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Herewith attached is Reconnaissance Arrow Drag and Power Summary.

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cc: R.F. Marshall.

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RECONNAISSANCE ARROW DRAG AND POWER SUMMARY

by W. Kuzyk

1.0 INTRODUCTION

The design target of the reconnaissance version of the Avro Arrow Mk. 3 fighter was chosen as M = 2.5 at 90,000 ft. altitude. This choice requires a considerable reduction in both trim and induced drag as well as doubling of power at altitude. This greatly improved performance capability provides the reconnaissance airplane with a very useful "dash" for (1) evading potential enemies and (2) for positioning prior to the observance and photographing of target areas.

The configuration proposed for a reconnaissance version is shown on figure 9, and the pertinent data are as follows:

Geometry

Wing Area	S_W = 1410 ft.^{2}
Canard Area	S_C = 32 ft.^{2}
Aspect Ratio	AR = 2.65
Side Fins	S_{SF} = 90 ft.^{2} (total)
Fin	S_F = 170 ft.^{2}
Rudder	S_R = 50 ft.^{2}
Ailerons	S_A = 100 ft.^{2} (total)

Weight Estimate

Mk. II O.W.E.(incl.arm.&cameras)	44,214 lb.	
Wing Tip Ramjets	3,600 lb.	
Canard (32 ft.^{2})	200 lb.	
Additional Wing Area (155 ft.^{2})	750 lb.	
Side Fins (90 ft.^{2})	400 lb.	
Additional Rudder (12 ft.^{2})	50 lb.	
Reconnaissance Arrow - O.W.E.		49,214 lb.
Fuel - Internal Fuel	19,438 lb.	
- plus Outer Wing	6,000 lb.	
		25,438 lb.
Reconnaissance Arrow - Full Internal Fuel		74,652 lb.

Long Range Reconnaissance Arrow

Plus One External Tank - Fuel	5,000 lb.	
Plus Two External Wing Tanks - Fuel	5,000 lb.	
Plus Tank Structure	1,000 lb.	11,000 lb.
Total		85,652 lb.

Undercarriage Development

From the foregoing it is felt that the probable high T.O. weight will warrant some development of the undercarriage. In this regard it is highly recommended that a design stress analysis be carried out on two design proposals.

(a) increasing capacity of present U/C design (Mk. II)

(b) Check the feasibility of the addition of outriggers at the wing tips

to cater for an increased normal T.O. weight of the order of 90,000 lb.

Location of Canard

The canard has been tentatively positioned so that there is minimum interference to the pilot's vision and to the intake. (Note that at altitude the fuselage angle of attack is around 10°.) However further study is required.

2.0 DRAG SUMMARY

A drag analysis of the Avro Arrow Mk. II showed that at M = 2.5, 90,000 ft. altitude and a W/P = 250,000 in.^{2} the drag components to be

	D/P in.^{2}	D lb.	% of Total
Profile Drag	16,600	4,080	18.5
Induced Drag	45,200	11,080	50
Trim Drag	28,200	6,960	31.5
	90,000	22,120	

The profile drag is a "fixed item" and any improvement of it was unlikely. Therefore the reduction is more probable in induced and trim drags. Increasing the wing area from 1225 ft.^{2} to 1410 ft.^{2} and the addition of the canard resulted in the following:

	D/P in.^{2}	D lb.	% Total	%Change over Mk.II
Profile Drag	19,900	4,900	37.5	+20%
Induced Drag	28,250	6,950	53.0	-37%
Trim Drag	5,600	1,230	9.5	-82%
	53,750	13,080		-41%

The separate effects of increasing the wing area, and addition of a canard is clearly shown in fig. 7. It follows then that modification of the Avro Arrow for increased speed and altitude should include a canard. The trim effect of the canard elevator combination is shown in fig. 6. Point "A" shows the trim drag to be 28,800 x .246 psi = 7,100 lb. for zero canard effect and a required -26° elevator angle, however utilization of the canard (see point "B") to the extent of its buffet limit results in a trim drag of 5600 x .246 psi = 1230 lb. for α_c canard = +23° and δ_e elevator = -8° - a reduction of 5,870 at M = 2.5, 90,000 ft. W/P = 250,000.

It is noteworthy that total drag of this version at M = .92, 40,000 ft. altitude, W/P 22,000 is 7,000 lb. as compared to 6,660 lb. for the Avro Arrow Mk. II at the same speed, altitude, and weight and this is not too great an increase in drag during a subsonic "cruise out".

Achievement of M 2.5 at 90,000 ft. altitude for an operational weight of 61,400 lb. requires a total of 13,000 lb. thrust, with 7,000 lb. being contributed by the Iroquois engines with after-burning, and the balance of 6,000 lb. by some other power source. Recommended on fig. 9 are wing tip ramjet pods.

3.0 POWER PLANT SUMMARY

The additional 6000 lb. thrust may be obtained by several different combinations of power plant and fuels, some of which are listed below:

	Powerplant	Fuel			
		Turbojet	A/B	Ramjet	Rocket
1	(Turbojet + A/B) + Ramjet	JP4	JP4	JP4	
2	(Turbojet + A/B) + Ramjet	JP4	JP4	Pentaborane	
3	(Turbojet + A/B) + Ramjet	JP4 + H_2O	JP4	JP4	
4	(Turbojet + A/B) + Ramjet	JP4 + H_2O	JP4	Pentaborane	
5	(Turbojet + A/B) + Rocket	JP4	JP4		85% H_2O_2 15% JP4

Some of the characteristics of each combination are tabulated in Table 1 following.

The fuel consumed during a dash of M 2.5, 90,000' alt. and W/P = 250,000' for a Reconnaissance Arrow shows that combinations (1) and (2) are the best (see fig. 10). Since combination (2) involves the use of "mixed" fuels and that the gains afforded by the use of High Energy fuels are not great it is felt that combination (1) is the most suitable for the Reconnaissance Arrow, and this combination is shown in fig. 9.

The use of high energy fuels such as pentaborane results in a decrease of ramjet frontal area from 14.1 $ft.^2$ to 11.9 $ft.^2$ (4.25 to 3.9' dia.) and a reduction of specific fuel consumption from 3.15 to 2.57. Somewhat lesser gains are to be realized from the use of a Boron Slurry.

Water injection is an easy way of "souping up" existing power plant and intake combinations. However, this feature is somewhat curtailed by the large increase in specific fuel consumption, e.g. the recommended Reconnaissance Arrow power plant combination would use at least 2½ times more liquid fuels (by weight) when water is injected into the turbojet intakes to the saturation point.

4.0 RECOMMENDATIONS & FURTHER INVESTIGATIONS

The indications of this note are that a M = 2.5, 90,000' altitude Reconnaissance Arrow is feasible within the present state of art. However, it should be immediately established whether there is a need for a reconnaissance or tactical bomber version of the Arrow via Market Research. Further, power investigations are also recommended with an effort to improving the range potential of the Arrow.

With respect to the Reconnaissance Arrow two plausible locations for reconnaissance equipment are:

(a) In the two inner stalls of the armament bay, thus removing ½ of the armament.

(b) In an extended portion of the nose section aft of the radar, thus maintaining full armament.

Further investigations are required to substantiate this summary. Some of the more important items to be looked into more fully are outlined in table 2.

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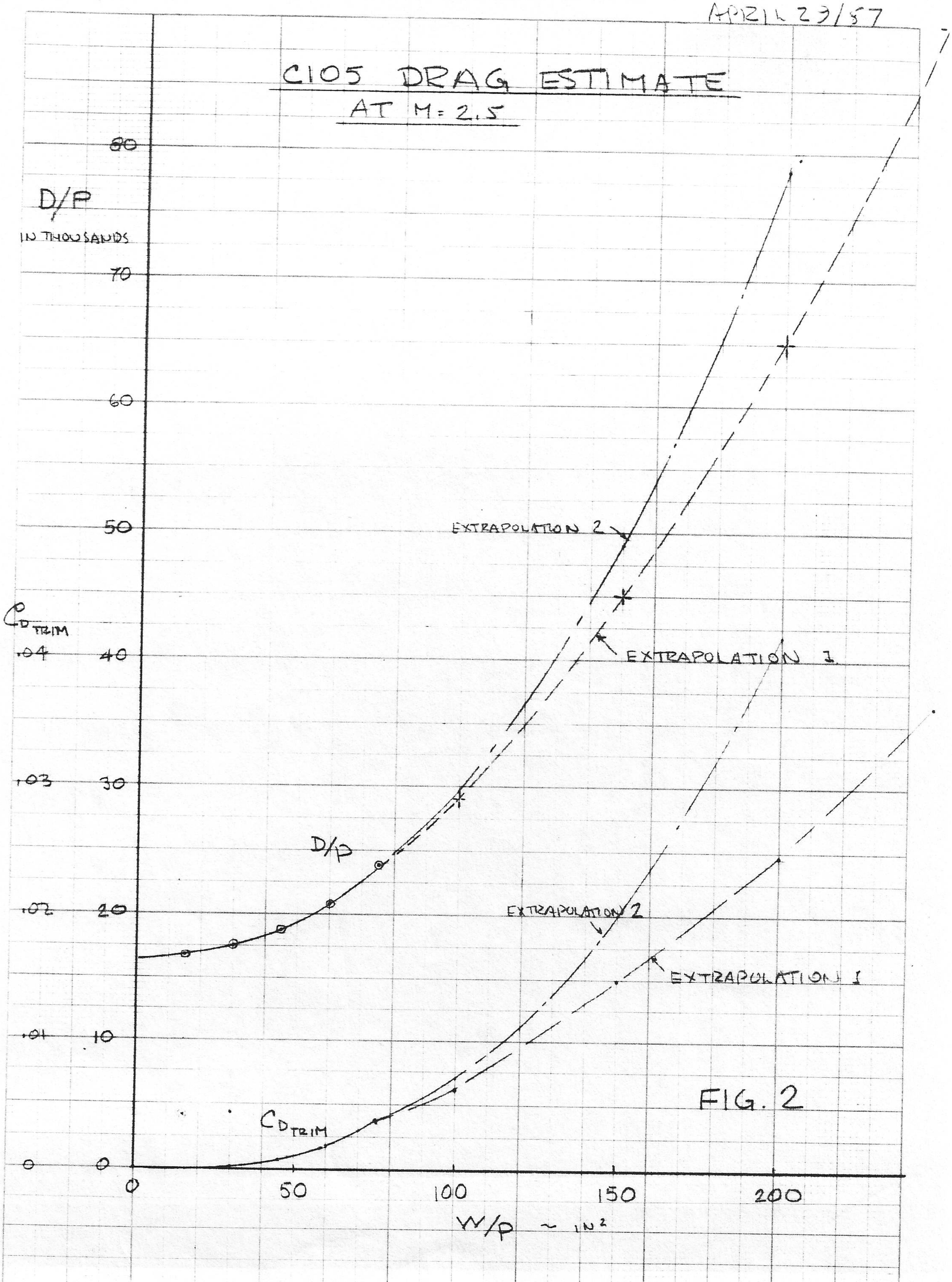

FIG. 2

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MARQUARDT
MODEL MA 20F

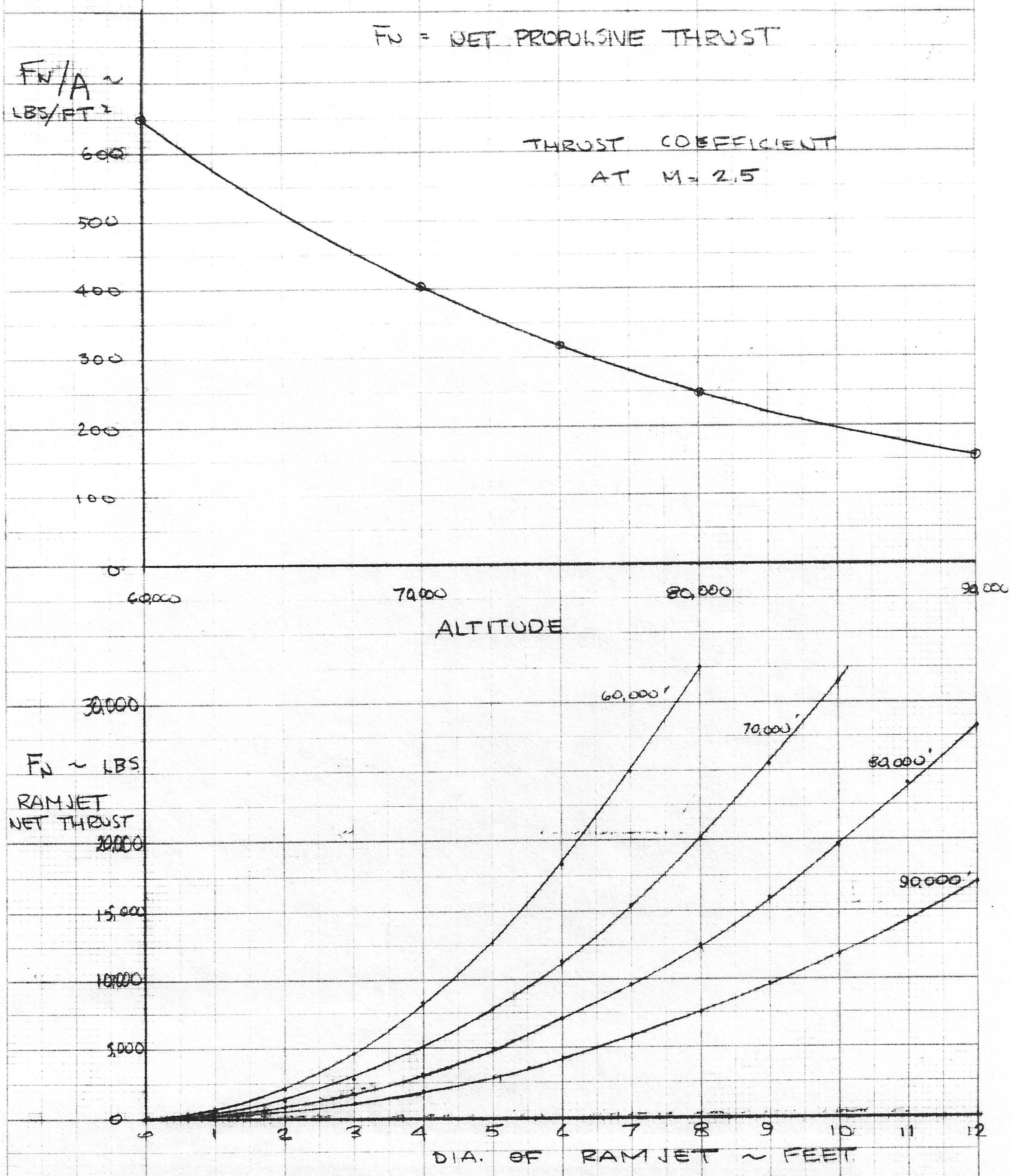

FIG. 3

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TOTAL RAMJET THRUST REQ'D TO ACHIVE M 2.5 AT ALT.

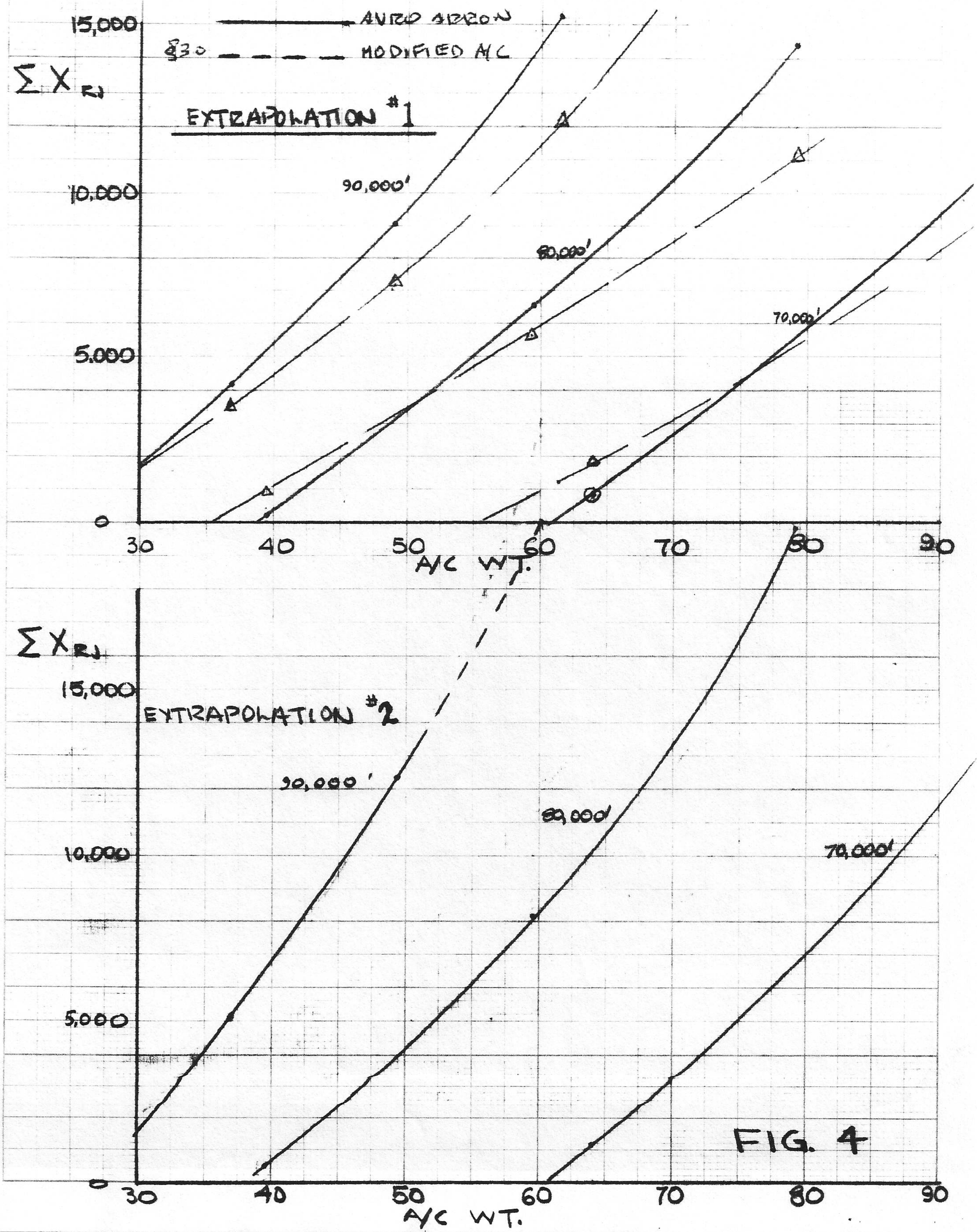

FIG. 4

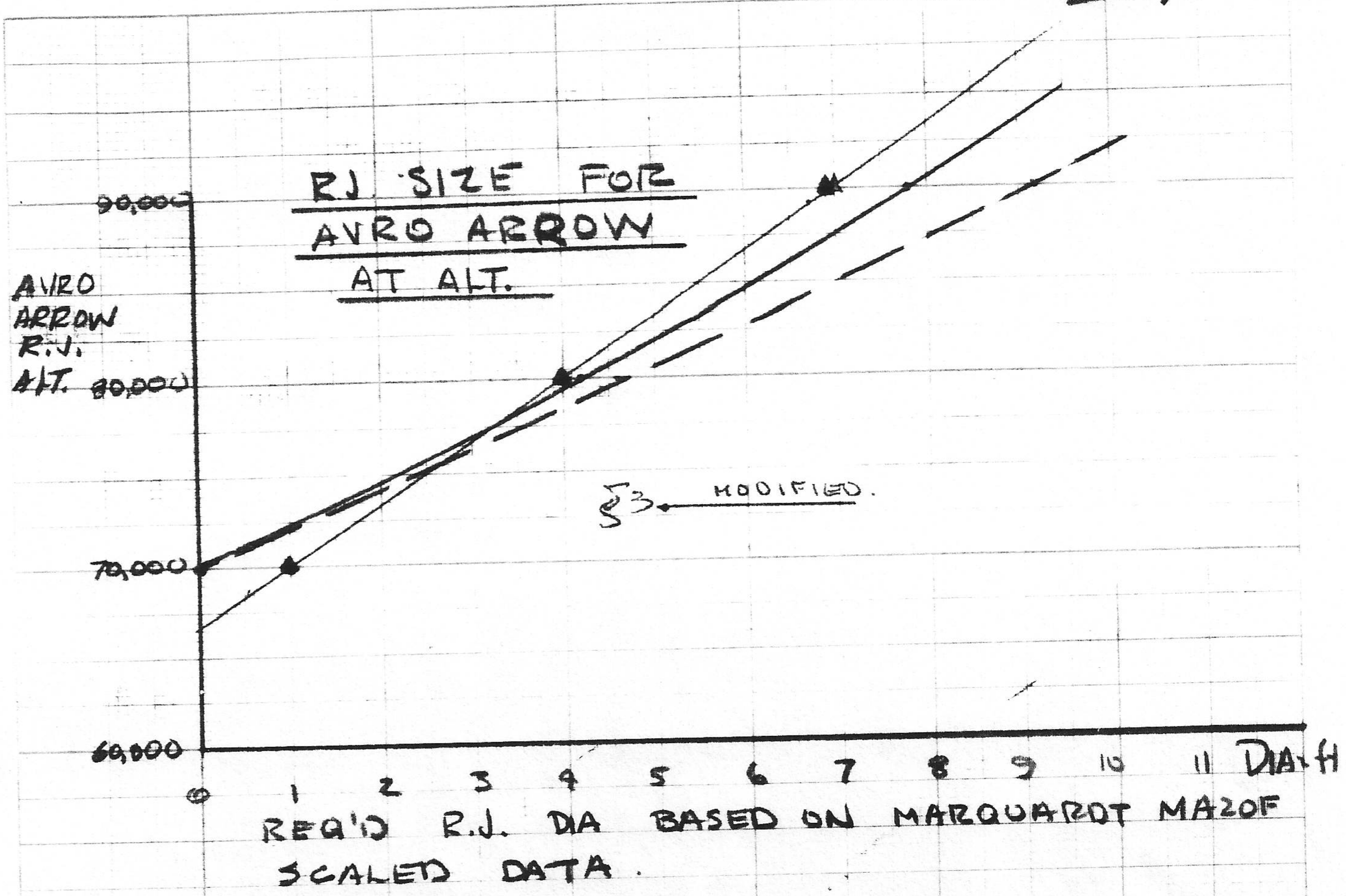
RJ SIZE FOR AVRO ARROW AT ALT.
AVRO ARROW R.J. ALT.
90,000
80,000
70,000
60,000
MODIFIED.
0 1 2 3 4 5 6 7 8 9 10 11 DIA. H.
REQ'D R.J. DIA BASED ON MARQUARDT MA20F SCALED DATA.

FIG. 5

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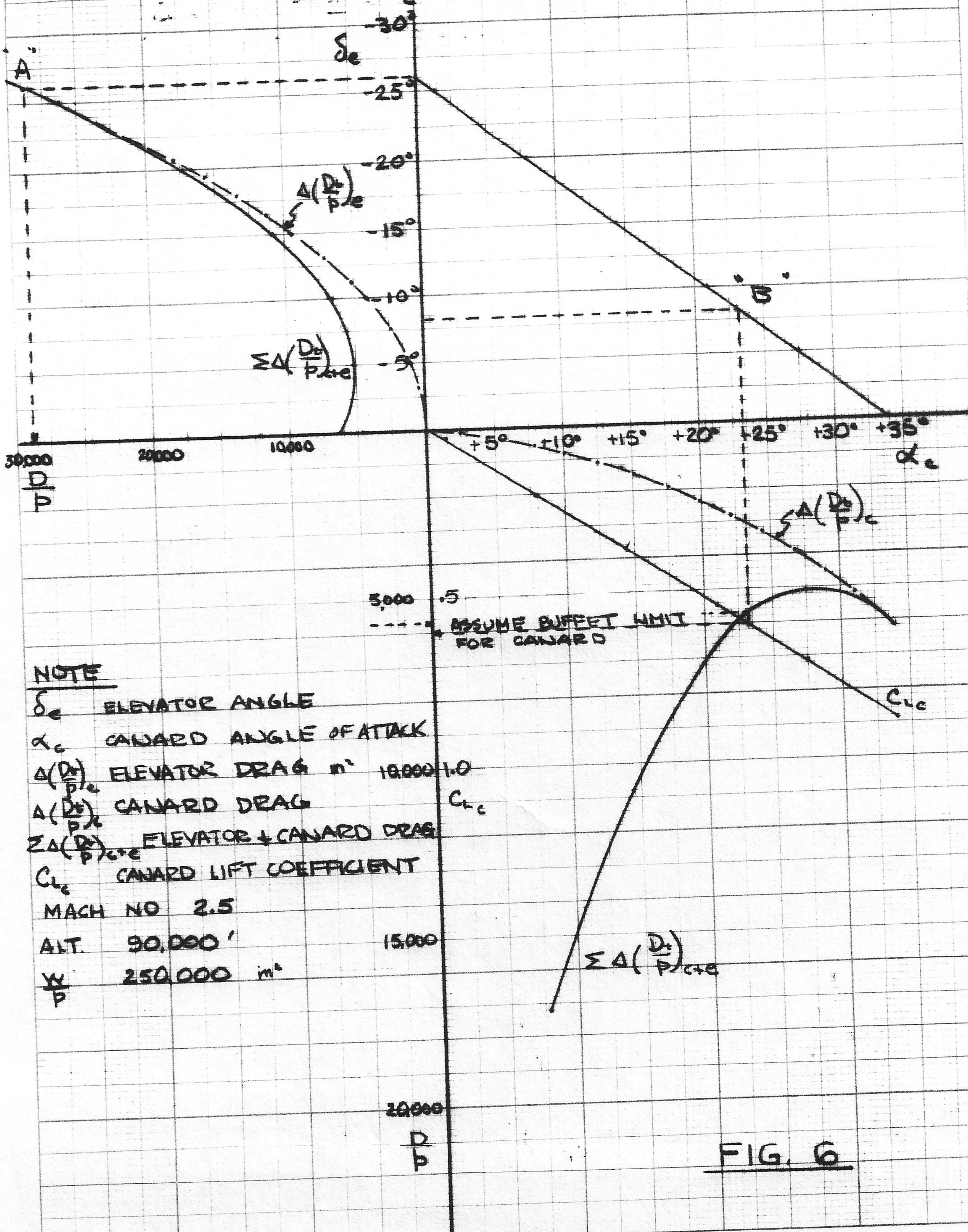
COMBINED CANARD - ELEVATOR CONTROL FOR AVRO ARROW

$\Delta C_{M_{CG_c}} + \Delta C_{M_{CG_e}} = 0.0338$



NOTE

δ_e ELEVATOR ANGLE

α_c CANARD ANGLE OF ATTACK

$\Delta(\frac{D_t}{P})_e$ ELEVATOR DRAG in²

$\Delta(\frac{D_t}{P})_c$ CANARD DRAG

$\Sigma\Delta(\frac{D_t}{P})_{c+e}$ ELEVATOR & CANARD DRAG

C_{L_c} CANARD LIFT COEFFICIENT

MACH NO 2.5

ALT. 90,000'

$\frac{W}{P}$ 250,000 in²

FIG. 6

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DRAG REDUCTION SUMMARY

W/p = 250,000, ALT = 90,000'

M = 2.5

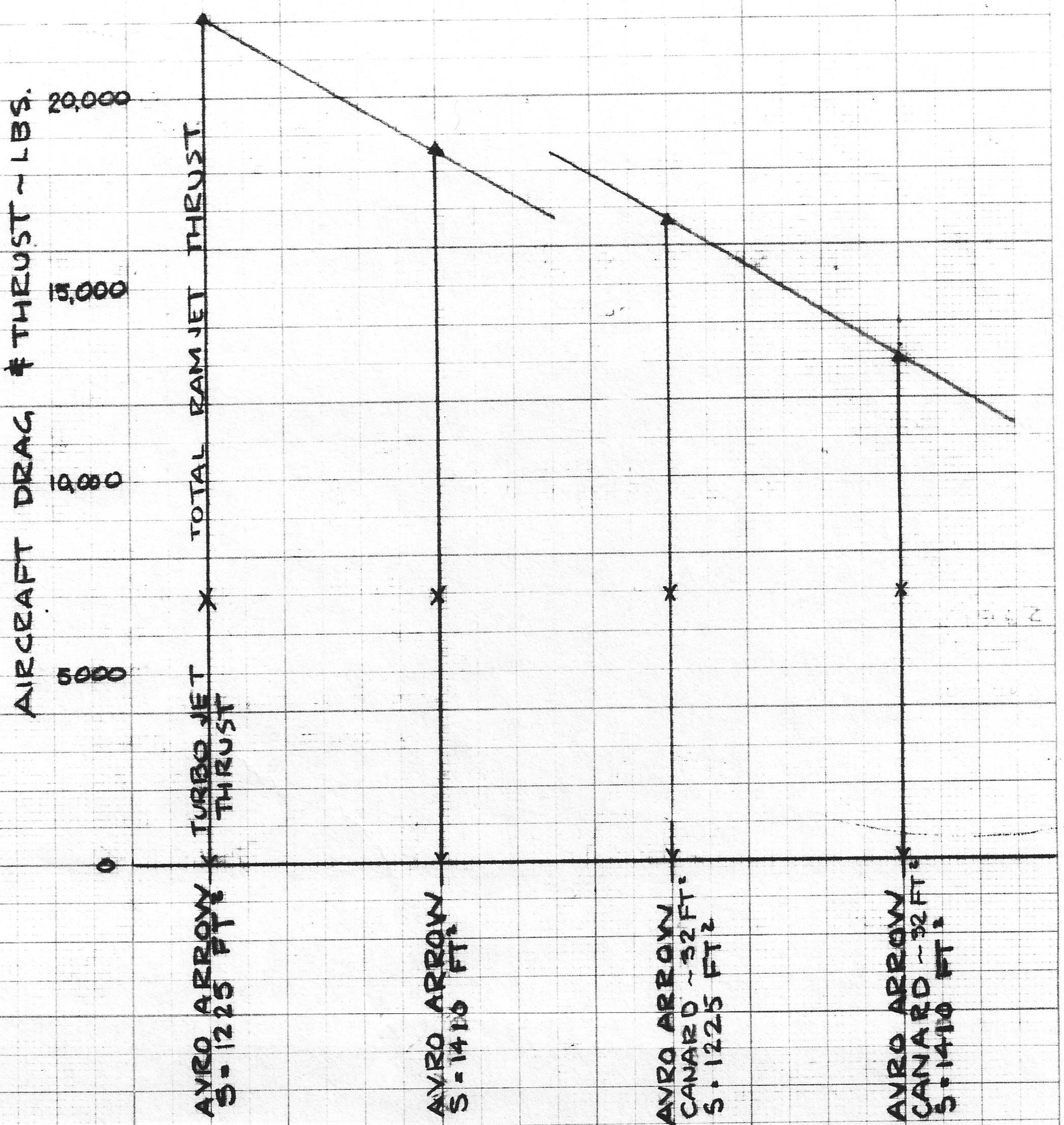

FIG. 7

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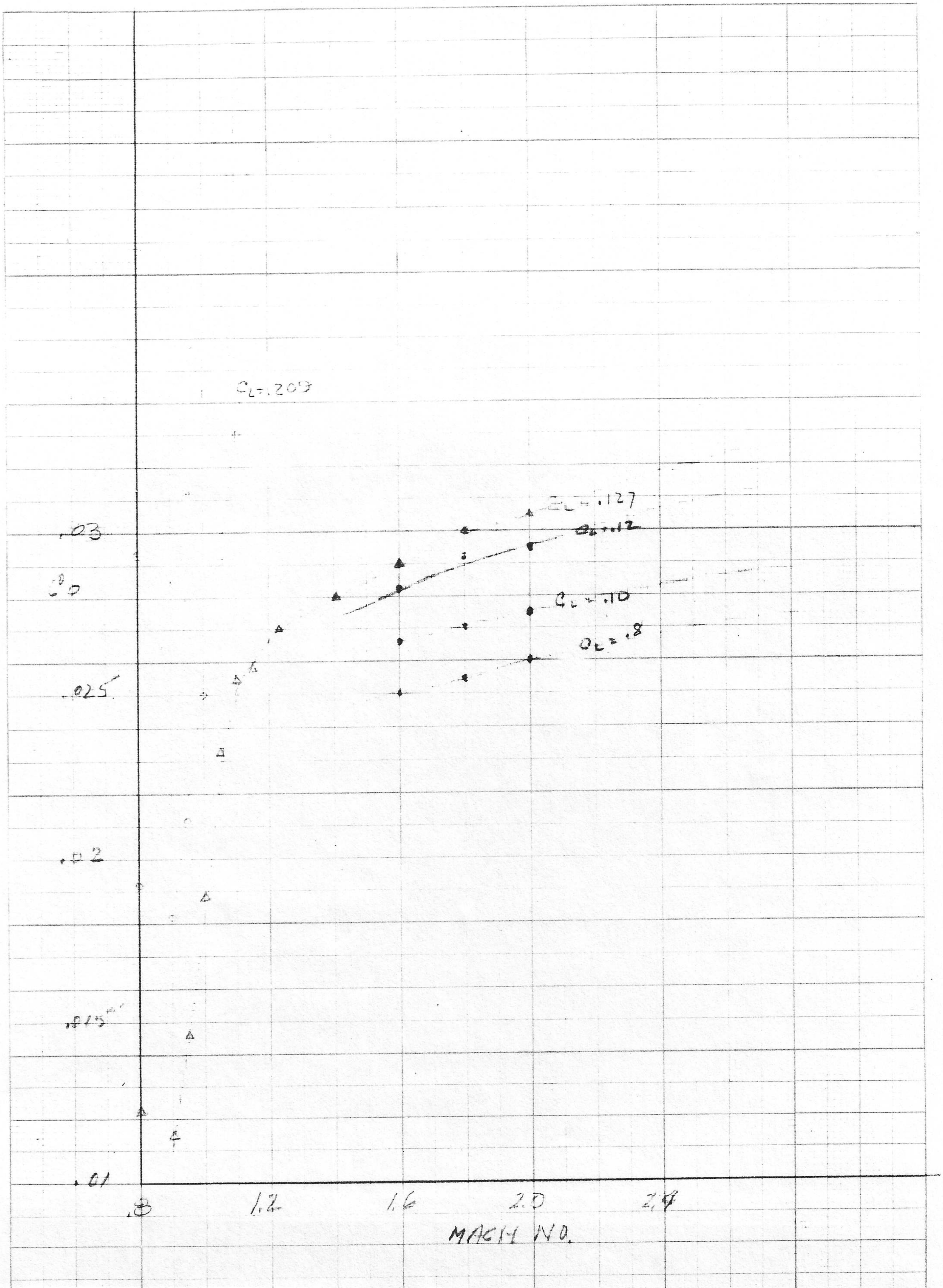

RECONNAISANCE ARROW

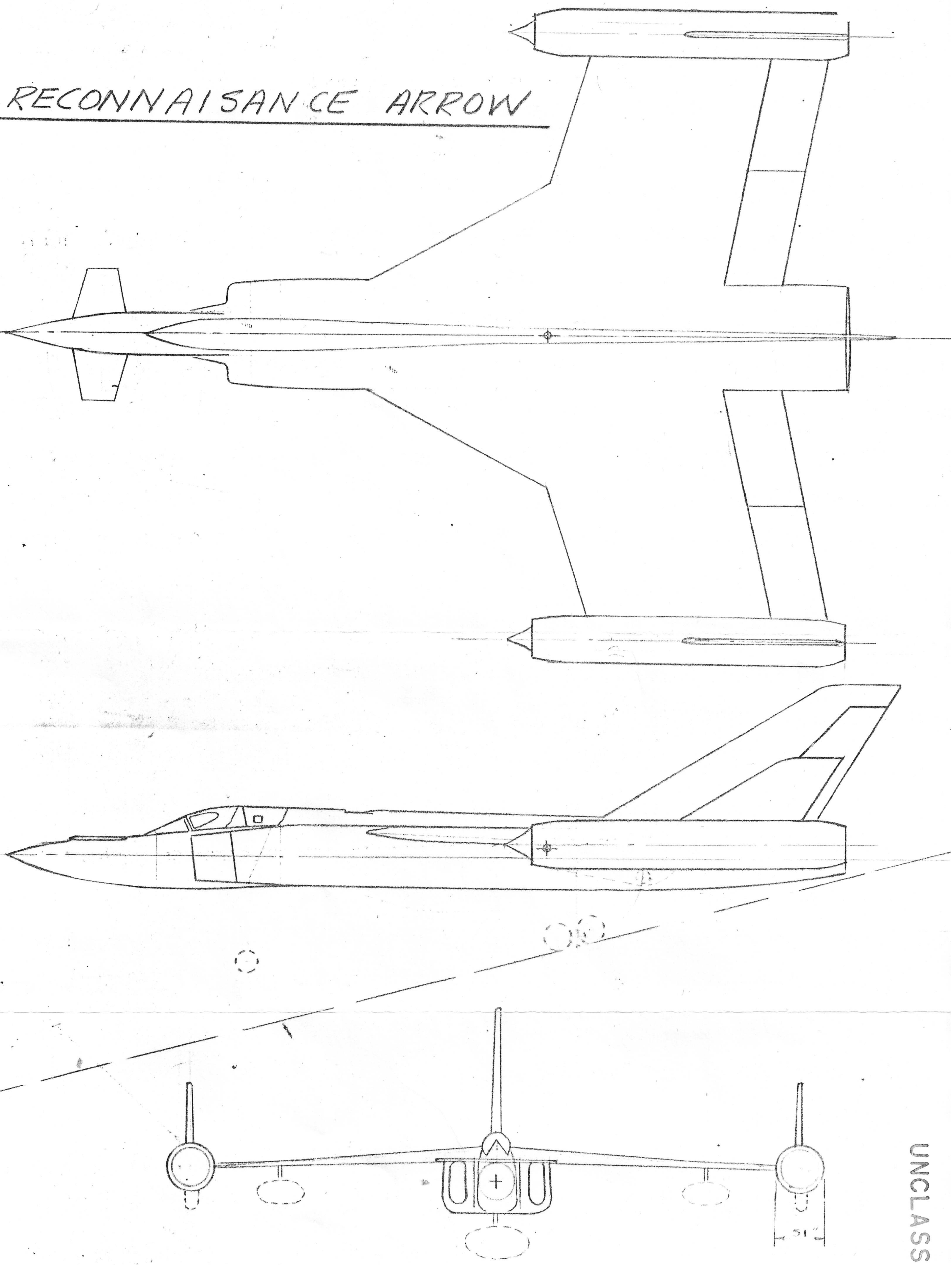

FIG. 9

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FUEL CONSUMPTION
DURING A DASH AT M = 2.5
90,000 FT ALT. & W/P = 250,000 IN^2

NOTE SEE TABLE 1 FOR CODE

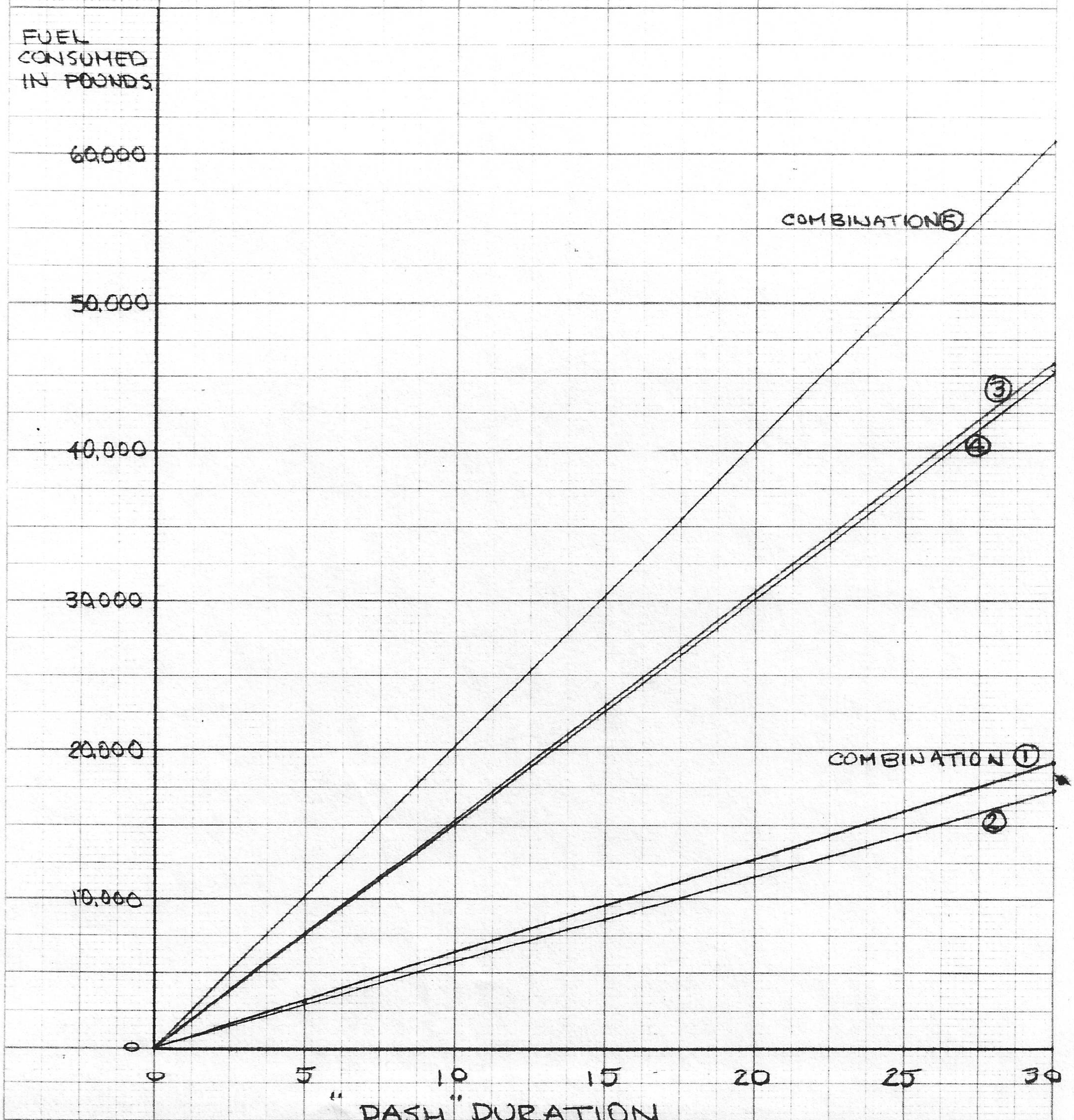

FIG. 10

TABLE 1

Power Plant Summary @ M 2.5, 90,000' Alt., W/P = 250,000 in.^{2}

Power Plant Combination	① Turbojet + A/B		① Ramjet	③ Turbojet + A/B		③ Ramjet	② Turbojet + A/B		② Ramjet	④ Turbojet + A/B		④ Ramjet	⑤ Turbojet + A/B		⑤ Rocket
Fuel	JP4		JP4	JP4 + H_2O		JP4	JP4		Pentaborane	JP4 + H_2O		Pentaborane	JP4		85% H_2O_2 15% JP4
SFC	2.8		3.15	8.42		3.15	2.8		2.57	8.42		2.57	2.8		17
Fuel Consumption lb./hr.	19,600		18,900	81,700		10,300	19,600		15,430	81,700		8,500	19,600		102,000
Propulsive Thrust lb.	7,000		6,000	9,700		3,300	7,000		6,000	9,700		3,300	7,000		6,000
Max. Dia. - ft.			4.25			3.14			3.9			2.9			
Max. Frontal Area - ft.^{2}			14.1			7.25			11.9			6.55			
Length - ft.			30			22			27.5			20.5			
Fuel Consumed in Pounds		+			+			+			+			+	
- 5 min.	1635	(3210)	1575	6810	(7670)	860	1635	(2923)	1288	6810	(7520)	710	1635	(10135)	8500
- 10 min.	3270	(6420)	3150	13620	(15340)	1720	3270	(5845)	2575	13620	(15040)	1420	3270	(20270)	17000
- 15 min.	4900	(9620)	4720	20450	(23030)	2580	4900	(8040)	3860	20450	(22580)	2130	4900	(30400)	25500
- 20 min.	6550	(12850)	6300	27200	(30640)	3440	6550	(11700)	5150	27,200	(30040)	2840	6550	(40550)	34000
- 25 min.	8170	(15050)	7880	34100	(38400)	4300	8170	(14610)	6440	34100	(37650)	3550	8170	(50670)	42500
- 30 min.	9810	(19260)	9450	40800	(45960)	5160	9810	(17540)	7730	40900	(45160)	4260	9810	(60810)	51000

NOTE: "Saturation" water injection considered in this table.

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TABLE 2

FURTHER INVESTIGATIONS OF RECONNAISSANCE ARROW

Market Research	Possible Uses	Power Plant & Fuels	Range & Performance	Stability & Control	Flutter & Vibration	Undercarriage	Structure & Weight Est.
Is there a need for (1) Reconnaissance version with M 2.5 90,000' dash (2) Tactical Bomber with M 2.5 90,000' dash	Reconnaissance Tactical Bomber Advanced Fighter	Turbojet + A/B Ramjet Rocket Hybrid Mixed High Energy Fuels	Exact Range & Mission Analysis	Trim control of Canard, and effect of canard and incr-eased wing area on C.G. limits	Ramjet Buzz Flutter & Vibration of Wing	Undercarriage Development 90,000 lb. T.O. Weight and 65,000 lb. landing weight	Weight estimate of Arrow
Suggest that Project Research and Sales & Service investigate this together, and an effort be made to pro-duce a specification.	Suggest that Project Research conduct an operational research study into the use-fullness of such vehicles in the western air forces.	The state of art presently being investigated by Project Research Group	Suggest this aspect be looked into by John Lucas of the Technical Office	Suggest this aspect be looked into by Stan Kwiatkowski of the Technical Office	Suggest this aspect be looked into by John McKillop	W. Alford of the Stress Office indi-cated an interest in this problem.	Suggest this aspect be looked into by Al Sen-tance of the Initial Project Office.