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A THRUST COMPUTER FOR TURBO-JET ENGINES

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ABSTRACT

The thrust of a turbo-jet engine is the primary parameter indicating engine performance, but this parameter is not directly measurable during flight. Gross thrust can be expressed as a thermodynamic function of exhaust and ambient pressures and engine constants. Thus, gross thrust must be determined during flight by automatic computing techniques. An airborne analog computer has been designed, constructed, and evaluated at the Naval Research Laboratory for continuous solution of gross thrust.

PROBLEM STATUS

This is a final report on the problem and unless otherwise notified by BuAer, the problem will be closed one month from the date of mailing the report.

AUTHORIZATION

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A THRUST COMPUTER FOR TURBO-JET ENGINES

INTRODUCTION

Effective operation of military aircraft requires instrumentation of engine performance. Complete instrumentation is essential for aircraft being evaluated during flight test programs. With the introduction of turbo-jet aircraft came the demand for instrumentation which includes a means for determining the engine's thrust. Thrust is the primary parameter indicating turbo-jet performance, but the components of thrust are not directly measurable during flight. Therefore, thrust must be computed according to the thermodynamic properties of the engine.

As thermodynamic functions are unavoidably complex, the pilot of a turbo-jet aircraft is not capable of accurate interpretation of engine performance when provided only with instruments indicating the parameters from which thrust can be computed. As a result, it is necessary to apply automatic computing techniques to thrust determination during flight. The purpose of this report is to present the fundamentals of design and operation of an automatic computer based on analog principles which can instantaneously and continuously solve a thermodynamic equation for thrust. Thus, it will be possible to indicate the thrust of a turbo-jet engine directly with a single instrument reading which will facilitate flight test programs and enable a pilot to determine engine performance with a degree of precision not presently possible.

GROSS THRUST MEASUREMENTS

The net thrust (F_n) developed by a turbo-jet engine is the resultant of the gross thrust (F_g) measured at the exhaust nozzle and the ram-drag (F_r) occurring at the air intake.

$$F_n = F_g - F_r \tag{1}$$

Net thrust is directly measurable only for engines at rest. Thus, when a jet aircraft is in motion net thrust must be computed from equation (1) where gross thrust and ram-drag are thermodynamic functions. The principal component of net thrust indicating turbo-jet performance is gross thrust. Gross thrust instrumentation for test of turbo-jet aircraft has involved lengthy computations from data recorded upon a photo panel during test flights. Naval establishments concerned with flight test programs, particularly Flight Test at the Patuxent River Naval Air Station, have found it desirable to record and/or indicate the instantaneous gross thrust continuously during flight evaluation operations.

Such a measurement can be obtained by automatic computation. Electric and electronic circuits capable of performing mathematical operations by appropriate control of input parameters are known as analog computers. An analog computer has been designed at the Naval Research Laboratory to solve a gross thrust function. This analog computer was designed to meet weight and space requirements for jet aircraft installation and could be easily adapted as a gross thrust indicator for operational aircraft. A prototype model, hereafter called the jet thrust computer, has been constructed and evaluated under controlled laboratory conditions.

The gross thrust of a turbo-jet engine can be expressed as a function of total (P_{tj}) and static (P_{sj}) pressures at the exhaust nozzle and the ambient pressure (P_a). Let the effective area of the exhaust nozzle in the region of pressure measurements be A_j, and let the ratio of specific heats at the exhaust be γ_j. The derivation of gross thrust from the thermodynamics of ideal gas flow is presented in several reports.[1,2,3] One equation expressing gross thrust is

$$F_g = A_j P_{sj} \frac{2\gamma_j}{\gamma_j - 1}\left[\left(\frac{P_{tj}}{P_{sj}}\right)^{\frac{\gamma_j - 1}{\gamma_j}} - 1\right] + A_j\left(P_{sj} - P_a\right). \qquad (2)$$

Momentum Thrust Term   Pressure Thrust Term

These pressures can be measured through pressure probes in the form of a rake across the exhaust or by single total and static probes critically located in the exhaust nozzle to give close approximations to integrated values of pressure.[4]

Equation (2) can be simplified for the purpose of designing an analog computer without sacrificing accuracy by expanding the bracketed portion of the momentum thrust term into an infinite power series of P_{tj}/P_{sj}. This is possible since γ_j remains nearly constant over usual operating conditions. This expansion gives

$$\left(\frac{P_{tj}}{P_{sj}}\right)^{\frac{\gamma_j - 1}{\gamma_j}} - 1 = \sum_{n=o}^{\infty} K'_n\left(\frac{P_{tj}}{P_{sj}}\right)^n \qquad (3)$$

where K'_n is the coefficient of the nth term. A satisfactory empirical representation can be obtained using the first three terms of such a power series as is evident from Figure 1, Curve A. The maximum deviation of the empirical curve from the theoretical curve within the range of Mach Numbers 0 to 1 is ± 0.3 percent. Substituting these first three terms of the series in equation (2) and multiplying each K'_n by

$$\frac{2\gamma_j}{\gamma_j - 1}$$

to become K_n gives the final equation for gross thrust.

$$F_g = A_j\left[K_1 P_{sj} + K_2 P_{tj} + K_3 \frac{P_{tj}^2}{P_{sj}} + K_4\left(P_{sj} - P_a\right)\right] \qquad (4)$$

where K_4 is equal to the unity coefficient of the pressure thrust term.

PRESSURE-POTENTIAL ANALOG

An analog computer has been designed to provide continuous solution of Equation (4) for gross thrust. This is accomplished by establishing analogs between pressures and

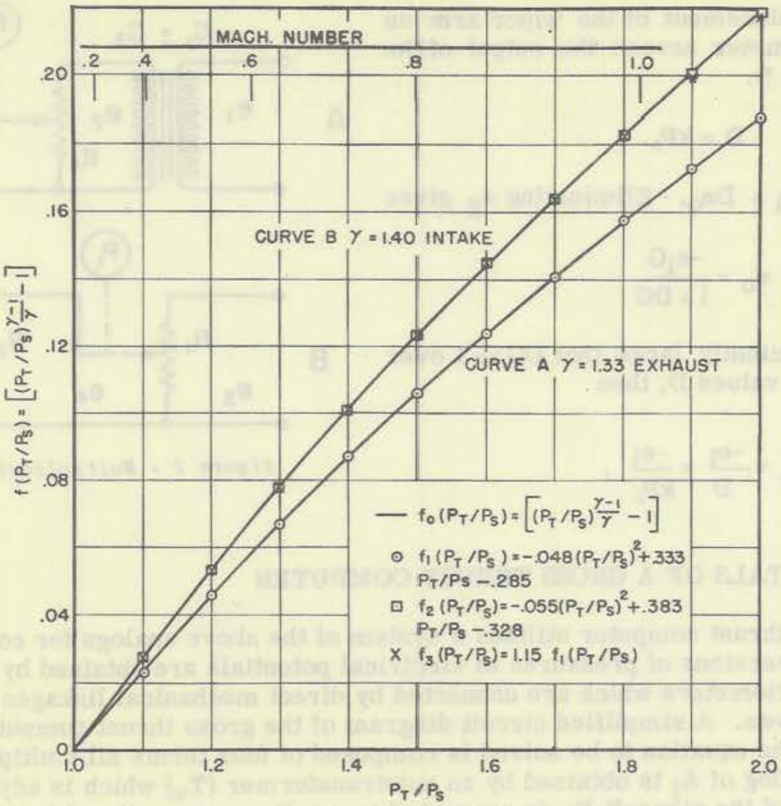


Figure 1 - Determination of empirical constants for exhaust and intake gases

electrical potentials in such a way that voltages proportional to each of the four terms of Equation (4) are developed for any conditions of pressure parameters. The sum of these four voltages, which are connected in series, is then proportional to the gross thrust.

The methods of multiplication used in this computer are flux linkages (transformers) and mechanical displacements applied to potentiometers. Consider the simple circuit shown in Figure 2A as a multiplication operator. The input voltage e_1 is applied to a potentiometer (R_1) through a transformer whose secondary to primary turns ratio is $C_2/C_1 = C'$ = a constant. The wiper arm of this potentiometer is displaced linearly with pressure P_1. If the impedance R_2 is much greater than R_1, then $e_O = e_1 C' kP_1 = e_1 CP_1$ where k relates pressure and wiper arm displacement. Therefore, this circuit performs two multiplication operations in series. Any function e_1 is multiplied by a constant and a variable.

This analog can be expanded to perform multiplication of a function by two variables through employing R_2 as a second potentiometer as shown in Figure 2B and controlling the displacement of this second potentiometer by a pressure P_2. Then

$$e_O = e_3 k P_1 k P_2 = e_3 k^2 P_1 P_2$$

provided that $R_3 \gg R_2 \gg R_1$.

The operation of division is accomplished using a negative feed-back amplifier similar to the circuit shown in Figure 3. This amplifier has a large amplification (G). Then

$$e_O = -e_g G.$$

Let the displacement of the wiper arm on the potentiometer across the output of the amplifier be D.

$$D = kP_3.$$

Then $e_g = e_i + De_o$. Eliminating e_g gives

$$e_o = \frac{-e_i G}{1 + DG}.$$

If G is sufficiently large that $DG \gg 1$ over the range of values D, then

$$e_o = \frac{-e_i}{D} = \frac{-e_i}{kP_3}.$$

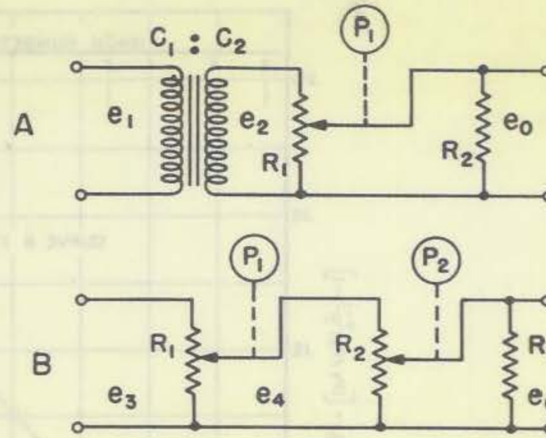


Figure 2 - Multiplication operators

FUNDAMENTALS OF A GROSS THRUST COMPUTER

The jet thrust computer utilizes a system of the above analogs for computing gross thrust. Conversions of pressures to electrical potentials are obtained by linear, low-torque potentiometers which are connected by direct mechanical linkages to pressure sensing bellows. A simplified circuit diagram of the gross thrust computer is shown in Figure 4. The equation to be solved is composed of four terms all multiplied by the area (A_j). An analog of A_j is obtained by an autotransformer (T_v) which is adjusted so that the line voltage of the aircraft E_L is converted to a voltage proportional to A_j. This voltage is applied to a special transformer T_R designed to introduce the required constants K_1, K_2, K_3 and K_4 by proper turn ratios between each of its secondary windings. The outputs of these secondaries are applied to a system of pressure transducers indicated in the diagram by the pressure actuated potentiometers. Then the voltage appearing between ground and the lowest sliding contact is

$$V_1 = A_j K_1 k P_{sj}. \tag{5}$$

The second term is obtained in the same manner as the first except that this transducer is controlled by P_{tj}.

Thus $$V_2 = A_j K_2 k P_{tj}. \tag{6}$$

The third term is a more complex function and requires a combination of operations. The total pressure is squared by using two potentiometers in series (Figure 2B) with both wiper arms being driven by P_{tj}.

$$V_i = A_j K_3 k^2 P_{tj}^2.$$

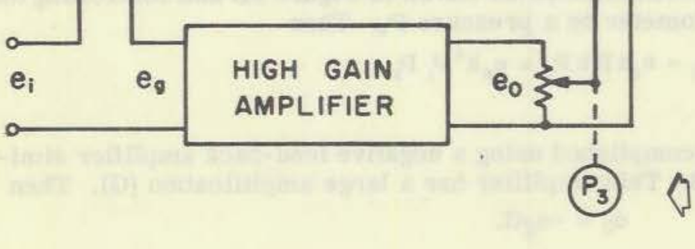
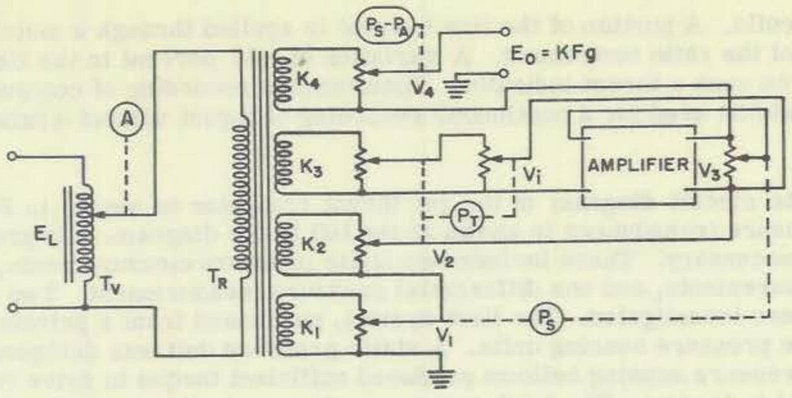


Figure 3 - A division operator



$$F_g = A\left[K_1 P_S + K_2 P_T + K_3 P_T^2 / P_S + K_4 (P_S - P_A)\right]$$

Figure 4 - Schematic diagram of a gross thrust computer

This voltage (V_i) is applied to the feed-back amplifier circuit (Figure 3) which divides V_i by $k\,P_{sj}$ or

$$V_3 = A_j K_3 k \frac{P_{tj}^{\,2}}{P_{sj}}. \quad (7)$$

The final term is generated by use of a differential pressure transducer. The wiper arm displacement in such a transducer is proportional to the difference of two applied pressures. This displacement is $k(P_{sj} - P_a)$,

and

$$V_4 = A_j K_4 k (P_{sj} - P_a)\,. \quad (8)$$

Adding these four voltages in series produces a voltage between ground and output lead of

$$V_O = kA_j\left[K_1 P_{sj} + K_2 P_{tj} + K_3 \frac{P_{tj}^{\,2}}{P_{sj}} + K_4\left(P_{sj} - P_a\right)\right], \quad (9)$$

or

$$V_O = k\,F_g\,. \quad (10)$$

A voltage indicator measuring V_O can be calibrated linearly in units of gross thrust.

THE JET THRUST COMPUTER

The prototype model of the jet thrust computer is designed for operation from a 115-volt - 400-cycle source. The 400-cycle supply was chosen for this model since that frequency is normally available in military aircraft. This type of computer could be designed for operation at another frequency by proper design of the transformers. The output voltage of the computer is directly proportional to the line voltage. To eliminate effects of line voltage variations, ratio type indicators may be used for indicating the thrust. This type of current measuring instrument has two coils which give a deflection proportional to the ratio of currents. The current sensing movements of Megger instruments are of this type. The computer output current is rectified by a half-wave crystal detector and applied to one of these current coils. A portion of the line current is applied through a matched crystal to the other coil of the ratio instrument. A variation of ±50 percent in the line voltage was not detectable on such a thrust indicator. Simultaneous recording of computer output and line voltage could be used for a continuous recording of thrust without a ratio type indicator.

A complete circuit diagram of the jet thrust computer is shown in Figure 5. The system of pressure transducers is shown at the left in the diagram. Six pressure measurements are necessary. These include two static pressure measurements, three total pressure measurements, and one differential pressure measurement. Two systems of transducers were investigated. The first system, purchased from a private contractor, used only three pressure sensing units. A static pressure unit was designed such that a single set of pressure sensing bellows produced sufficient torque to drive two potentiometers connected in tandem. The total pressure unit was similar in that one set of bellows operated three potentiometers. The differential pressure unit was of conventional design. This system was employed in an attempt to decrease space requirements as compared to a system of six individual transducers each having its own pressure sensing elements. However, recent developments in small size transducers do not make such compounding necessary. Compact units of the order of two-inch cubes are now available commercially. A second system of transducers using six single units was obtained recently. This system actually requires less space than the first system. Figure 6 shows the assembly of the three-unit system, and Figure 7A shows the six-unit system. A single transducer of the six-unit system is shown in Figure 7B.

A component list for the circuit shown in Figure 5 is given in Appendix A. The method for determining the design constants for the ratio transformer T_R is presented in Appendix B. Rheostats are connected in series with three of the secondaries of the ratio transformer to compensate for a slight nonuniformity among the transducers. No resistance should be added in series with secondary K_3, since the resistance across this secondary must be as small as practical for accurate multiplication. Therefore, transducers P_3 and P_4 are used as standards, and the other transducers are compensated if necessary to these standards. (See Appendix B.)

The amplifier for the dividing circuit is composed of a high mu pentode R-C coupled to a power pentode. These electron tubes and the power supply rectifier are miniature types. The gain is approximately 300 with no external feed-back. The internal feed-back path across the power stage through R_6 and C_5 is necessary for stabilization throughout the external feed-back range. It was necessary to insulate the mounting of the power transformer from the chassis to prevent coupling between the power and ratio transformers. The shell of the magnetically shielded power transformer was connected to its secondary center tap. It should be noted that the negative side of the electronic power supply must not be grounded.

All connecting cables external to the chassis are shielded to avoid stray coupling. The shielding is grounded to the chassis. Also, the grid lead to the first stage and the leads on the secondary of the amplifier output transformer are electrostatically shielded.

The autotransformer for introducing the effective area of the exhaust nozzle could be eliminated if the computer were designed for a specific type of turbo-jet engine having a fixed effective area. The constant A_j could then be included in the design of the ratio transformer or instrument calibration. For those turbo-jet engines having variable exhaust area, the movable arm of the autotransformer could be automatically controlled through a mechanical linkage to this area control.

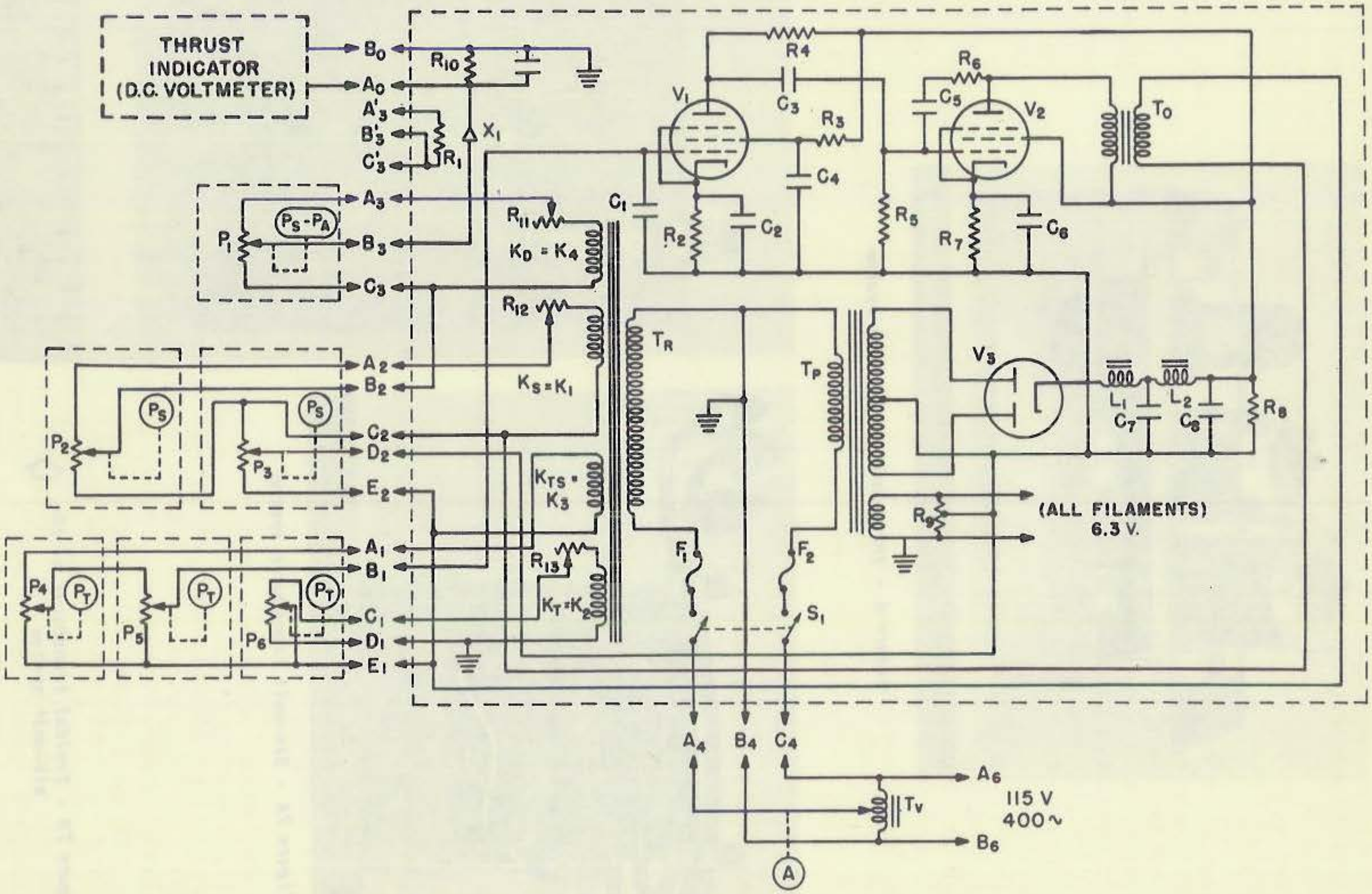


Figure 5 - Jet thrust computing circuit

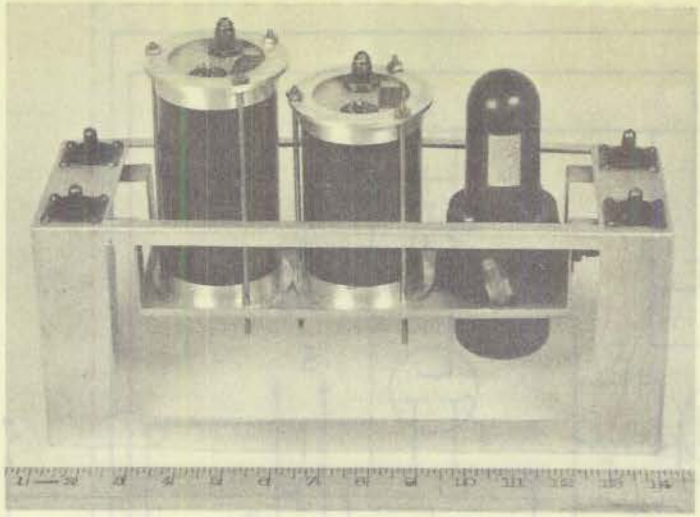


Figure 6 - Three-unit transducer system

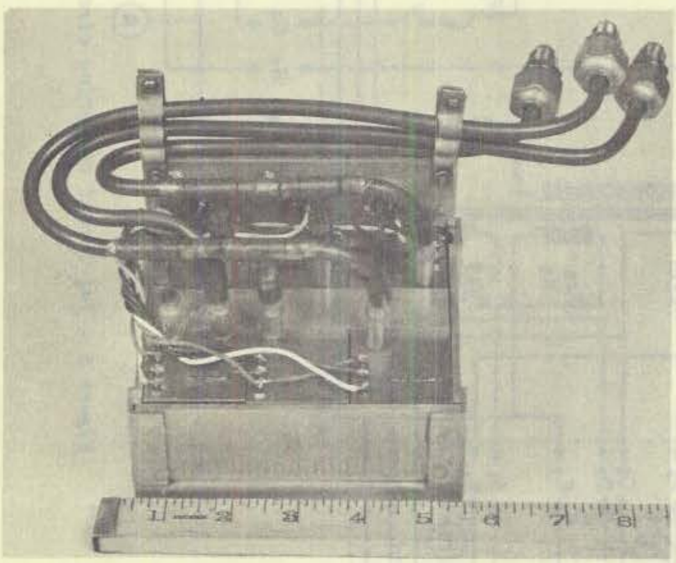


Figure 7A - Six-unit transducer system

Figure 7B - Typical transducer of the six-unit system ⇨

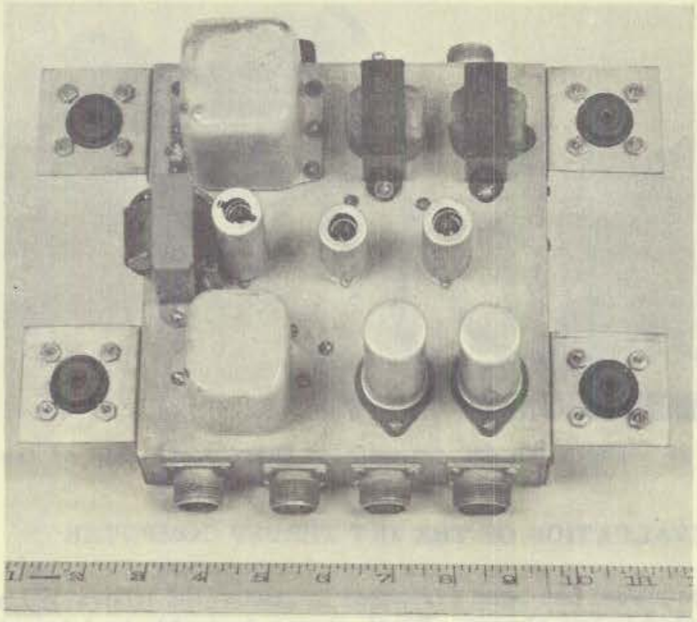


Figure 8 - Jet thrust computer chassis

Figure 8 shows a photograph of the computer chassis on which is mounted the ratio transformer, the feed-back amplifier and its power supply. To facilitate work upon circuitry during tests, the size of this chassis is larger than necessary. Figure 9 shows the complete jet thrust computer for measuring gross thrust using the six-unit transducer system. This complete computer equipment weighs about sixteen pounds exclusive of the weight of connecting cables and plumbing which depends on the actual installation. The connectors for the various cables were chosen so that incorrect assembly is not possible. After the computer has been initially adjusted for a particular type engine, no further adjustments should be required.

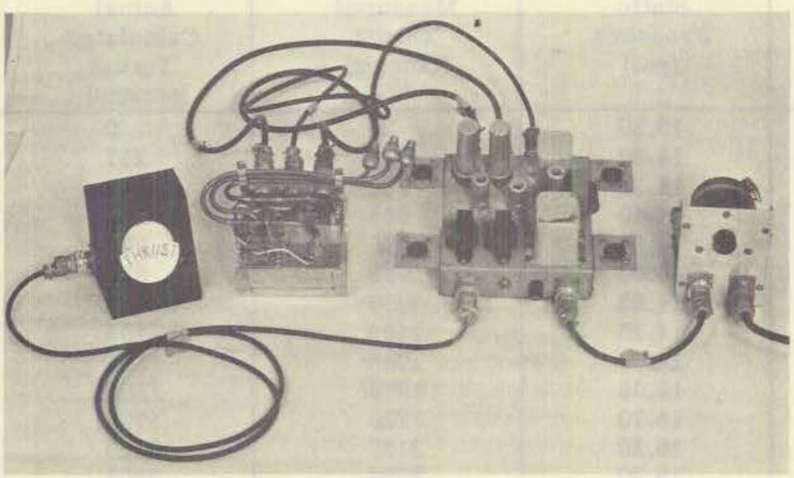


Figure 9 - Complete gross thrust computer system with indicator

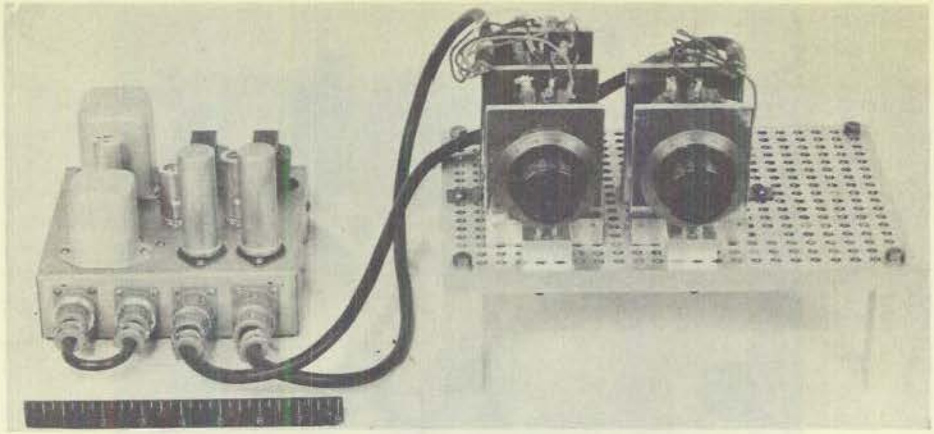


Figure 10 - Equipment for determining maximum accuracy of the computer

LABORATORY EVALUATION OF THE JET THRUST COMPUTER

The prototype model has been evaluated by controlled laboratory measurements. Evaluation was conducted in two phases. First, it was desirable to determine the limits of accuracy of the complete analog computer without including errors due to transducer characteristics. The results of these measurements included an actual evaluation of the analog principles used in the thrust computer. This was accomplished by use of calibrated potentiometers which could be adjusted manually for feeding equivalent pressure data into the computer. These potentiometers were assembled in ganged units similar to the three-unit transducer system. Figure 10 shows this equipment as assembled for momentum thrust computations. Typical momentum thrusts, as computed by this equipment, are shown in Table 1. The maximum error introduced by the empirical representation of thrust and analogs is ±0.61 percent.

TABLE 1
Jet Thrust Computer Accuracy Tests

Total Pressure (psi)	Static Pressure (psi)	Measured Thrust (pounds)	Actual Calculated Thrust (pounds)	Deviation (Percent of max. thrust)
13.80	13.80	20	0	+0.61
15.20	14.30	260	257	+0.09
15.65	14.35	350	368	-0.06
16.40	14.40	545	538	+0.21
17.35	14.50	755	760	-0.15
18.10	14.60	935	938	-0.09
18.80	14.65	1070	1090	-0.61
19.35	14.70	1195	1205	-0.30
19.85	14.80	1295	1305	-0.30
21.30	15.05	1570	1580	-0.30
22.00	15.10	1720	1720	0.00
24.00	15.20	2130	2120	+0.30
26.00	15.30	2520	2505	+0.45
28.00	15.40	2860	2860	0.00
30.00	15.50	3180	3180	0.00

Therefore, the accuracy of the jet thrust computer should be largely a function of the accuracy of the transducers. Transducer characteristics (pressure versus displacement) were measured for each potentiometer. These characteristics were linear to within ±2 percent for the ganged transducers and the six-unit system. The ganged units showed a maximum deviation of ±0.5 percent due to a hysteresis effect observable between increasing and decreasing pressure variations. The maximum hysteresis measured on any of the single units was ±0.4 percent. Some of the transducers tested did not indicate zero displacement at zero pressure, i.e., the characteristics did not intersect the origin. This is an objectionable feature in that it is impossible to compensate such a characteristic when these potentiometers are involved in the (P_t^2/P_S) term. Certain transducers of the six-unit system indicated a finite residual displacement at zero pressure. To compensate for this condition a separate negative voltage source was connected in series with the computer output voltage. This source was obtained by rectification of the output of a separate 6.3-volt transformer by a 1N35 crystal. The extra transformer is shown on the chassis in Figure 8 at the far left. Such means of compensation is not desirable and could be eliminated in future computers by more rigid specifications on transducer characteristics. Slight corrections in the slopes of the pressure displacement characteristics are compensatable by use of rheostats in series with secondaries of the ratio transformer as discussed in Appendix B.

Next, complete transducer systems were connected through a series of manually controlled needle valves to a source of compressed air. In this manner controlled constant pressures could be applied to the jet thrust computer simulating independent total and static pressures. Ambient pressure was simulated for various altitudes by a controlled vacuum line. These pressures were measured with aircraft manifold pressure gauges which were calibrated against a mercury manometer. Gross thrusts as calculated according to the original thermodynamic equation for steady-state conditions of total, static and ambient pressures were compared with the computer outputs. Table 2 shows the results of this type of evaluation when the ganged transducer system was used. Table 3 shows the results for the same type evaluation using the six single units. The simulated exhaust pressures indicated in Tables 2 and 3 are values taken from data recorded on a FH-1 during flight. The two columns of measured thrusts in Table 3 indicate the minimum and maximum thrusts observed for any given set of conditions during repeated measurements. Therefore, the column of errors shown in Table 3 are the maximum errors observed during a series of tests. The average error observed was of the order of ±3.5 percent. The average error using the ganged system was about ±2.5 percent. These errors may be reducible in the future through improved design of low-torque potentiometers. The primary difficulty encountered with the ganged system of transducers was a shift of the characteristics with time due to a slow leak in the bellows of one unit. Otherwise, the two systems are comparable and give approximately the same accuracy.

RAM-DRAG MEASUREMENTS

An analysis of ram-drag at the air intake of a moving turbo-jet engine is incomplete at the present time. Several theories, varying in basic concepts, have been proposed, yet no particular theory is generally accepted. It is not the purpose of this section of the report to develop evidence in support of any particular theory. But, the jet thrust computer has certain properties that makes it applicable to certain types of ram-drag measurement. These possibilities will now be presented.

The jet thrust computer is adaptable to investigating ram-drag when ram-drag is considered a function of the gas velocities at the entrance of the air intake and adiabatic compression of these gases is assumed.[5] Under these conditions it can be shown that the

TABLE 2
Jet Thrust Measurements Using Assimilated Exhaust Pressures and the Jet Thrust Computer with the Three Unit Transducer System

Altitude (Feet)	R.P.M.	Total Pressure (in. Hg)	Static Pressure (in. Hg)	Measured Thrust (Pounds)	Actual Calculated Thrust (Pounds)	Deviation (Percent of Max. Thrust)
5000	11800	31.4	27.9	500	500	0.0
	12800	33.2	28.9	600	630	-1.8
	13800	36.4	30.3	820	860	-2.4
	15500	40.7	32.9	1180	1130	+2.9
	16700	45.7	36.3	1380	1370	+0.6
	16800	49.7	38.8	1680	1680	0.0
10000	11800	26.7	22.7	520	500	+1.2
	13800	30.6	25.1	740	760	-1.2
	15500	36.1	28.4	1060	1100	-2.4
	16800	42.0	32.2	1420	1470	-2.9
15000	12800	23.3	19.8	510	460	+2.9
	13800	25.2	20.8	620	610	+0.6
	15500	29.5	23.1	910	910	0.0
	16800	33.1	25.1	1120	1130	-0.6
20000	13800	20.7	17.1	580	510	+4.1
	15600	24.6	19.2	780	780	0.0
	16900	27.9	21.4	1000	980	+1.2

relationship between total and static pressures at the intake and ram-drag is similar to momentum thrust of the exhaust gases. Explicitly,

$$F_r = A_i P_{si} \frac{2\gamma_i}{\gamma_i - 1}\left[\left(\frac{P_{ti}}{P_{si}}\right)^{\frac{\gamma_i - 1}{\gamma_i}} - 1\right] \qquad (11)$$

This equation is the same as for the representation of momentum thrust except that the exhaust parameters are replaced by intake parameters. γ_i varies only to a second order with ambient temperature and can be assumed constant. If P_{ti}/P_{si} is plotted against

$$\left[\left(\frac{P_{ti}}{P_{si}}\right)^{\frac{\gamma_i - 1}{\gamma_i}} - 1\right]$$

for $\gamma_i = 1.40$ one obtains curve B in Figure 1. A determination of empirical constants for the power series representation of this function yields a characteristic which is within ±0.5 percent of the original function within the range of gas velocities between Mach numbers 0 and 1. It was found that the ratios between these empirical constants and those determined for momentum thrust can be considered constant for all practical purposes. $K_1'' = C K_1'$, $K_2'' = C K_2'$ etc. where C = 1.15.

TABLE 3
Jet Thrust Measurements Using Assimilated Exhaust
Pressures and the Jet Thrust Computer With the Six Unit Transducer System

Altitude (Feet)	R.P.M.	Total Pressure (in. Hg)	Static Pressure (in. Hg)	Measured Thrust (Pounds)		Actual Calculated Thrust (Pounds)	Maximum Deviation (Percent of Max. Thrust)
				min.	max.		
5000	11800	31.4	27.9	500	560	500	3.3
	12800	33.2	28.9	580	670	630	2.8
	13800	36.4	30.3	820	920	860	3.3
	15500	40.7	32.9	1100	1200	1130	3.9
	16700	45.7	36.3	1320	1460	1370	5.0
	16800	49.7	38.8	1590	1720	1680	5.0
10000	11800	26.7	22.7	480	520	500	1.1
	13800	30.6	25.1	700	780	760	3.3
	15500	36.1	28.4	1100	1160	1100	3.3
	16800	42.0	32.2	1370	1500	1470	5.5
15000	12800	23.3	19.8	510	510	460	2.8
	13800	25.2	20.8	620	680	610	3.9
	15500	29.5	23.1	890	960	910	2.8
	16800	33.1	25.2	1100	1210	1130	4.4
20000	13800	20.7	17.1	550	590	510	4.4
	15600	24.6	19.2	740	800	780	2.2
	16900	27.9	21.4	960	1000	980	1.1

Thus, it becomes possible to compute ram-drag on the basis of gas velocities at the air intake with the jet thrust computer. This is accomplished by using a jumper to bypass the pressure thrust components and introducing the constant ratio (C) by the autotransformer. Figure 5 shows the simple circuitry for bypassing the pressure thrust components. The bypass cable is connected from $A_3B_3C_3$ to $A'_3B'_3C'_3$ instead of to the terminals of the differential transducer. The resistor R1 has the same resistance as the potentiometer P1 for maintaining a balanced load on the ratio transformer.

If it is established in the future that ram-drag can be measured in the manner discussed, then net thrust can be measured during flight by connecting two jet thrust computers (gross thrust and ram-drag) in series opposition. The voltage developed across this combination should be proportional to net thrust.

RECOMMENDATIONS ON FLIGHT TEST PROGRAM

The final test of any new type equipment should involve a study of that device in actual operation. The installation of the jet thrust computer on a turbo-jet engine remains to be investigated. The results of the jet thrust computer using simulated conditions of operation in the laboratory are encouraging, yet a satisfactory design can only be determined after application with a jet aircraft.

The prototype model of the jet thrust computer has been available for a flight test program since 1 April 1949. The Bureau of Aeronautics found it impossible to obtain a jet aircraft for the flight test of the computer at that time. An alternative test program was arranged through the Bureau of Aeronautics at the Air Experimental Station, NAMC, Philadelphia. This program involved installation of the thrust computer on a 3200-pound thrust engine which was to be evaluated in a test cell. This engine was to be operated under simulated flight conditions. The prototype model was delivered to NAMC for this program. On 4 November 1949, information was received through the Bureau of Aeronautics that the proposed tests at NAMC would be delayed at least six months.

In the test cell installation at NAMC the turbo-jet engine is supported by strain gages which measure the net thrust. For sea level conditions (engine at rest) ram-drag is zero and net thrust then equals gross thrust. Thus, for this condition the output of the jet thrust computer can be calibrated against the strain gage indicated gross thrust. The computer output should also be checked against calculated gross thrusts. For flight conditions the only means of evaluating the computer as a gross thrust indicator is by comparison with calculated thrusts.

It is recommended that an actual flight test program be established by the Bureau of Aeronautics upon completion of the program at NAMC. This program should include a ground calibration on a jet aircraft test stand similar to the test at NAMC. The gross thrust of the aircraft during flight can be calculated from a recording of pressure data and compared with a synchronized recording of the automatically computed thrusts. It is proposed that this synchronized data be obtained from a photopanel containing total, static and ambient pressure gages, a voltmeter indicating line voltage, and a voltmeter indicating the computed gross thrust. A final evaluation of the jet thrust computer can then be determined from a study of final data obtained from each photographed frame.

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APPENDIX A
Components of Jet Thrust Computer

P1	10,000 ohms	Linear potentiometer of differential pressure transducer (0-10) psi
P2	10,000 ohms	Linear potentiometers of static
P3	20,000 ohms	pressure transducers (0-30) psi
P4	2,000 ohms	Linear potentiometers of total
P5	20,000 ohms	pressure transducers (0-30) psi
P6	10,000 ohms	
R1	10,000 ohms	1/2 W.
R2	22,000 ohms	1/2 W.
R3	160,000 ohms	1/2 W.
R4	280,000 ohms	1/2 W.
R5	390,000 ohms	1/2 W.
R6	56,000 ohms	1/2 W.
R7	560 ohms	1/2 W.
R8	10,000 ohms	10 W.
R9	100 ohms	1 W.
R10	1 megohm	1/4 W.
R11	1,000 ohm rheostat	
R12	1,000 ohm rheostat	
R13	3,000 ohm rheostat	
C1	0.05 microfarads	
C2	10 microfarads	25 volts
C3	0.10 microfarads	
C4	20 microfarads	600 volts
C5	.0012 microfarads	
C6	10 microfarads	25 volts
C7	20 microfarads	600 volts
C8	20 microfarads	600 volts
C9	0.10 microfarads	
L1	15 henries	70 milliamperes
L2	15 henries	70 milliamperes
V1	9001	Voltage amplifier
V2	6AK6	Power amplifier
V3	6X4	Rectifier
TR	Ratio Transformer NRL No. 3423	Pri. 115 v. 400 cycles Sec. Kd = 9.5 v, Kts = 10v, Kt = 71.4 v, Ks = 61.1 v.
TP	Power Transformer NRL No. 3425	Pri. 115 v. 400 cycles Sec. 6.3 v. and 350-0-350v.
TO	Output Transformer	Thordson Type T72S58

TV	Autotransformer	Variac Type 200B
S1	Double pole double throw switch	
F1	Fuse 1a.	
F2	Fuse 3a.	
X1	1N35 Crystal Rectifier	

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