H H Brown
~~Parsons~~

MR Aug. 1944

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

WARTIME REPORT

ORIGINALLY ISSUED

August 1944 as
Memorandum Report

A PRELIMINARY EVALUATION OF THE EXPLOSION JET-PROPULSION ENGINE

By J. C. Sanders

Aircraft Engine Research Laboratory
Cleveland, Ohio

NACA

WASHINGTON

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

MEMORANDUM REPORT

for the

Bureau of Aeronautics, Navy Department

A PRELIMINARY EVALUATION OF THE EXPLOSION JET-PROPULSION ENGINE

By J. C. Sanders

SUMMARY

The theoretical sea-level performance of an explosion jet-propulsion engine similar to the one used in the German flying bomb was computed to show the effects on performance of heat added and supercharging and a comparison was drawn between the performance of the explosion jet-propulsion engine and the constant-pressure jet-propulsion engine. The explosion jet-propulsion engine was found to be more efficient than the constant-pressure jet-propulsion engine at compressor pressure ratios below 3.0 when the maximum gas temperature of the constant-pressure engine is 1600° F. With more efficient compressors and higher gas temperatures, however, the constant-pressure jet-propulsion engine is more efficient. The compressor for the constant-pressure jet-propulsion engine absorbs more power than the compressor for the explosion jet-propulsion engine when the two engines develop the same power.

INTRODUCTION

The most widely known and successful jet-propulsion engine consists of a centrifugal compressor, a constant-pressure combustion chamber, and a turbine to extract enough energy from the hot gas to drive the compressor. (See reference 1 and fig. 1(a).) The cycle efficiency of this type of engine is limited indirectly by a comparatively low maximum permissible gas temperature of 1600° F at the turbine to prevent destruction of the turbine blades. Furthermore, a highly efficient compressor capable of producing a pressure ratio of 4 or more is required.

A method of circumventing these limitations of the turbine and compressor is to use an explosion jet-propulsion engine in which the air is inducted at low pressure into a vessel, exploded to generate a high pressure, and expelled through a nozzle. (See fig. 1(b).) This type of propulsion engine was patented by Marconnet in 1909 and later patented by Schmidt in 1931 (reference 2). The Schmidt patent describes the type of engine used by the Germans to propel their flying bombs against England. Mention is also made of this type of engine in reference 3.

The explosion type of engine is not limited in cycle temperatures and may use a fuel-air ratio to give the maximum temperature possible in the combustion of air; furthermore, it does not require a compressor, although a compressor improves its performance.

This report presents the results of calculations showing the performance of an explosion jet-propulsion engine. The effects of supercharging on cycle efficiency and propulsive efficiency were computed and a comparison of the sea-level performance of the supercharged explosion jet-propulsion engine and the constant-pressure jet-propulsion engine was made. A schematic diagram of the supercharged engine is shown in figure 1(c).

The computations were made at the NACA Aircraft Engine Research Laboratory, Cleveland, Ohio, during February and March 1944, as a part of an investigation of means of increasing the cycle efficiencies of jet-propulsion engines.

DESCRIPTION OF THE EXPLOSION JET-PROPULSION ENGINE

The simple type of explosion jet-propulsion engine used in the German flying bombs is shown diagrammatically in figure 1(b). A combination of the dynamic pressure resulting from the forward motion of the flying bomb and the inertia effects of the previous charge being expelled from the combusion chamber serves to induce a charge of fresh air through the intake valve at the front. Fuel is sprayed into the combustion chamber and a spark plug ignites the mixture. The increasing pressure closes the valve and rises to a high value, which causes a rapid expulsion of the charge rearward and thereby generates the propulsive thrust. An idealized sketch of a captured German flying bomb using this type of propulsion engine is shown in figure 2.

Inspection of the thermodynamic cycle of the explosion jet-propulsion engine shows that both the cycle efficiency and the power can be increased by supercharging. Consequently, consideration was given to the more elaborate explosion jet-propulsion engine shown in figure 1(c). In this type of engine, a centrifugal supercharger delivers compressed air to a battery of combustion chambers provided with intake valves and possibly with exhaust valves. An auxiliary engine drives the supercharger.

ASSUMED CONDITIONS FOR CALCULATIONS

The calculations were made for the supercharged engine shown in figure 1(c), assuming a compressor efficiency of 70 percent and a compressor driving motor having a thermodynamic cycle efficiency of 60 percent. The assumed efficiencies of the turbine and the compressor in the constant-pressure jet-propulsion engine were 80 and 75 percent, respectively. No other losses were considered.

The following operating conditions were assumed:

Altitude	Sea level
Atmospheric temperature, °F	100
Velocity of aircraft, miles per hour	400
Gas temperature before turbine, °F	1600

The combined efficiency of the explosion jet-propulsion engine was computed for a range of heat supplied per pound of air (fuel-air ratio) from 0 to 750 Btu per pound. These calculations were made for compressor pressure ratios of 1, 2, 3, 4, and 8. For comparative purposes, the efficiency of the constant-pressure jet-propulsion engine was computed for the same compressor pressure ratios.

Calculations were also made to compare the thrust powers obtained from a given size compressor as first used with constant-volume combustion and second, with constant-pressure combustion. A maximum heat input of 750 Btu per pound was assumed for the constant-volume combustion and a maximum gas temperature of 1600° F was assumed for the constant-pressure combustion. A range of compressor pressure ratios from 1 to 8 was investigated.

The symbols used in the computations are given in appendix A. Details of the computations for the explosion jet-propulsion engine are described in appendix B and for the constant-pressure jet-propulsion engine, in appendix C.

DEFINITIONS OF TERMS

Cycle efficiency η_{cycle} is the ratio of the net work of the thermodynamic cycles to the heat absorbed from the fuel by the working fluid, including the fluid used by the auxiliary engine driving the compressor. The efficiency of combustion is thus excluded from the calculations.

Propulsive efficiency η_p is the ratio of the useful propulsive work to the net work added to the fluid by the jet-propulsion engine.

Combined efficiency η is the ratio of the useful propulsive work to the heat absorbed from the fuel by the working fluid, including the fluid used by the auxiliary engine driving the compressor. The combined efficiency may be obtained by multiplying the cycle and propulsive efficiencies, provided that they can be evaluated.

Blowdown is the portion of the explosion cycle following combustion during which enough gas is expelled from the combustion chamber to permit the pressure in the explosion chamber to fall to the exhaust back pressure.

ESTIMATED PERFORMANCE OF THE EXPLOSION JET-PROPULSION ENGINE

The combined efficiencies of the explosion jet-propulsion engine at sea level and a speed of 400 miles per hour are shown in figure 3 for compressor pressure ratios of 1, 2, 3, 4, and 8. The maximum combined efficiency is about 10 percent. In general, the combined efficiency is less at maximum heat input than at half the maximum heat input, although this difference is small. At low supercharger pressure ratios, the combined efficiency falls off rapidly at very low values of heat input.

A comparison of the efficiencies of jet-propulsion engines using constant-volume combustion and constant-pressure combustion is shown in figure 4. The constant volume of the explosion jet-propulsion engine is more efficient at compressor pressure ratios below 3.0. A single-stage centrifugal supercharger is capable of producing a pressure ratio of 4. Inspection of figure 4 shows that the explosion jet-propulsion engine with a compression ratio of 4 is about 4 percent less efficient than a constant-pressure jet-propulsion engine having the same compressor pressure ratio.

The ratio of powers obtainable from these two types of engine with the same size compressors is shown in figure 5. The power obtainable with constant-pressure combustion is less than the power obtainable with constant-volume combustion and, of course, falls to the very low efficiency of an engine using the dynamic pressure of the air when the compressor pressure ratio is 1.

The advantage of the higher efficiency obtained by supercharging is obtained at the cost of a large and heavy engine to drive the supercharger. Figure 6 shows that the power required by the compressor engine exceeds the net thrust power when the supercharger pressure ratio is 2.0 or greater. It therefore appears that supercharging is practical only for low pressure ratios.

DISCUSSION

Reliability of calculations. - The trends of the performance curves shown in figures 3, 4, and 5 were expected because examination of the working cycles of the explosion and constant-pressure jet-propulsion engines shows that the efficiency of the constant-pressure cycle must be zero with a compressor pressure ratio of 1, assuming no dynamic compression. Furthermore, the explosion cycle permits expansion of most of the gas from a much higher pressure than is available in a constant-pressure cycle and therefore usually has a higher cycle efficiency. In spite of the lower cycle efficiency of the constant-pressure engine, its combined efficiency is expected to exceed the efficiency of the explosion jet-propulsion engine under conditions of optimum design because the propulsive efficiency of the explosion jet-propulsion engine is very low as a result of the high jet velocities at the beginning of blowdown.

The assumption was made in these calculations that the blowdown to atmospheric pressure was complete. Consequently, the velocity of discharge during scavenging was negligible. It is possible, however, that the explosion vessel would blow down to supercharger pressure and the residual gases would be expelled at a velocity corresponding to the pressure drop from supercharger pressure to atmospheric pressure. Calculations of combined efficiencies with this type of operation (shown in fig. 3 for comparison with performance with complete blowdown) show lower efficiencies at high heat inputs but higher efficiencies at very low heat inputs than in the case of complete blowdown.

Other factors that may lower the performance of the explosion jet-propulsion engine are energy losses in charging and scavenging the combustion chamber, poor scavenging of the combustion chamber, poor combustion, and degeneration of the ideal cycle resulting from expulsion of gas through the nozzle before combustion is complete. Insufficient data are available to evaluate the significance of these factors and they were therefore not considered in the calculations.

Charging. - The charging process in the explosion jet-propulsion engine may be similar to the uniflow-type two-stroke cycle engine in which inlet and exhaust valves are at opposite ends of the cylinders. The indicated mean effective pressures developed by a representative two-stroke cycle engine at 1800 cycles per minute (reference 4) indicates that effective scavenging may be secured.

The Schmidt patent (reference 2) specified the utilization of inertia effects arising from blowdown to induce a fresh charge. Erickson (reference 5) has shown that considerable pressure resulting from inertia in the intake system may be utilized.

Suitability of the explosion jet-propulsion engine. - The chief claim for the desirability of the explosion jet-propulsion engine is its simplicity and consequent ease of development. Its efficiency is comparable with a constant-pressure jet-propulsion engine although the constant-pressure engine may be expected to become the more efficient as materials for turbine blades are improved.

CONCLUSIONS

Theoretical calculations of the thermodynamic cycles for an explosion jet-propulsion engine and a constant-pressure jet-propulsion engine indicate that:

1. The combined efficiency of the explosion jet-propulsion engine (cycle efficiency times propulsive efficiency) is 8 to 10 percent as compared with 3 to 11 percent for a constant-pressure engine at a maximum gas temperature of 1600° F and an aircraft speed of 400 miles per hour.

2. The explosion jet-propulsion engine is more efficient than the constant-pressure jet-propulsion engine at pressure ratios below 3.0.

3. Supercharging up to a pressure ratio of 4 increases the efficiency of the explosion jet-propulsion engine.

4. The power absorbed by the compressor in the explosion jet-propulsion engine is less than in the constant-pressure jet-propulsion engine.

Aircraft Engine Research Laboratory,
National Advisory Committee for Aeronautics,
Cleveland, Ohio, August 11, 1944.

APPENDIX A

SYMBOLS

a	pressure-rise ratio occurring during combustion
b	pressure-rise ratio of the compressor
c	ratio of stagnation pressure to free-stream pressure
β	correction for compressibility, 1.064 at 400 miles per hour
c_p	specific heat of the gas at constant pressure, (Btu)/(slug)(°F)
c_v	specific heat of the gas at constant volume, (Btu)/(slug)(°F)
$\frac{d\rho}{dt}$	rate of expulsion of charge, (slug)/(sec)
ϵ	specific energy input, $\frac{w_o - w_t}{V_o^2/2}$
F	thrust force, (lb)
h	heat added to air during combustion, (Btu)/(lb air)
I_V	impulse per cubic foot of vessel
I_{slug}	impulse per slug of gas
K	internal drag coefficient, assumed to be zero
η	combined efficiency of explosion or constant-pressure jet-propulsion engine at an airspeed of 400 miles per hour
η_{ad}	adiabatic efficiency of the compressor, 0.7
η_c	compressor efficiency, assumed to be 0.8
η_{cycle}	cycle efficiency of compressor driving engine, 0.6
η_p	propulsive efficiency
η_t	turbine efficiency, assumed to be 0.9
p_1	exhaust back pressure, (lb)/(sq ft)
p_2	stagnation pressure before inlet to compressor, (lb)/(sq ft)

p_3	pressure of gas entering turbine, (lb)/(sq ft)
p_4	pressure of surrounding atmosphere, (lb)/(sq ft)
P_o	total pressure of gas in vessel after completion of combustion, (lb)/(sq ft)
γ	ratio of the specific heats at constant volume and constant pressure, 1.35
γ_1	ratio of the specific heats at constant volume and constant pressure, 1.32
γ_2	ratio of the specific heats at constant volume and constant pressure, 1.4
R	gas constant, (ft-lb)/(slug)($^{\circ}$F)
ρ	weight of gas remaining in vessel at any instant, (slug)
ρ_o	weight of initial charge, (slug)
ρ_b	weight of charge remaining in vessel at end of any assumed blowdown process, (slug)
ρ_4	density of air at atmospheric conditions, (slugs)/(cu ft)
T_o	temperature of gas in vessel after completion of combustion, $^{\circ}$F
T_1	temperature of air entering supercharger, $^{\circ}$F absolute
T_2	temperature of air leaving supercharger, or at end of compression, $^{\circ}$F absolute
T_3	temperature of air entering compressor, accounting for adiabatic temperature rise to stagnation, $^{\circ}$F absolute
T_4	temperature of gas approaching turbine, $^{\circ}$F absolute
V_o	velocity of aircraft with respect to earth, (ft)/(sec)
V_r	velocity of escaping gas relative to airplane, (ft)/(sec)
w_b	thrust work developed during blowdown, (ft-lb)/(cu ft)
w_h	work equivalent of heat added to fluid in auxiliary engine driving the compressor, or added to gas during combustion, (ft-lb)/(lb of fluid passed through nozzle of jet), or (ft-lb)/(slug)

w_o	total work available in adiabatic expansion, (ft-lb)/(slug)
w_N	net thrust work, (ft-lb)/(slug of air)
w_t	work abstracted by turbine to drive compressor, (ft-lb)/(slug)
Z	effective thrust coefficient

APPENDIX B

CALCULATIONS FOR THE EXPLOSION JET-PROPULSION ENGINE

The equation for the combined efficiency of a jet-propulsion engine is:

$$\eta = \frac{\text{Net thrust work}}{\text{Energy supplied by fuel}} \tag{1}$$

The net thrust work is the thrust work developed by the vessel blowing down minus the work required to bring the charge air to a zero velocity with respect to the airplane. The energy supplied to the working fluid includes the heat added to the air in the combustion chamber and the heat added to the working fluid in the auxiliary motor driving the compressor. In computing the thrust work developed during blowdown, it is necessary to determine the maximum amount of heat to be supplied to the cycle by the fuel. These computations therefore describe in turn (1) a derivation of the expression for thrust work of a vessel blowing down, (2) the work of the fluid in the engine driving the supercharger, (3) a determination of the maximum heat supplied, and (4) the final equation for the efficiency of an explosion jet-propulsion engine.

Thrust developed by a vessel blowing down. - The vessel is considered to be filled with its charge and combustion complete, with the gas pressure P_0 and temperature T_0. The vessel then blows down to atmospheric pressure p_4. If the volume of the vessel is 1 cubic foot the weight of the initial charge is ρ_0 slugs. The thrust force at any instant is

$$F = V_f\left(\frac{d\rho}{dt}\right)$$

The thrust work developed during the expulsion of the charge $d\rho$ is

$$dw_b = FV_0 dt$$

$$= V_0 I_V$$

Substituting the value of F and integrating the left side gives

$$I_V = \int_{\rho_o}^{\rho_b} V_f d\rho \qquad (2)$$

If it is assumed that the gas obeys the general gas law, PV = wRT, then

$$V_f = 223.7 \left(\frac{c_p P_o}{R \rho_o}\right)^{\frac{1}{2}} \sqrt{\rho^{\gamma-1}\left[1 - \left(\frac{p_1}{P_o}\right)^{\frac{\gamma-1}{\gamma}} \left(\frac{\rho_o}{\rho}\right)^{\gamma-1}\right]} \qquad (3)$$

Substituting the value of V_f from equation (3) in equation (2) and simplifying and converting to impulse per slug of gas in cylinder before blowdown yields

$$I_{slug} = 223.7 \left(\frac{c_p P_o}{R \rho_o}\right)^{\frac{1}{2}} Z \qquad (4)$$

where Z is the effective thrust coefficient defined as

$$Z = \int_{\rho_o}^{\rho_b} \sqrt{\left(\frac{\rho}{\rho_o}\right)^{\gamma-1} - \left(\frac{p_1}{P_o}\right)^{\frac{\gamma-1}{\gamma}}}\, d\,\frac{\rho}{\rho_o} \qquad (5)$$

Values of Z obtained by arithmetic integration of equation (5) are shown in figure 7.

The value of P_o was determined as follows:

$$P_o = p_4 \times abc \qquad (6)$$

The value of a was determined by

$$a = \frac{h}{c_v T_2} + 1 \qquad (7)$$

The value of c was determined by

$$c = \frac{p_4 + \left(\frac{1}{2}\rho_4 V_o^2 \beta\right)}{2117} \qquad (8)$$

The value of ρ_o is calculated from

$$\rho_o = \rho_4 (bc)^{0.714}$$

$$= 0.00250\ b^{0.714}$$

When the proper values are substituted, equation (4) becomes:

$$I_{slug} = 53.0\left(\frac{P_o}{b^{0.714}}\right)^{\frac{1}{2}} Z \qquad (9)$$

where

$$P_o = 2520b + 25.2b^{0.714}h \qquad (10)$$

The net thrust work is

$$w_N = V_o I_{slug} - V_o^2$$

$$w_N = \left[53.0 \times 587\left(\frac{P_o}{b^{0.714}}\right)^{\frac{1}{2}} Z\right] - 587^2$$

Work of fluid in the engine driving the supercharger. - The work of the fluid in the engine driving the supercharger was computed by dividing the energy required for adiabatic compression by the adiabatic efficiency of the compressor and the cycle efficiency of the compressor driving engine:

$$w_h = \frac{\gamma}{\gamma-1} RT_1 \left(b^{0.286}-1\right)\frac{1}{(\eta_{ad})(\eta_{cycle})} \qquad (11)$$

The value of T_1 is equal to

$$T_1 = T_3\ (c)^{0.286} = 1.19\ T_3$$

and

$$w_h = 262{,}000\ \left(b^{0.286}-1\right) \qquad (12)$$

Maximum heat supplied in explosion. - It was assumed that the combustion in an explosion jet-propulsion engine would be similar to combustion in an internal-combustion engine using spark ignition and that the maximum heat added to a pound of mixture in the spark-ignition engine would likewise be the maximum added in a jet-propulsion engine. Indicator-card analysis in reference 6 showed that the maximum heat was delivered to the charge with a fuel-air ratio of 0.082. Analysis of the indicator card for this fuel-air ratio showed that 750 Btu were added per pound.

Final equation for efficiency of jet-propulsion engine. - From equation (1)

$$\eta = \frac{I_{slug} V_o - V_o^2}{32.2(778h + \text{supercharger work})}$$

Substituting the proper values from equations (9) and (12) gives:

$$\eta = \frac{966\left(P_o/b^{0.714}\right)^{\frac{1}{2}} Z - 10,700}{788h + 262,000\left(b^{0.286} - 1\right)} \qquad (13)$$

APPENDIX C

CALCULATIONS FOR CONSTANT-PRESSURE JET-PROPULSION ENGINE

The efficiency of the constant-pressure jet-propulsion engine is given by the equation

$$\eta = \frac{(w_o - w_t)\eta_p}{w_h} \qquad (14)$$

Total work available in adiabatic expansion. - The total work w_o available in adiabatic expansion is given by the usual equation for the work of an air motor:

$$w_o = \frac{\gamma_1}{\gamma_1 - 1} RT_4 \left[1 - \left(\frac{p_4}{p_3}\right)^{\frac{\gamma_1 - 1}{\gamma_1}}\right] \qquad (15)$$

Work abstracted by turbine. - The work abstracted by the turbine is given by the equation:

$$w_t = \frac{\gamma_2}{\gamma_2 - 1} RT_3 \left\{\left[\left(\frac{p_3}{p_2}\right)^{\frac{\gamma_2 - 1}{\gamma_2}} - 1\right] \frac{1}{\eta_c \eta_t}\right\} \qquad (16)$$

Propulsive efficiency. - The propulsive efficiency was computed by the use of equation (14) of reference 7, which is:

$$\eta_p = \frac{2}{1 + \sqrt{1 + \epsilon - K}}$$

Heat added during combustion. - The heat added during combustion was computed by the following equation:

$$h = 778\ c_p\ (T_o - T_2) \qquad (17)$$

The temperature T_2 is computed by adding to the ambient atmospheric temperature (assumed to be 560° F absolute) the adiabatic temperature rise to stagnation before the intake to the compressor and the temperature rise through the compressor.

REFERENCES

1. Smith, G. Geoffrey: Gas Turbines and Jet Propulsion for Aircraft. Aerosphere, Inc. (New York), 1944.

2. Gohlke: Thermal-Air Jet-Propulsion. Aircraft Engineering, vol. 14 , no. 156, Feb. 1942, pp 32-39.

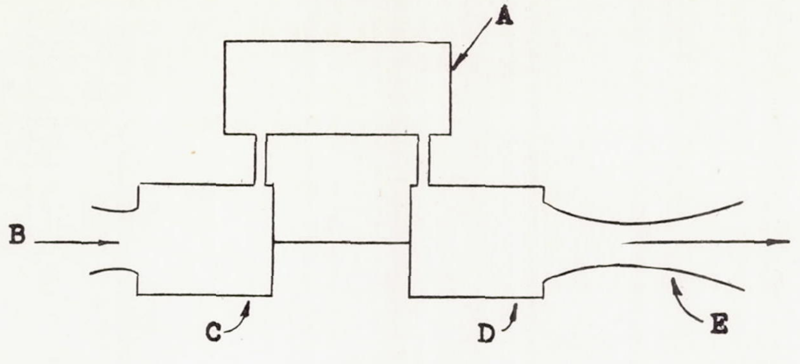
3. Suplee, H. H.: The Gas Turbine. J. B. Lippincott Co., 1910.

4. Rogowski, A. R., and Bouchard, C. L.: Scavenging a Piston-Ported Two-Stroke Cylinder. NACA TN No. 674, 1938.

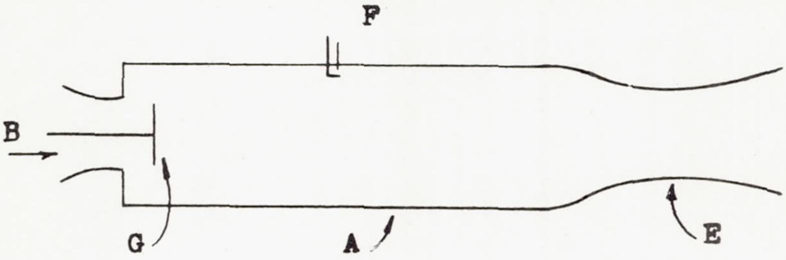
5. Erickson, Albert C.: Periodically Interrupted Flow through Air Passages. Jour. Aero. Sci., vol. 2, no. 3, May 1935, pp 118-122.

6. Gerrish, Harold C., and Voss, Fred: Analysis of Cylinder-Pressure-Indicator Diagrams Showing Effects of Mixture Strength and Spark Timing. NACA TN No. 772, 1940.

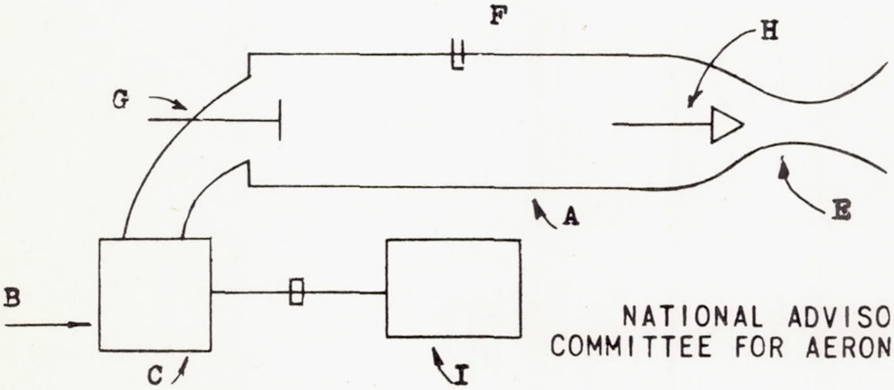
7. Williams, David T.: The Reaction Jet as a Means of Propulsion at High Speeds. NACA ACR, June 1941.



(a) A jet-propulsion engine using constant-pressure combustion.



(b) A simple explosion jet-propulsion engine.



NATIONAL ADVISORY
COMMITTEE FOR AERONAUTICS

(c) A supercharged explosion jet-propulsion engine.

A Combustion chamber
B Air intake
C Compressor
D Turbine
E Nozzle

F Spark plug
G Intake valve
H Exhaust valve
I Motor for driving supercharger

Figure 1. - Schematic diagrams of jet-propulsion engines using constant-pressure and constant-volume combustion.

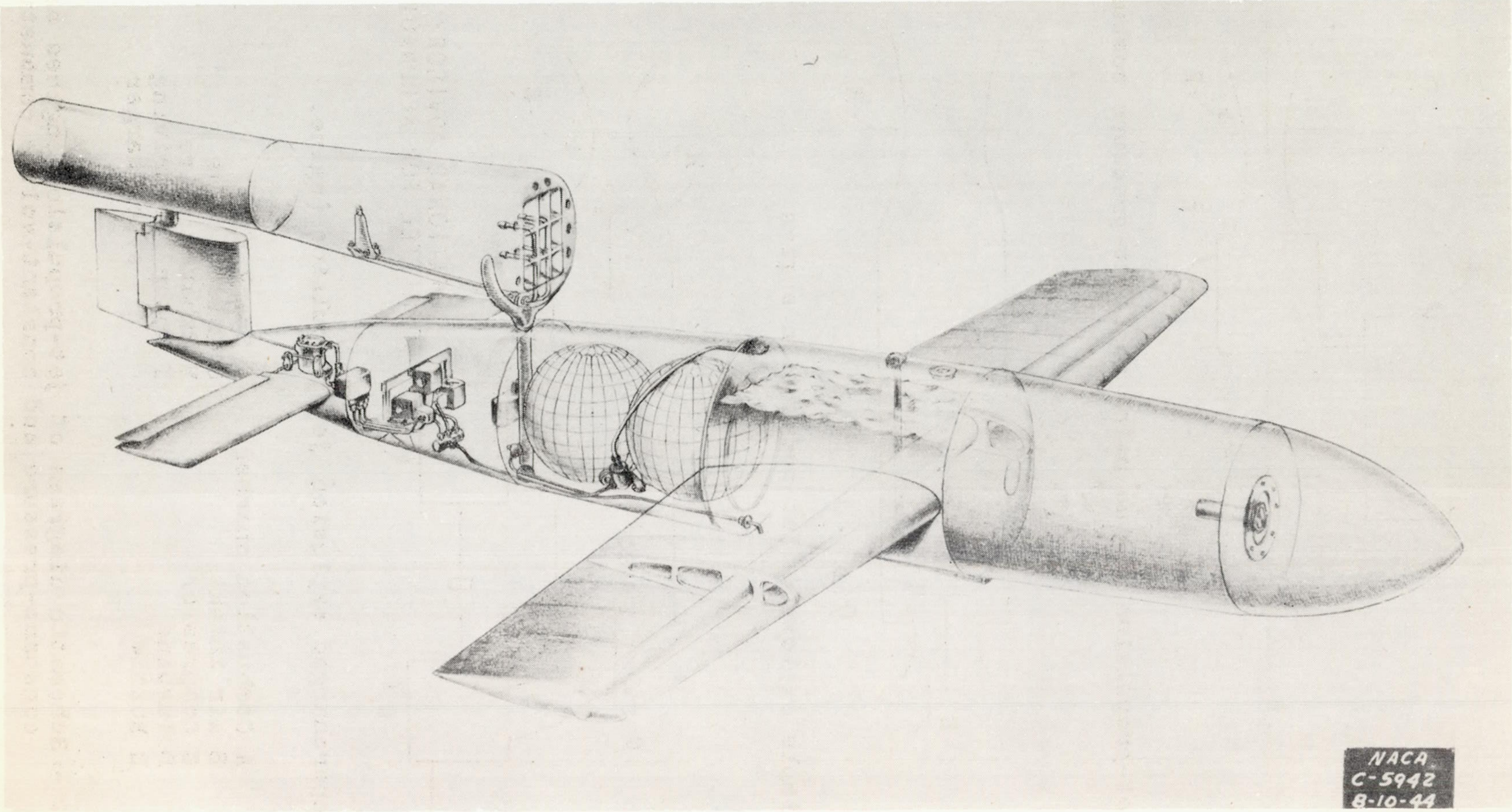


Figure 2. - Idealized drawing of German flying bomb propelled by a simple explosion jet-propulsion engine.

273

E-243

E243

273

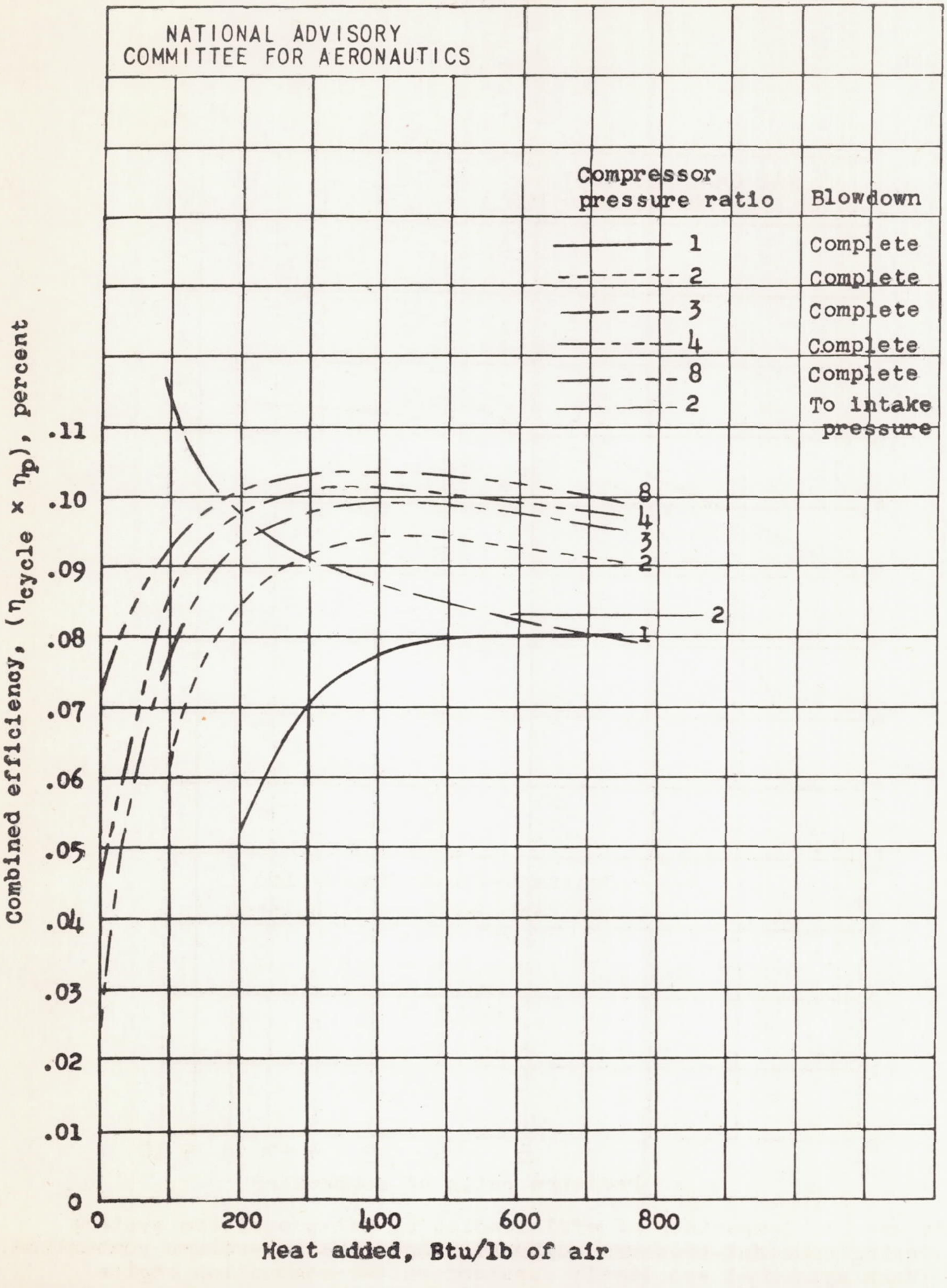


Figure 3.- Effect of heat input and pressure ratio of the compressor on the combined efficiency of an explosion jet-propulsion engine.

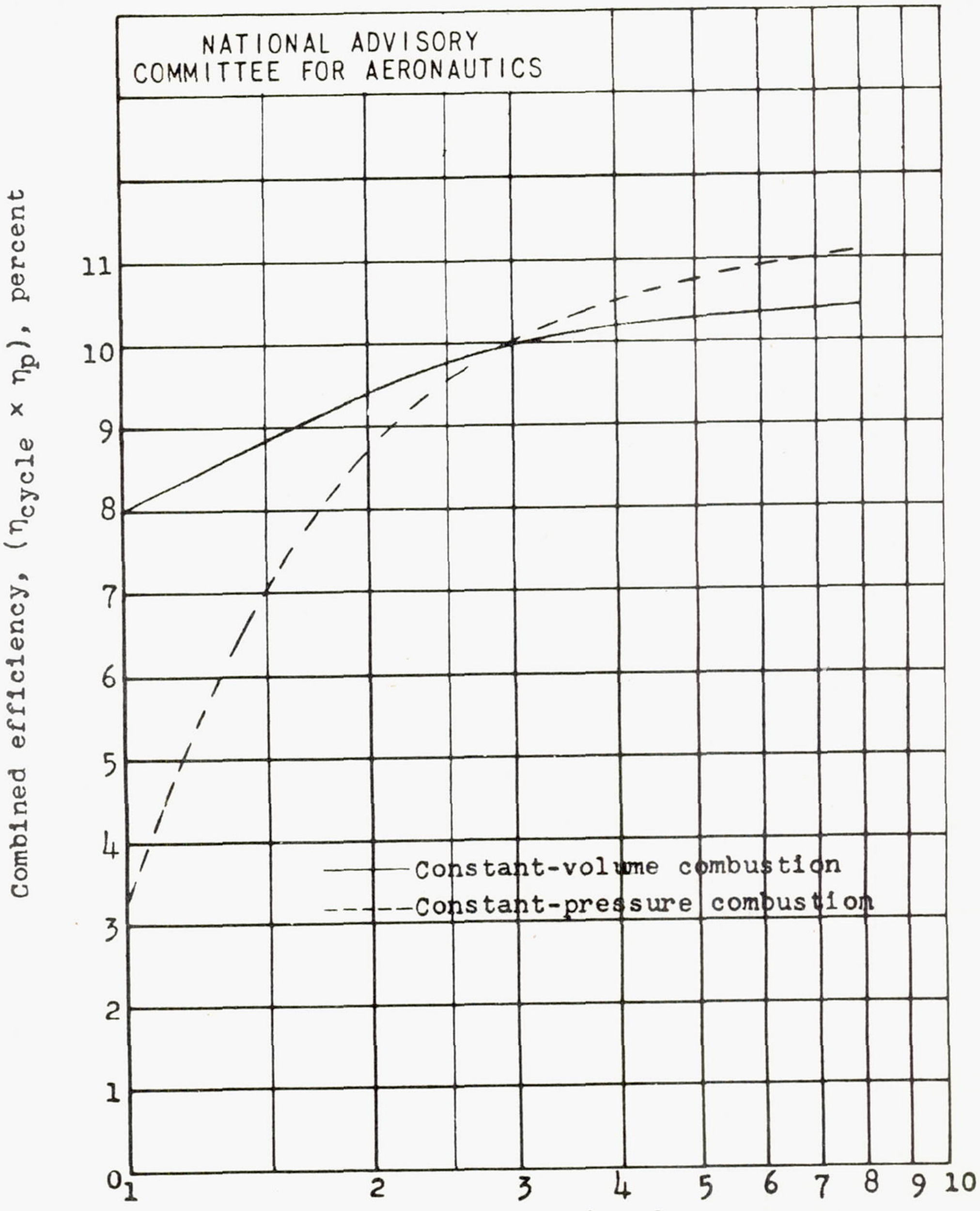


Figure 4.- Comparison of efficiencies of jet-propulsion systems using constant-pressure combustion and constant-volume combustion. Each system at sea level; constant-volume-combustion engine using heat input for maximum economy.

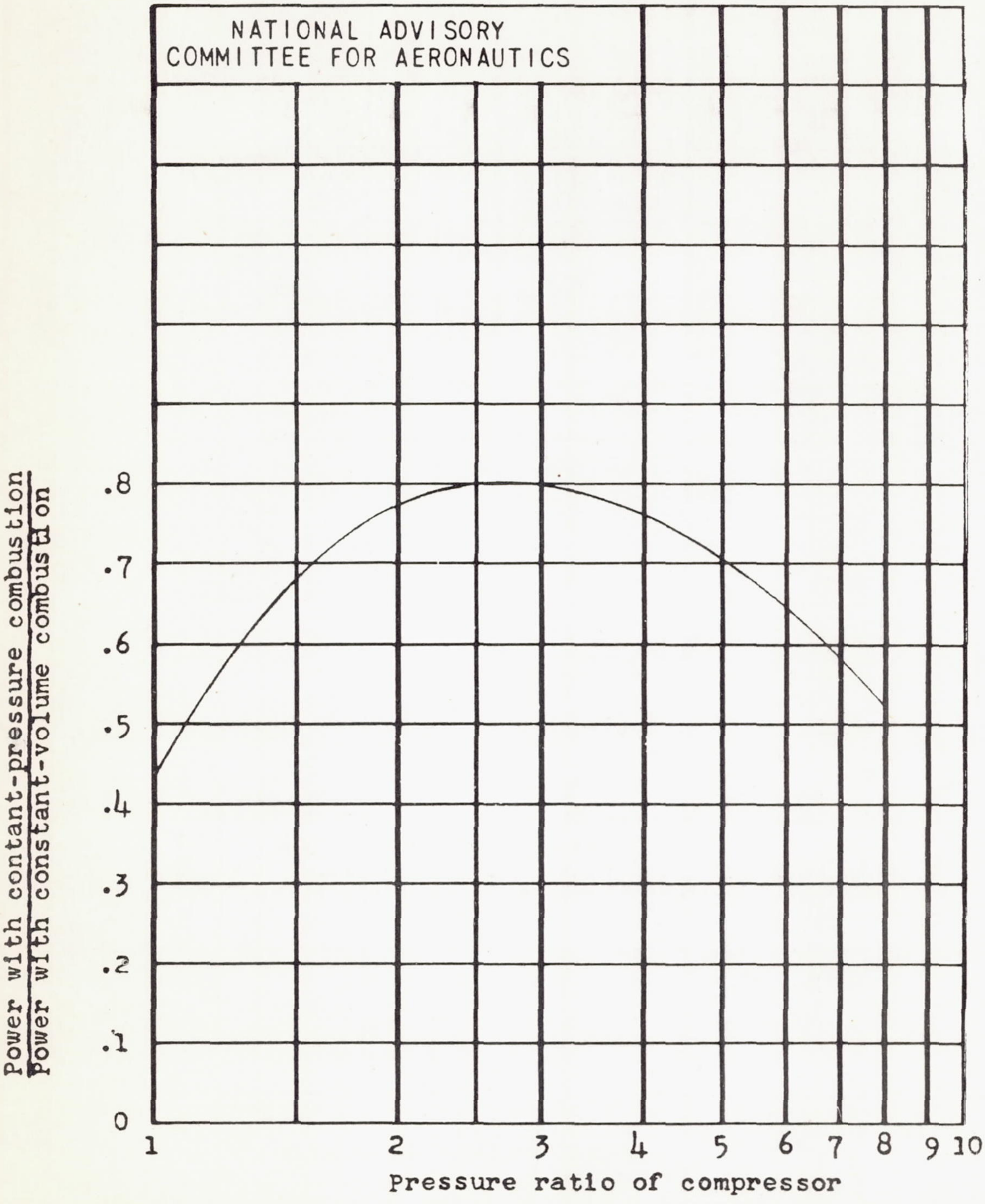


Figure 5.- Comparison of the thrust power obtainable from a given compressor in jet-propulsion cycles using constant-pressure and constant-volume combustion.

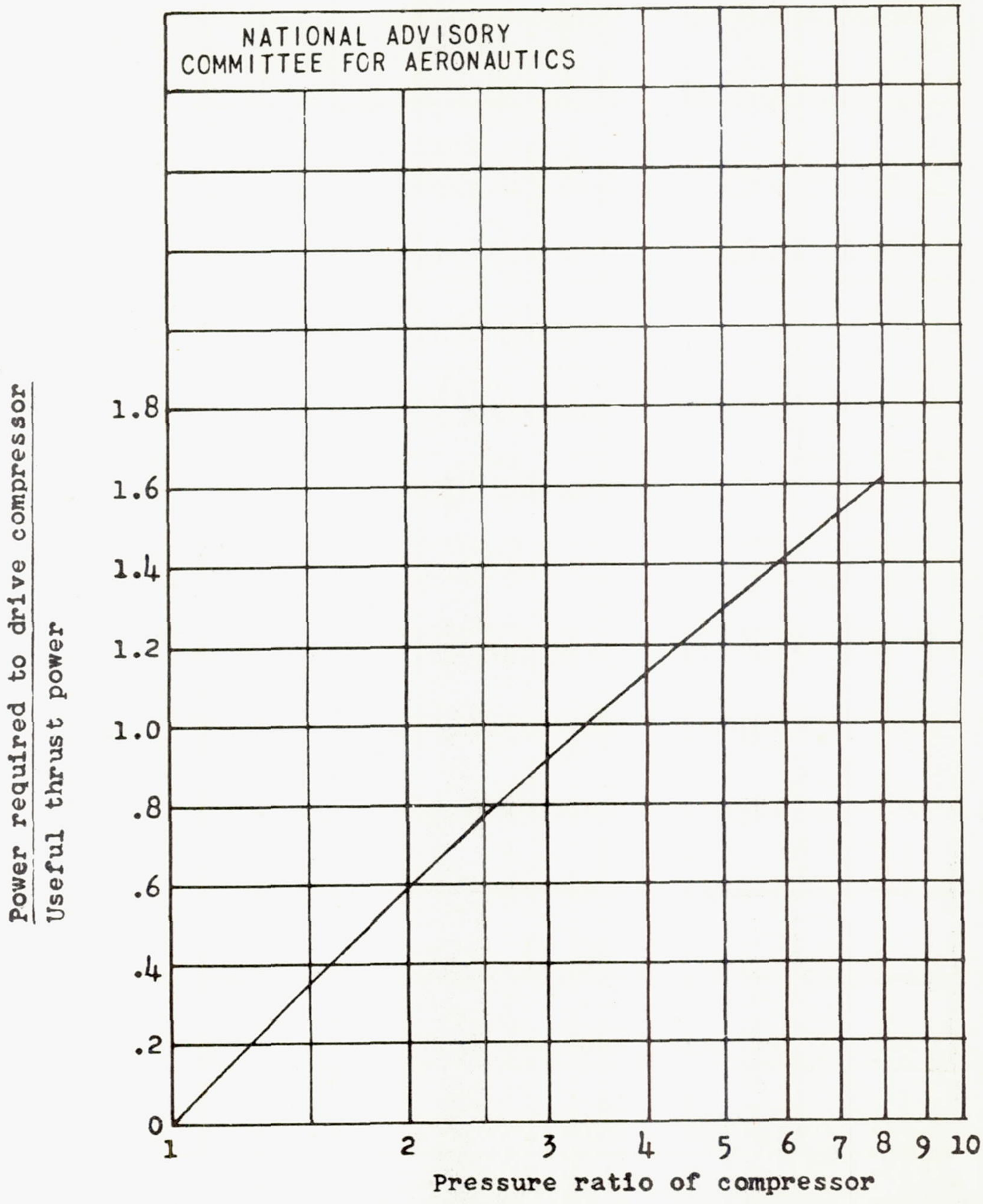


Figure 6.- Relation of useful thrust power of an explosion jet-propulsion engine to the power required to drive its compressor.

E 243

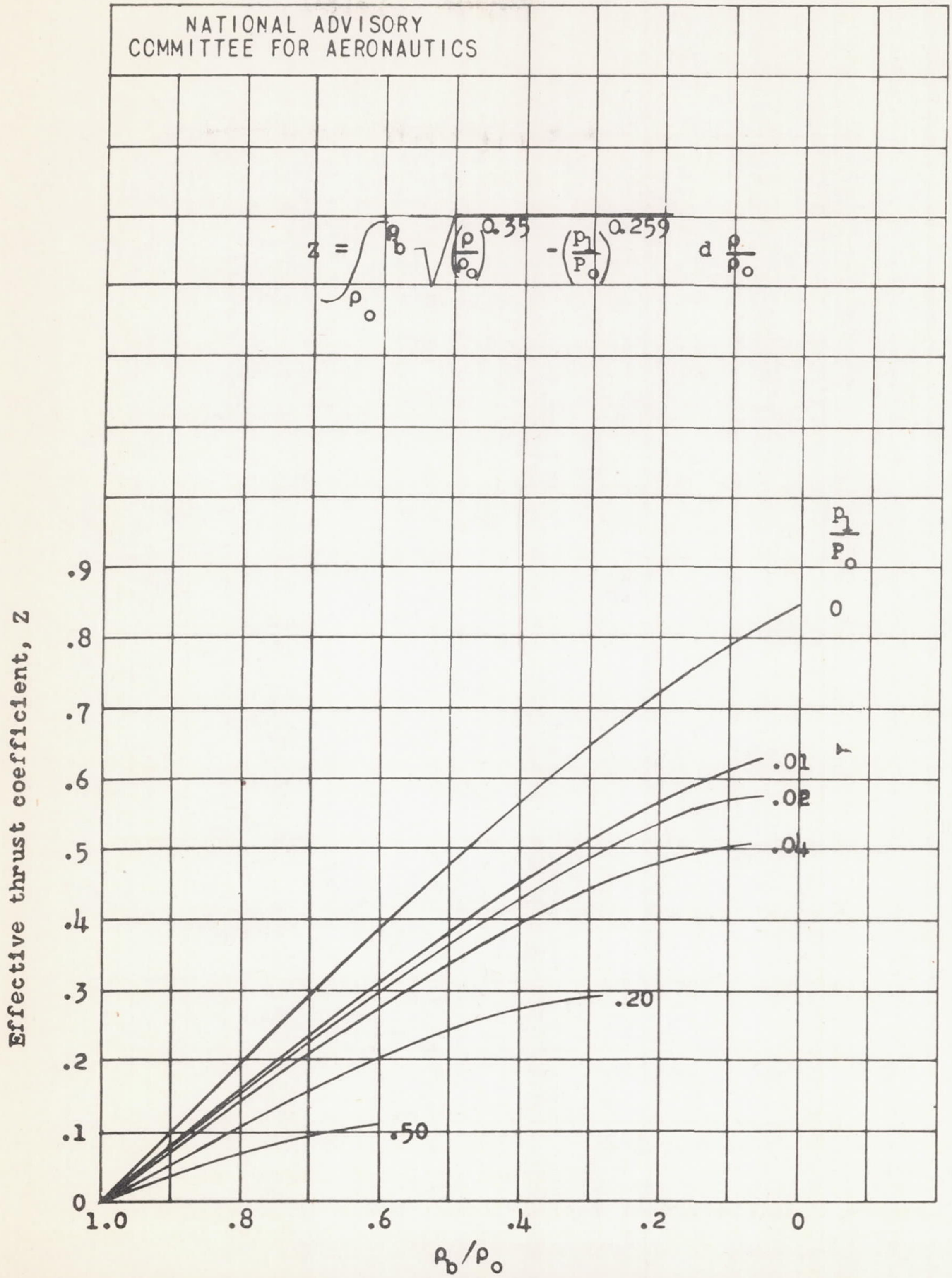


Figure 7.- Values of the effective thrust coefficient Z for a vessel periodically discharging from high pressure.

273

TSDIN FORM 60 B (13 MAR 47)

Cancel Classification

ATI- 20974

Sanders, J. C.

AUTHOR(S)

DIVISION: Power Plants, Jet and Turbine (5)
SECTION: Performance (16)
CROSS REFERENCES: Engines, Pulse jet - Performance data (34025)

ORIG. AGENCY NUMBER

REVISION

AMER. TITLE: A preliminary evaluation of the explosion jet-propulsion engine

FORG'N. TITLE:

ORIGINATING AGENCY: National Advisory Committee for Aeronautics, Washington, D. C.

TRANSLATION:

COUNTRY	LANGUAGE	FORG'N.CLASS	U. S.CLASS.	DATE	PAGES	ILLUS.	FEATURES
U.S.	Eng.		Confd'l	Aug'44	24		diagr, graphs, drwg

ABSTRACT

The theoretical performance of a pulse jet engine was computed to determine the effects of added heat and supercharging on performance. The pulse jet engine was more efficient than the constant pressure jet propulsion unit at compressor pressure ratios below 3.0 when maximum gas temperature of constant-pressure power plant is 1600°F. The combined efficiency (cycle times propulsive efficiency) of pulse jet engine is 8 to 10% as compared with 3 to 11% for a constant-pressure engine at a maximum gas temperature of 1600°F and an aircraft speed of 400 mph. Supercharging up to a pressure ratio of 4 increases efficiency of pulse jet engine.

dressed to: N.A.C.A., Washington, D.C.

WRIGHT FIELD, OHIO, USAAF

WF-O-21 MAR 47 15M

ATI No: 8-4-3837 C-22051

US Classification: Unclass.

OA No: MR-E-243

TITLE: A Preliminary Evaluation of the Explosion Jet-Propulsion [illegible]

AUTHOR(S): Sanders, J.

OA: National Advisory Committee for Aeronautics, Washington, D. C.

CANCELLATION

Foreign Title:

Previously cataloged under No:

Translation No:

Subject Division:

Section:

WF-O-24 JUN 48 100

MCI - Form 89B
Library Card

Classification cancelled

~~or changed to~~

AUTH: List No. 1 NACA Mar. 49

By Marion J Streib Capt USAF

Signature and Grade

Date APR 22 1949 P21/5

& Pulse Jet Engines
Combustion Stability