



CIRCULAR 1 — AN/1

AIRWORTHINESS

(AIR)

**THE EFFECT OF AIR TEMPERATURE UPON
THE RATE OF CLIMB OF AN AIRPLANE EQUIPPED
WITH A CONSTANT SPEED PROPELLER**

**INTERNATIONAL
CIVIL AVIATION
ORGANIZATION
MONTREAL • CANADA**

This Publication is issued in English, French and Spanish.

Published in Montreal, Canada, by the
International Civil Aviation Organization.
Correspondence concerning the publications
should be addressed to the Secretary General
of ICAO, Dominion Square Building,
Montreal, Canada.

Orders for ICAO publications should be sent, on payment:

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Price: 10 cents (Canadian) (Montreal)

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REFERENCES

- a. Wright Aeronautical Corporation "Engineering Notes"
- (Second Edition)
- b. Pratt and Whitney Specification No. 5854, Curve No. T-461
- c. NACA Technical Report No. 642
- d. Flight Engineering Report No. 10

F O R E W O R D

This is the first of a new series of ICAO publications. The ICAO Circulars will treat of many different subjects, but they will have the common purpose of distributing information bearing upon the progress of ICAO's work more widely than would be possible for the ordinary series of documents.

The present Circular is a republication of a national study on a matter that has already been the subject of one special ICAO meeting and that will have to be further discussed in future meetings - the effect of temperature upon the performance of aircraft and upon their allowable operating weights. Future circulars will compare and analyze national practices in the administration of the various phases of service to air navigation and its regulation. Others will report the degree of implementation by the nations of the world of ICAO's Standards and other recommendations resulting from ICAO meetings.

A great work has been initiated in the past three years through this Organization. The progress that has been made, and that will be made in coming months, is of interest far beyond the limits of the Governments' aeronautical services. The records of progress concern the whole aircraft-operating world; they deserve a wider distribution than they have had; and the series of ICAO Circulars, of which this is No. 1, are designed to make it possible for them to receive it.

Edward Warner

NOTE

The report reproduced in this Circular was first issued by the Civil Aeronautics Administration of the United States of America, as Flight Engineering Report No. 12, entitled "The effect of air temperature upon the rate of climb of an aeroplane equipped with a constant speed propeller". Consequent upon recommendations made by the Airworthiness Division, the report was submitted to ICAO for publication, has been translated by the Secretariat into French and Spanish and is being published as an ICAO Circular in English, French and Spanish.

INTRODUCTION

This report covers the derivation of equations by means of which to calculate the effect of air temperature upon the rate of climb, applies the equations to a typical airplane, and discusses the significance of the results of this application.

The derivation is based upon the fundamental equation for rate of climb; the generally accepted relationship between the brake horsepower output of an engine and the temperatures of the air involved in the carbureting, cooling and supercharging processes; and upon a rational treatment of the effect of outside air temperature upon propeller aerodynamic characteristics. No new experimental data are contained in this report.

The equations are believed useful for the purpose of calculating the effect of temperature upon a rate of climb determined by testing at a given temperature and require for their application the establishment of certain engine characteristics normally available in the standard engine power output and certain propeller characteristics.

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DERIVATIONGeneral

The rate of climb of an airplane in feet per minute may be expressed by means of the following equations:

$$C = \frac{33,000}{W} (THP_a - THP_r) \text{ - - - - - (1)}$$

where:

W = Airplane weight in pounds

THP_a = thrust horsepower available

THP_r = thrust horsepower required

Now: $THP_a = BHP\eta \text{ - - - - - (2)}$

where:

BHP = brake horsepower output of engine(s)

η = propulsive efficiency

and:

$$THP_r = \frac{fV^3}{1100} + \frac{2W^2}{550\pi\rho eb^2V} \text{ - - - - - (3)}$$

where:

ρ = Mass density of air in slugs/cu.ft.

f = Airplane parasite area in sq. ft.

V = Airplane airspeed (true) in ft./sec.

e = Airplane efficiency factor = $\frac{C_L^2}{\pi AR C_{D1}}$

b = Airplane wing span in feet

The above equations indicate that, in order to establish the effect of air temperature upon the rate of climb, it is necessary to consider the effect upon the terms involved in equations (2) and (3); viz: BHP, η , $\frac{fv^3}{1100}$, and $\frac{2W^2}{550\pi p \text{ eb}^2v}$; separately. This is done immediately hereunder.

Brake Horsepower = BHP

The experimental data available indicate there are at least two separate effects of air temperature upon the power output of an engine operating at a given manifold pressure, rpm, and mixture strength. One of these manifests itself in a reduction of power with increase in the temperature of the air entering the carburetor. The magnitude of the effect is ordinarily expressed by means of the following relation;

$$BHP = BHP_o \sqrt{\frac{T_o}{T}}_c$$

where;

T_o = the absolute temperature of the carburetor air under the conditions producing BHP_o (ie: it is the temperature in degrees Fahrenheit plus 459.4)

T = the absolute temperature of the carburetor air under the conditions producing BHP.

The second such effect is an observed reduction in power with increase in the temperature of the air entering the cooling process for an air cooled engine. Although not so well supported by the experimental evidence as in the case of carburetor air, the magnitude of this effect is ordinarily expressed:

$$BHP = BHP_o \sqrt{\frac{T_o}{T}}$$

where:

T_o and T = the absolute temperature of the cooling air but are otherwise as defined above.

The primary effect of temperature upon the brake horsepower is then:

$$BHP = BHP_o \sqrt{\frac{T_o}{T}}_c \sqrt{\frac{T_o}{T}}_r \text{ - - - - - (4)}$$

Propulsive Efficiency = η

If propulsive efficiency, η , be plotted as contours upon the standard power coefficient versus advance ratio chart (C_p vs. $\frac{V}{ND}$ @ β), the resulting diagram (see Fig. 1 for example, which has been prepared from the data of Ref. (C) will indicate, in the region representative of climbing conditions (ie: comparatively high values of C_p and low values of $\frac{V}{ND}$), that, at a constant value of $\frac{V}{ND}$, an increase of C_p is accompanied by a decrease in efficiency and also that at a constant value of C_p , an increase in $\frac{V}{ND}$ is accompanied by an increase in efficiency.

This situation may be summarized by the following equations:

$$\left. \begin{aligned} \frac{d\eta}{dC_p} \frac{V}{ND} &= \text{a constant} &= A \\ \frac{d\eta}{d\frac{V}{ND}} C_p &= \text{a constant} &= B \end{aligned} \right\} \text{----- (5)}$$

It can be shown that the values of A and B, so defined, remain reasonably constant over the ranges of C_p and $\frac{V}{ND}$ respectively resulting from any temperature change which must be dealt with and also the value of A is substantially independent of any value of $\frac{V}{ND}$ and that of B substantially independent of any value of C_p either of which must be considered, then the rate at which efficiency changes with both C_p and $\frac{V}{ND}$ is substantially:

$$d\eta = AdC_p + Bd\frac{V}{ND} \text{----- (6)}$$

In order to indicate the nature, magnitude and variation of the values of A and B with C_p and $\frac{V}{ND}$, Figures 2 and 3 have been prepared from the data of Figure 1. These data indicate the assumption of appropriate constant values of A and B to be a reasonably close approximation to the actual variation of η . (This is further discussed below.)