AVRO AIRCRAFT LIMITED

INTER - DEPARTMENTAL MEMORANDUM

Ref 4072/20/J
Date November 4, 1957
To Mr. J. D. Hodge, Technical Flight Teet Co-ordinator
From J. Lucas, Chief of Performance Evaluation
Subject <u>PERFORMANCE DATA FROM ARROW 1 FLIGHT TESTS</u>

Attached herewith, please find report 71/PERF/2, Ieeue 2, on Programming for Performance Data from Arrow 1 Flight Tests. This issue supereedee the original iseue of report 71/PERF/2 and includes clarification and refinemente to the list of available instrumentation, Sanborn editing records and to the applicable formulae for I.B.M. 704 computations. A note on aircraft weight and C.G. data (Appendix I) ie added.

It ie realized that performance testing on Arrow 1 aircraft ie of secondary importance but useful results are readily obtainable from the exieting program using available instrumentation. Adequacy of thrust measuring instrumentation is discueeed under report 70/PERF/ 1 App. II.

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PROGRAMMING FOR PERFORMANCE DATA FROM ARROW 1 FLIGHT TESTS INTRODUCTION:-

This report on programming for performance data from Arrow 1 flight tests is divided into three main sections, i.e. 1) Available instrumentation. 2) Sanborn trace recorder for editing and 3) Input - output summary and applicable formulae and charts for I.B.M. 704 computations.

Use is made of available instrumentation, which can be used for obtaining preliminary performance data during the course of Arrow 1 flight testing. Instrumentation accuracy is given in dimensional units with corresponding percent accuracy of full range varying between 0.2% for measured angle of attack to 3.0% for dive brake angle, but generally between 0.5 and 1.0% for all other instrumentation. Standard recording frequency is 20 per second except were noted as continuous. However, overall data processing at 2 per second will suffice with a maximum frequency of 5 per second and a minimum frequency of every 5 seconds when required. Hence before final data processing on the I.B.M. digital computor, the data will need to be transformed to the lower frequencies either on the computor itself or on an intervalometer.

A Sanborn trace recorder will be used to edit the flight test data prior to entering on the I.B.M. 704 computor. This trace recorder will also show traces of all measurements which require no further computations, such as elevator angle, pitch angle, air brake angle etc. This would eliminate the need to enter them on the I.B.M. 704 computor and would simplify programming. It would be desireable to convert ambient (static and dynamic) pressure measurements to indicated Mach number and indicated altitude on the Sanborn recorder to facilitate editing as well as to record accelerations and R.P.M. settings to determine the steadiness of each manoeuvre. A total of 8 traces per record is available, with paper speeds of .25, .5, 1.0, 2.5, 5.0, 10, 25, 50 & 100 mms/sec and a paper length of 200 feet. At the editing stage, time frequencies between 5 seconds intervals and 5 per second will be decided for 704 computations.

Computations will then be made by the 704 computor from which all output will be presented as time plots and tabulated when required, except from steady level speed tests where the stabilized portion will be previously obtained by editing and the computor output tabulated only. Cross plots of computor output data will be made only when specifically requested.

All records should be identified by aircraft number, flight number and run number.

AVRO AIRCRAFT LIMITED MALTON - ONTARIO TECHNICAL DEPARTMENT		REPORT NO. 71/PERF/2 Issue 2 SHEET NO. 2	
AIRCRAFT:		PREPARED BY	DATE
ARROW 1	PERFORMANCE FLIGHT TESTS	R.Waechter	Nov. 1957
		CHECKED BY	DATE

SECTION I :- AVAILABLE INSTRUMENTATION

	ITEM		RANGE	ACCURACY	REMARKS
1)	Time scale		40 min.	±.01 sec.	
2)	Record indentification or coding		-	±.01 sec.	Pending
3)	Ambient static pressure	a)	0-2160 psf.	± 15 psf.	Require range selector.
		b)	0-720 psf.	± 5 psf.	
		c)	0-288 psf.	± 2 psf.	
4)	Ambient differential pressure	a)	0-2880 psf.	± 20 psf.	Require range selector.
		b)	0-1440 psf.	± 10 psf.	
		c)	0-720 psf.	± 5 psf.	
5)	$O.A.T_M$		-65 + 350°F	± 2°F	
6)	Longitudinal acceleration		± 1g	± .01g	Parallel to fuselage datum.
7)	Lateral acceleration		± 1g	± .01g	Continuous recording(and telemetered).
8)	Normal acceleration		-3 + 8 g	± .05g	Continuous recording(and telemetered).
9)	Angle of attack (α)		-10 + 40°	± .1°	Continuous recording.
10)	Angle of pitch (θ) complete range		± 60°	± 0.5°	
	sensitive range ★		± 10°	± 0.1°	
11)	Rate of change of pitch ($\dot{\theta}$)		± 30°/sec.	± .30°/sec.	Continuous recording.
12)	Elevator angle (port and stbd.)		-30 + 20°	± .3°	Continuous recording.
			± 10°	± .1°	
13)	Air brake angle(port and stbd.)		0 to 60°	± 2°	Only port or stbd. required ★
14)	L.P.Comp.R.P.M.(N_1)(port and stbd.)		0 - 110%	± .5%	
15)	H.P.Comp.R.P.M.(N_2)(port and stbd.)		0- 110%	± .5%	
16)	Engine fuel flow (port and stbd.)		600-25,000 lb/hr	± 125 lb/hr.	
17)	A/B fuel flow (port and stbd.)		5000-65000 lb/hr	± 650 lb/hr.	Maximum range value could be reduced to 40,000 lbs. for better accuracy.

ORM 1319A

AVRO AIRCRAFT LIMITED MALTON - ONTARIO TECHNICAL DEPARTMENT		REPORT NO. 71/PERF/2 Iss 2 SHEET NO. 3	
AIRCRAFT:		PREPARED BY	DATE
ARROW I	PERFORMANCE FLIGHT TESTS	R.Waechter	Sept. 1957.
		CHECKED BY	DATE

ITEM	RANGE	ACCURACY	REMARKS
18) Fuel remaining, per tank (14 off)	0-300 gals each (max.)	± 6 gals (max.)	
19) Engine intake P_2 (port and stbd)	0-30 psia	± .3 psi	Representative probes after rake calibration.
20) Engine intake p_2 (port and stbd)	"	"	
21) Engine intake T_2 (port and stbd) optional	-75+350°F	± 4°F	May substitute free stream T.
22) Turbine discharge P_7 (port and stbd)	0-45 psia	± .45 psi	Manifolded rake measurements.
23) Turbine discharge T_7 (port and stbd)	0-1400°F	± 14°F	
24) By-pass gills shut ind. lights, 2 off(port and stbd) (one on side gills and one on oil cooler gill)		shut -not shut and shut and fully open	
25) By-pass temp. above and below jet pipe T_B (port)	0-500°F	± 5°F	
26) By-pass press. below mid jet pipe P_B (port)	0-35 psia	± .35 psi	Static pressure measurement here assumed = downstream total press.
27) Diff. static in lower ejector just upstream of final nozzle, relative to ambient static (port) (p_B - p_1)	- 3 to 0 psig	± .05 psi	
28) By-pass temp. above and below turbine (port) ☆	0-500°F	± 5°F	Of incidental use only, in performance measurements.
29) By-pass static press. above rear comp. (port) ☆	0-35 psia	± .35 psi	(items 28 and 29, bracketed)

NOTE:- Items 25,26 and 27 are available on port side only and will be assumed identical on starboard side.

Item denoted thus ☆, are not required for the program as detailed herein but should be available if and when needed.

RM 1319A

SECTION II :- SANBORN EDITING RECORDS

Sanborn trace records will consist of a time history of direct measurements for editing purposes and recording data which requires no further computation. These traces should be recorded versus time to within ± .01 sec. such that accurate correlation with succeeding I.B.M. 704 records can be made. Overall accuracy to Sanborn trace output, including instrument measuring accuracy, should be within ± 2% of full scale reading. In the case of ambient pressure measurements the most sensitive reading should be selected for recording and if conveniently possible they should be converted to traces of indicated Mach number and indicated altitude using the following formulae.

$$\left(\frac{P_T}{p}\right)_i = (1 + .2\,M_i^2)^{3.5} \quad \text{for} \left(\frac{P_T}{p}\right)_i \leq 1.894$$

$$\left(\frac{P_T}{p}\right)_i = (1 + .2\,M_i^2)^{3.5} \times \left[\frac{1}{\left(\dfrac{M_i^2 + 5}{6\,M_i^2}\right)^{1.4} \left(\dfrac{7\,M_i^2 - 1}{6}\right)}\right]^{2.5}$$

$$\text{for} \left(\frac{P_T}{p}\right)_i > 1.894$$

$$H_i = 145{,}447 \left[1 - \left(\frac{p_i}{2116}\right)^{0.1903}\right] \quad \text{for } p_i \geq 472.7 \text{ psf}$$

$$H_i = 164{,}221 - 47{,}907 \log p_i \quad \text{for } p_i < 472.7 \text{ psf}$$

Two Sanborn records, consisting of 8 items each, are required i.e.

1. a) Ambient static pressure p_i } convert to M_i and H_i if conveniently possible
   b) Ambient dynamic pressure $q_{c_i} = P_{T_i} - p_i$
   c) H.P.compressor R.P.M., port N_{2_p}
   d) H.P.compressor R.P.M., stbd.N_{2_s}
   e) Afterburner fuel flow rate, port $(Q_{A/B})_p$ (for A/B on or off indication only)
   f) Normal acceleration } as measured relative A/C datums
   g) Longitudinal acceleration
   h) Lateral acceleration
2. a) Angle of pitch
   b) Air brake angle
   c) By-pass gill position (port and stbd) shut-not shut indications
   d) Oil cooler gill (port and stbd) shut and fully open indications
   e) Elevator angle (complete range, port)
   f) Elevator angle (sensitive range, port)
   g) Elevator angle (complete range, stbd.)
   h) Elevator angle (sensitive range, stbd.)

The first record will be used for editing and thereafter for reference only, while the second record will be used in conjunction with I.B.M. 704 computor output data.

Some identification signal should be available on the Sanborn records where the pilot has noted the start and/or finish of a test. This signal may be obtained from the pilot's voice recording or from a pilot's coding button. When this identification signal is made available it may replace item 2 h.) on the Sanborn records.

SECTION III:- <u>INPUT -OUTPUT SUMMARY AND APPLICABLE FORMULAE OR CHARTS FOR I.B.M. 704 COMPUTOR</u>

In general, I.B.M. 704 computor output will be presented graphically versus time except when specifically requested to be tabulated or be cross plotted. Graphical presentation will be made with 4 outputs versus time on one graph and therefore the following input - output summary is grouped such that each successive 4 outputs are related and will appear on one graph.

Reading accuracy of time scale should be ± .01 seconds

Engine Symbols used are such that

capital	P	=	total pressure
small	p	=	static pressure
capital	T	=	Total Temperature
subscript	P	=	port
"	S	=	stbd.
"	N	=	net thrust
"	G	=	gross thrust
	F	=	installed engine thrust
	X	=	basic or primary engine thrust
subscript	0	=	free stream static (or initial conditions)
"	1	=	station 1, free stream total
"	2	=	station 2, engine face
"	7	=	station 7, turbine outlet
"	10	=	station 10, final nozzle (primary)
"	B	=	station 10, in by-pass
no subscript		=	free stream conditions

All instrument calibrations, which are in the form of "$Y = a x + b$" conversions from electrical signal to the required units, are taken for granted in the overall data processing, either prior to entering on the 704 computor or on the computor itself.

It is assumed that
a) acceleration measurements are converted to "g" units
b) ambient pressure measurements are converted to psf
c) engine inlet, turbine outlet and bypass pressure measurements are converted to psi
d) all temperature measurements (ambient and in and around engine) are converted to °K.

Hence ensuing formulae are derived using the above units. Where outputs such as L/p, F_N/p, D/p etc are required in units of square inches, conversions are made by appropriate constants in the applicable formulae.

ARROW I - PERFORMANCE FLIGHT TESTS INPUT - OUTPUT SUMMARY AND APPLICABLE FORMULAE OR CHARTS FOR I.B.M. 704 COMPUTOR	SHEET NO. 7 DATE Sept, 1957. REPORT NO. [illegible] PREP. BY R. WAEGATER

INPUT		OUTPUT		APPLICABLE FORMULAE, OPERATION OR CHART	REMARKS
0.) 1)	Time (T) Differential Pressure ($P_{T_i} - p_i$) 0-2380, 1440 and 720 psf			a) Select reading of greatest sensitivity b) Determine P_{T_i}/p_i	
2)	Ambient Static Pressure p_i 0-2160, 720 and 288 psf			c) Determine P_T/p Chart I $\Delta\left(P_{T_i}/p_i\right)$ vs P_{T_i}/p_i	Pitot correction (unique curve)
				Chart II $\Delta\left(P_T/p_i\right)$ vs P_T/p_i	Static correction (unique curve)
		1a)	M	d) Determine M from $P_T/p = (1+.2M^2)^{3.5}$	$P_T/p \leq 1.894$
				or $\frac{P_T}{p} = (1+.2M^2)^{3.5} * \left[\frac{1}{\left(\frac{M^2+5}{6M^2}\right)^{1.4}\left(\frac{7M^2-1}{6}\right)}\right]^{2.5}$	$P_T/p > 1.894$
				e) Determine p using chart II $\frac{\Delta p}{p_i} = \frac{-\Delta\left(P_T/p_i\right)}{P_T/p}$ $p = p_i + \left(\Delta p/p_i\right) p_i$	
		1(b)	Hp (fit)	f) determine Hp $Hp = 145,447\left[1-\left(\frac{p}{2116}\right)^{0.1903}\right]$ $H_p = 164,221 - 47,907 \log p$	$p \geq 472.7$ psf. } I.C.A.O. $p < 472.7$ psf. } I.C.A.O.
		1(c)	R_{o_1}	$R_{o_1} = (1 + .2M^2)^{3.5}$	Ref: NACA TR 1235

SHEET NO. 8
DATE Sept. 1957

REPORT NO. [illegible] ISS. 2
PREP. BY R. WAECHTER

ARROW I - PERFORMANCE FLIGHT TESTS

INPUT - OUTPUT SUMMARY AND APPLICABLE FORMULAE OR CHARTS FOR I.B.M. 704 COMPUTOR

INPUT		OUTPUT		APPLICABLE FORMULAE, OPERATION OR CHART	REMARKS
3.	Amb. air temp T_M °K	1 (d)	T_o °K	$T_o = T_{MM} / (1 + .2KM^2)$	K = constant, initially = 1
		2 (a)	$P_1\sqrt{T_1}$	$P_1\sqrt{T_1} = \frac{R_{01}\,p}{144}\sqrt{T_o\,(1+.2M^2)}$	
		2(b)	$(R/C)_1$ (fpm)	$(R/C)_1 \text{ fpm} = \frac{\Delta H_p \text{ (ft)}}{\Delta T \text{ (secs)}} \times 60$	Non steady level flight only
		2(c)	$(R/C)_2$ (fpm)	$(R/C)_2 \text{ fpm} = 4030 \frac{\Delta (M^2 T_o)}{\Delta T \text{ (secs)}}$	Note:- $\frac{(R/C)_2}{M\sqrt{T_o}} \equiv 3945 \times a_L$ for a_L in 'g' units
		2(d)	$\frac{R/C}{\sqrt{\theta}}$	$\frac{R/C}{\sqrt{\theta}} = \frac{(R/C)_1 + (R/C)_2}{\sqrt{T_o/288}}$	
4.	Angle of pitch θ deg.				$\theta \equiv$ fus. datum rel. horizontal
5.	Rate of pitch $q = \dot{\theta}$ deg/sec				
6.	Angle of attack α_i	3(a)	Angle of attack α	$\alpha = \alpha_{ii} + \Delta\alpha - \frac{q\,(X - X_{C.G.})}{3765\,M\sqrt{T_o}}$	$\Delta\alpha$ = corr^n for bending & upwash $(X - X_{C.G.})$ = vane distance from C.G. = 45.8 feet
7.	Normal accel. a_{N_i} (g units)	3(b)	Normal accel a_N	$a_N = [a_{N_i} - \cos\theta] \times \cos\alpha + [a_{L_i} - \sin\theta] \times \sin\alpha$	Inputs relative to A/C datum Outputs relative to flight path. See P/AERO DATA/92 Iss. 2 for pitch rate corrections if instrumentation not at C.G. } negligible
8.	Long. accel a_{L_i} (g units)	3(c)	Long accel a_L	$a_L = [a_{L_i} - \sin\theta] \times \cos\alpha - [a_{N_i} - \cos\theta] \times \sin\alpha$	
9.	Fuel remain. (14 tanks)			F_1 and F_2 = fuselage tanks fuel remain, (LBs.) F_3, F_4, F_5, F_6, F_7, and F_8 = wing tanks (port + stbd) fuel remain (LBs.)	} useable fuel only
10(a)	Operational weight empty = W_o				
10(b)	C.G. position $(C.G.)_o$ % M.A.C. at W_o, U/c up, water methonal and alcohol tanks full	3(d)	C.G. % M.A.C. (U/c up)	$C.G. = \frac{W_o \times (C.G)_o - 22.5 F_1 - 0.5 F_2 + 2.8 F_3 + 1[illegible]4 F_4 + 31.2 F_5 + 42.3 F_6 + 52.8 F_7 + 66.0 F_8}{W_o + \Sigma F}$	See Appendix I

ARROW I - PERFORMANCE FLIGHT TESTS

INPUT - OUTPUT SUMMARY AND APPLICABLE FORMULAE OR CHARTS FOR I.B.M. 704 COMPUTOR

NO. 9 REPORT NO. 71/PERF/2 ISS. 2
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INPUT		OUTPUT		APPLICABLE FORMULAE, OPERATION OR CHART	REMARKS
		4(a)	$\frac{nW}{p}$	$\frac{NW}{p} = \frac{a_N(W_o + \Sigma F)}{p/144}$	
		4(b)	C_{L_W}	$C_{L_W} = \frac{a_N (W_o + \Sigma F)}{.7\ p\ M^2\ S}$	S = 1225 sq.ft. wing area = 176,300 sq. inches. See output 13(a) and (b) fo. thrust corrected values
		4(c)	$C_{L_W}^2$		
		4(d)	$N_2/\sqrt{\theta}$	$N_2/\sqrt{\theta} = \frac{N_{2P_i} + N_{2S_i}}{2\sqrt{T_o/288}} \times 8732$	
11.	L.P. rpm port $N_{1_{P_i}}$ %	5(a)	$N_{1_P}/\sqrt{T_1}$	$N_{1_P}/\sqrt{T_1} = \frac{N_{1P_i} \times 6774}{\sqrt{T_o(1 + .2M^2)}}$	100% N_1 = 6774
12.	L.P. rpm stbd. $N_{1_{S_i}}$ %	5(b)	$N_{1_S}/\sqrt{T_1}$	$N_{1_S}/\sqrt{T_1} = \frac{N_{1S_i} \times 6774}{\sqrt{T_o(1 + .2M^2)}}$	
13.	H.P. rpm port $N_{2_{P_i}}$ %	5(c)	$N_{2_P}/\sqrt{T_1}$	$N_{2_P}/\sqrt{T_1} = \frac{N_{2P_i} \times 8732}{\sqrt{T_o(1 + .2M^2)}}$	100% N_2 = 8732
14.	H.P. rpm stbd. $N_{2_{S_i}}$ %	5(d)	$N_{2_S}/\sqrt{T_1}$	$N_{2_S}/\sqrt{T_1} = \frac{N_{2S_i} \times 8732}{\sqrt{T_o(1 + .2M^2)}}$	
[illegible]	Port eng. intake p_{2_P} (psi)				
[illegible]	Stbd. eng. intake p_{2_S} (psi)				

ARROW I - PERFORMANCE FLIGHT TESTS INPUT - OUTPUT SUMMARY AND APPLICABLE FORMULAE OR CHARTS FOR I.B.M. 704 COMPUTOR	SHEET NO. 10 Sept. 1957	REPORT NO. [illegible] ISS. 2 PREP. BY. R. WAECHTER

INPUT		OUTPUT		APPLICABLE FORMULAE, OPERATION OR CHART	REMARKS
17.	Port eng. intake P_{2P} (psi)	6(a)	P_{2P}/P_1	$P_1 = \frac{R_{o_1} p}{144}$	
18.	Stbd. eng. intake P_{2S} (psi)	6(b)	P_{2S}/P_1		
19.	Port eng. intake T_{2P} (°K)				Availability pending, can use ambient T_1 for computations
20.	Stbd. eng. intake T_{2S} (°K)				
		6(c)	$\left(\frac{W_E\sqrt{T_1}}{P_1}\right)_P$	$W_E = \frac{p_2 A_2 \sqrt{g}}{\sqrt{RT_2}\left(\frac{p_2}{P_2}\right)^{\frac{\gamma-1}{\gamma}}} \sqrt{\frac{2\gamma}{\gamma-1}\left[1-\left(\frac{p_2}{P_2}\right)^{\frac{\gamma-1}{\gamma}}\right]}$ Increase measured p_2 by 1% to allow for station of measurement $T_1 = T_{\infty}(1 + .2M^2)$ $P_1 = \frac{R_{o_1} p}{144}$	$\gamma = 1.4$ A_2 = effective engine face area initially .97xgeom. area (sq.ins) R = 96.02 for T °K W_E UNITS IN LBS/SEC
		6(d)	$\left(\frac{W_E\sqrt{T_1}}{P_1}\right)_S$		
21.	Turbine Disch. (port) P_{7_P} (psi)	7(a)	$(P_7/P_2)_P$		
		7(b)	$\left(\frac{\frac{X_G}{C_g A_{10} p} + 1}{R_{o_1}}\right)_P$	$\left(\frac{X_G}{C_g A_{10} p} + 1\right)_P = 8.06\left(\frac{P_{7_P}}{p}\right)^{.248} - 7.06$ for $\frac{P_{7_P}}{p} < 1.852$ $= 1.255 \frac{P_{7_P}}{p}$ for $\frac{P_{7_P}}{p} \geq 1.852$	P_7/p must be derived from consistent units
22.	Turbine Disch. (stbd) P_{7_S} (psi)	7(c)	$(P_7/P_2)_S$		
		7(d)	$\left(\frac{\frac{X_G}{C_g A_{10} p} + 1}{R_{o_1}}\right)_S$	$\left(\frac{X_G}{C_g A_{10} p} + 1\right)_S = 8.06\left(\frac{P_{7_S}}{p}\right)^{.248} - 7.06$ for $\frac{P_{7_S}}{p} < 1.852$ $= 1.255 \frac{P_{7_S}}{p}$ for $\frac{P_{7_S}}{p} \geq 1.852$	

ARROW I - PERFORMANCE FLIGHT TESTS

INPUT - OUTPUT SUMMARY AND APPLICABLE FORMULAE OR CHARTS FOR I.B.M. 704 COMPUTOR

INPUT		OUTPUT		APPLICABLE FORMULAE, OPERATION OR CHART	REMARKS
		8(a)	$\frac{X_{N_P}}{p}$	$\frac{X_{N_P}}{p} = \frac{X_{G_P}}{p} - \frac{(m_E \; V)}{p}$ $\frac{X_G}{p} = \left[1.255 \frac{P_7}{p} - 1\right] C_g A_{10}$ for $\frac{P_7}{p} > 1.352$	$\frac{X_G}{p} = 3.06 \left[\left(\frac{P_7}{p}\right)^{.243} - 1\right] C_g A_{10}$ for $\frac{P_7}{p} < 1.352$ $\frac{P_7}{p}$ must be derived from consistent units
		8(b)	$\frac{X_{N_S}}{p}$	Similar to 8 (a) output A_{10} = constant for each engine initially 508 □" A/B off = 924 □" A/B on C_g = constant for all J75 engines Chart III C_g vs $\frac{P_7}{p}$ and H_p, A/B off Chart IV C_g vs $\frac{P_7}{p}$, A/B on $(m_E \; V) = \frac{W_E \, M \, 65.3 \sqrt{T_o}}{32.2 \times p/144}$	Require A/B on or off signal (or $Q_{A/B}$ signal) to differentiate A_{10} and C_g for A/B on and off W_E in lbs/sec. (see output 6c and d)
23)	Turb. Disch. port T_{7_P} °K	8(c)	T_{7_P}/T_1	$\frac{T_{7_P}}{T_1} = \frac{T_{7_P} \; K^o}{T_o \, (1+.2M^2)}$	
24)	Turb. Disch. stbd. T_{7_S} °K	8(d)	T_{7_S}/T_1	$\frac{T_{7_S}}{T_1} = \frac{T_{7_S} \; ^oK}{T_o \; (1+.2M^2}$	
25)	Port eng. fuel flow QP.E.	9(a)	$Q_{P.E.}/P_1\sqrt{T_1}$	Input Q = out.Q $P_1 = R_{O_1} \times p \div 144$ $T_1 = T_O \; (1 + .2M^2)$	

ARROW I - PERFORMANCE FLIGHT TESTS

INPUT - OUTPUT SUMMARY AND APPLICABLE FORMULAE OR CHARTS FOR I.B.M. 704 COMPUTOR

SHEET NO. 12 REPORT NO. 71/PERF/2 Iss. 2
DATE Oct. 1957 PREP. BY R. Waechter

	INPUT		OUTPUT	APPLICABLE FORMULAE, OPERATION OR CHART	REMARKS
26)	Stbd. eng. fuel flow $Q_{S.E.}$	9(b)	$Q_{S.E.}/P_1\sqrt{T_1}$		
27)	Port A/B fuel flow $Q_{P.A.}$	9(c)	$Q_{P.A.}/P_1\sqrt{T_1}$	Input Q_i = output Q $P_1 = R_{O_1}\, p \div 144$ $T_1 = T_0\,(1+.2M^2)$	
28)	Stbd.A/B fuel flow $Q_{S.A.}$	9(d)	$Q_{S.A.}/P_1\sqrt{T_1}$		
29)	By-pass air T_B (port) above and below mid jet pipe No. 45 and 46 FAR/105/1 Part 3, Iss. 9.			Average upper and lower readings & convert. T_B from °F to °K	Assume identical on stbd side
30)	By-pass air p_B (port) below mid jet pipe No.61 of FAR/105/1 Part 3, Iss. 9.			Take mid jet pipe $p_B \approx \frac{P_B}{1.07}$ near final nozzle i.e. mid jet pipe $M \approx .31$	Assume identical on stbd side
31)	By-pass air $p_B - p_i$ (port) where p_B is near final nozzle No. 63 FAR/105/1 Part 3, Iss. 9.			$(p_B - p_i) + \frac{p_i}{144} = P_B$	p_i = indicated ambient static Assume p_B identical on stbd. side
		10(a)	W_B (port)	$W_B = \dfrac{p_{IB} A_B \sqrt{g}}{\sqrt{RT_B}\left(\dfrac{p_B}{P_B}\right)^{\frac{\gamma-1}{\gamma}}} \sqrt{\dfrac{2\gamma}{\gamma-1}\left[1-\left(\dfrac{p_B}{P_B}\right)^{\frac{\gamma-1}{\gamma}}\right]}$	$\gamma = 1.4$ Assume identical on stbd side A_B = effective by-pass area near final nozzle, sq. inches for p_B in psi. (initially A_B = .93x geom. area) R = 96.02 for T°K W_B units in lbs/sec.
		10(b)	F_N/p (port)	$\dfrac{F_N}{p} = \dfrac{F_G}{p} - \dfrac{mV}{p} - \dfrac{D_S}{p}$	Use port engine data for calculating F_N/p port, and stbd
		10(c)	F_N/p (stbd)	$\dfrac{mV}{p} = \dfrac{(W_E + W_B)\, M \times 65.8\sqrt{T_0}}{32.2 \times p/144}$ $\dfrac{F_G}{p} = \dfrac{F_G}{XG} \times \dfrac{XG}{p}$ (A/B on) $= \dfrac{F_G}{X_iG} \times \dfrac{X_iG}{p}$ (A/B off)	engine data for calculating F_N/p stbd ; except W_B(port) can be used to determine (F_N/p) port and stbd. Require A/B on or off (Q) signal

ARROW I - PERFORMANCE FLIGHT TESTS

INPUT - OUTPUT SUMMARY AND APPLICABLE FORMULAE OR CHARTS FOR I.B.M. 704 COMPUTOR

Sheet No. 13 Report No. 71/PERF/2 Iss. 2
Date Oct. 1957 Prep. by R. Waechter

INPUT	OUTPUT	APPLICABLE FORMULAE, OPERATION OR CHART	REMARKS
		$\frac{XiG}{p} = \frac{XiG}{XG} \times \frac{XG}{p}$	
		$\frac{XiG}{XC}$ from chart $\overline{V}$ using P_{T7}/p	
		$\frac{XG}{p}$ from 8a) output calcs.	
		$\frac{FG}{XiG}$ (A/B off) from chart $\overline{VI}$ knowing μ and $\frac{P10}{p}$	
		$\frac{FG}{XG}$ (A/B on) from chart $\overline{VII}$ knowing μ and $\frac{P10}{p}$	
		$\frac{P10}{p} = 99\% \frac{P_7}{p}$ (A/B off)	Assumed
		$= \frac{Cg}{.965}\left(\frac{P_7}{p}\right) - \left(\frac{Cg}{1.206}\right) + 0.8$ (A/B on)	$\frac{P_7}{p}$ must be derived from consistant units
	10(d) μ (port)	$\mu = \frac{WB}{WE} \times \sqrt{\frac{T_B}{T_7}}$ (A/B off)	WE assumed = W_{10} (A/B off) i.e. eng. fuel offsets airbleed and leakage
	11(a) μ (stbd)	$\mu = \frac{WB}{W10} \times \sqrt{\frac{TB}{T10}}$ (A/B on)	
		$W_{10} \approx W_E + \frac{Q_{A/B}}{3600}$ (A/B on)	
		$\sqrt{T_{10}}_{A/B\ on} = \left[\frac{XG \times .745}{W_E + \frac{Q_{A/B}}{3600}}\right] \times \left[\frac{.0009\frac{XG}{p} + 0.8}{.00219\frac{XG}{p} - .02}\right]$ °K	$\frac{X_G}{p}$ (sq. inches) from 8(a) output calcs.
		$\frac{D_s}{p} = 4130\ C_{D_S}\ M^2$	S = 40.98 sq. ft. = 5,900 sq. inches

ARROW I - PERFORMANCE FLIGHT TESTS

INPUT - OUTPUT SUMMARY AND APPLICABLE FORMULAE OR CHARTS FOR I.B.M. 704 COMPUTOR

Iss. 2

SHEET NO. 14 REPORT NO. 71/PERF/2

DATE Oct. 1957 PREP. BY R. Waechter

INPUT		OUTPUT	APPLICABLE FORMULAE, OPERATION OR CHART	REMARKS
			$C_{D_S} = \frac{\partial C_{D_S}}{\partial\left(\frac{m_i}{m_o}\right)}\left[\frac{W_E + W_B + 5}{6.97\,\frac{pM}{\sqrt{T_o}}} - \frac{.308(1+.2M^2)^3}{M}\left(\frac{P_{t_h}}{P_1}\right)\right]$	Spillage drag coefficient See Report 70/PERF/1 App.II for derivation
			$\frac{\partial C_{D_S}}{\partial\left(\frac{m_i}{m_o}\right)}$ from Chart $\overline{VIII}$	
			$\frac{P_{t_h}}{P_1}$ from Chart $\overline{IX}$	
	11(b)	$3945\, a_L\, M \sqrt{T_o}$	a_L in 'g' units	For comparison with $(R/C)_2$
	11(c)	$D/_p$ (at mean interval)	$D/P = \left(\frac{F_{N_P}}{p} + \frac{F_{N_S}}{p}\right) \cos(\alpha - 2.58^\circ)$ at mean interval $= \frac{(R/C)_1}{3945\, M\sqrt{T_o}} \times \frac{W}{p}$ $= \left(a_L \times \frac{W}{p}\right)$ at mean interval	In steady level flight $D/_p = \left(\frac{F_{N_P}}{p} + \frac{F_{N_S}}{p}\right) \cos(\alpha - 2.58^\circ)$ not at mean interval. May substitute $\left(a_L \times \frac{W}{p}\right)$ by $\left(\frac{(R/C)_2}{3945\, M\sqrt{T_o}} \times \frac{W}{p}\right)$ if $(R/C)_2$ has less scatter than $\left(3945\, a_L\, M\sqrt{T_o}\right)$.
	11(d)	C_D (at mean interval)	$C_D = D/_p \times \frac{1}{123{,}600\, M^2}$	In steady level flight C_D does not occur at mean interval
	12(a)	$\frac{V\,\delta}{Q}$	$V = 38.9\, M\sqrt{T_o}$ (knots) & $\delta = P/2116$ $Q = Q_{P.E.} + Q_{S.E.} + Q_{P.A.} + Q_{S.A.}$	Steady level flight only
	12(b)	$\frac{Q}{F_{N_T}\sqrt{\theta}}$	$F_{N_T} = F_{N_P} + F_{N_S}$ $\theta = T_o/288$	
	12(c)	$\frac{Q_P}{X_{N_P}\sqrt{\theta}}$	$Q_P = Q_{P.E.} + Q_{P.A.}$	
	12(d)	$\frac{Q_S}{X_{N_S}\sqrt{\theta}}$	$Q_S = Q_{S.E.} + Q_{S.A.}$	

INPUT	OUTPUT		APPLICABLE FORMULAE, OPERATION OR CHART	REMARKS
	13(a)	$\frac{L}{p}$	$\frac{L}{p} = \frac{a_N\ (W_0 + \Sigma F)}{p/144} - \left(\frac{F_N}{p}\ \text{port} + \text{stbd.}\right)\sin(\alpha - 2.58^\circ)$	where 2.58° = angle of thrust axis relative to fuselage datum
	13(b)	C_L	$C_L = \frac{L/p}{\frac{\gamma}{2} M^2 S}$ where $\gamma = 1.4$, $S = 176{,}300$ sq.inches	
	13(c)	$C_L{}^2$		
	13(d)	M_B (port only)	$M_3 = \sqrt{5\left[\left(\frac{P_B}{p_B}\right)^{.286} - 1\right]}$	Note:- P_B (near exit.) ≈ measured mid jet pipe p_B x 1.07
	14(a)	M_2 (port)	$M_{2_p} = \sqrt{5\left[\left(\frac{P_2}{p_2}\right)_p^{.286} - 1\right]}$	Increase measured p_2 by 1% to allow for station of measurement
	14(b)	M_2 (stbd)	Similar to 14a)	
	14(c)	R (N.A.M.)	$R = \Sigma\left(38.95\ M\sqrt{T_0}\ \times \Delta T_{HRS}\right)$	

AVRO AIRCRAFT LIMITED
MALTON - ONTARIO
TECHNICAL DEPARTMENT

AIRCRAFT:		REPORT NO. 71/PERF/2 Iss. 2	
		SHEET NO.	
ARROW 1	PERFORMANCE FLIGHT TESTS	PREPARED BY	DATE
		R. Waechter	Nov. 1957
		CHECKED BY	DATE

Chart I (nose probe pitot correction) of

$\Delta\left(\frac{P_{T_i}}{p_i}\right)$ versus $\frac{P_{T_i}}{p_i}$ where $\frac{P_{T_i}}{p_i} + \Delta\left(\frac{P_{T_i}}{p_i}\right) = \frac{P_T}{p_i}$

will be inserted when flight results become available.

Initially $\Delta\left(\frac{P_{T_i}}{p_i}\right)$ is assumed zero, until flight results prove otherwise.

Chart I

FORM 1319 A

AVRO AIRCRAFT LIMITED MALTON - ONTARIO TECHNICAL DEPARTMENT		REPORT NO. 71/PERF/2 APP.I SHEET NO. 1	
AIRCRAFT:		PREPARED BY	DATE
ARROW I	PERFORMANCE FLIGHT TESTS	R. Waechter	Nov. 1957
		CHECKED BY	DATE

AIRCRAFT WEIGHT AND C.G.DATA (For reference only, see also report No.7-0400-44-10)

First aircraft, operational weight empty O.W.E., no ballast = 47,759 lb. with C.G. at sta. 554.51" = 32.7% M.A.C.
Standard MK I, O.W.E. with 959 lb. ballast at sta. 86.60" = 48,718 lb. with C.G. at sta. 545.30" = 30.2% M.A.C.
MK I first flight, O.W.E. with 1432 lb. at sta. 89.16" and 165 lb. in Nav. seat = 49,356 lb. with C.G. at sta. 541.8" = 29.2% M.A.C.

The above C.G. positions and A/C weights are given for the normal "in flight" condition with u/c up and water methonal and alcohol tanks full, and with cylindrical ejector. On later flights a divergent ejector will be fitted, increasing the A/C weight by 204 lbs. including 79 lbs.ballast to maintain C.G. at the same position . All C.G. and A/C weight values, should be checked by actual weighings before flight and after any A/C modifications.

Correction for u/c down and water methonal and alcohol tanks empty = + 0.8%. Using fuel system proportioners, aft C.G. limits therefore are
31% M.A.C. for Standard MK I
30% M.A.C. for MK I first flight.

Effect of u/c position is such that the C.G. is shifted aft by .55% M.A.C. at 48,500 lb. A.U.W. and .39% M.A.C. at 68,561 lb. when the u/c is selected down.

Draining of the water methonal and alcohol tanks causes a mean aft C.G. shift of approx. 0.22% M.A.C. These tanks should always be full or ballasted unless specifically mentioned in the flight report after each flight.

For the standard MK I airplane, with u/c up and water methonal and alcohol tanks full, and using fuel system proportioners the aircraft C.G. position varies linearly from 29.68% M.A.C. at 68,561 lb. A.U.W. (full fuel) to 30.20% M.A.C. at 48,718 lb. A.U.W. (no useable fuel). This total variation is only 0.52% M.A.C. with a rate of change of + .026% per 1000 lb. decreased A.U.W. Hence C.G.position could readily be estimated "by hand" at any stage of flight knowing:-

1) Initial C.G. position, $(C.G.)_o$
2) Total fuel used in a given flight, F (lbs)
3) Flight time to point under consideration ΔT and
4) Total flight time, T

i.e. $$C.G.\ position = (C.G.)_o + \frac{\Delta T}{T} \times \frac{F}{1000} \times .026$$

FORM 1319A

AVRO AIRCRAFT LIMITED
MALTON - ONTARIO
TECHNICAL DEPARTMENT

REPORT NO. 71/PERF/2 APP. I
SHEET NO. 2

AIRCRAFT:		PREPARED BY	DATE
ARROW I	PERFORMANCE FLIGHT TESTS	R. Waechter	Nov. 1957
		CHECKED BY	DATE

This value can be used to check an "IBM 704 computed" value based on fuel remaining measurements from 14 fuel tanks. This latter method is more univerisal in determining C.G. position for any possible variations in fuel sequencing but depends on the reliability of 14 fuel tank measurements. The following table gives the useable fuel capacities and horizontal C.G. positions of the 14 fuel tanks.

Tank	Useable Fuel Capacity at 7.8 lbs. per gallon	C.G. Position Station	%M.A.C.
1. (fuselage)	2161 lbs.	354.35"	-22.5
2. (fuselage)	2192 "	433.99"	- 0.5
3. (port + stbd. wing)	2355 "	446.14"	2.8
4. " " "	1404 "	502.47"	18.4
5. " " "	2278 " (collector)	548.87"	31.2
6. " " "	2402 "	589.11"	42.3
7. " " "	4352 "	627.57"	52.8
8. " " "	2699 "	675.52"	66.0
	19,843 lbs. Total		

FORM 1319A

Note % M.A.C. = $\frac{\text{C.G. sta}^{n} - 435.82''}{362.61''} \times 100$

Hence for I.B.M. 704 computations, the aircraft C.G. position is determined as follows:-

a) Denote fuel remaining in fuselage tanks as F_1 & F_2

b) Add port & stbd wing fuel from corresponding tanks and denote F_3, F_4, F_5, F_6, F_7 & F_8.

c) Denote O.W.E. = W_o and initial C.G. @ W_o = $(C.G.)_o$ for U/C up and water methonal and alcohol tanks full. Then at any time during flight with U/C up:- C.G. % M.A.C. =

$$\frac{W_o \times (C.G.)_o - 22.5F_1 - 0.5F_2 + 2.8F_3 + 18.4F_4 + 31.2F_5 + 42.3F_6 + 52.8F_7 + 66.0F_8}{W_o + \Sigma F}$$

If the aircraft is weighed prior to flight with full fuel, and C.G. determined by relative weights on main & nose wheels, then $(C.G.)_o$ for U/C up =

$$\frac{(\text{C.G. as meas. U/C down}) \times (\text{W as meas.}) - 28.4 \times 19{,}843 - .55 \times 48{,}500}{(\text{W as meas.}) - 19{,}843}$$

Where 28.4 = fuel C.G. position (% M.A.C.) tanks full or porportionately full
19,843 = useable fuel tank fuel when full (lbs)
.55 = A/C C.G. shift, % M.A.C., when the U/C is selected up @ W = 48,500 #

ACCURACY REQUIRED IN C.G. MEASUREMENT

1. At 50,000 feet @ M = 1.5 @ 1.5g, 1° change in elevator angle changes aircraft drag approximately 4% (ref:- 72/PERF/4).

2. At 50,000 feet @ M = 0.9 to 2.0 @ 1g, a shift of 2% MAC in C.G. position will change the required elevator angle for trimmed flight by 1° (± 0.2°)

3. 1° elevator change per 2% MAC shift in C.G. position at 50,000 feet at M = 0.9 to 2.0 @ 1g is directly proportional to g loading and will approximately double its value at 60,000 feet.

4. Using 50,000 feet @ M = 1.5 @ 1.5g as design criteria, then 1.0° elevator change ≡ 1.33% MAC shift in C.G. position ≡ 4.0% Change in A/C drag.

Therefore, for 1% error in drag, elevator angle must be measured to within ± ¼ or ± 0.25° and c.g. position must be measured to within ± 1.33/4 or ± 0.33% M.A.C. Since the total C.G. travel is only .52% M.A.C. (using fuel system proportioners) a complete flight from full fuel to no fuel need only be broken into 2 stages of constant mean C.G. position.

SHEET NO. REPORT NO.
DATE Nov. 1957 PREP. BY

CF105 REF. P/WT/121

ESTIMATED POSITION ERROR CORRECTION FOR NOSE PROBE ~ STATIC

$$P_T/p = P_T/p_i + \Delta\left(P_T/p_i\right)$$

P_T = True indicated total pressure
p_i = Indicated static pressure
p = True ambient static pressure

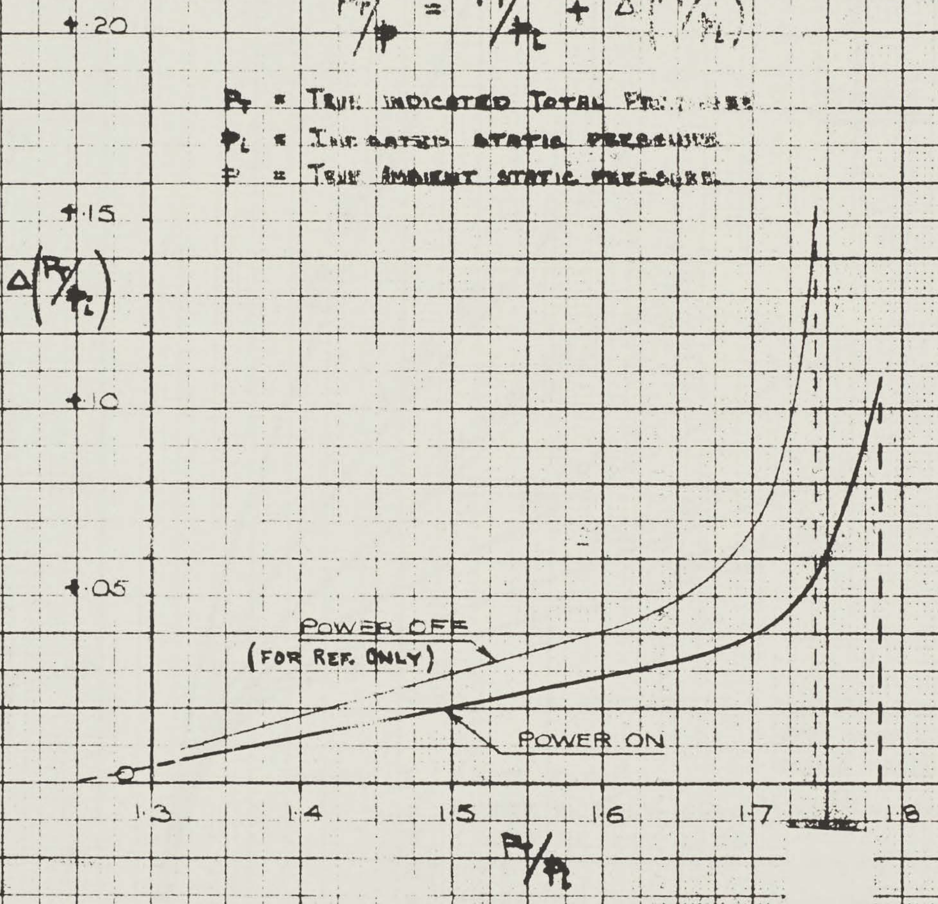
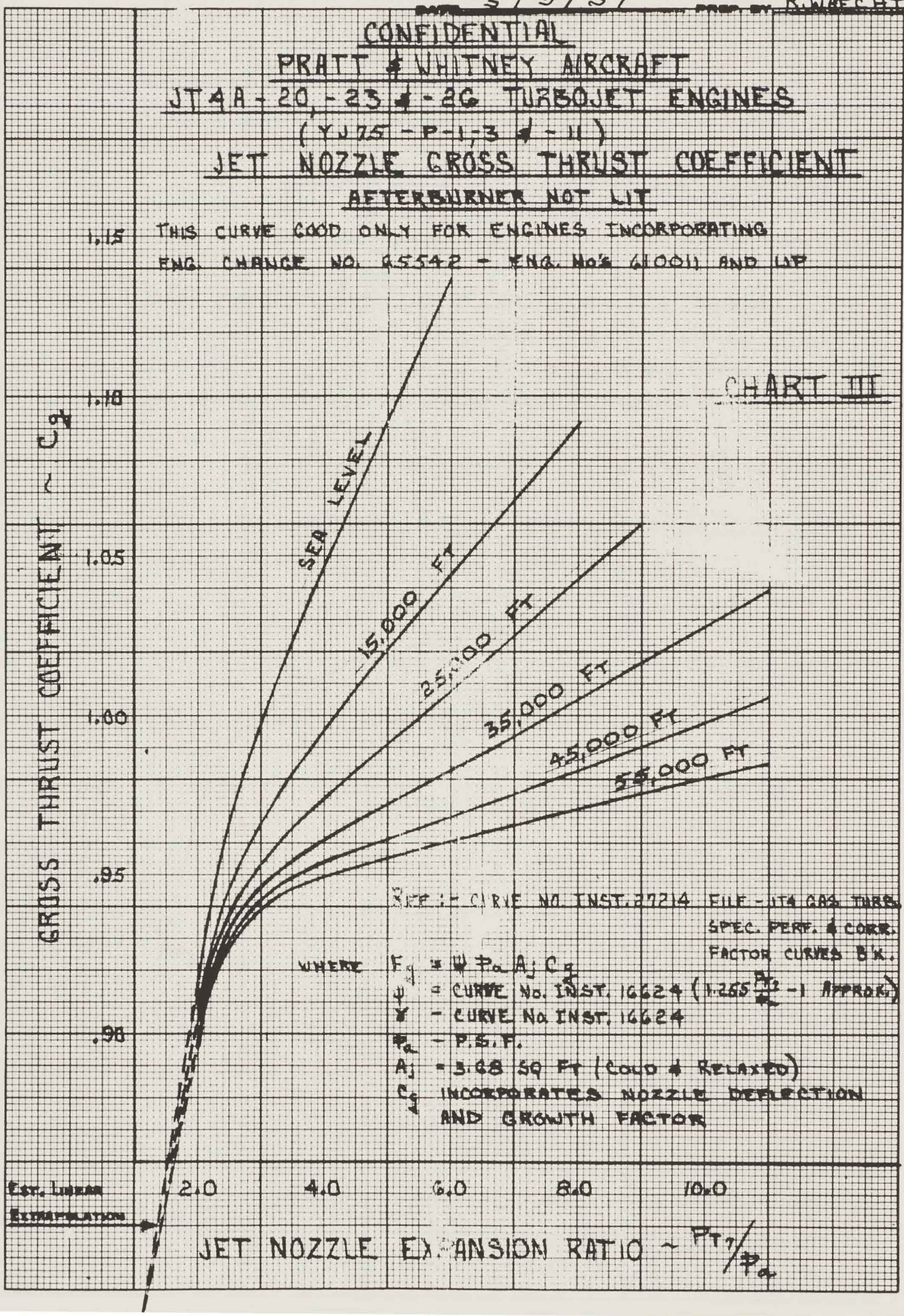


CHART II

SHEET NO. REPORT NO. 71/PERF/2
DATE 3/9/57 PREP. BY R. WAECHTER



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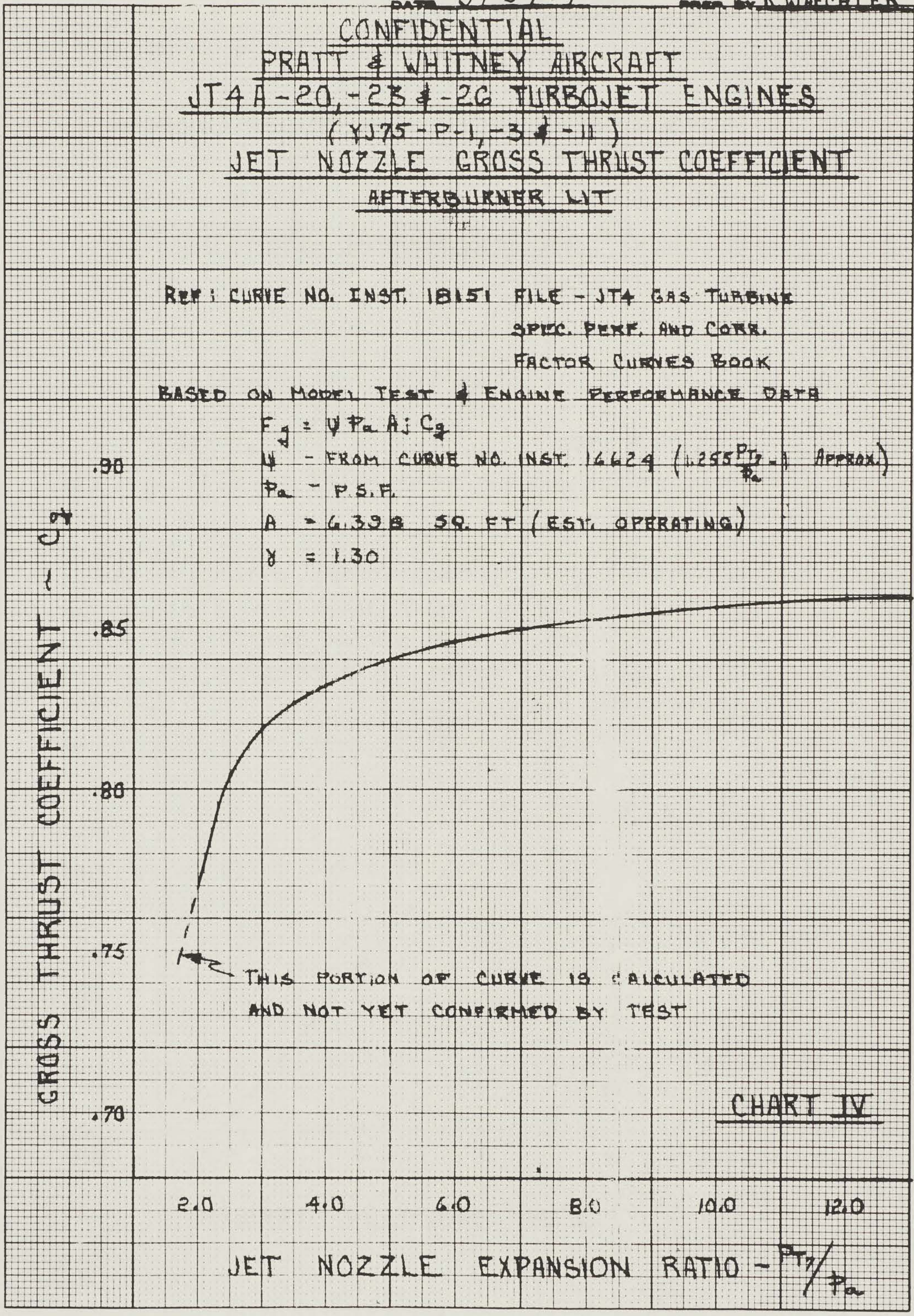

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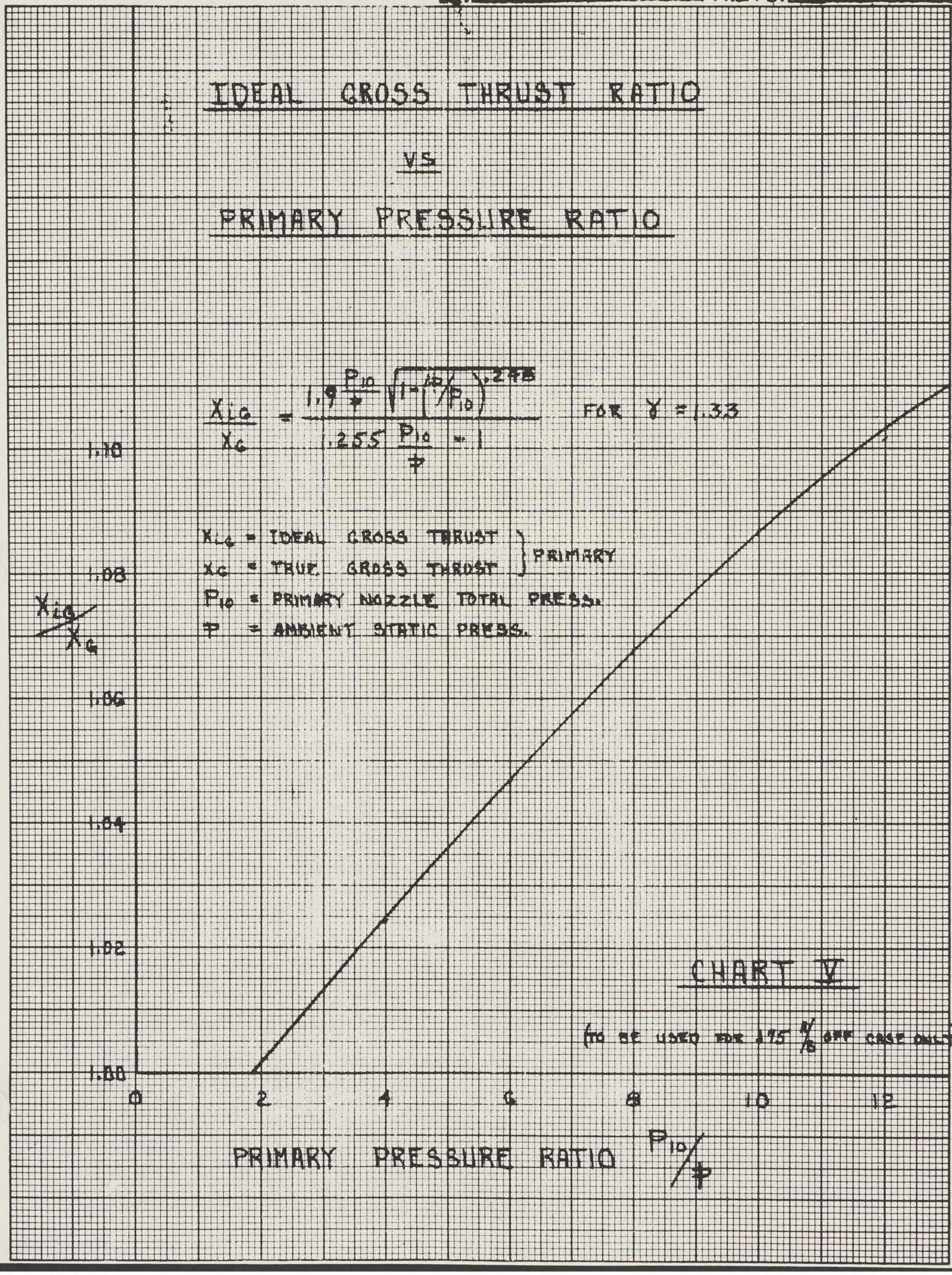


Report no. 91/Perk/2
Date Oct. 1957 Prep. by R. Wechter

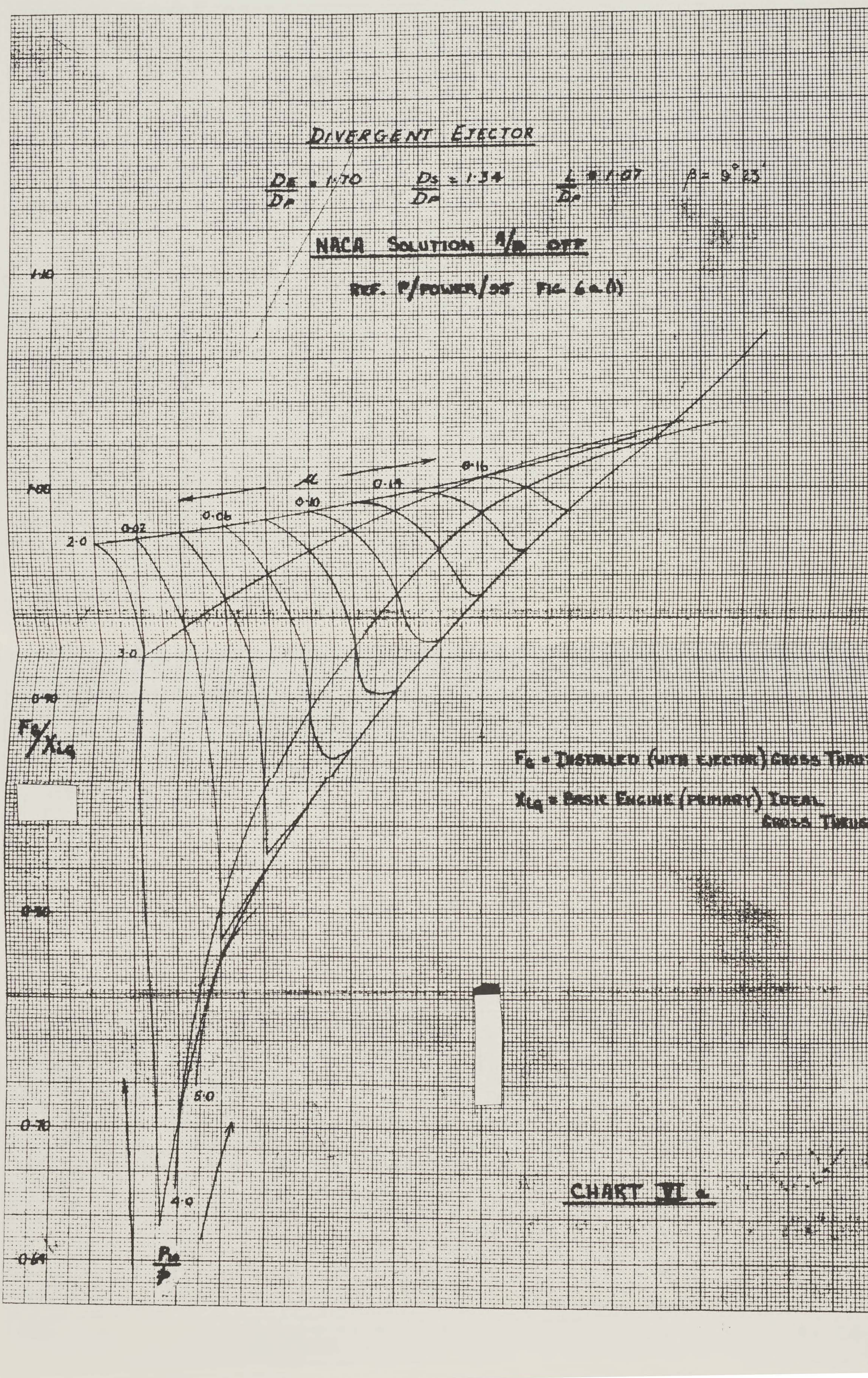
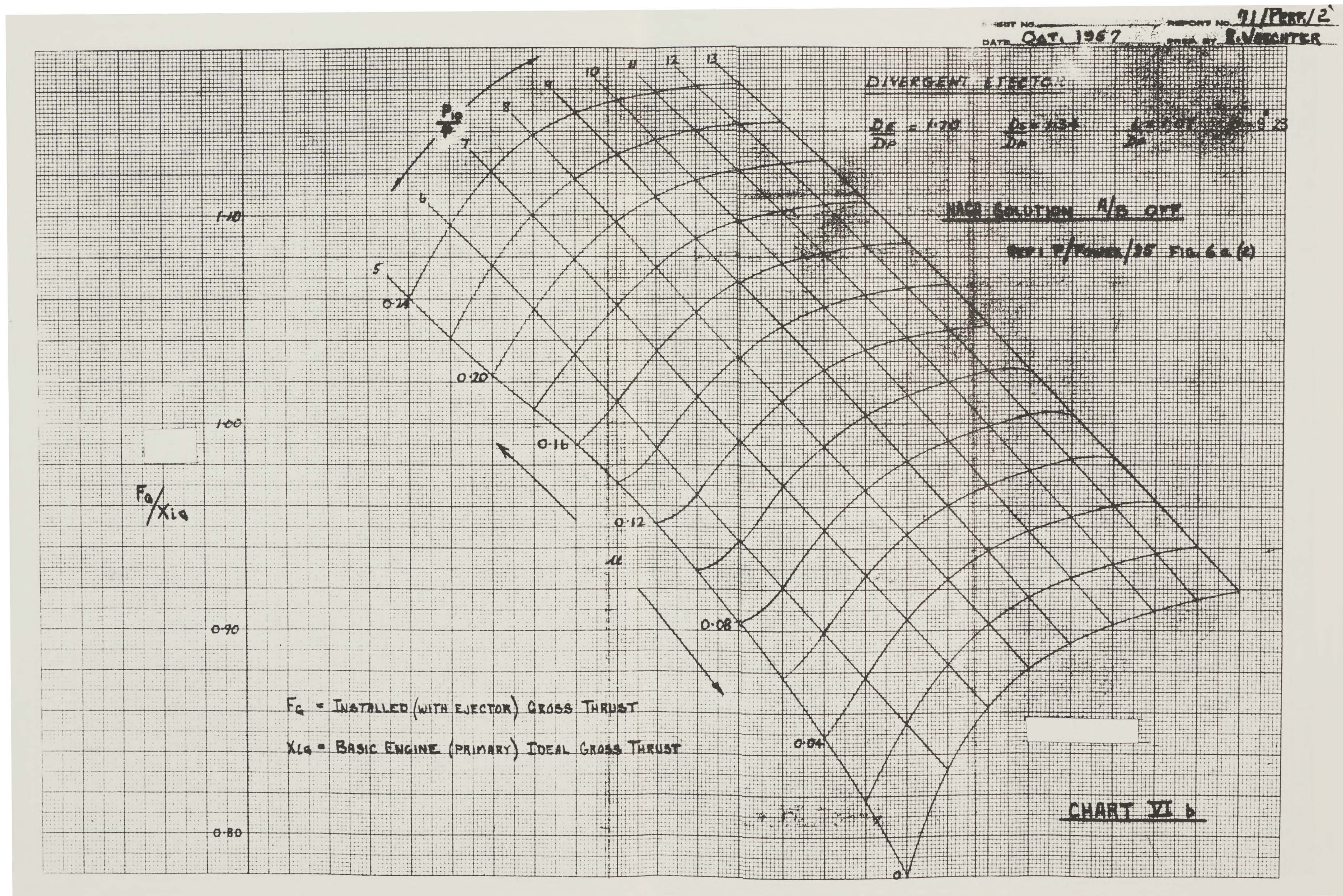
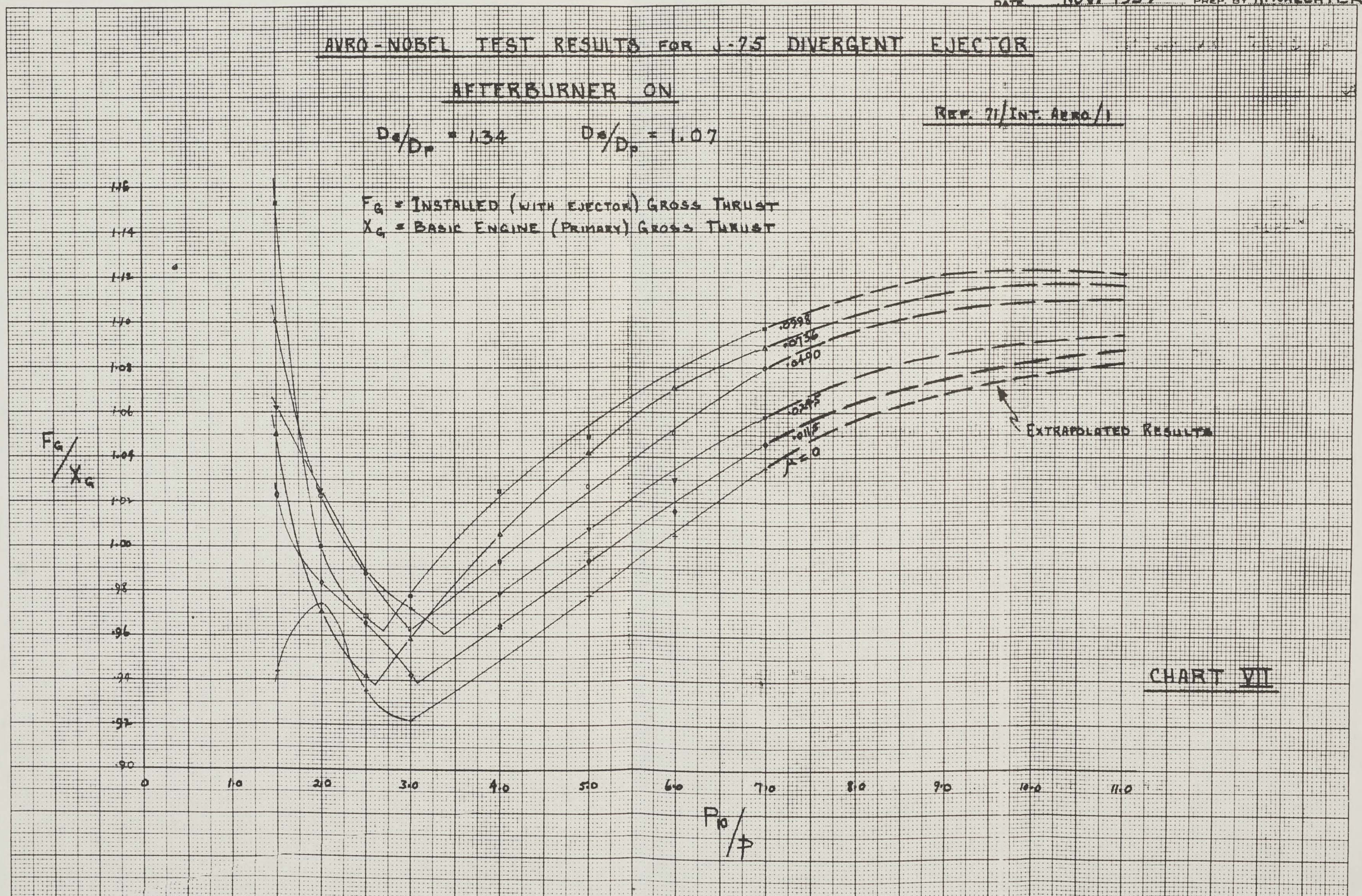


CHART VI a



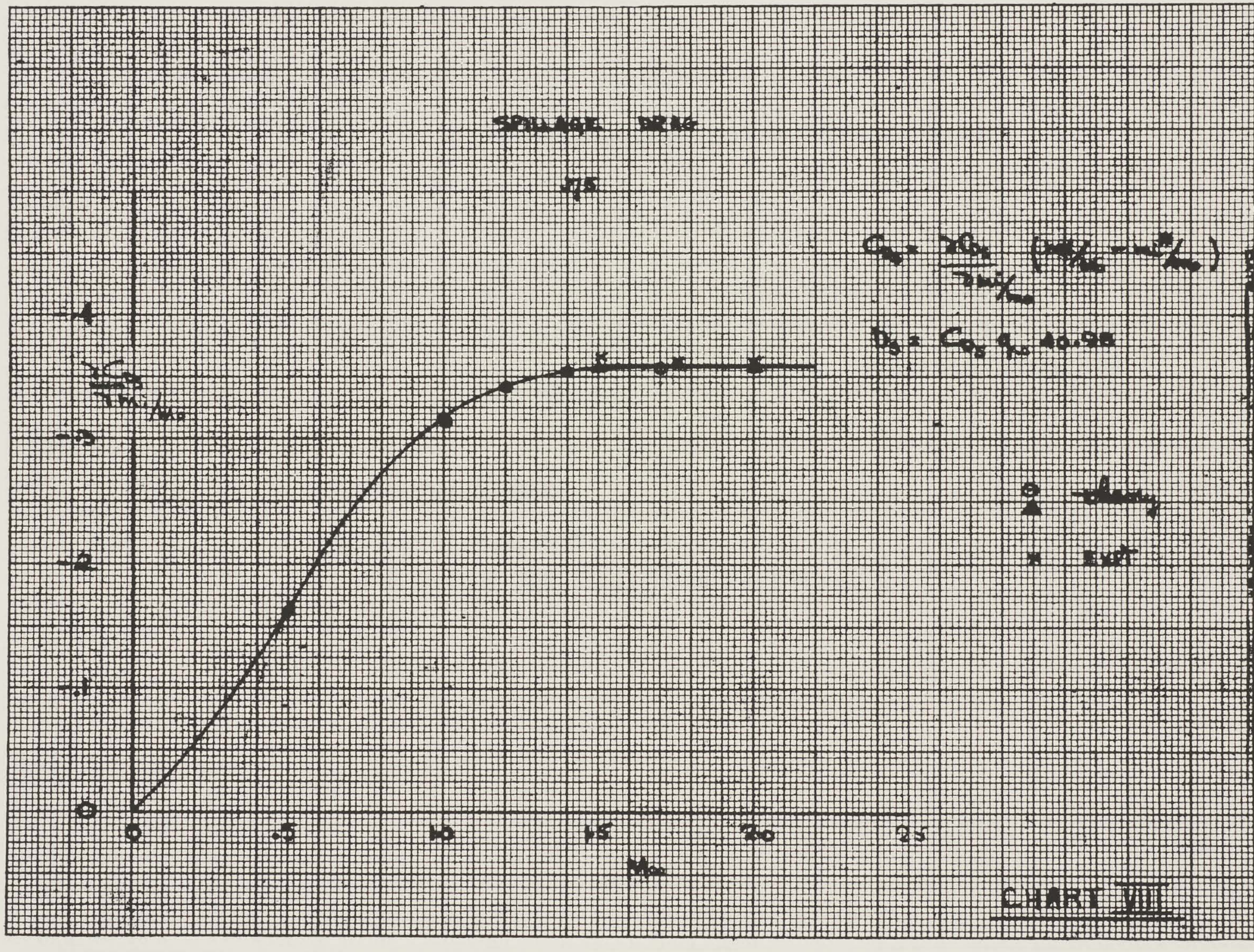
REPORT NO. 71/PERF/2
DATE OCT. 1967
BY R. WECHTER
DIVERGENT EJECTOR
NACA SOLUTION A/B OFF
FIG. 6 a (2)
1·10
1·00
0·90
0·80
F_G/X_IG
0·24
0·20
0·16
0·12
0·08
0·04
0
5
6
7
8
9
10
11
12
13
F_G = INSTALLED (WITH EJECTOR) GROSS THRUST
X_IG = BASIC ENGINE (PRIMARY) IDEAL GROSS THRUST
CHART VI b

SHEET NO. ______ REPORT NO. 71/PERF./2 Iss.2
DATE NOV. 1957 PREP. BY R. WAECHTER



REPORT No. 21/PERF/2 ISS. 2

DATE DEC. 1957



Report No. 71/PERE/6 Iss. 2

Date: Dec. 1957