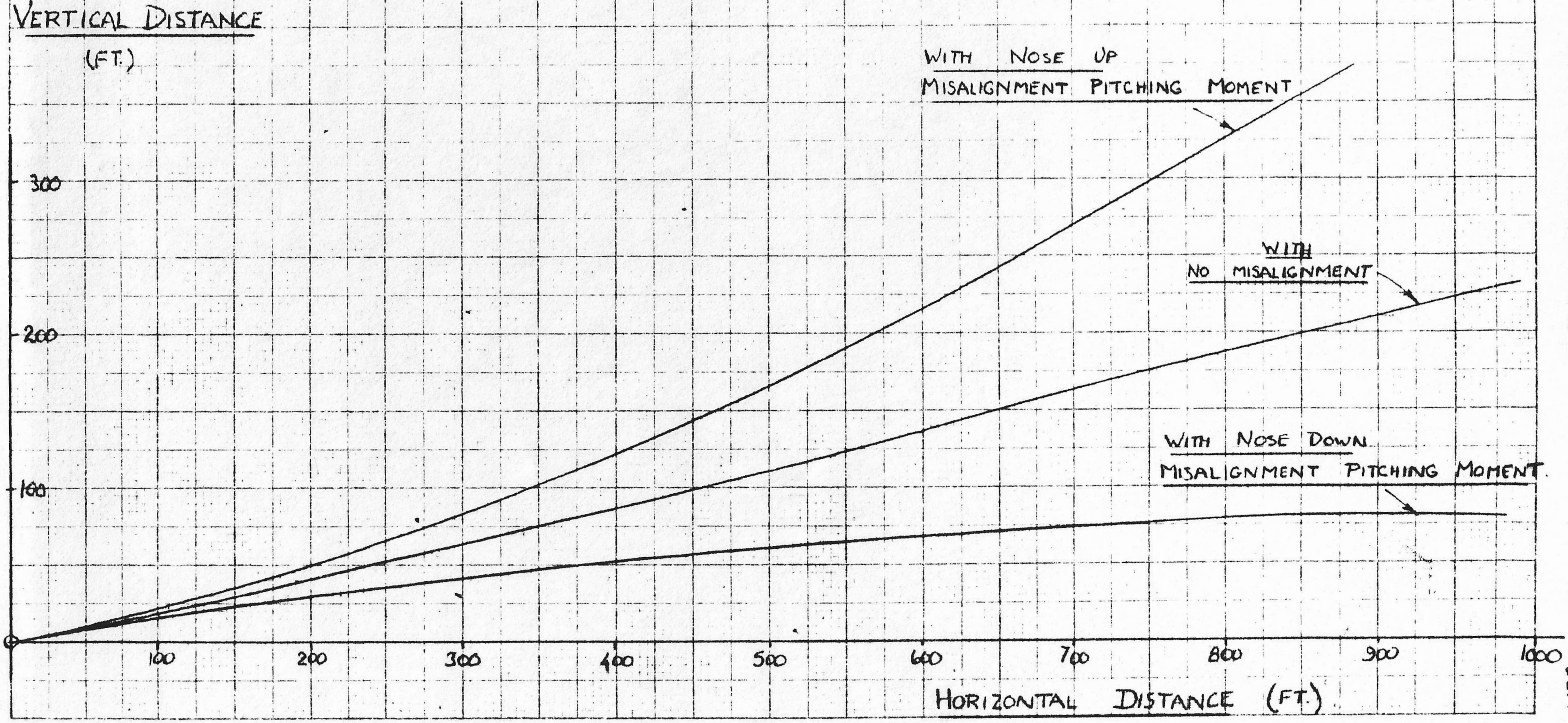
ARROW 2A ZERO LENGTH LAUNCH STANDARD DAY 77°F

FIG 4 RESPONSE TO MISALIGNMENT PITCHING MOMENTS.

(ALL CONTROL ANGLES ZERO).

0°15' THRUST MISALIGNMENT C.G. DISPLACED 1" IN Z DIRECTION

1 TRAJECTORY



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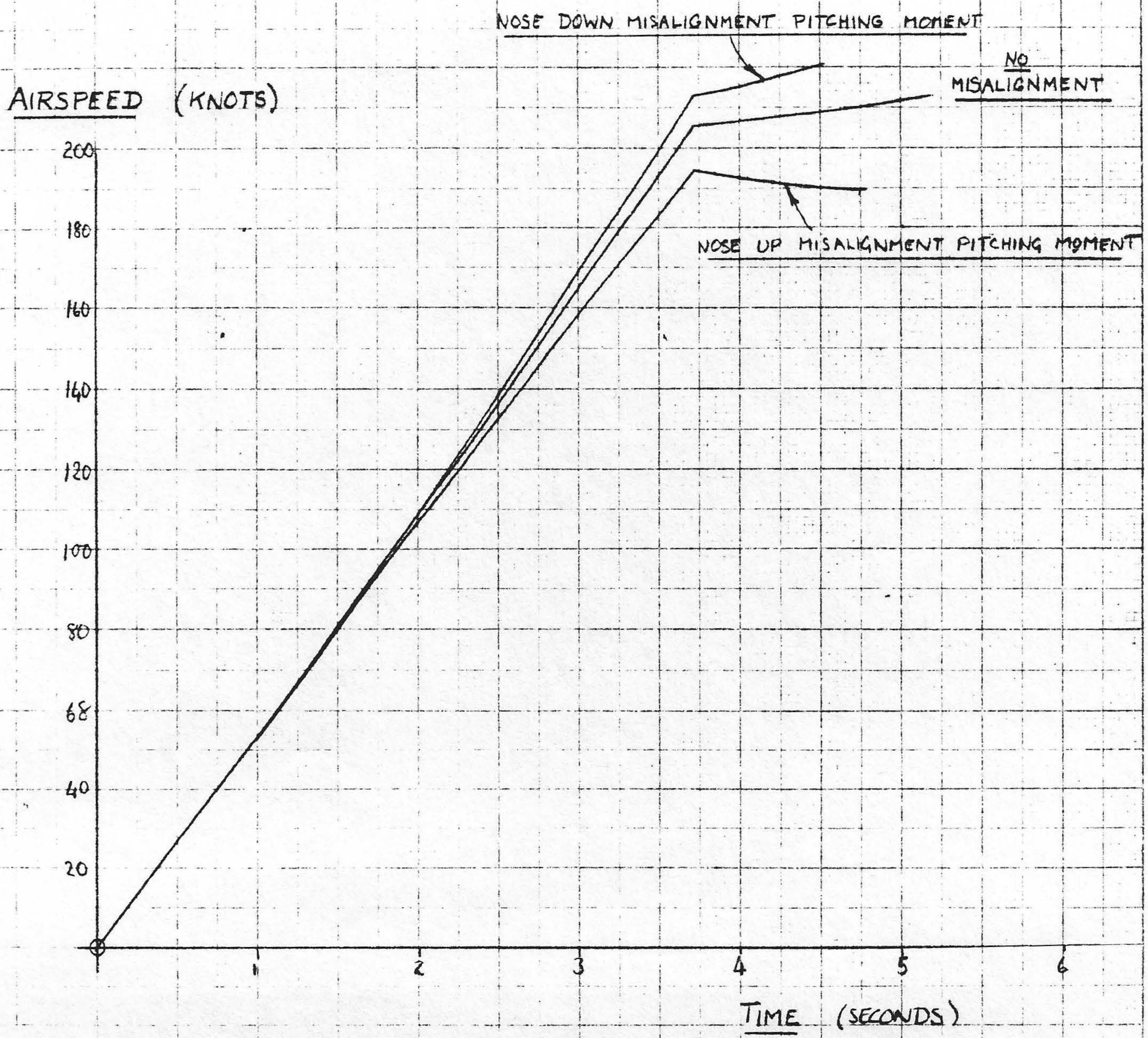
ARROW 2A ZERO LENGTH LAUNCH STANDARD DAY (77°F)

FIG 4 RESPONSE TO MISALIGNMENT PITCHING MOMENTS
(ALL CONTROL ANGLES ZERO)
0°15' THRUST MISALIGNMENT C.G. DISPLACED 1" IN Z DIRECTION

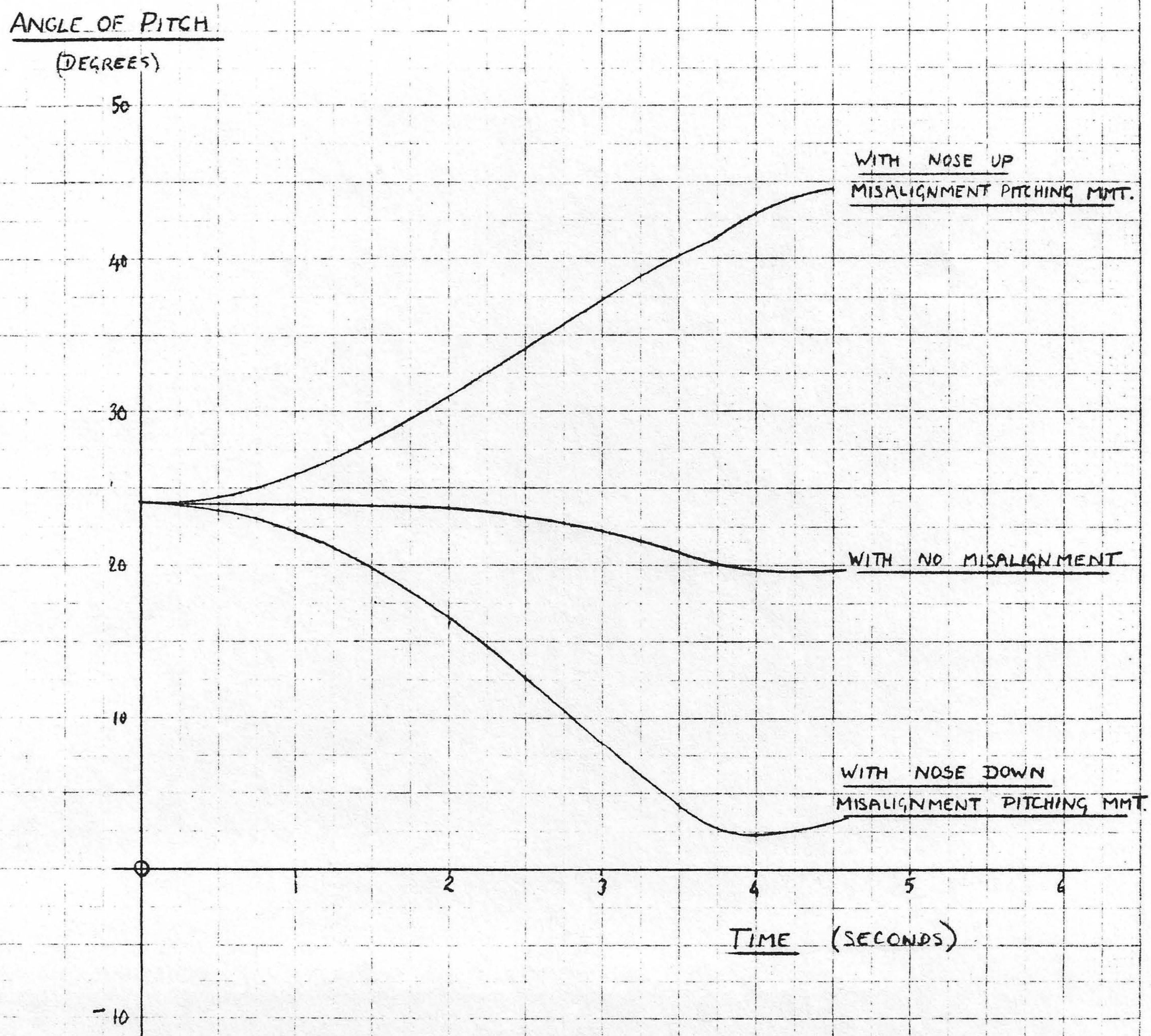
2 VARIATION OF AIRSPEED WITH TIME



ARROW 2A ZERO LENGTH LAUNCH STANDARD DAY (77°F)

FIG 4 RESPONSE TO MISALIGNMENT PITCHING MOMENTS
(ALL CONTROL ANGLES ZERO)
0°15' THRUST MISALIGNMENT C.G DISPLACED 1" IN Z DIRECTION.

3 VARIATION OF ANGLE OF PITCH WITH TIME



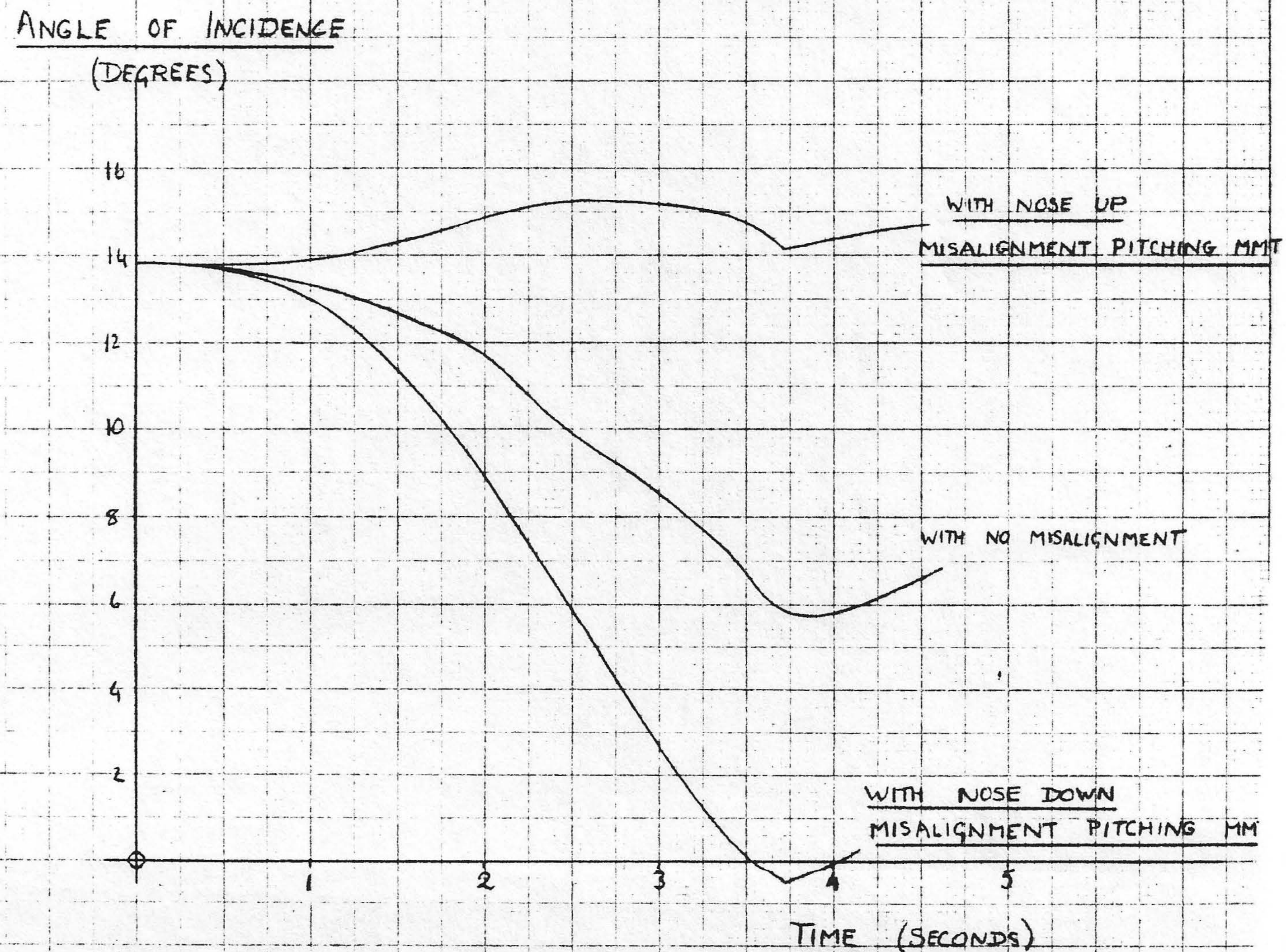
ARROW 2A ZERO LENGTH LAUNCH STANDARD DAY (77°F)

FIG 4 RESPONSE TO MISALIGNMENT PITCHING MOMENTS

(ALL CONTROL ANGLES ZERO)

0°15' THRUST MISALIGNMENT C.G. DISPLACED 1" IN Z DIRECTION

4 VARIATION OF ANGLE OF INCIDENCE WITH TIME



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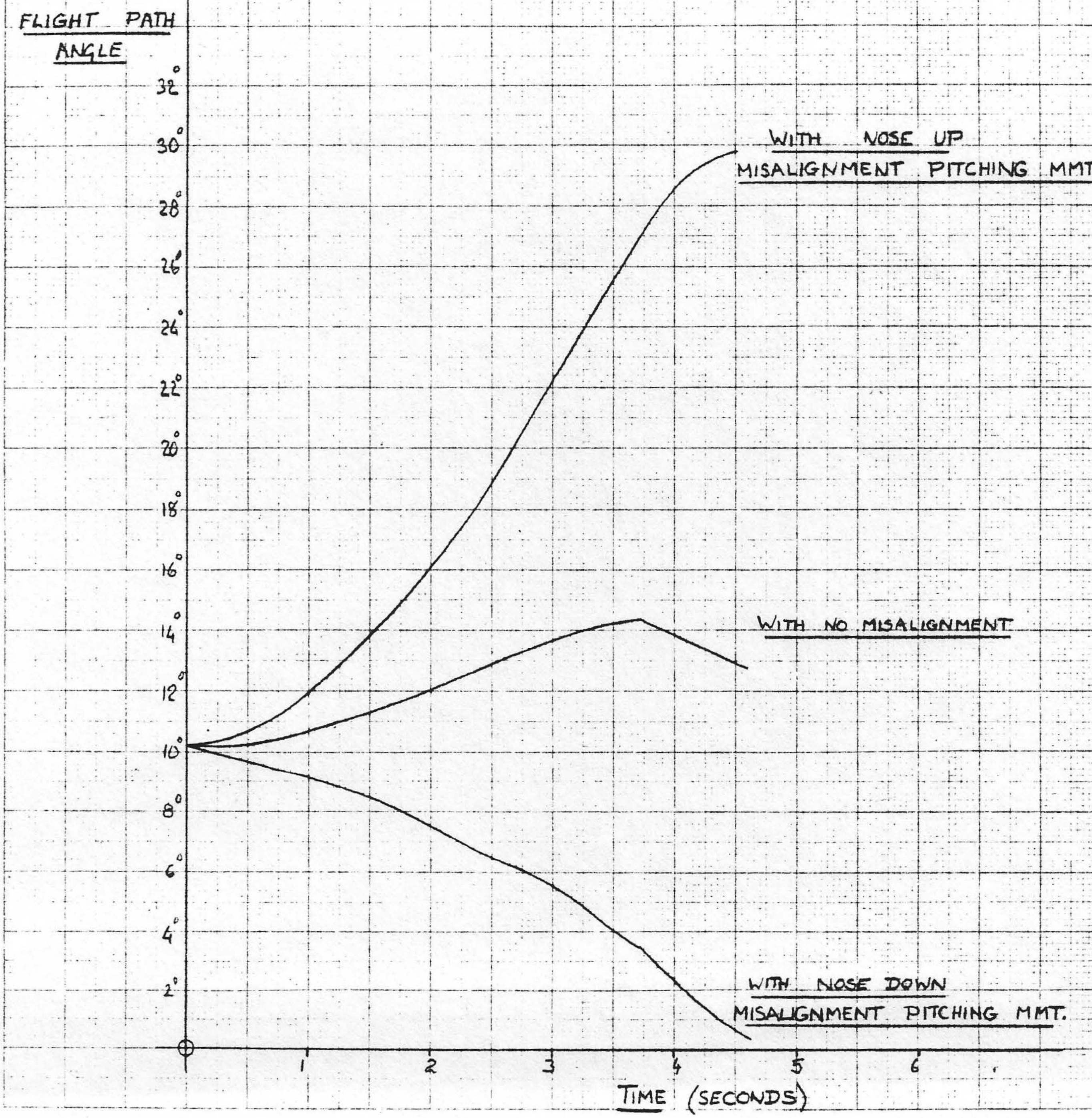
ARROW 2A ZERO LENGTH LAUNCH STANDARD DAY (77°F)

FIG 4 RESPONSE TO MISALIGNMENT PITCHING MOMENTS

ALL CONTROL ANGLES ZERO

0°15' THRUST MISALIGNMENT C.G DISPLACED 1" IN Z DIRECTION

5 VARIATION OF FLIGHT PATH ANGLE WITH TIME



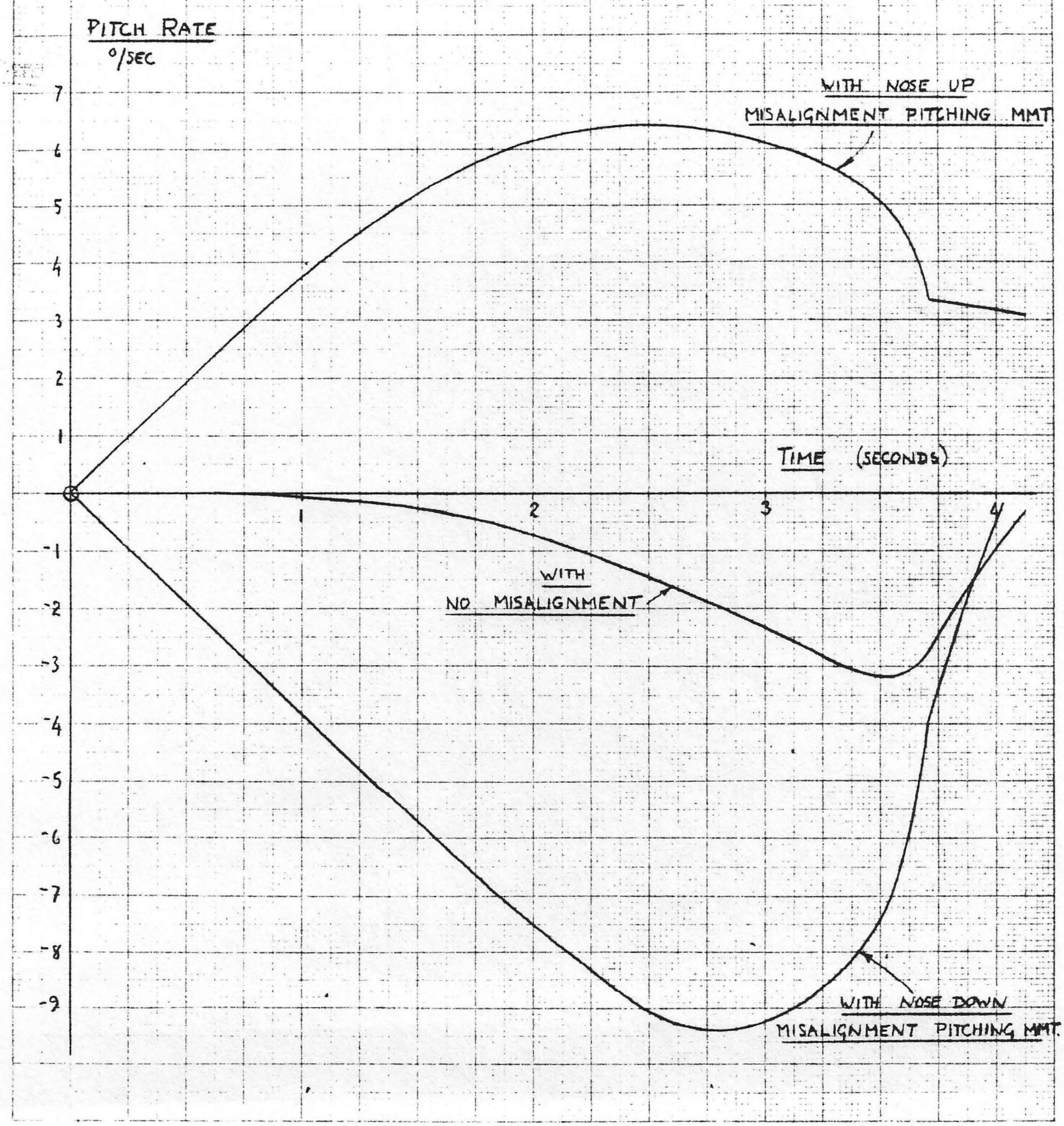
ARROW 2A ZERO LENGTH LAUNCH STANDARD DAY (77°F)

FIG 4 RESPONSE TO MISALIGNMENT PITCHING MOMENTS

(ALL CONTROL ANGLES ZERO)

0°15' THRUST MISALIGNMENT C.G DISPLACED 1" IN Z DIRECTION.

b) VARIATION OF PITCH RATE WITH TIME

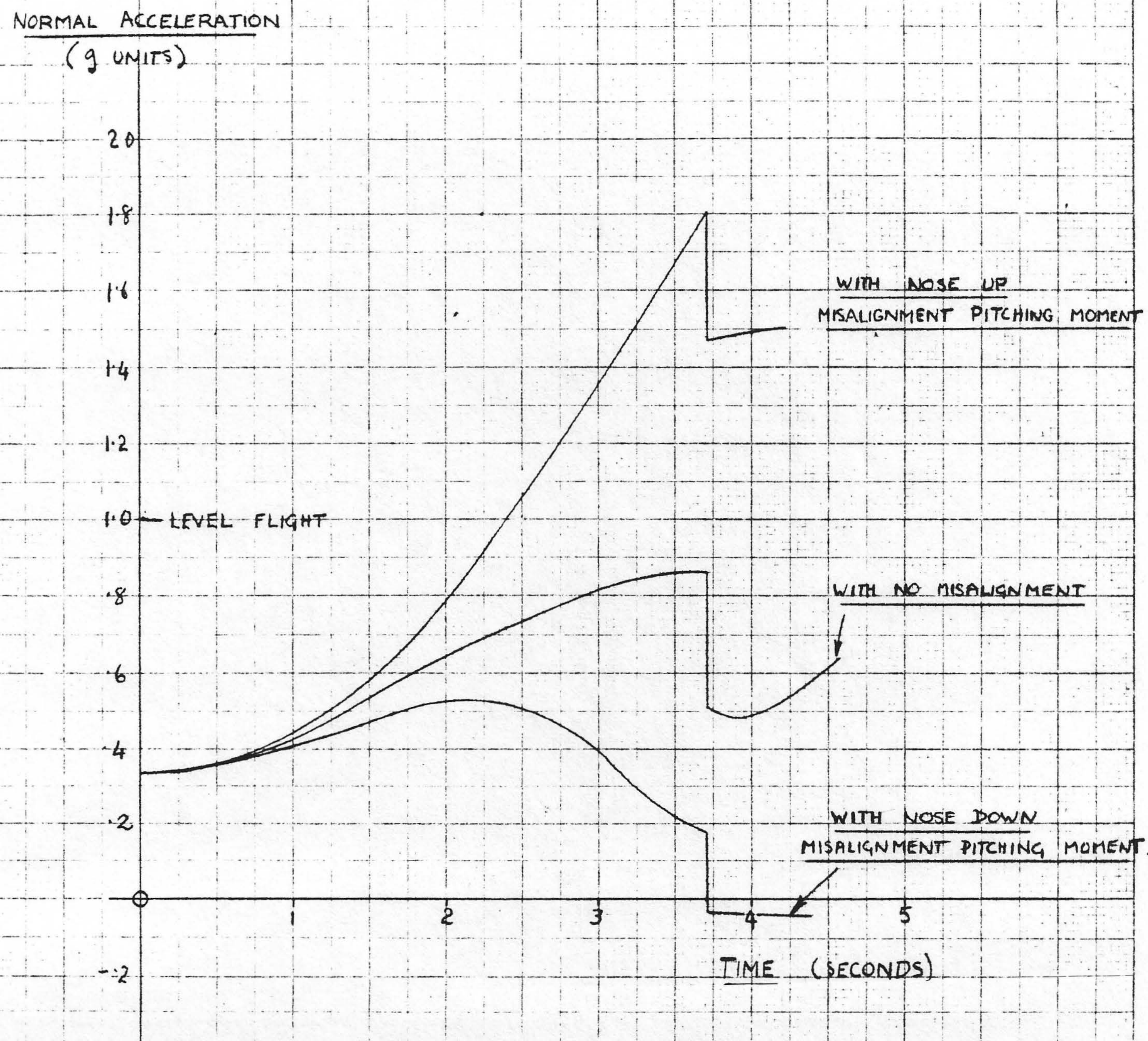


ARROW 2A ZERO LENGTH LAUNCH STANDARD DAY (77°F)

FIG 4 RESPONSE TO MISALIGNMENT PITCHING MOMENTS
(ALL CONTROL ANGLES ZERO)

0°15' THRUST MISALIGNMENT C.G DISPLACED 1" IN Z DIRECTION.

7 VARIATION OF NORMAL ACCELERATION (AT AIRCRAFT C.G.) WITH TIME

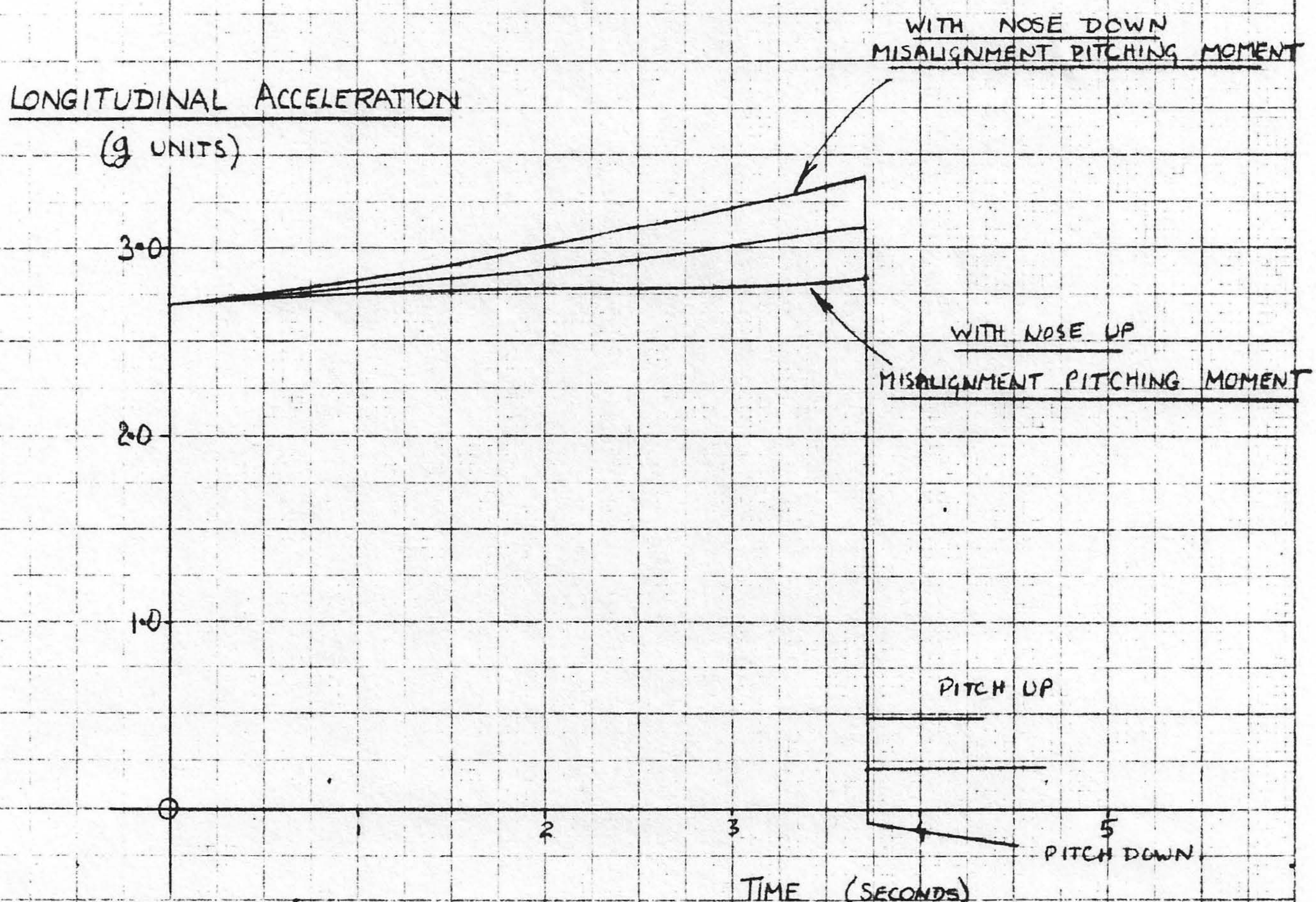


ARROW 2A ZERO LENGTH LAUNCH STANDARD DAY (77°F)

FIG 4 RESPONSE TO MISALIGNMENT PITCHING MOMENTS
(ALL CONTROL ANGLES ZERO)

0°15' THRUST MISALIGNMENT C.G. DISPLACED 1" IN Z DIRECTION

8 VARIATION OF LONGITUDINAL ACCELERATION WITH TIME.



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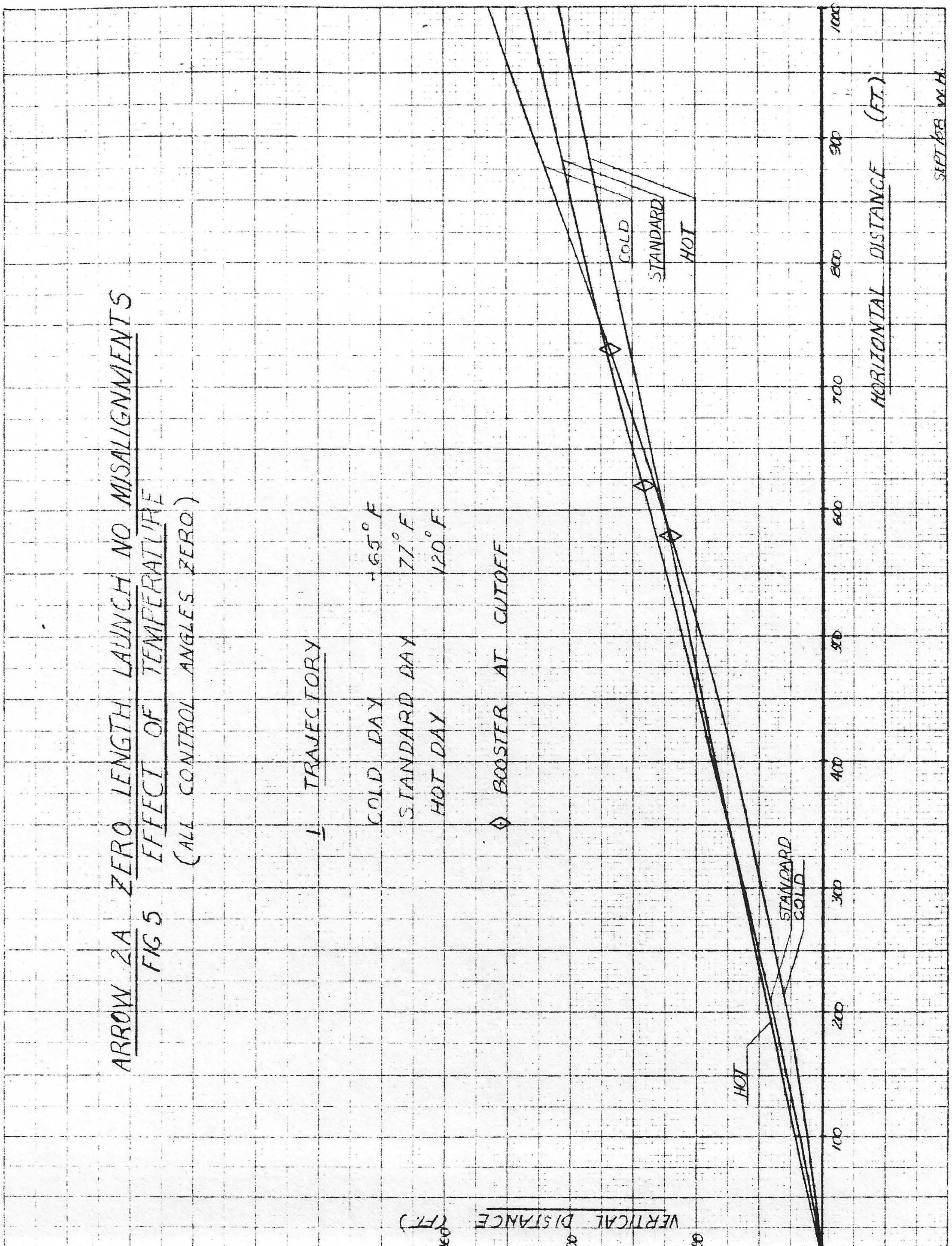


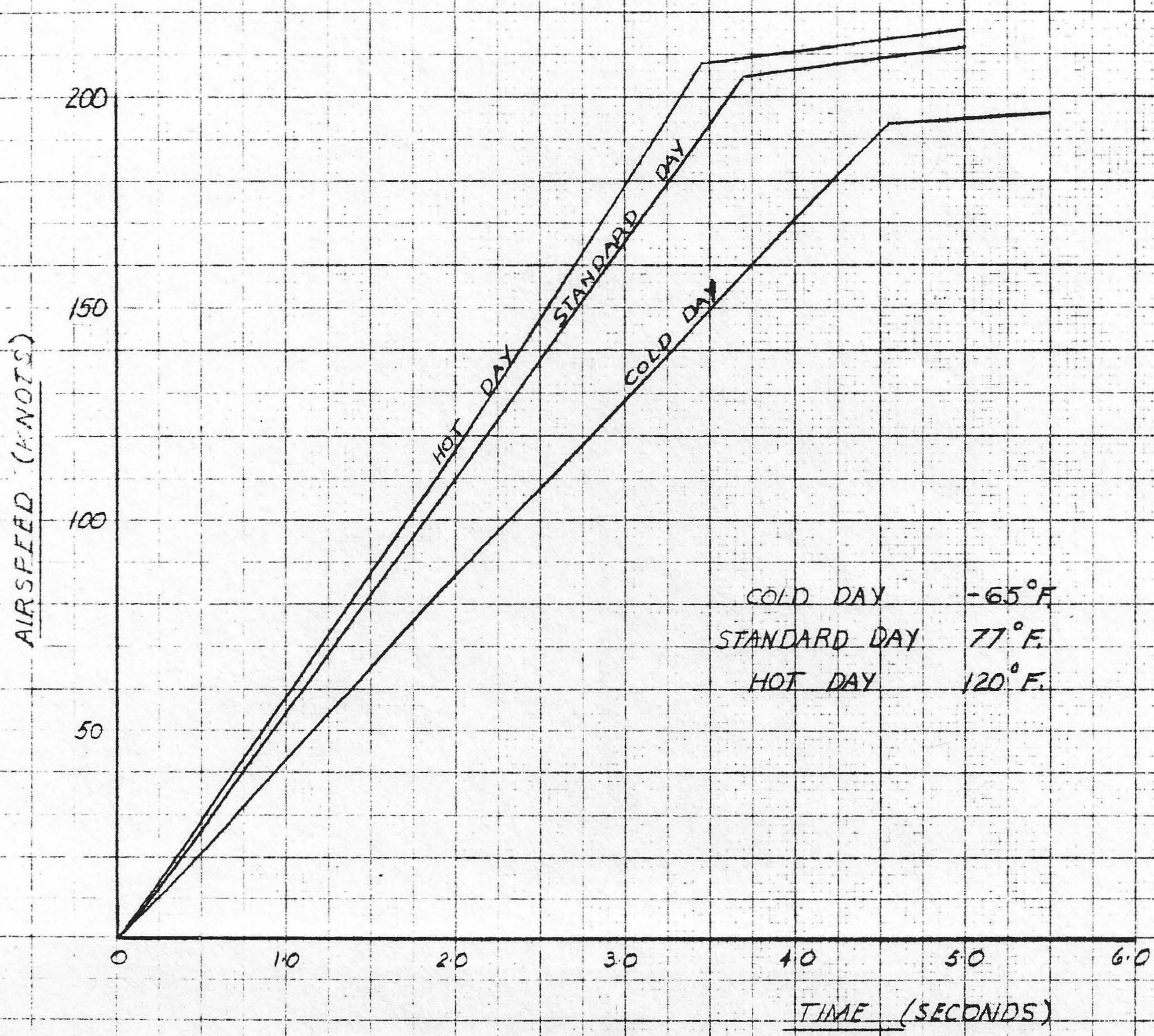
K+E 10 X 10 TO THE 1/2 INCH KEUFFEL & ESSER CO. 359-12 MADE IN U.S.A.

ARROW 2A

ZERO LENGTH LAUNCH NO MISALIGNMENTS

FIG 5 EFFECT OF TEMPERATURE
(ALL CONTROL ANGLES ZERO)

2. VARIATION OF AIRSPEED WITH TIME



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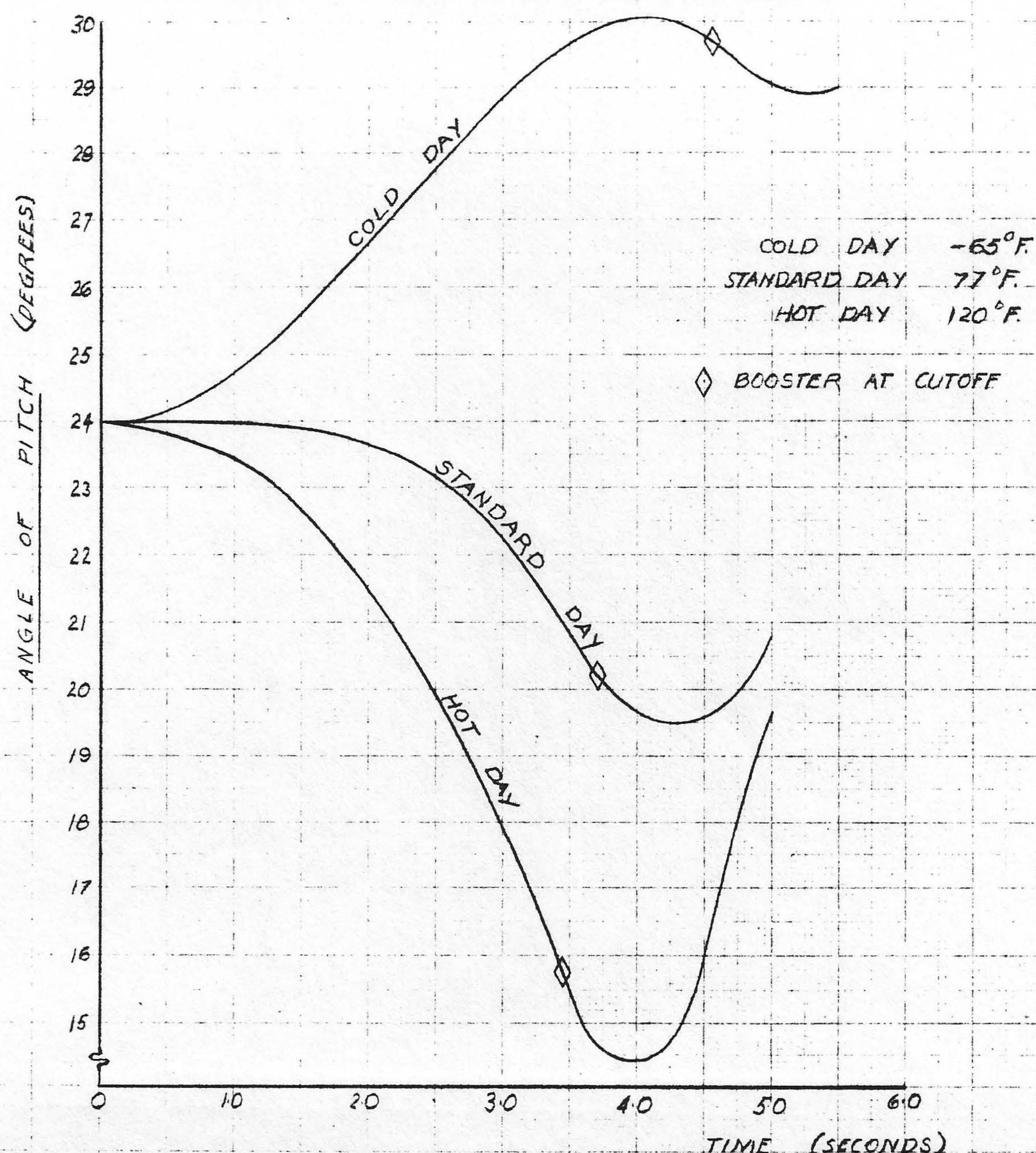
ARROW 2A

ZERO LENGTH LAUNCH NO MISALIGNMENTS

EFFECT OF TEMPERATURE

(ALL CONTROL ANGLES ZERO)

VARIATION OF PITCH ANGLE WITH TIME



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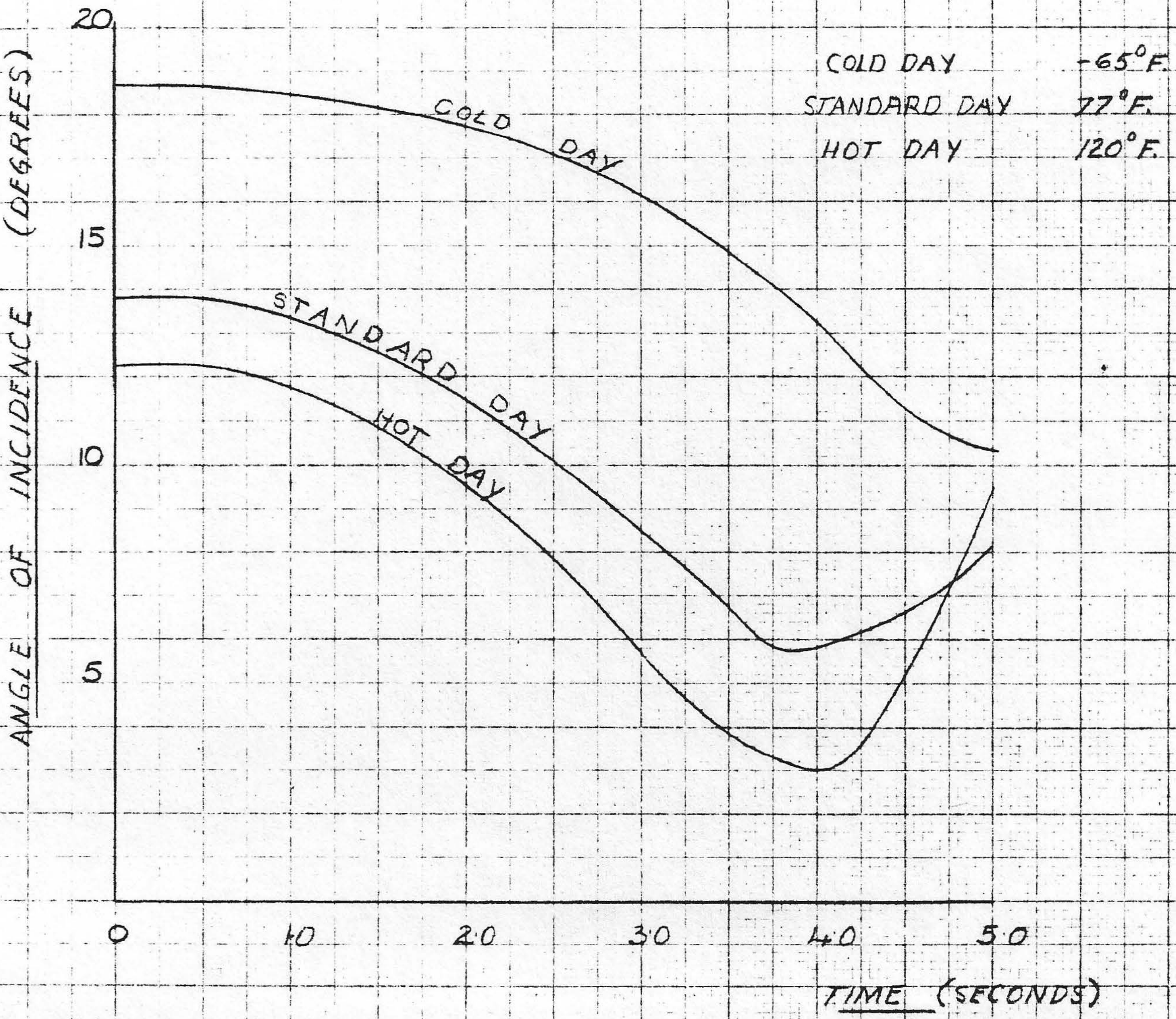
ARROW 2A

ZERO LENGTH LAUNCH NO MISALIGNMENTS

(ALL CONTROL ANGLES ZERO)

FIG 5 EFFECT OF TEMPERATURE

a) VARIATION OF ANGLE OF INCIDENCE WITH TIME



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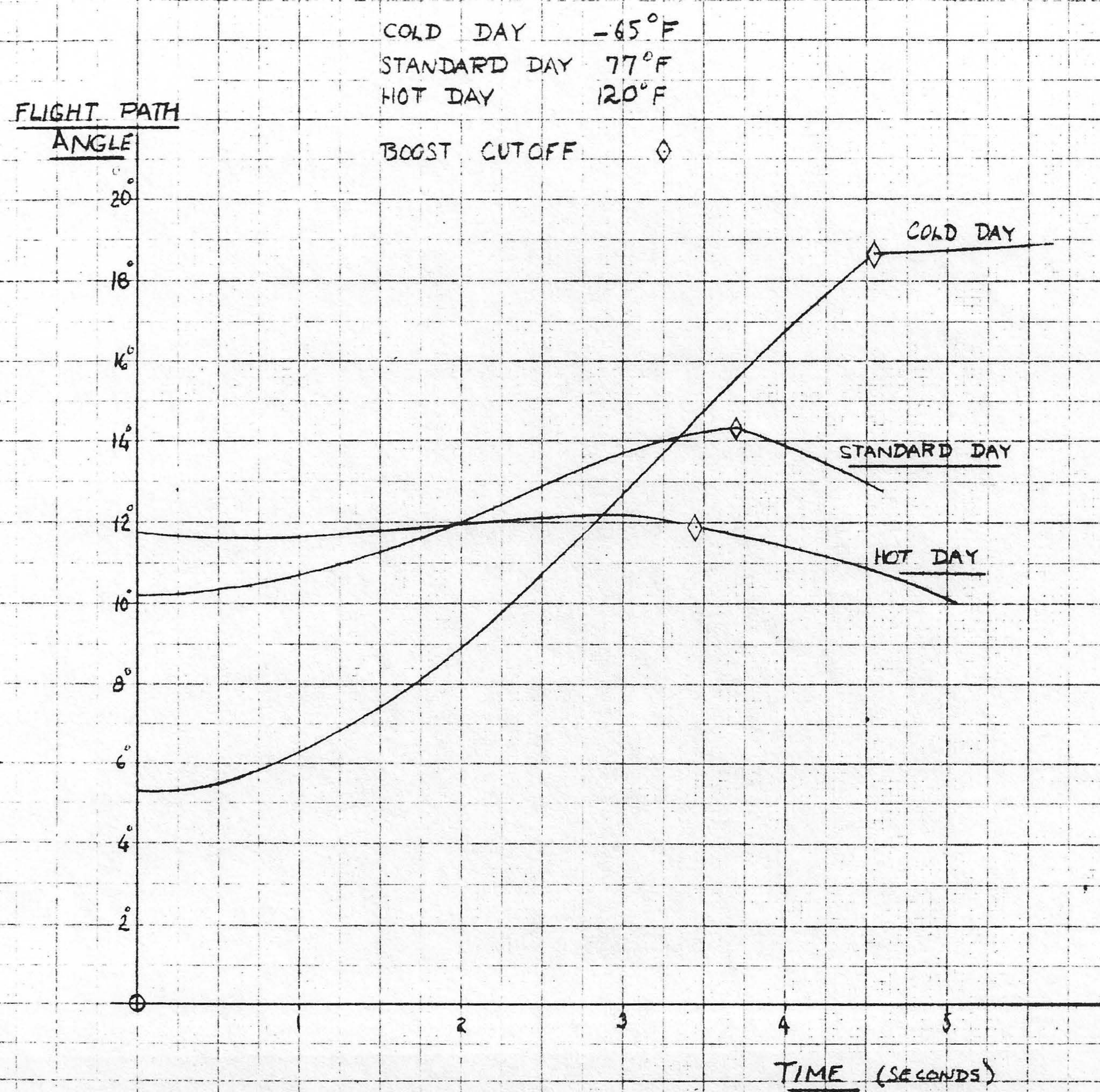
ARROW 2A

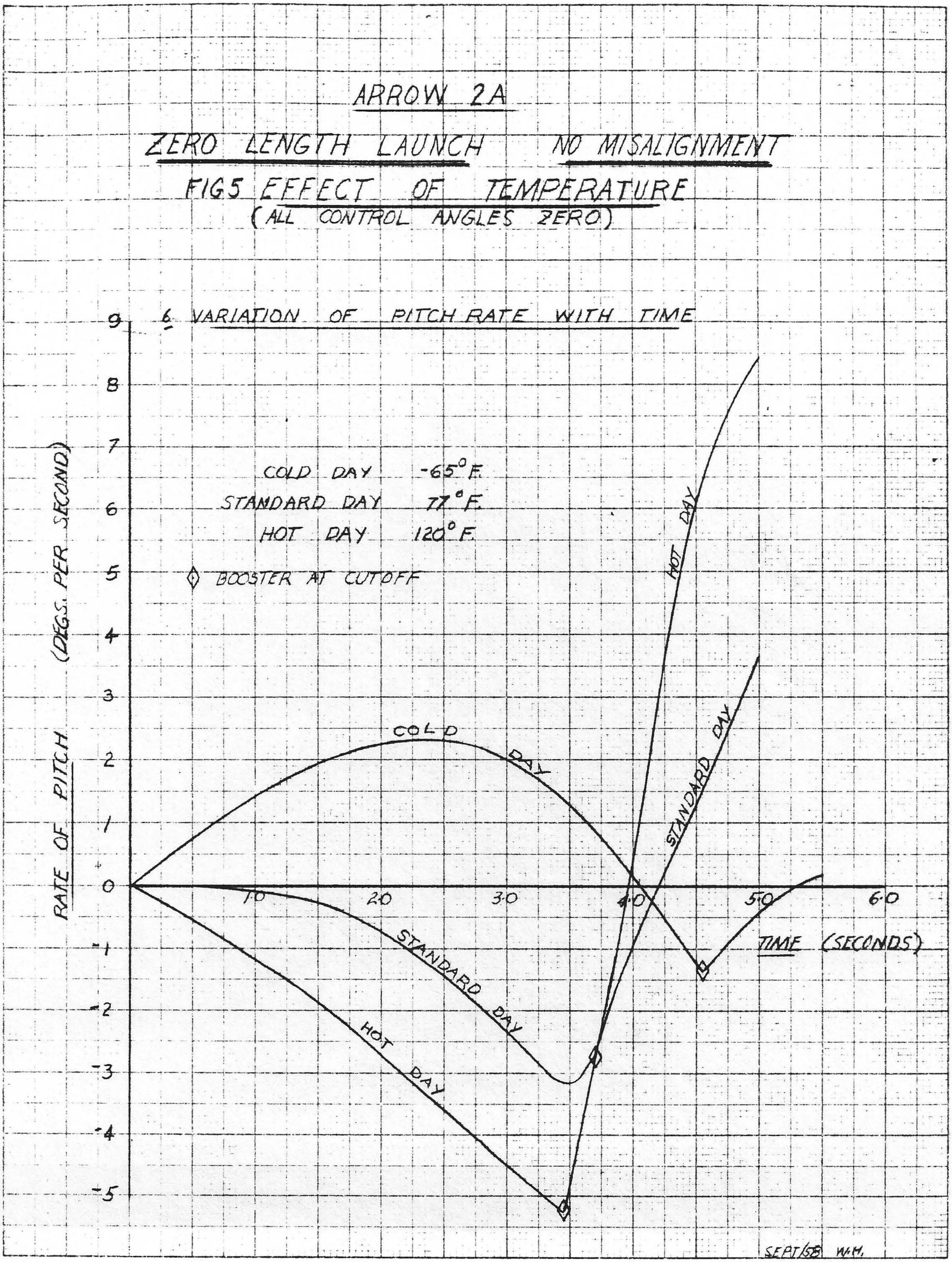
ZERO LENGTH LAUNCH   NO MISALIGNMENTS

FIG 5 EFFECT OF TEMPERATURE

(ALL CONTROL ANGLES ZERO)

5 VARIATION OF FLIGHT PATH ANGLE WITH TIME



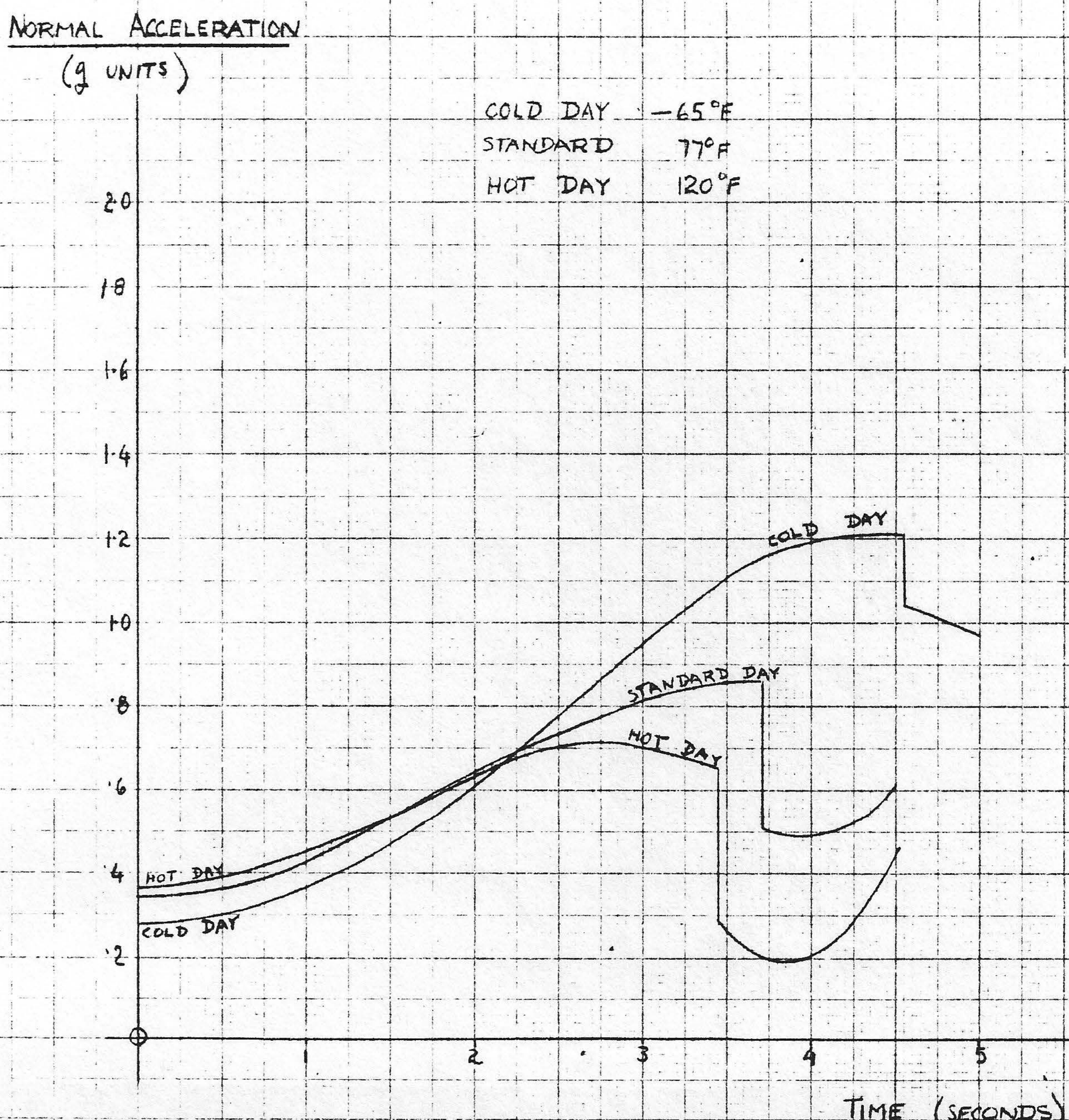

ARROW 2A
ZERO LENGTH LAUNCH NO MISALIGNMENT
FIG 5 EFFECT OF TEMPERATURE
(ALL CONTROL ANGLES ZERO)
6 VARIATION OF PITCH RATE WITH TIME
COLD DAY -65° F.
STANDARD DAY 77° F.
HOT DAY 120° F.
◊ BOOSTER AT CUTOFF
RATE OF PITCH (DEGS. PER SECOND)
TIME (SECONDS)
COLD DAY
STANDARD DAY
HOT DAY
9
8
7
6
5
4
3
2
1
0
-1
-2
-3
-4
-5
1.0
2.0
3.0
4.0
5.0
6.0
SEPT/58 W.H.

ARROW 2A

ZERO LENGTH LAUNCH NO MISALIGNMENTS

FIG 5 EFFECT OF TEMPERATURE
(ALL CONTROL ANGLES ZERO)

7 VARIATION OF NORMAL ACCELERATION WITH TIME



ARROW 2A

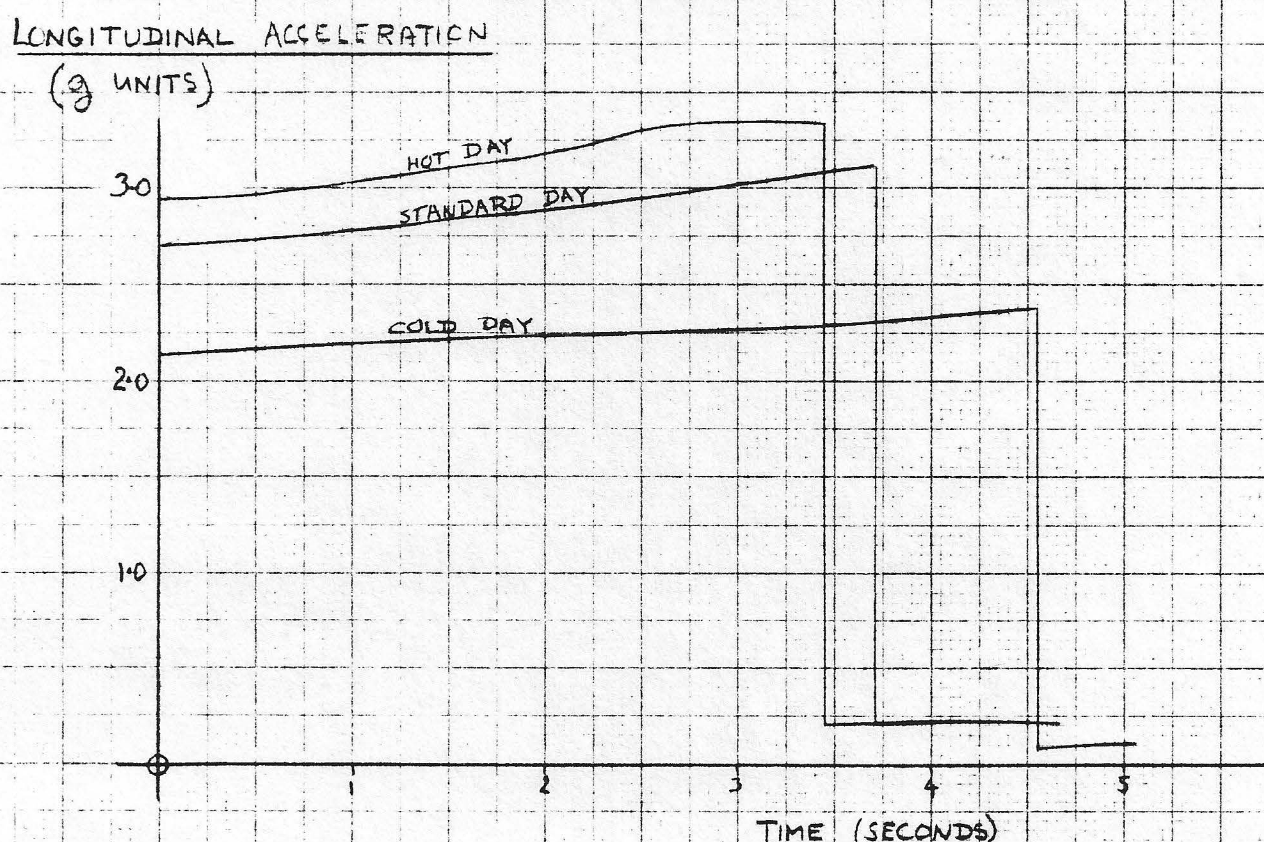
ZERO LENGTH LAUNCH NO MISALIGNMENTS

FIG 5 EFFECT OF TEMPERATURE

(ALL CONTROL ANGLES ZERO)

8 VARIATION OF LONGITUDINAL ACCELERATION WITH TIME

COLD DAY	−65°F
STANDARD DAY	77°F
HOT DAY	120°F



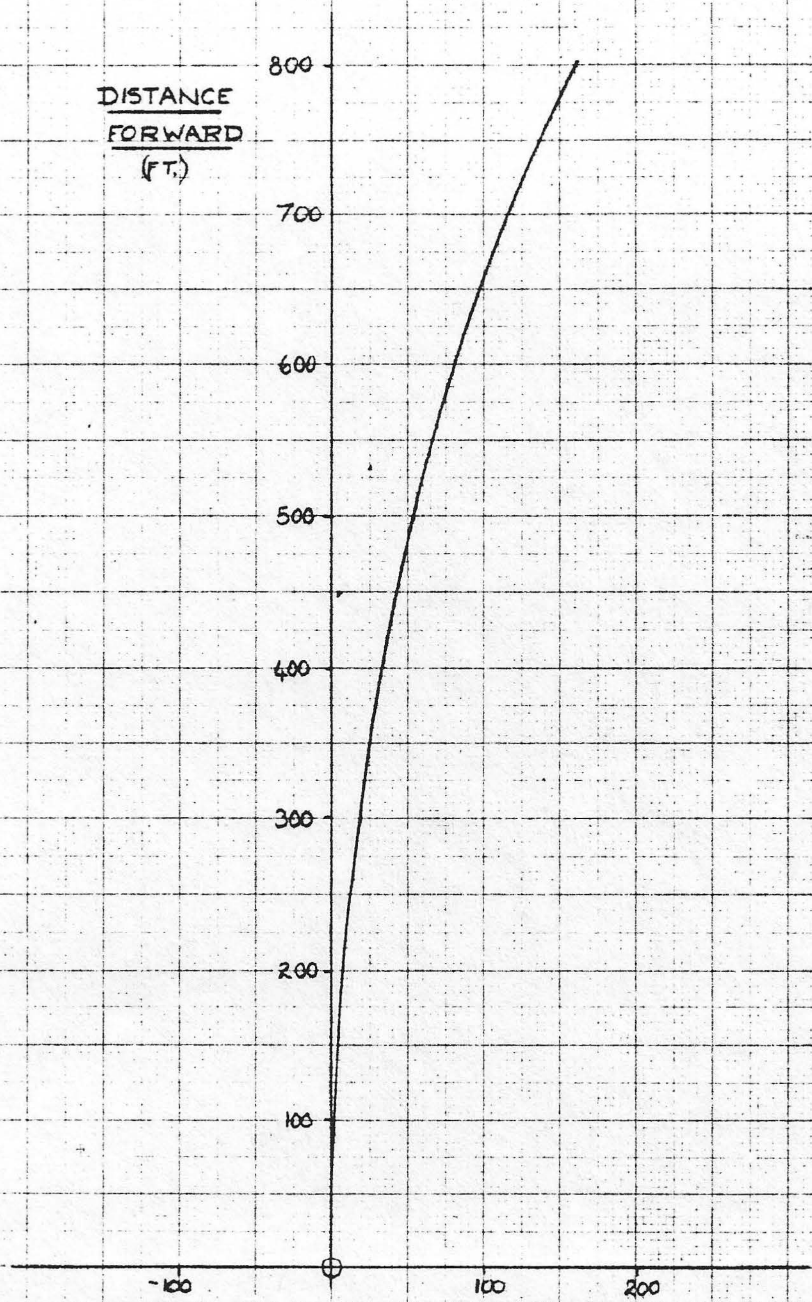
ARROW 2A ZERO LENGTH LAUNCH

FIG 6 RESPONSE TO MISALIGNMENTS CAUSING MAXIMUM YAWING MOMENTS

1" C.G OFFSET 0°15' BOOSTER THRUST MISALIGNMENT 5% THRUST INCREASE

ALL CONTROL ANGLES ZERO STANDARD DAY (77°F)

1 TRAJECTORY



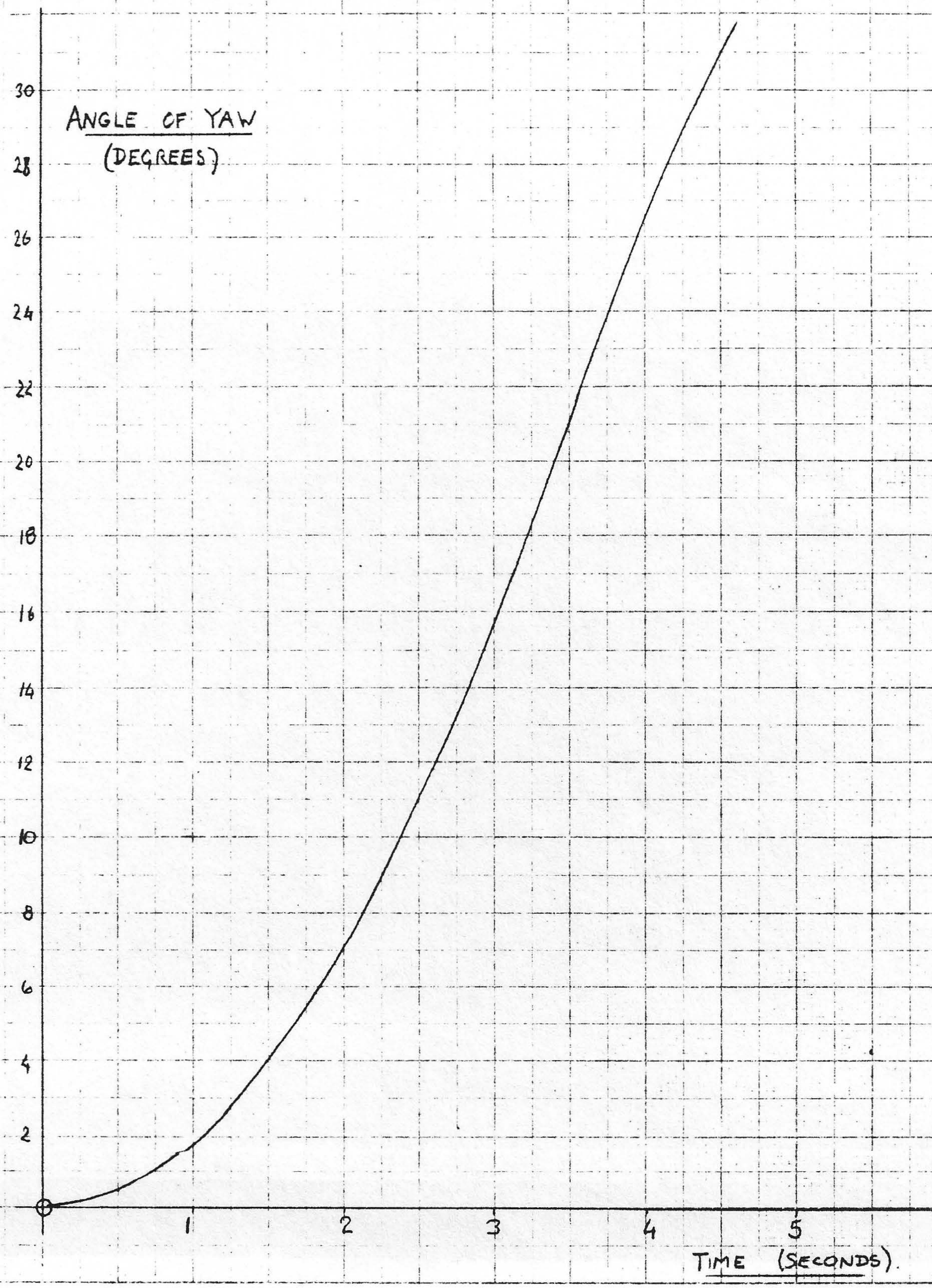
ARROW 2A ZERO LENGTH LAUNCH

FIG 6 RESPONSE TO MISALIGNMENTS CAUSING YAWING MOMENTS

ALL CONTROL ANGLES ZERO STANDARD DAY (77°F)

1" C.G. OFFSET 0°15' BOOSTER THRUST MISALIGNMENT 5% THRUST INCREASE

& RESPONSE IN ANGLE OF YAW.



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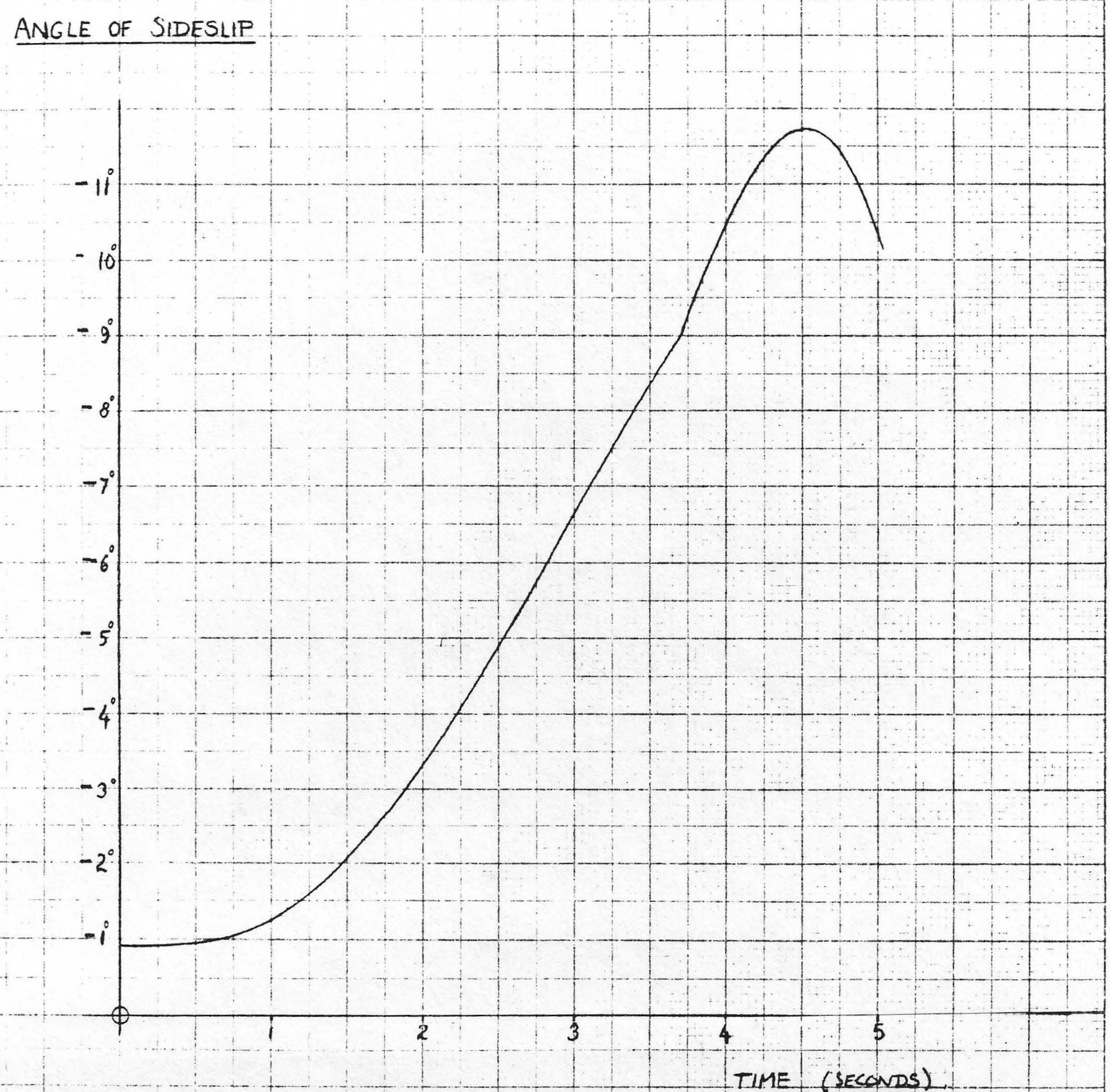
ARROW 2A ZERO LENGTH LAUNCH

FIG 6 RESPONSE TO MISALIGNMENTS CAUSING MAXIMUM YAWING MOMENT

ALL CONTROL ANGLES ZERO STANDARD DAY (77°F)

1" C.G. OFFSET 0°15' BOOSTER THRUST MISALIGNMENT 5% THRUST INCREASE

3 RESPONSE IN ANGLE OF SIDESLIP



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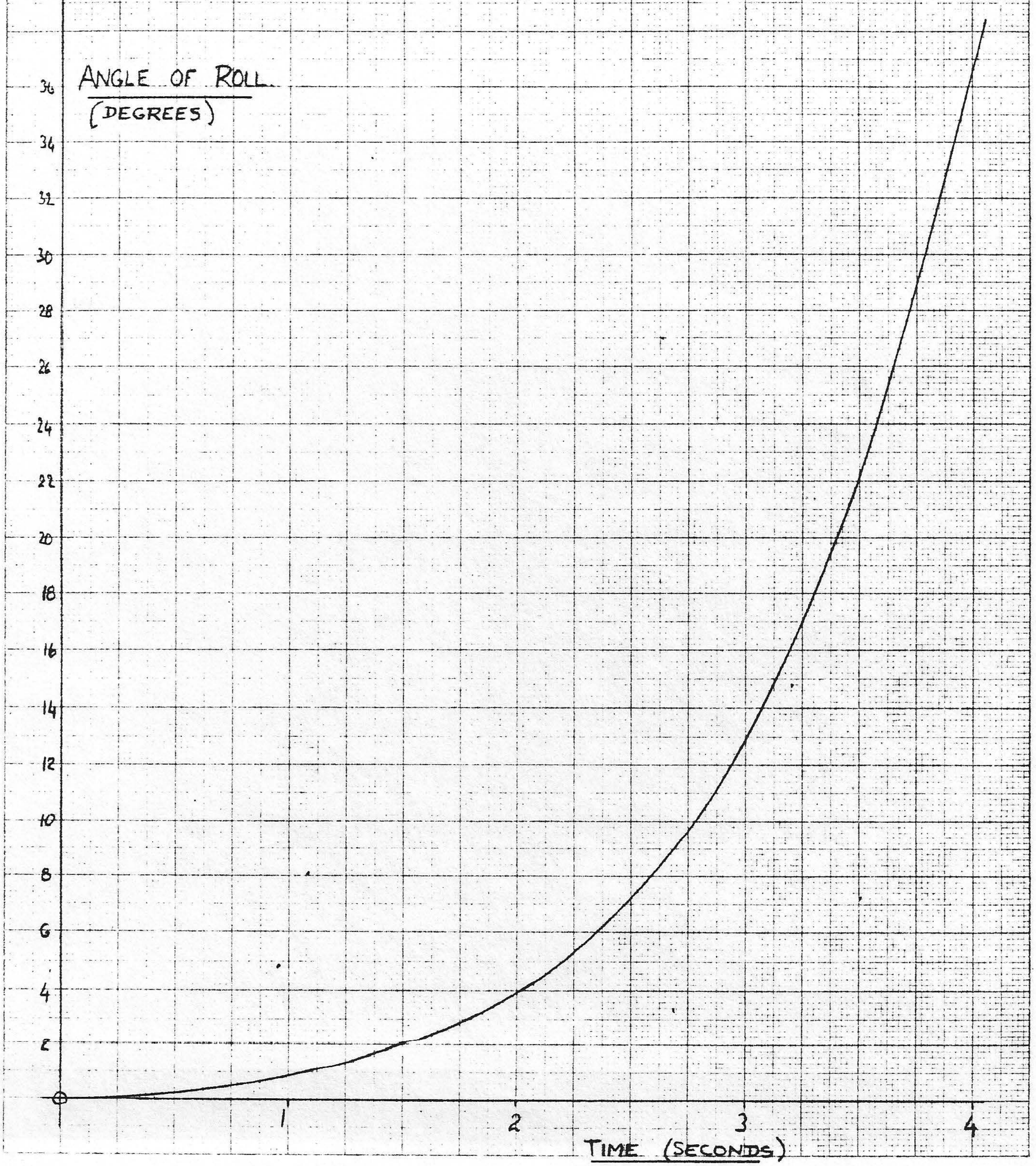
ARROW 2A ZERO LENGTH LAUNCH

FIG 6 RESPONSE TO MISALIGNMENTS CAUSING YAWING MOMENTS

ALL CONTROL ANGLES ZERO STANDARD DAY (77°F)
1" C.G. OFFSET 0°15' BOOSTER THRUST MISALIGNMENT 5% THRUST INCREASE.

4 RESPONSE IN ANGLE OF ROLL



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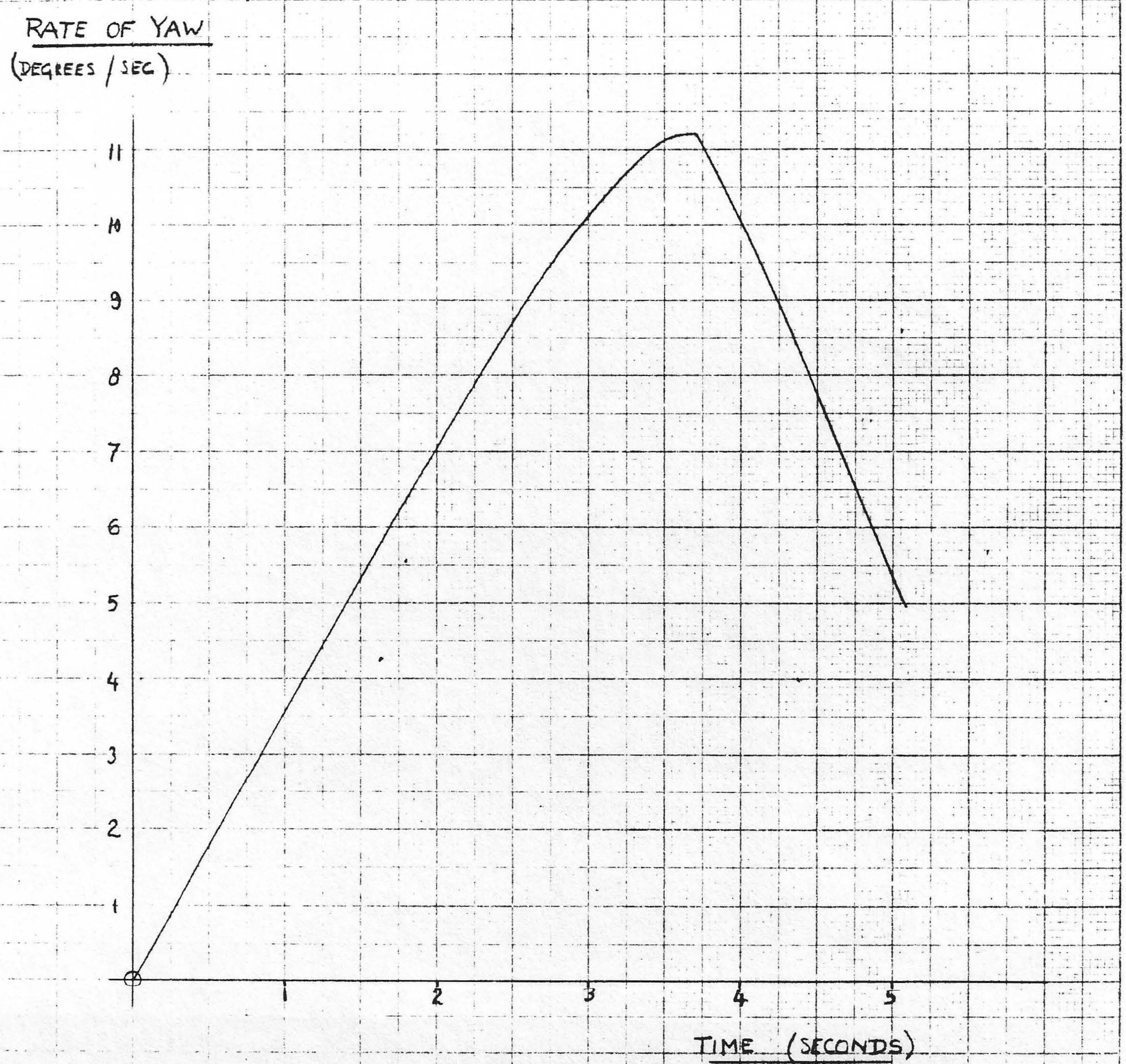
ARROW 2A ZERO LENGTH LAUNCH

FIG 6 RESPONSE TO MISALIGNMENTS CAUSING MAXIMUM YAWING MOMENT

ALL CONTROL ANGLES ZERO STANDARD DAY 77°F

1" C.G. OFFSET 0°15' BOOSTER THRUST MISALIGNMENT 5% THRUST INCREASE.

5 RESPONSE IN RATE OF YAW



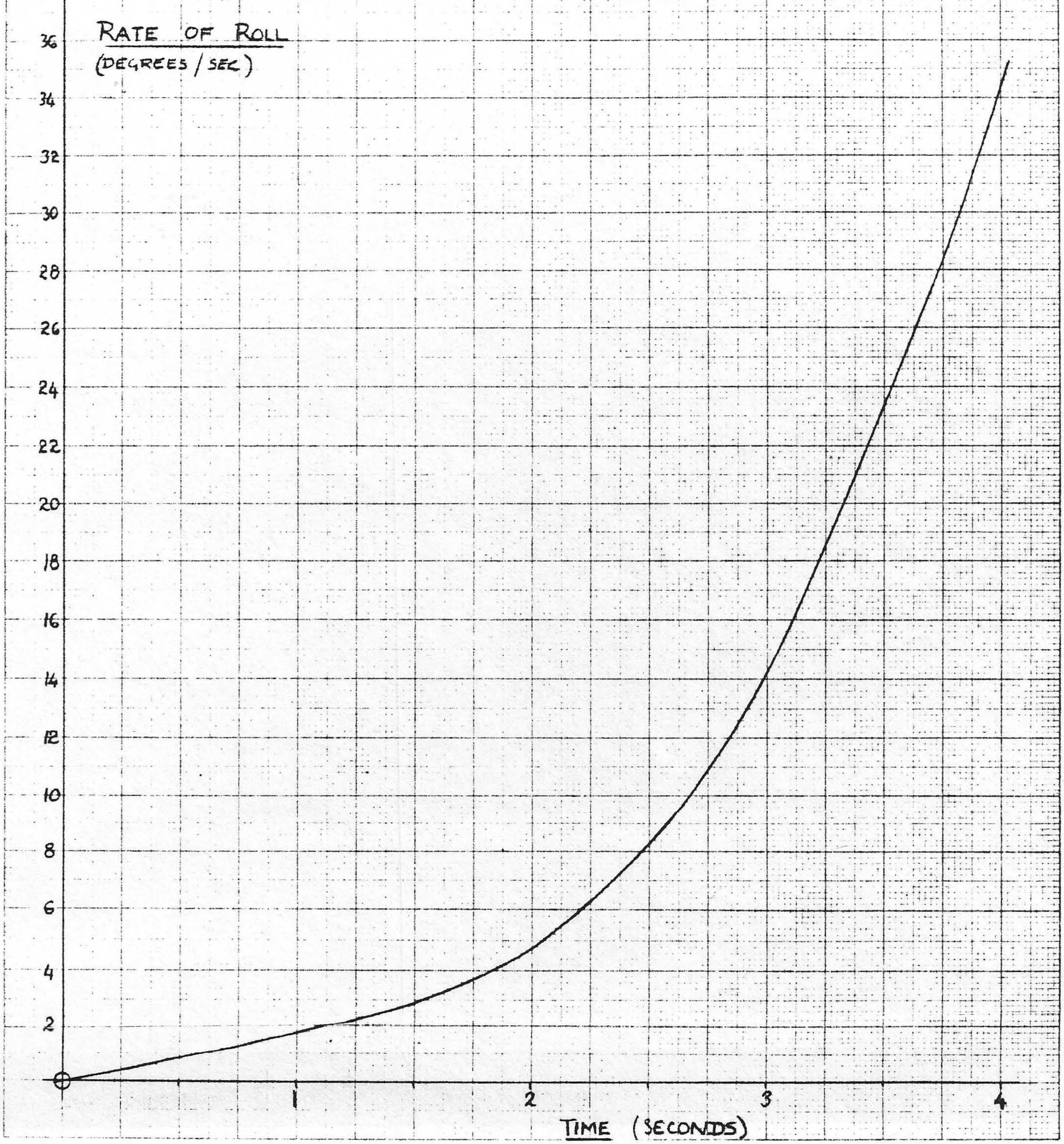
ARROW 2A ZERO LENGTH LAUNCH

FIG 6 RESPONSE TO MISALIGNMENTS CAUSING MAXIMUM YAWING MOMENT.

ALL CONTROL ANGLES ZERO STANDARD DAY (77°F)

1" C.G OFFSET 0°15' BOOSTER THRUST MISALIGNMENT 5% THRUST INCREASE

6 RESPONSE IN RATE OF ROLL



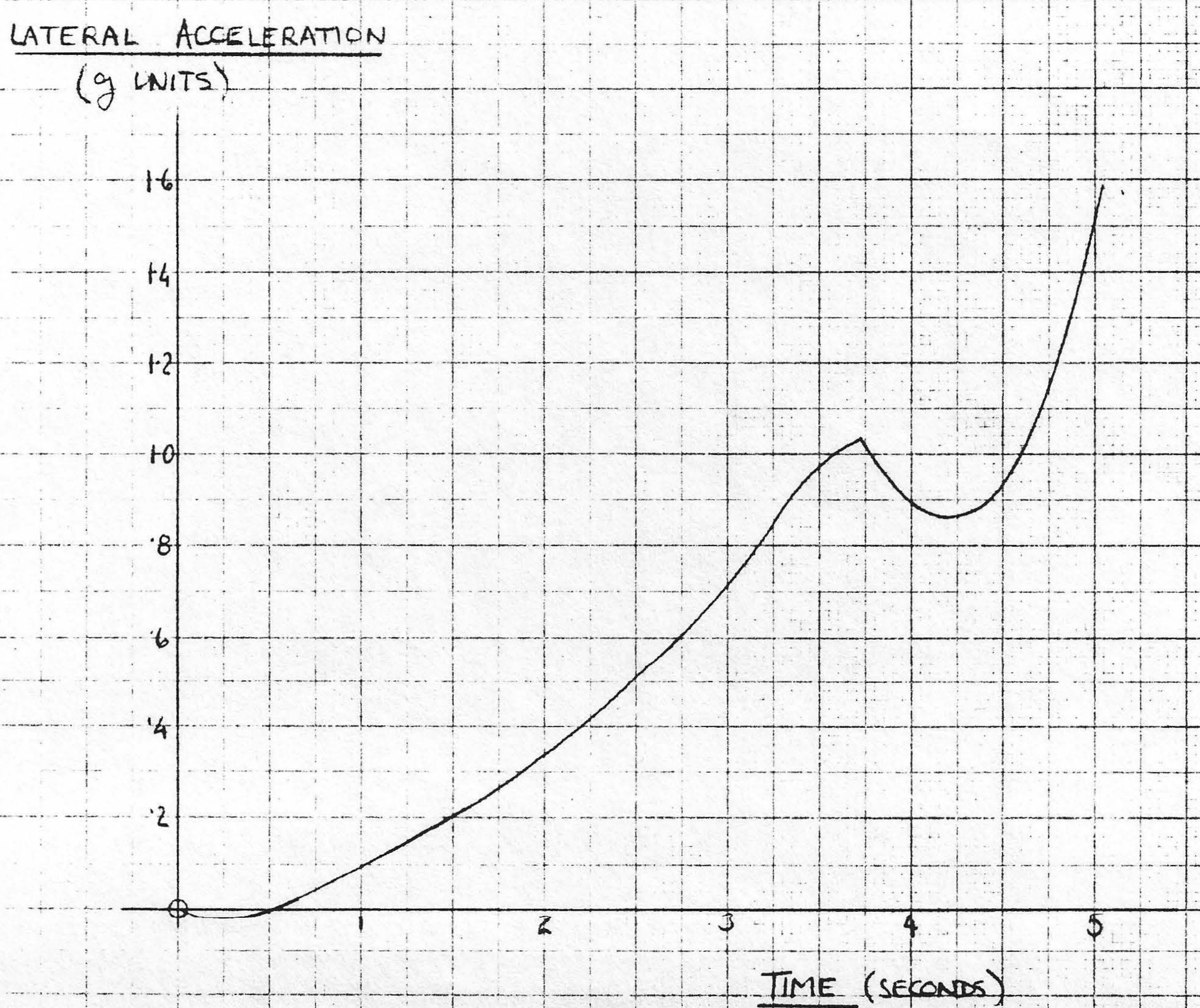
ARROW 2A ZERO LENGTH LAUNCH

FIG 6 RESPONSE TO MISALIGNMENTS CAUSING MAXIMUM YAWING MOMENT

ALL CONTROL ANGLES ZERO STANDARD DAY (77°F)

1" C.G. OFFSET 0°15' BOOSTER THRUST MISALIGNMENT 5% THRUST INCREASE

7. VARIATION OF LATERAL ACCELERATION WITH TIME



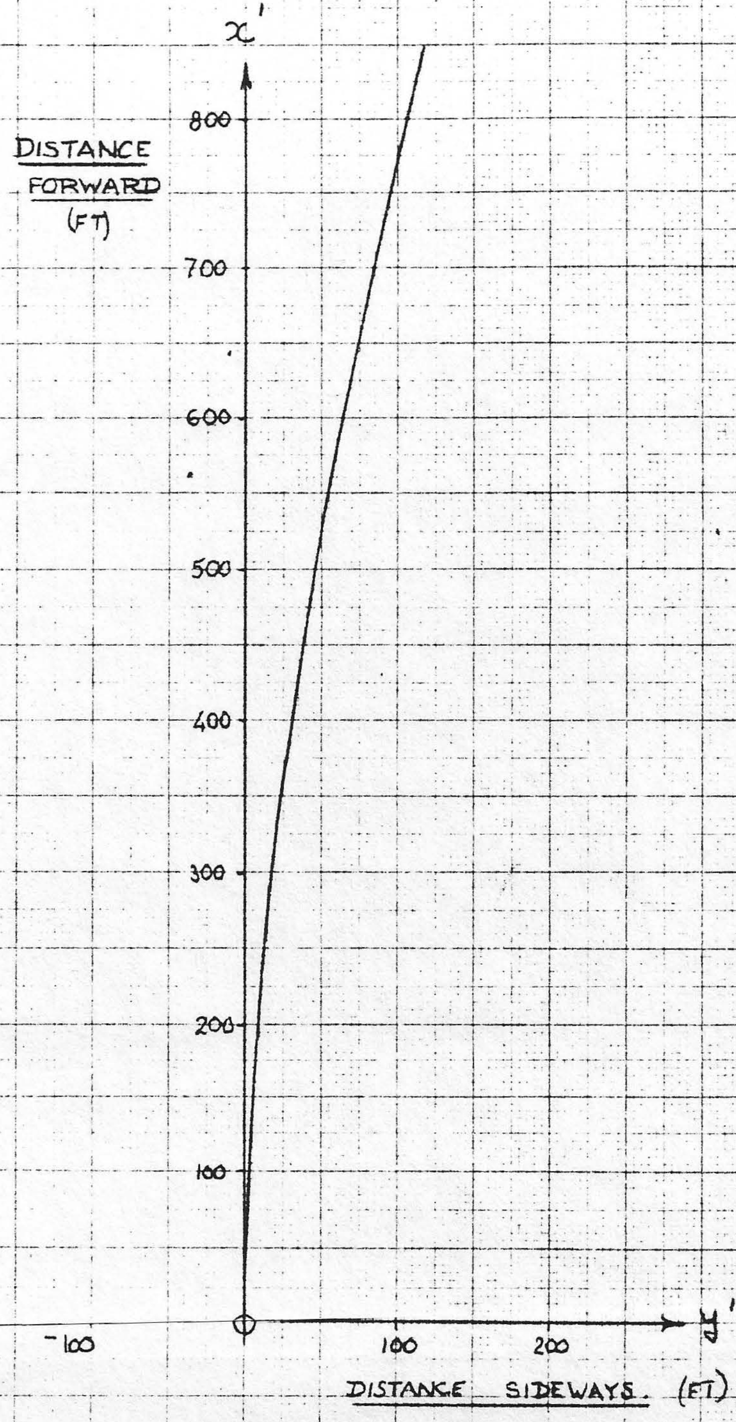
ARROW 2A ZERO LENGTH LAUNCH

FIG 7 RESPONSE TO MISALIGNMENTS CAUSING MAXIMUM ROLLING MOMENTS

1" C.G. OFFSET   0°15' BOOSTER THRUST MISALIGNMENT   5% THRUST INCREASE

ALL CONTROL ANGLES ZERO   STANDARD DAY (77°F)

1 TRAJECTORY



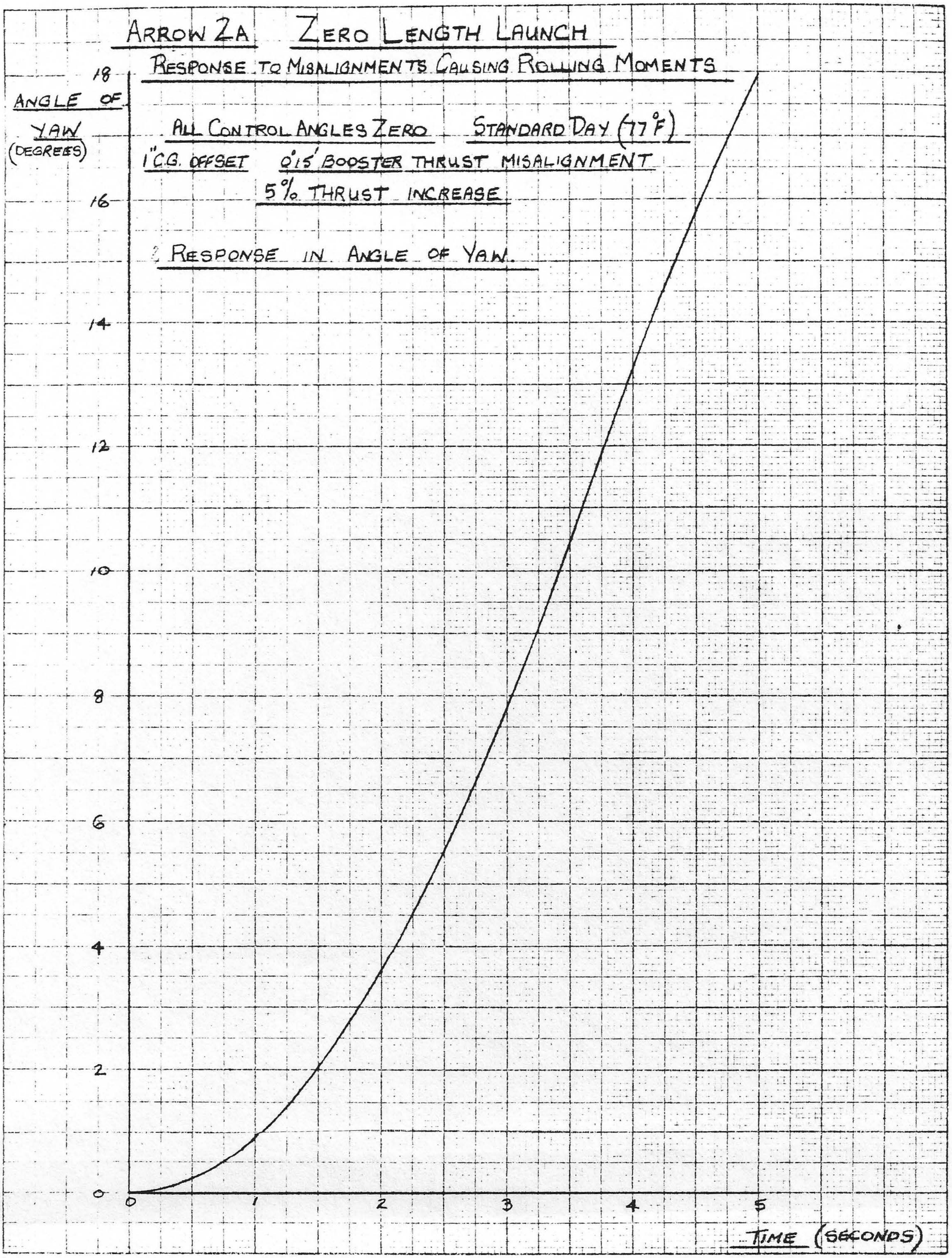

ARROW 2A ZERO LENGTH LAUNCH
RESPONSE TO MISALIGNMENTS CAUSING ROLLING MOMENTS
ALL CONTROL ANGLES ZERO STANDARD DAY (77°F)
1" C.G. OFFSET 0°15' BOOSTER THRUST MISALIGNMENT
5% THRUST INCREASE
RESPONSE IN ANGLE OF YAW.
ANGLE OF YAW (DEGREES)
18
16
14
12
10
8
6
4
2
0
0
1
2
3
4
5
TIME (SECONDS)

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FIG 7

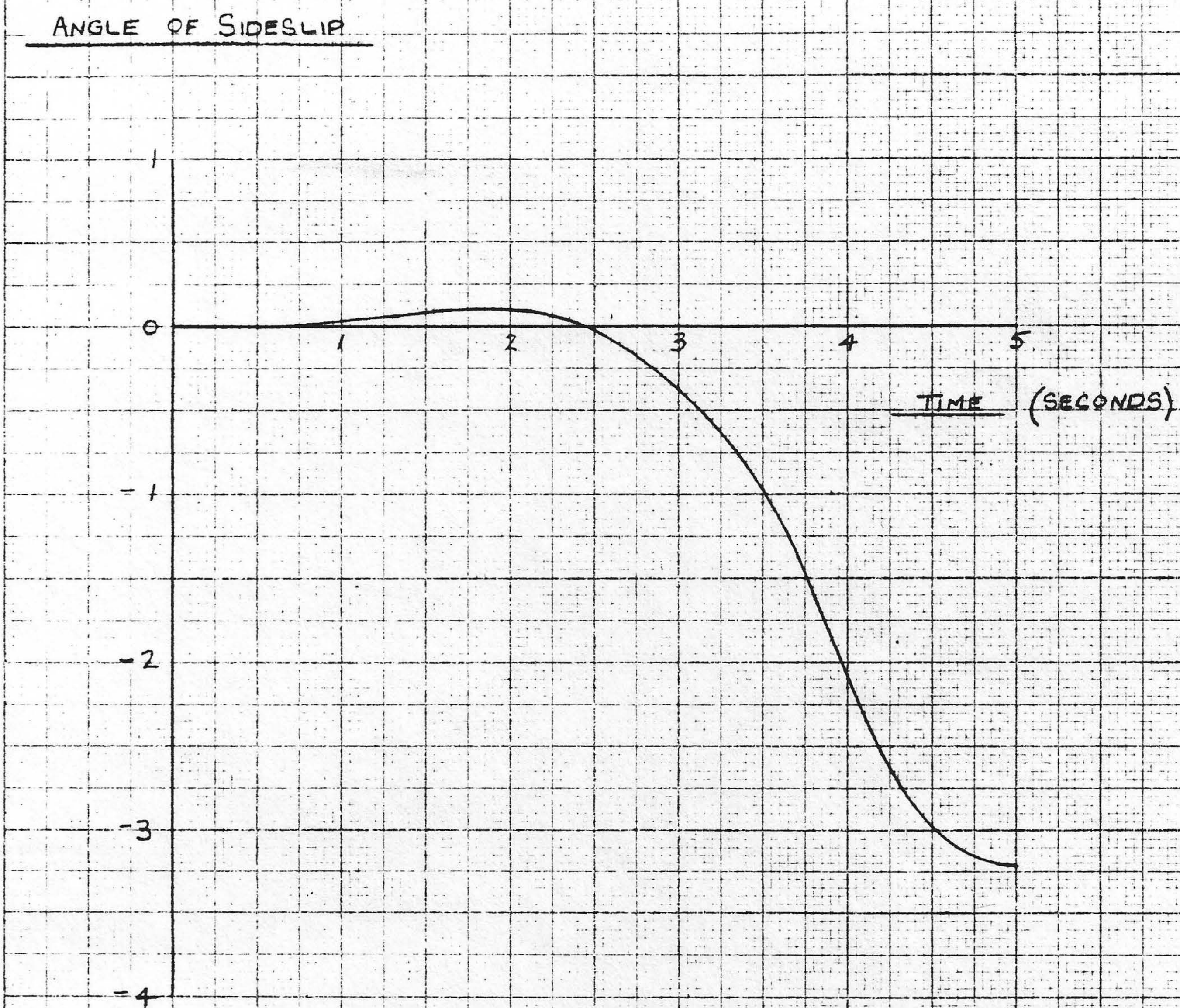
ARROW 2A ZERO LENGTH LAUNCH

RESPONSE TO MISALIGNMENTS CAUSING MAXIMUM ROLLING MOMENTS

ALL CONTROL ANGLES ZERO STANDARD DAY (77°F)

1" C.G. OFFSET 0°15' BOOSTER THRUST MISALIGNMENT 5% THRUST INCREASE

3 RESPONSE IN ANGLE OF SIDESLIP



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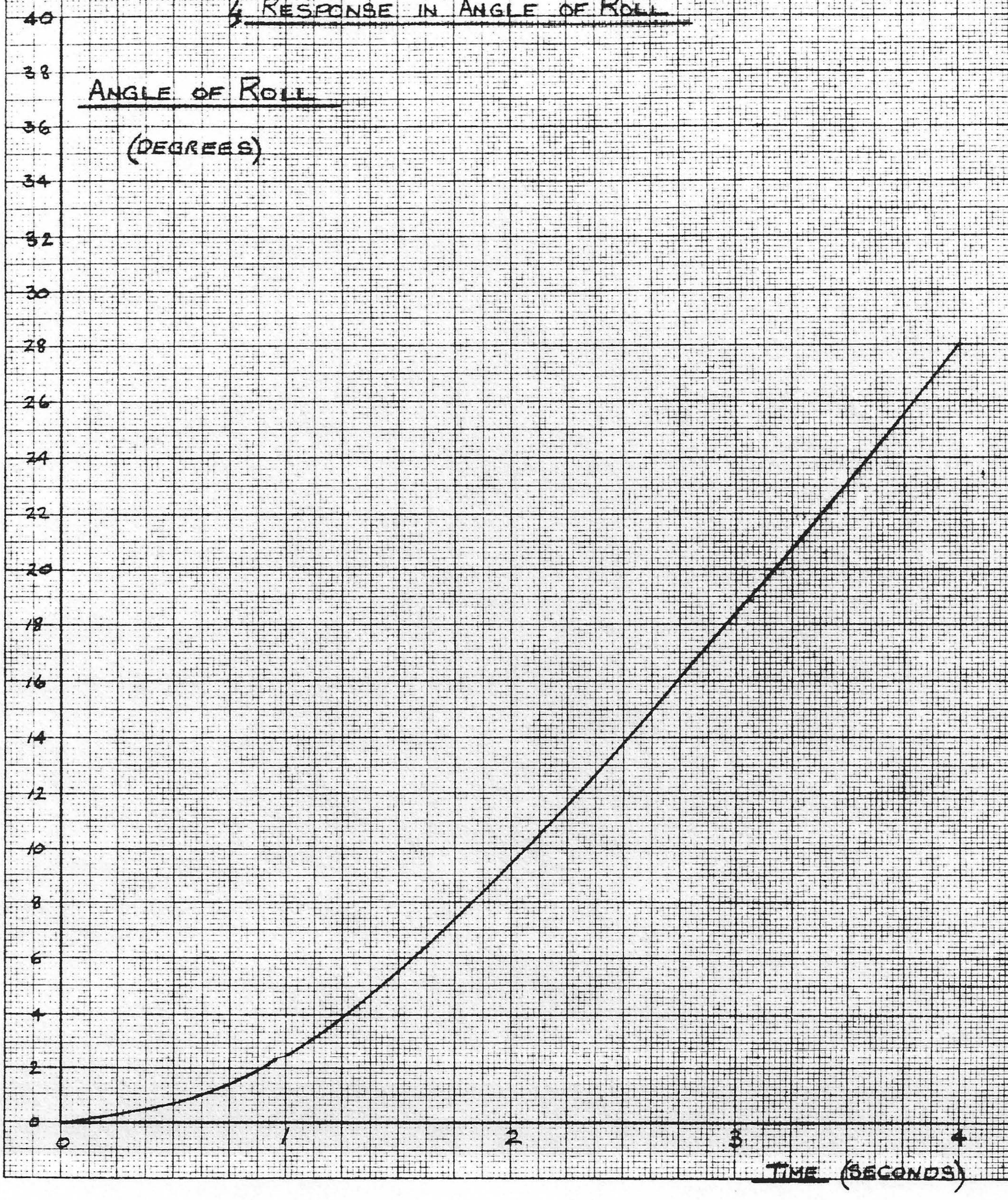
ARROW 2A ZERO LENGTH LAUNCH

FIG 7 RESPONSE TO MISALIGNMENTS CAUSING ROLLING MOMENTS

ALL CONTROL ANGLES ZERO STANDARD DAY (77°F)
1" CG OFFSET 0°15' BOOSTER THRUST MISALIGNMENT 5% THRUST INCREASE

b RESPONSE IN ANGLE OF ROLL



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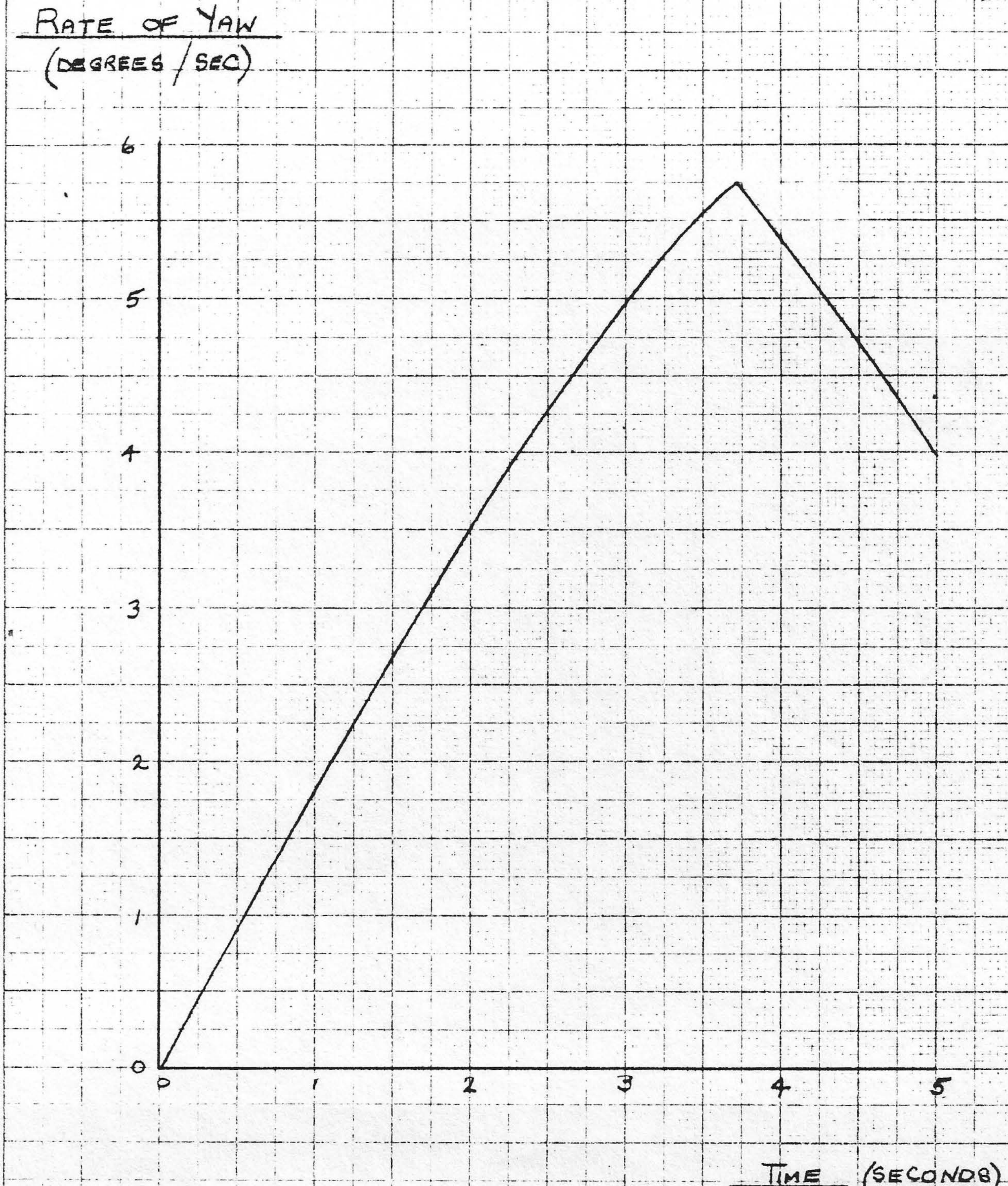
ARROW 2A ZERO LENGTH LAUNCH

FIG 7 RESPONSE TO MISALIGNMENTS CAUSING MAXIMUM ROLLING MOMENT

ALL CONTROL ANGLES ZERO STANDARD DAY 77°F.

1" C.G. OFFSET 0°15' BOOSTER THRUST MISALIGNMENT 5% THRUST INCREASE.

5 RESPONSE IN RATE OF YAW



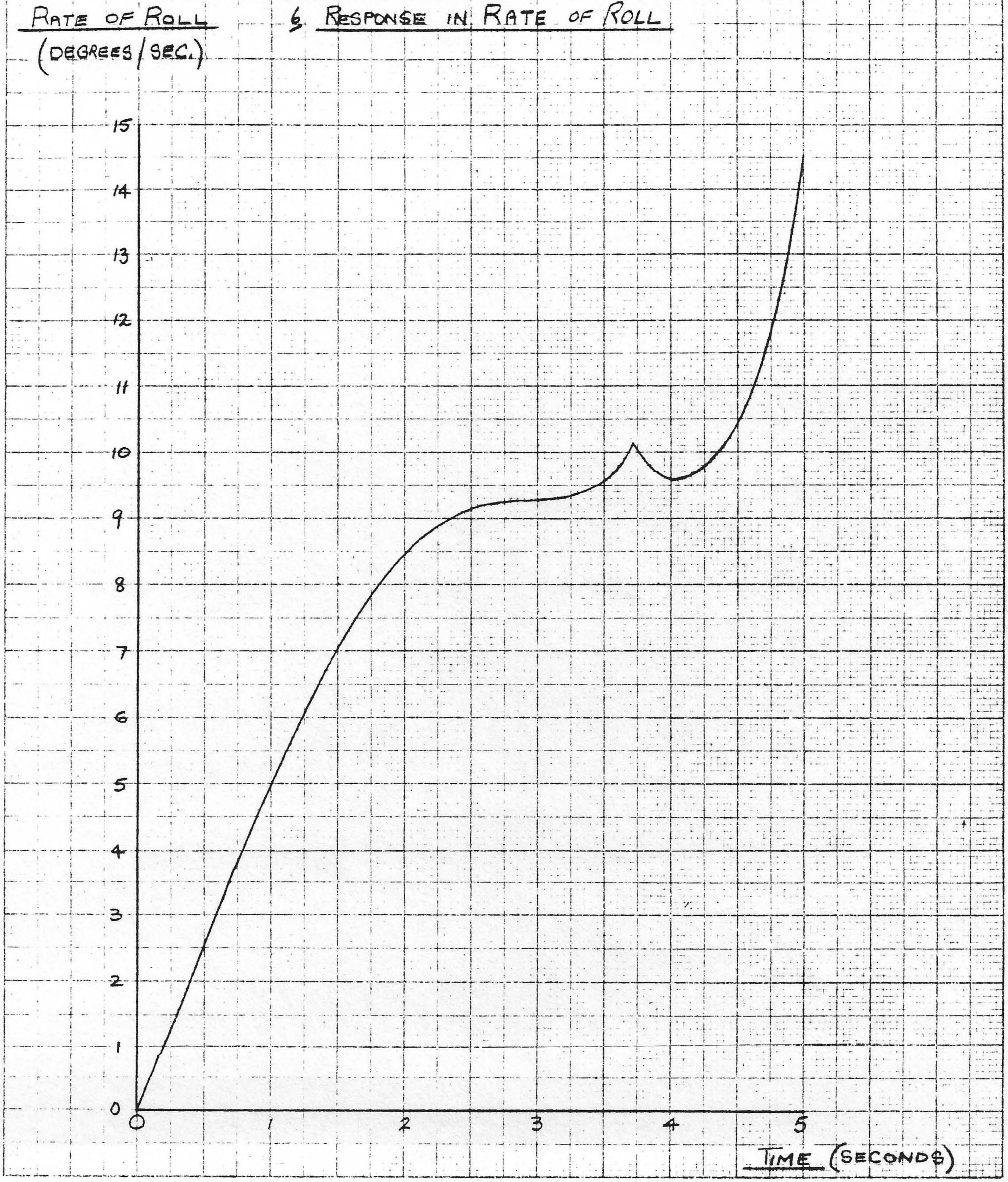
ARROW 2A ZERO LENGTH LAUNCH

FIG 7 RESPONSE TO MISALIGNMENTS CAUSING MAXIMUM ROLLING MOMENTS

1" C.G. OFFSET 0°15' BOOSTER THRUST MISALIGNMENT 5% THRUST INCREASE.

ALL CONTROL ANGLES ZERO STANDARD DAY (77°F)

6. RESPONSE IN RATE OF ROLL



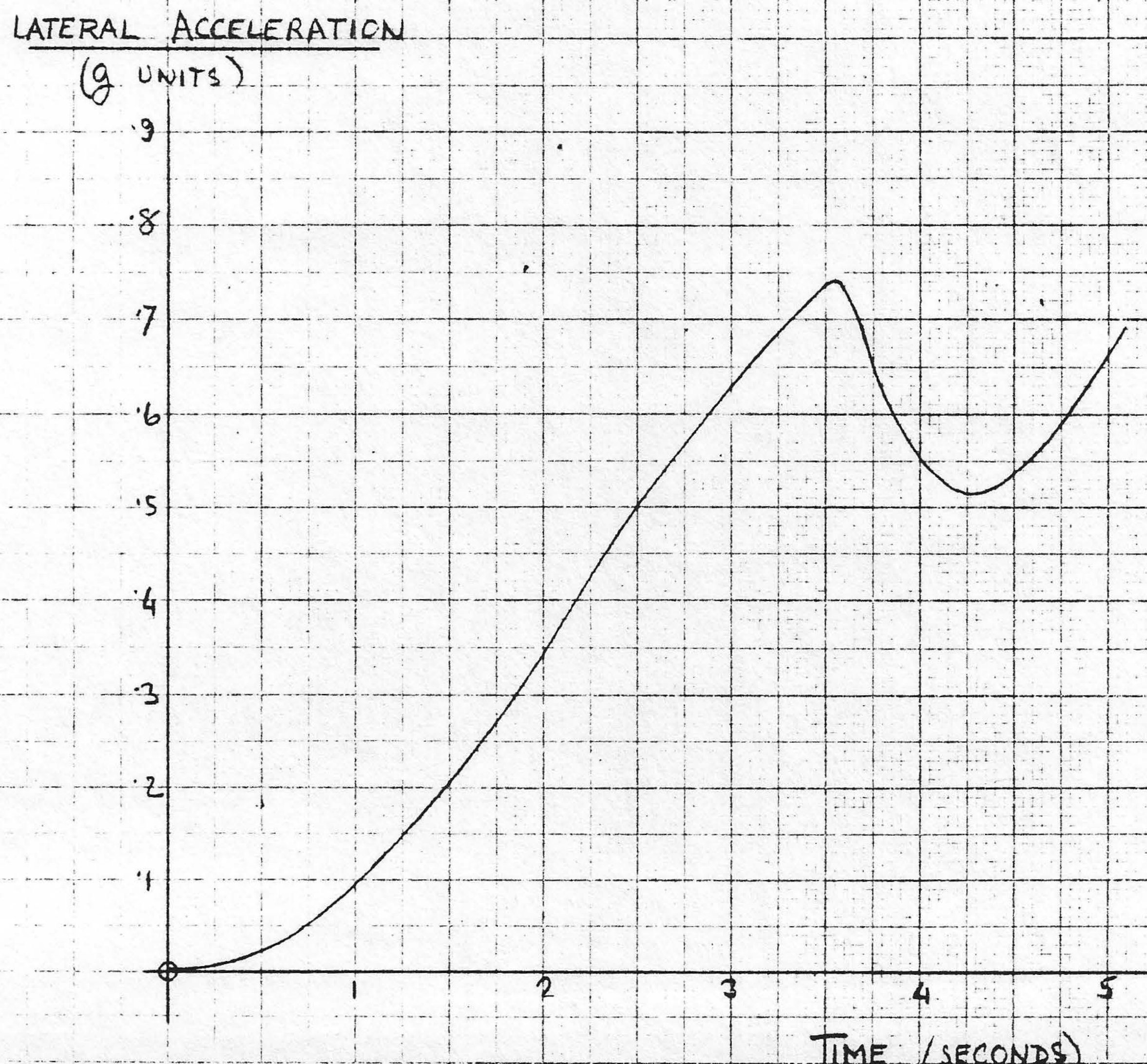
ARROW 2A ZERO LENGTH LAUNCH

FIG 7 RESPONSE TO MISALIGNMENTS CAUSING MAXIMUM ROLLING MOMENT

ALL CONTROL ANGLES ZERO STANDARD DAY (77°F)

1" C.G OFFSET 0°15' BOOSTER THRUST MISALIGNMENT 5% THRUST INCREASE

7 VARIATION OF LATERAL ACCELERATION WITH TIME



#3

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ARROW 2A ZERO LENGTH LAUNCH INVESTIGATION

OCTOBER 1958

AVRO AIRCRAFT LIMITED

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CONTENTS

1. SUMMARY

An investigation has been made of a zero length launching method for the Arrow.

The method adapted consists of mounting two JATO Type 121 Units under the wings, the take-off being accomplished from a ramp supporting the aircraft by means of its undercarriage.

The general configuration of the aircraft, method of mounting the booster units, arrangement of the ramps, and method of ejecting the boosters, are shown on the referenced drawings.

A preliminary study of the dynamic characteristics of the launch has been made by the Aerodynamics Department (Ref. Report No. 72/STAB/45). This study included effects of malalignment of thrust, variation of c.g. position, and effects of temperature. The report indicates the importance of c.g. position tolerance in particular, as well as booster thrust axis alignment. The maximum acceptable tolerance for the former is of the order of ± 1 inch and for the latter, 15 minutes of arc.

Examination of loads and stresses indicated that some modifications would be required in the vicinity of the booster attachment points to the wing, but these do not appear to be of a serious nature.

2. INTRODUCTION

2.1 A request has been made that the company investigate the feasibility of a method of launching the Arrow to flying speed without the use of any ground run. It was assumed in this study that the zero launch operation would be required to be located at any point in the country and would be set up on a 24 hour "at the ready" basis.

2.2 The purpose of this report is to present the results of this investigation. The reasons for the equipment selected and its adaptation to the Arrow are discussed. Modifications that would be required to the airframe and controls are pointed out. Mention is made of necessary ground ancillary equipment. Finally, the analysis of dynamic characteristics and the limitations to thrust and weight tolerances are summarized.

2.3 A zero length launch requires a thrust, in addition to that provided by the engines, sufficient to provide an aircraft trajectory of at least 10° in elevation. This additional thrust must also be of sufficient magnitude and duration to ensure flight speed in the shortest possible time consistent with the acceleration tolerances imposed by the airframe and crew.

Assuming a flight speed of 170 knots and a constant acceleration of 3g:

$$\text{duration of launch } t = \frac{170 \times 1.689}{3 \times 32.16} = 2.977 \text{ secs.}$$

$$\text{distance of launch } S = \frac{170 \times 1.689}{2} (2.977)$$

$$= 426.5 \text{ ft.}$$

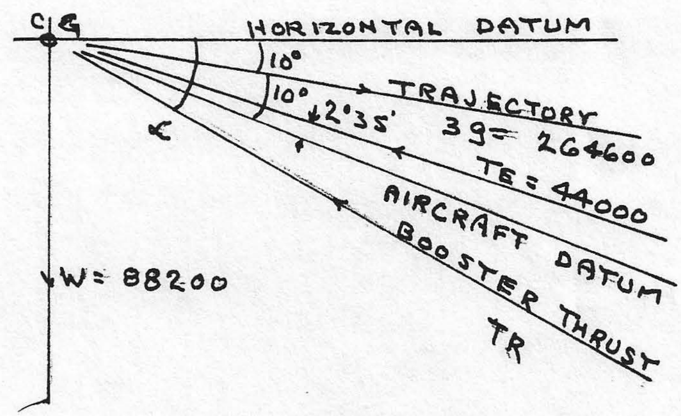
2.3 **(Continued)**

Higher accelerations would produce a launch of reduced duration and distance but are not recommended on account of crew and airframe limitations.

The launching distance under 3g acceleration therefore would indicate that a thrust booster be used which is an integral part of the aircraft, though it may be jettisoned at the end of the launch.

Hence, this investigation concerned itself with the adaptation of rocket boosters for the zero-launch operation.

An approximate value for the rocket thrust required can be obtained by considering the forces involved, neglecting moments and aerodynamic loads.



Engine Thrust Assumed = 44,000 Lb. = T_E

Gross Weight of Aircraft = 88,200 Lb.

Balance Vertical Forces:

$$88,200 + 264,600 \sin 10^\circ - 44,000 \sin 17^\circ 25' - T_R \sin \alpha = 0$$

$$88,200 + 45,900 - 13,160 - T_R \sin \alpha = 0$$

$$T_R \sin \alpha = 120,946$$

2.3 (Continued)

Balance Horizontal Forces:

$$264,600 \cos 10^\circ - 44,000 \cos 17^\circ 25' - T_R \cos \alpha = 0$$

$$260,060 - 42,000 - T_R \cos \alpha = 0$$

$$T_R \cos \alpha = 218,000$$

$$\tan \alpha = .5555$$

$$\alpha = 29^\circ 2'$$

$$\sin \alpha = .48532$$

$$T_R = 249,000$$

2.4 Examination of the airframe structure revealed that it would be extremely unlikely that such a single thrust could economically be applied. It was resolved, therefore, to use two rocket boosters, mounted symmetrically to the lower side of the wing.

2.5 The economics of choosing an existing booster for which performance and reliability were known, led to the selection of JATO Unit 121, Type 405-130000 X226A1. This booster is used on Snark and the characteristics are as follows:-

Weight per Booster		= 5,125 Lbs.
Thrust	at 77°F	= 132,000 Lbs.
	at 120°F	= 143,500 Lbs.
	at -65°F	= 101,500 Lbs.
Burning Time	at 77°F	= 3.72 seconds
	at 120°F	= 3.45 seconds
	at -65°F	= 4.55 seconds

2.6 It should be pointed out that figures given for -65°F temperature are extrapolated, whereas it is recommended that the booster be stored and fired at a minimum environmental temperature of -20°F. Improved propellants may extend this temperature to lower limits.

2.7 The tolerances on thrust and burn-out time for this booster are not exactly known and further information on latest data would be required for confirmation. It can be assumed that, as propellants are being continuously developed, the tolerances would be sufficiently close to minimize adverse effects when using two boosters.

3.0 DESCRIPTION OF BOOSTER APPLICATION

3.1 One JATO Unit, Type 405-130000 X226A1 is disposed on each wing, each being mounted beneath the main box spar, and attached to the wing structure by three struts. The forward strut which is rigidly attached to the booster, is pinned to a wing fitting at the juncture of the main spar and rib no. 4. Two rear struts, each pinned to the booster near the aft end, pick up on fittings at the juncture of the rear spar at ribs number 4 and 5.

The bodies of the JATO units are substantially parallel to the aircraft datum whereas the axis of the booster nozzles are oriented so that the thrust line projected passes almost, but not quite, through the aircraft gross centre of gravity. They meet, of course, at the plane of symmetry and hence lateral components cancel each other. The intersection on the vertical and fore and aft co-ordinates is such as to produce the desired trajectory, this positive mal-alignment being necessary to balance engine thrust moments about the c.g.

3.2 Both boosters must be jettisoned at the point of burn-out. Investigation of jettisoning by free release showed that powerful pitch-up aerodynamic forces were present, which would cause interference with the aft under surface of the wing and result in damage. Hence, positive downward ejection of the boosters is provided.

Each booster strut is locked into its fitting on the wing by means of a hook lever. The three levers are connected to a single operating source on the top centre of the rocket by means of rods and bellcranks. The gas operated jacks for jettisoning are located in the front and rear inner struts. Gas pipes connect these jacks with the same operating source servicing the release levers. The operating source consists of a cartridge, manifolded to a gas jack which operates the release levers. At the instant of this release gas is fed to the ejection jacks which propel the booster downward clear of the wing. It is proposed to proportion the ejection loads produced by the jacks in such a manner that a pitching moment is applied to the booster during ejection, forcing the nose down to a position where the free air stream will cause it to have further negative pitching.

3.3 Firing of the boosters is accomplished simultaneously by a pilot's actuating button or switch.

4.0 AIRCRAFT ATTITUDE

A trajectory of 10 degrees was considered the minimum to provide adequate clearance for the launch. At the same time a minimum trajectory requires minimum boost thrust and reduces the time to controllable flight speed. Ten degrees was chosen in consideration of these two characteristics.

4.0 (Continued)

At the period in the launch at which controllable flight speed is reached, or at the slightly higher speed at which burn-out of the boosters occurs, it is desirable that the incidence of the aircraft be the normal one for that speed. This provides a smooth transition from boosted launch to normal climb and obviates a sudden demand on the pilot to correct for incidence, at a time when he is probably correcting for other deviations.

Combining the trajectory with the incidence gives a 20° attitude for the aircraft datum and this applies to the static position on the ramps. The aircraft is supported on three ramps, one for each undercarriage. Due to the 20° datum angle, it is necessary to raise the main undercarriage above the ground to avoid interference of the rear of the jet pipes with the ground.

The aircraft is winched up onto the ramps, the main wheels are locked to prevent roll-back, and the nose gear then elevated to give the desired datum angle. The nosewheels must be locked to the ramp during elevation and subsequently because the c.g. normal to the ground passes very close to the main gear fulcrum point.

At the instant of firing the boosters, all locks between aircraft and ramps are released and the nose gear ramp is quickly lowered to allow the rear bottom fuselage to clear on take-off.

5.0 <u>MODIFICATION TO AIRFRAME</u>

Consideration of the reactions induced in the airframe by booster thrust and acceleration, and the manner in which they are distributed through the main wing torsion box, indicates that no serious problem regarding the structure exists. The preliminary findings are as follows:-

5.1 Rib 4

A redesign is probably necessary to incorporate additional web material and flange material to diffuse the fore and aft booster thrust loads into the skins over a considerable chordwise length. If the rib be made capable of distributing the loadings to the skin over its whole length, no skin thickening would be necessary.

5.2 Front Spar

Local redesign likely required to suit booster strut pick-up fitting just outboard of Rib. 4.

5.3 Rear Spar

Local strengthening between ribs 7 and 4 in the form of increased web thickness and flange sizes is indicated to accommodate local moment and differential shear loads applied by the rear mounting points.

5.4 Rib 6

There is a possibility that modification is required from the rear spar to the centre spar aft to provide a balance path for loads from rear outboard fitting.

5.5 Skins

A possible increase in thickness aft of the centre spar aft between ribs 4 and 6 to accommodate local differential shears between the aft mounting points.

5.6 Fuselage Sidewalls

Possible increase in skin gauge below rib 4 to longeron to carry that portion of thrust loads which is reacted by fuselage inertias.

5.7 Deflections

Analysis indicates the following wing deflections under launching conditions.

a. forward pick-up point downward deflection = 0.12 inch

b. Rear inboard pick-up point downward deflection = 0.41 inch

c. Rear outboard pick-up point downward deflection = 1.80 inch.

This results in a nose up movement of the booster thrust axis of about 0.36 degrees due to wing deflections only. Some angular movement nose outboard will accompany this deflection and will be of the same order.

Deflections of the booster struts and the booster body will be additional to the above.

5.7 (Continued)

It is submitted that these deflections can be catered for with regard to mal-alignment by presetting the booster thrust axes to cancel deflections while under thrust loads.

As pointed out elsewhere, the problem of thrust mal-alignment is alleviated to some degree by maintaining a very close tolerance on a standard c.g. position for the aircraft.

6.0 GROUND SUPPORT EQUIPMENT

Minimum ground support equipment will include the following:-

6.1 Main gear and nose gear ramps, together with tie downs, winching gear and nose elevating and release gear.

6.2 Temperature control of boosters, missiles and radar. This may be accomplished by a unit heater supplying controlled temperature air to the units, or by surrounding the aircraft with an insulated hangar, the air and contents of the hangar being maintained at the required temperature by means of a heating unit and controls.

6.3 Equipment for handling the booster units on the base, capable of raising them to a position for coupling to the aircraft. Also required are booster alignment tools for aligning the booster thrust to within required tolerances.

6.4 Ground starting equipment for the main engines.

6.5 Ground crew and flight crew quarters.

6.6 An insulated hangar for the aircraft. This is required to be as small and as light as possible and be of prefabricated construction. It must be possible to transport the panels of which it is assembled to the site by whatever transport is specified for this operation. Volume and surface area must be a minimum to keep the environmental heating or cooling load as low as possible. It is not considered possible to "fire" the aircraft out of the hangar even though both ends be open. The energies of engine eflux and booster efflux would be sufficient to demolish a light structure. Hence, it is proposed to move the hangar sideways out of the damage zone. This requires that one side be removed, which can be done by folding the side accordian fashion and moving it sideways with the hangar. Provision would be necessary to remove any ancillary equipment contained in the hangar at the same time, either sideways with the hangar or to some other protected area.

6.7 It is presumed that facilities exist for fuelling the aircraft, or would be provided. This does not necessarily involve the launching procedure under discussion.

7.0 WEIGHT ANALYSIS

Weight of Arrow 2A with drop tank	81,000
Less Weight of drop tank and fuel	4,250
	76,750
Plus 2 JATO Boosters	10,250
Plus Booster Struts and Gear	1,000
Plus Mods. to Aircraft	200
Total Gross Weight	**88,200 lbs.**

8.0 DYNAMIC CHARACTERISTICS

A preliminary investigation has been done for the zero-length launch, the results are described in Avro Report No. 72/Stab/45.

8.1 In this report, the trajectory and time histories of the incidence, pitch angle, accelerations, speed, yawing and rolling moments, rates of yaw and roll etc. have been worked out for standard conditions and for non-standard conditions. The latter include effects of temperature, of mal-alignment of thrust axes and movements of centre of gravity. Effects of pilot control or damping system were not considered.

8.2 Although the final design may differ in geometry, weight, etc. from that assumed in the analysis, and hence, the responses will differ, the acceptable tolerances of boost alignment and c.g. position estimated in the report give a representative range of values to be expected and emphasize their importance.

8.3 This investigation indicated that the maximum acceptable tolerances of c.g. positions and booster thrust mal-alignment should be:

8.3.1 Aircraft Centre of Gravity

Longitudinal	$\pm$ 0.5% M.A.C.= $\pm$ 1.8 inch
Lateral	$\pm$ 1.0 inch
Vertical	$\pm$ 1.0 inch

8.3.2 Booster thrust axes mal-alignment: 15 minutes of arc.

8.4 These tolerances produce deviations in the flight envelope as shown on Figures 1, 2, 3, and 4. Further details may be found in Avro Report 72/STAB/45.

8.5 Combining the responses due to geometric mal-alignment with those due to the maximum temperature range, will produce responses which are somewhat wider in spread than for each one separately. A very rough estimate may be made by combining them additively as shown in the above reference.

8.6 The booster thrust alignment tolerance of 15 minutes will be difficult to meet. This alignment is aggravated somewhat by random gas mal-alignment of the booster, a quantity unpredictable except by statistics.

8.7 Report 72/STAB/45 shows that for pitching and yawing responses produced by thrust mal-alignment, a thrust mal-alignment of 15 minutes is equivalent to a c.g. movement of 0.8 inch. Hence, a tighter tolerance on c.g. movement would allow an increase in thrust mal-alignment, e.g. if the tolerance on c.g. is fixed at $\pm$ 0.25 inch, thrust mal-alignment may be increased to approximately $\pm 0^{\circ} 30'$.

8.8 A consideration of the responses shows up two critical points:-

a. After 3 seconds, height gained by be as low as 18 ft.

b. Incidence may be 19.5°

These indicate the significance of mal-alignment and the c.g. position.

8.9 Figure 3 shows that at 2 seconds from zero, the air speed is 108 knots and at three seconds, it is 165 knots. Hence, up to 2 seconds, controls will be ineffective and from 2 to 3 seconds, control will

8.9 (Continued)

increase rapidly. This allows the pilot to correct to a great extent for the deviations calculated, starting at approximately the 2 second point. Hence, it is submitted that the calculated envelope of responses, as shown on the graphs, may be modified from a divergent trend to a converging value and by the time burn-out occurs, normal attitude and climb will be attained.

9.0 CONCLUSIONS

The comments outlined in the previous section are confirmed to a certain extent by Reference 1, where an F-100D airplane was launched by the aid of a single booster of similar size as that proposed for the Arrow. During the simulator training programme, quote "It was learned, for instance, that booster thrust misalignments up to 1.5 inches in any direction could be safely handled."

"Proper control techniques were developed on the simulator for handling rates of change of control effectiveness that take place during the launch. During the first two seconds all controls are relatively ineffective, but by the time booster burn-out occurs, they are very effective indeed. Thus, too great a pitch control correction early in the boosted portions of the launch could very easily result in an over-control condition a second or two later."

From his descriptions of the actual launch, quote, "For the normal launch, from the very first shot, it was evident that ZEL accelerations forces do not have the surprise effect that identical forces experienced on the steam catapult have. (note:- ZEL refers to zero launch). With ZEL, I felt that I was flying the airplane off the launcher with no apparent time required for recovery from the initial jolt".

10. REFERENCES

1. Making Like a Missile - A.W. Blackburn
From Flying Safety, September 1958 - U.S.A.F.

2. Weight and Balance Problems of "Zero-Length" Launching.
W.J. Griffey, Project Weight Engineer - G.L. Martin Co. -
May 1954.

3. Zero Length Launch - 72/STAB/45
D.L. Martin - Avro Aircraft Limited

4. Artillery and Aircraft Rockets - CIT-VM-1 - W.A. Fowler

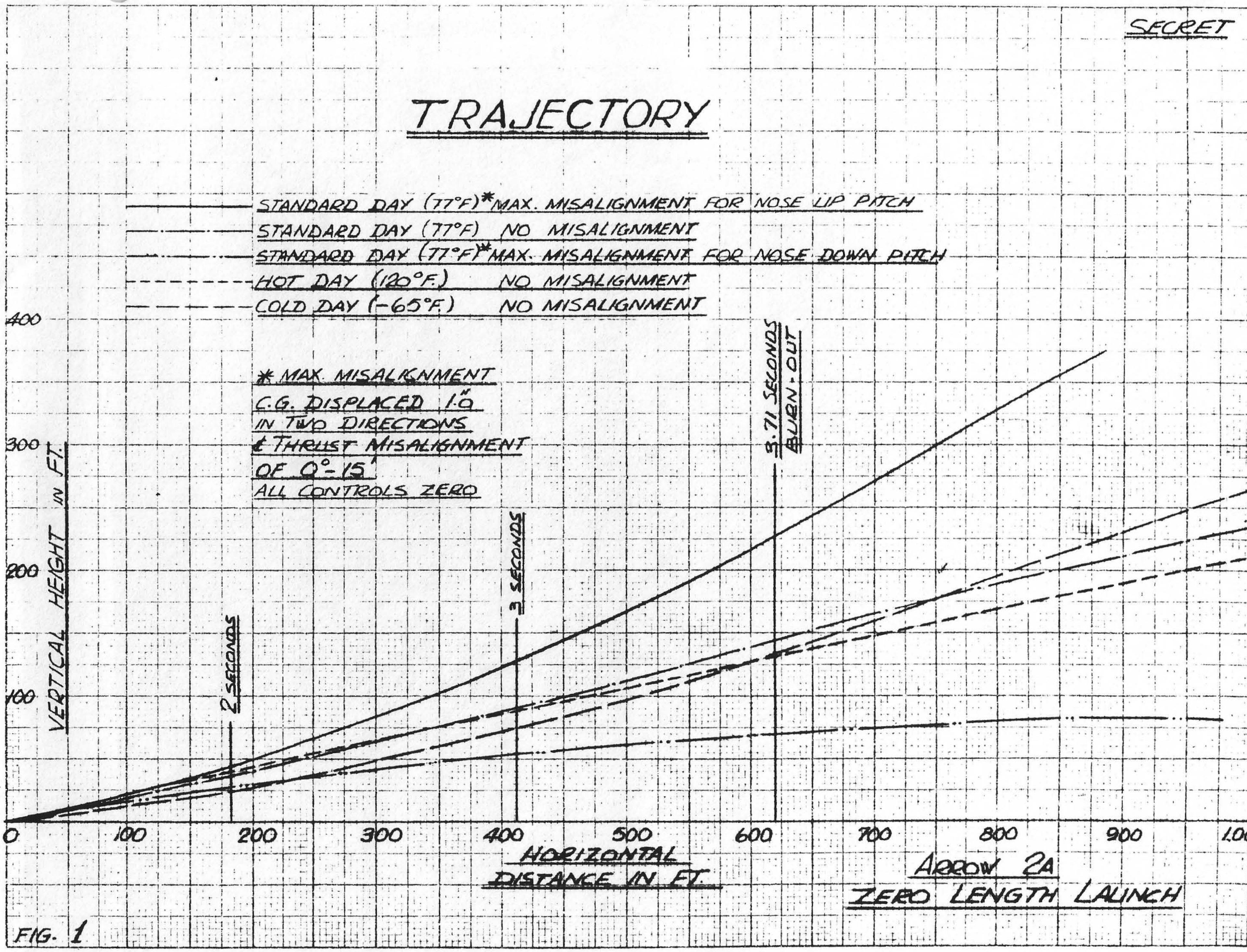
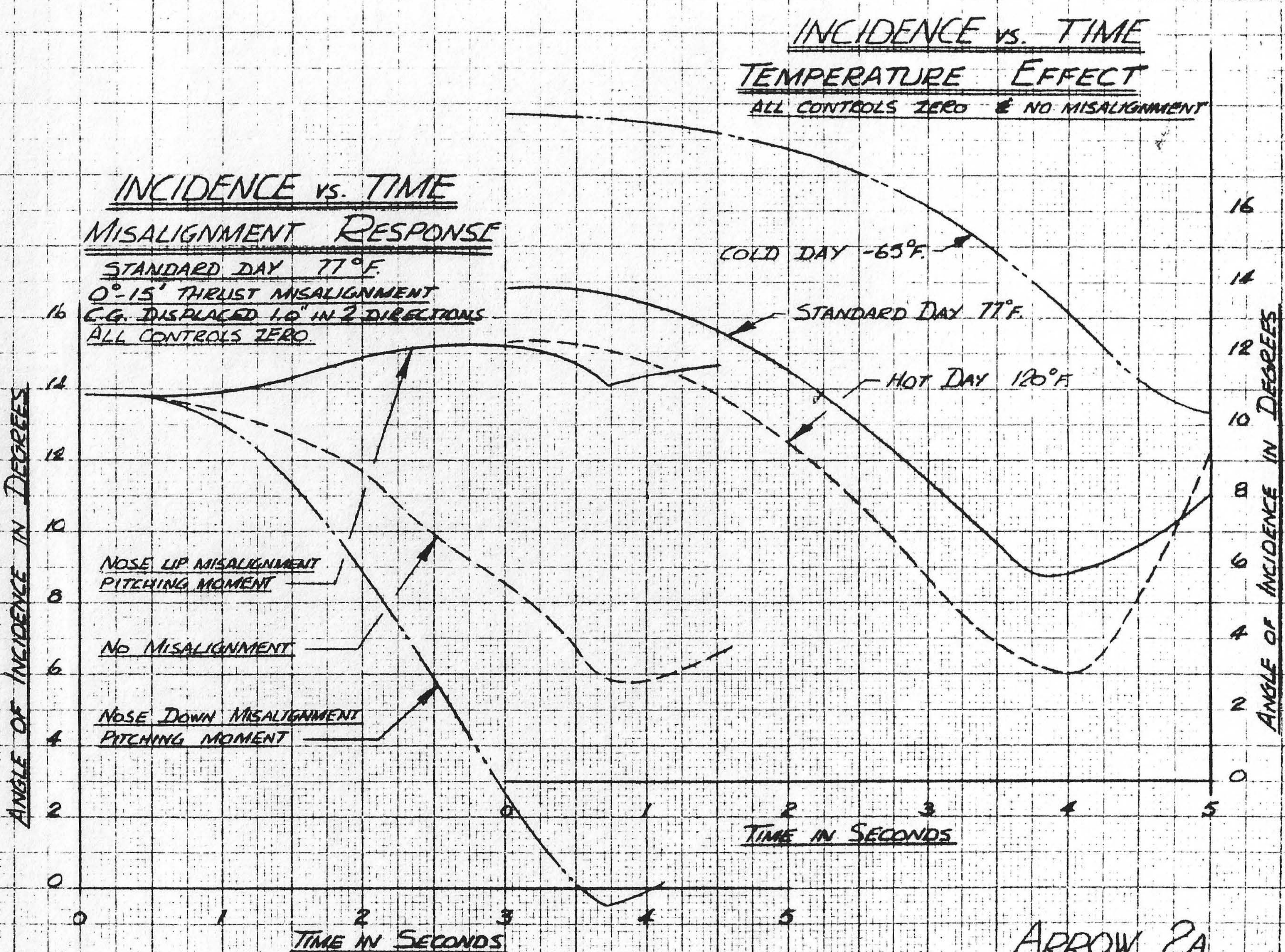

TRAJECTORY
STANDARD DAY (77°F)*MAX. MISALIGNMENT FOR NOSE UP PITCH
STANDARD DAY (77°F) NO MISALIGNMENT
STANDARD DAY (77°F)*MAX. MISALIGNMENT FOR NOSE DOWN PITCH
HOT DAY (120°F.) NO MISALIGNMENT
COLD DAY (-65°F.) NO MISALIGNMENT
* MAX. MISALIGNMENT
C.G. DISPLACED 1.0"
IN TWO DIRECTIONS
& THRUST MISALIGNMENT
OF 0°-15'
ALL CONTROLS ZERO
2 SECONDS
3 SECONDS
3.71 SECONDS BURN-OUT
VERTICAL HEIGHT IN FT.
400
300
200
100
0
100
200
300
400
500
600
700
800
900
1,000
HORIZONTAL DISTANCE IN FT.
ARROW 2A
ZERO LENGTH LAUNCH

FIG. 1

K+E 10 X 10 TO THE ½ INCH 359-12 KEUFFEL & ESSER CO.

SECRET



ARROW 2A

ZERO LENGTH LAUNCH

FIG. 2

UNCLASSIFIED

SECRET

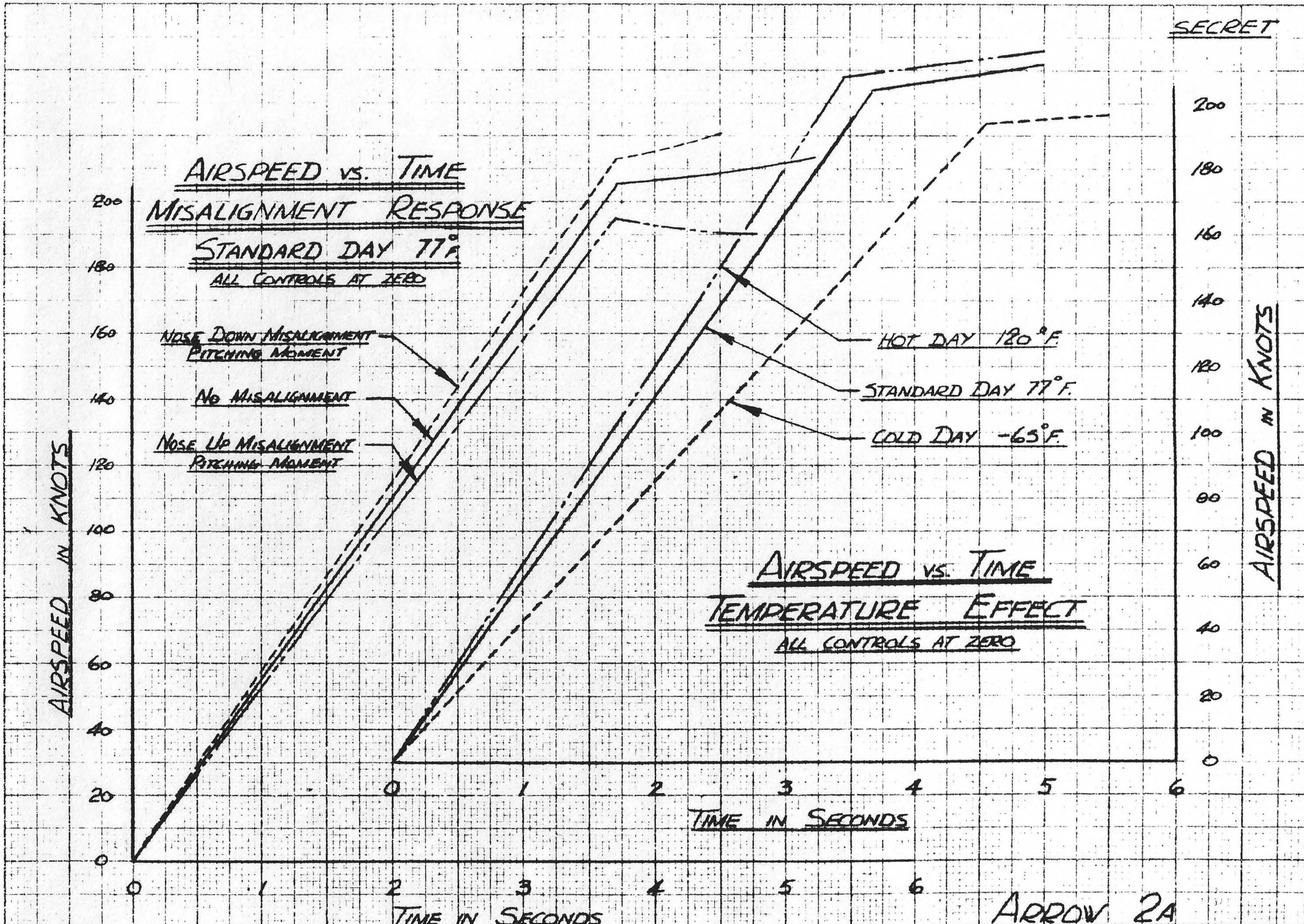


FIG. 3

ARROW 2A
ZERO LENGTH LAUNCH

UNCLASSIFIED

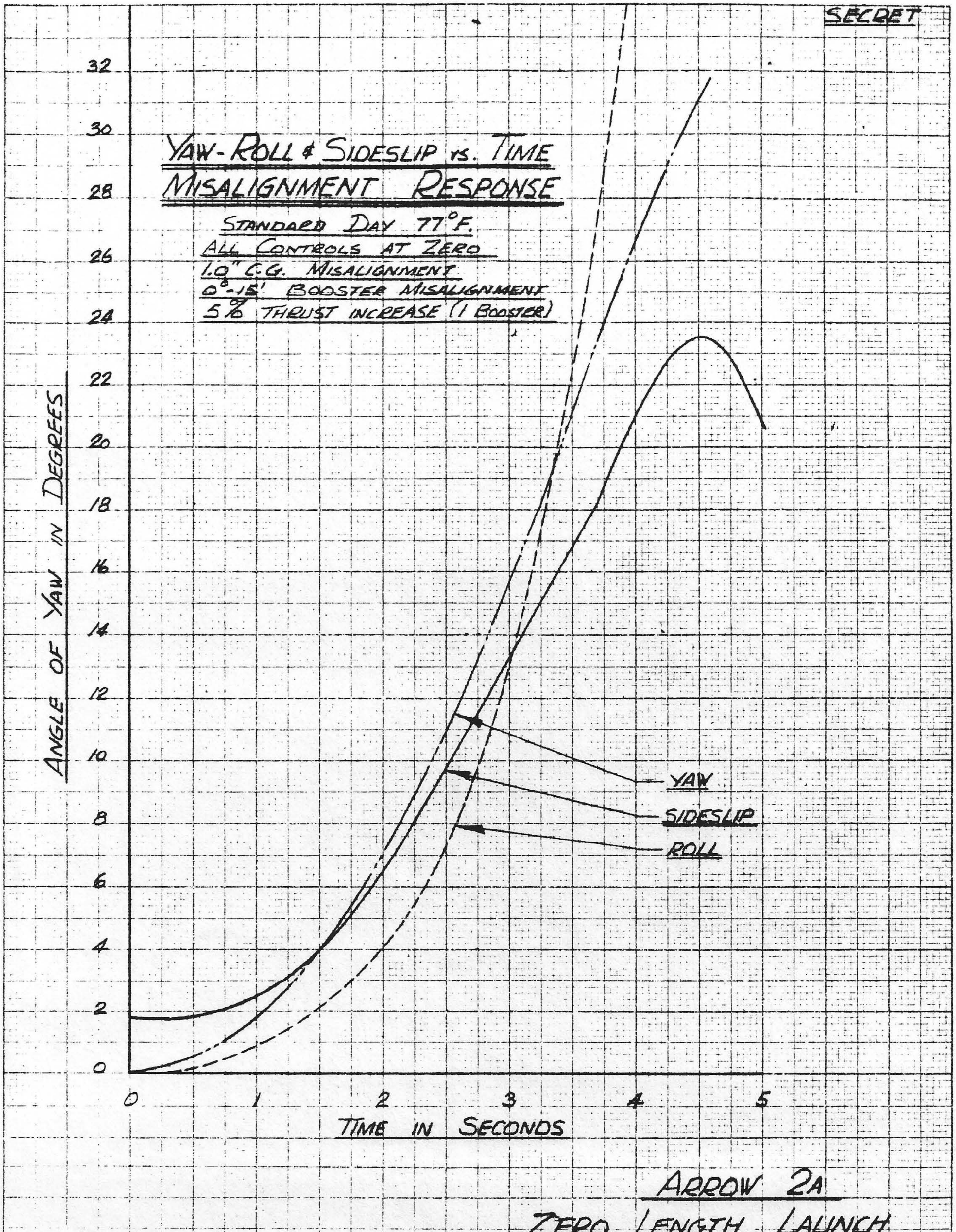
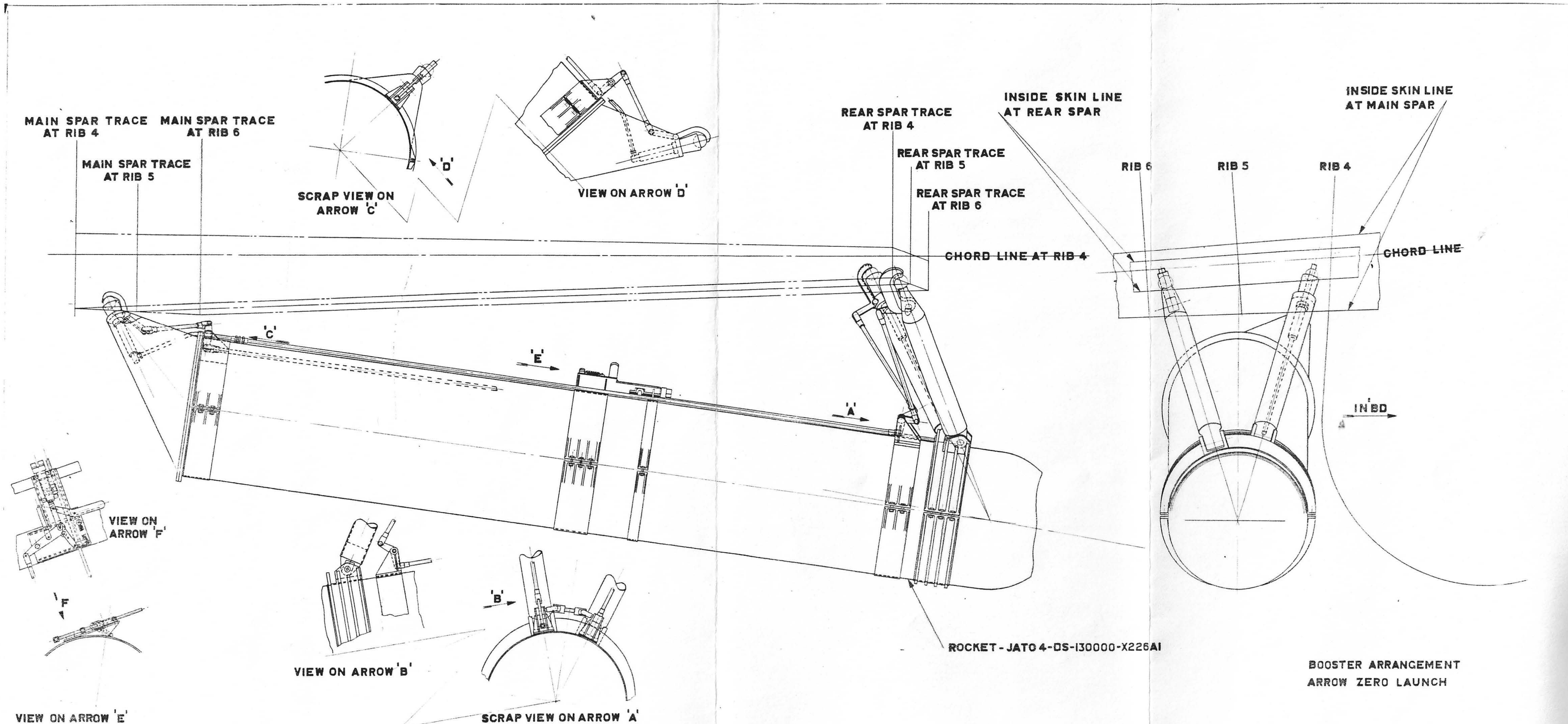
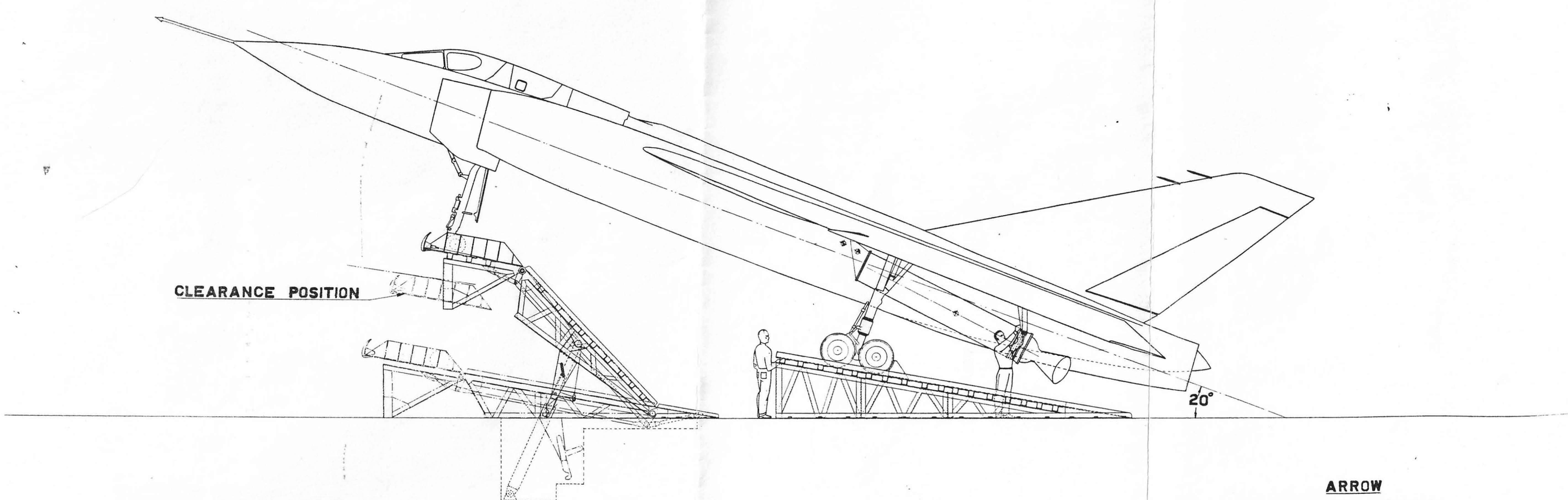

SECRET
YAW-ROLL & SIDESLIP vs. TIME
MISALIGNMENT RESPONSE
STANDARD DAY 77°F.
ALL CONTROLS AT ZERO
1.0" C.G. MISALIGNMENT
0°-15' BOOSTER MISALIGNMENT
5% THRUST INCREASE (1 BOOSTER)
ANGLE OF YAW IN DEGREES
0
2
4
6
8
10
12
14
16
18
20
22
24
26
28
30
32
TIME IN SECONDS
0
1
2
3
4
5
YAW
SIDESLIP
ROLL
ARROW 2A
ZERO LENGTH LAUNCH

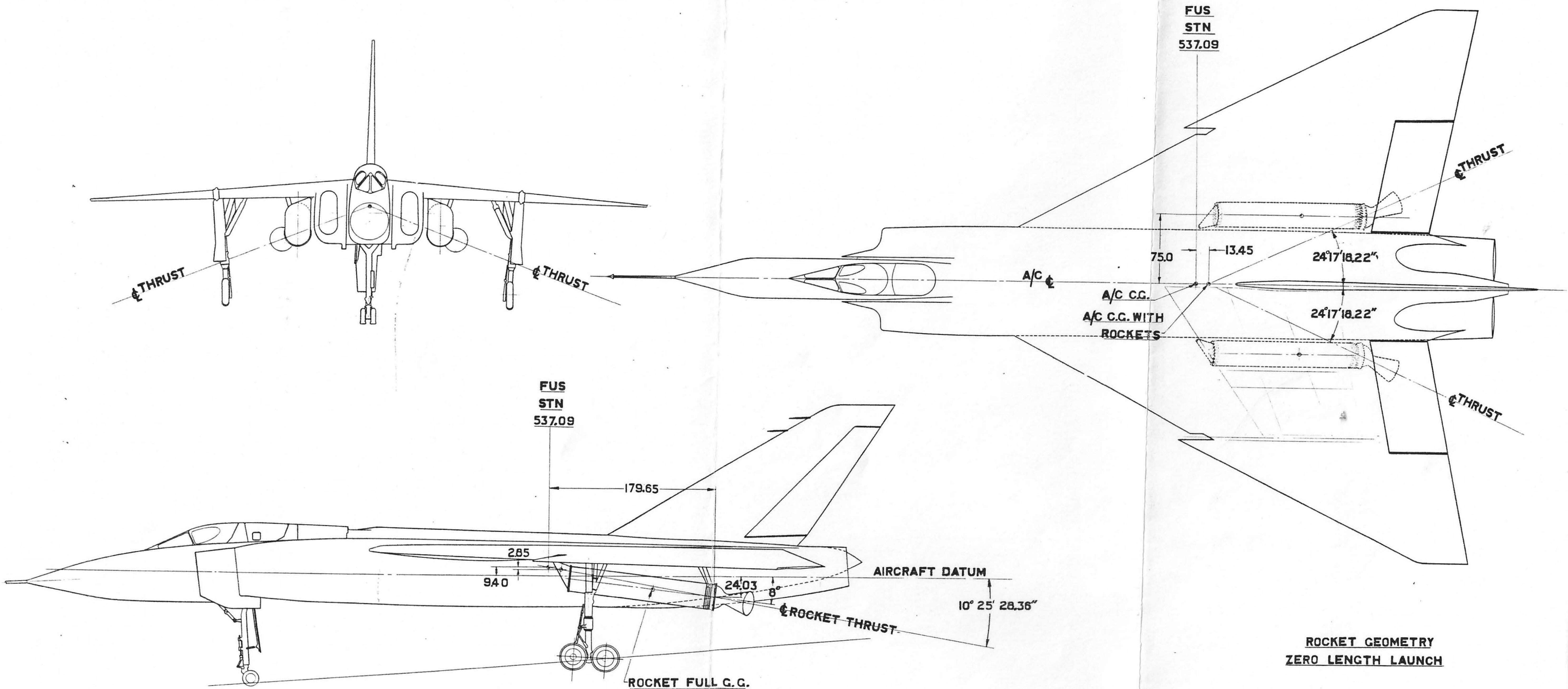
FIG. 4



BOOSTER ARRANGEMENT
ARROW ZERO LAUNCH



ARROW
LAUNCHING POSITION
FOR ZERO LENGTH LAUNCH



ROCKET GEOMETRY
ZERO LENGTH LAUNCH