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# Altitude-Dependent Range and Endurance Estimation Using Breguet Theory

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**A B S T R A C T**

The range of an aircraft refers to the ground distance traveled along its flight path, while endurance represents the total time the aircraft remains airborne from takeoff to landing. A comprehensive understanding of these two parameters, along with the factors influencing them, is crucial for pilots during flight planning. Range and endurance are determined not only by pre-flight conditions such as takeoff weight and aerodynamic configuration but are also significantly influenced by in-flight variables including cruising altitude and wind speed.

This paper aims to investigate the effects of cruising altitude on both range and endurance, with a particular focus on the IAK-130 aircraft.

Keywords: Flight altitude, Aircraft Range, Flight endurance, Cruising Flight, Flight Speed.

## Introduction

Range and endurance depend on fuel consumption rates per hour, per kilometer, and the amount of fuel loaded. However, fuel consumption is influenced by multiple factors, primarily takeoff weight, fuel load, and cruising altitude. Therefore, the range and endurance of an aircraft are functions of takeoff weight, cruising altitude, and fuel load. This paper presents a method for calculating range and endurance, and analyzes the effect of cruising altitude on these parameters for the IAK-130 aircraft, assuming constant takeoff weight and fuel load.

### 2. Methodology

During each flight, the cruising phase accounts for the majority of both flight time and range. Therefore, to determine flight range and flight time, we focus on the cruising condition. In cruising flight, the forces acting on the aircraft are illustrated in the diagram below.

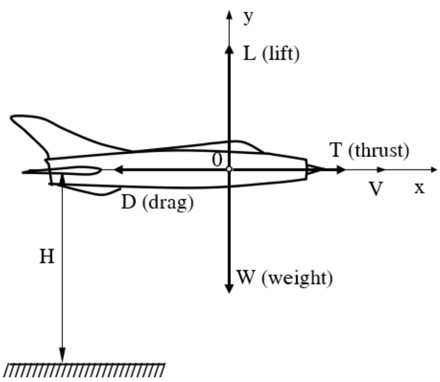


**Figure 1: Forces acting on the aircraft during cruising flight**

From the diagram, the Lift calculated using the formula:

L = W = mg

Lift Coefficient:

$$C_D = \frac{mg}{q \cdot S}$$

Where: q – Dynamic pressure , calculated as $q = 0{,}7 \cdot p \cdot M^2$

p – The air pressure at the current altitude;

The drag is calculated using the formula:

$D = C_D \frac{\rho V^2}{2} S$

Where: $C_D$ – Drag coefficient, calculated as $C_D = C_{D0} + A \cdot C_L^2$

$C_{D0}$ – The zero-lift drag coefficient, dependent on the shape of the aircraft.

A – coefficient representing the variation of the induced drag coefficient with respect to the lift coefficient of the aircraft.

Breguet Range Equation:

$R = \frac{V}{c_e} \times \frac{L}{D} \times \ln(\frac{W_i}{W_f})$ [km]

Breguet Endurance Equation:

$E = \frac{1}{c_e} \times \frac{L}{D} \times \ln(\frac{W_i}{W_f})$ [h]

Where: R – Range (km)

E – Endurance (h)

V- True airspeed (TAS) during cruise (km/h)

$C_e$ - Specific fuel consumption (kg/N·h)

$W_i$ – Initial aircraft weight at beginning of cruise (kG)

$W_f$ – Final aircraft weight at end of cruise (kG)

The specific fuel consumption is calculated using the following formula:

$$C_e(M, H, \overline{R}) = C_{e_0} \cdot \bar{C}_e \cdot \hat{C}_e(\overline{R}); \left[\frac{kg}{N \cdot h}\right]$$

Where: $C_{e_0}$- the specific fuel consumption at conditions V=0 and H=0;

$\bar{C}_e$- coefficient representing the influence of altitude and flight speed on specific fuel consumption;

$\hat{C}_e(\overline{R})$ - coefficient representing the influence of deceleration characteristics on specific fuel consumption.

Based on the theoretical framework for calculating flight range and flight time, the calculation sequence is developed as shown in Figure 2.

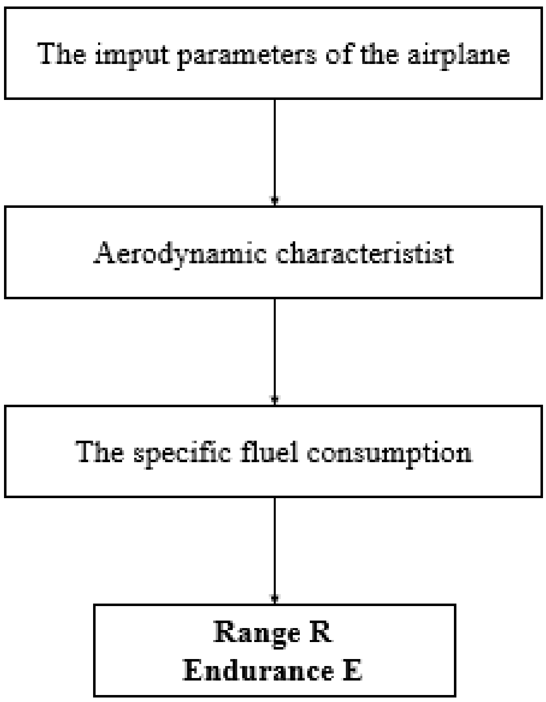


**Figure 2: Diagram of the calculation process for flight Range and Endurance**

## 3. Results and discussion

Each aircraft is characterised by specific aerodynamic parameters. For the IAK-130 aircraft, the key characteristics are as follows: a wing area of 23.5 m², engine thrust at maximum cruise mode of 3600 kg, specific fuel consumption of 0.063 kg/(N·h), and a fuel capacity of 1700 kg without external tanks or 2600 kg with external tanks.

To investigate the effect of altitude on the range and flight time of the aircraft at a constant mass, the author selected a cruising weight of 7530 kG. Based on the theoretical framework, the calculated results for range and flight time as a function of altitude at a weight of were computed using Excel. From these results, graphs illustrating the dependence of range and flight time on altitude were developed, as shown in Figures 3 and 4.

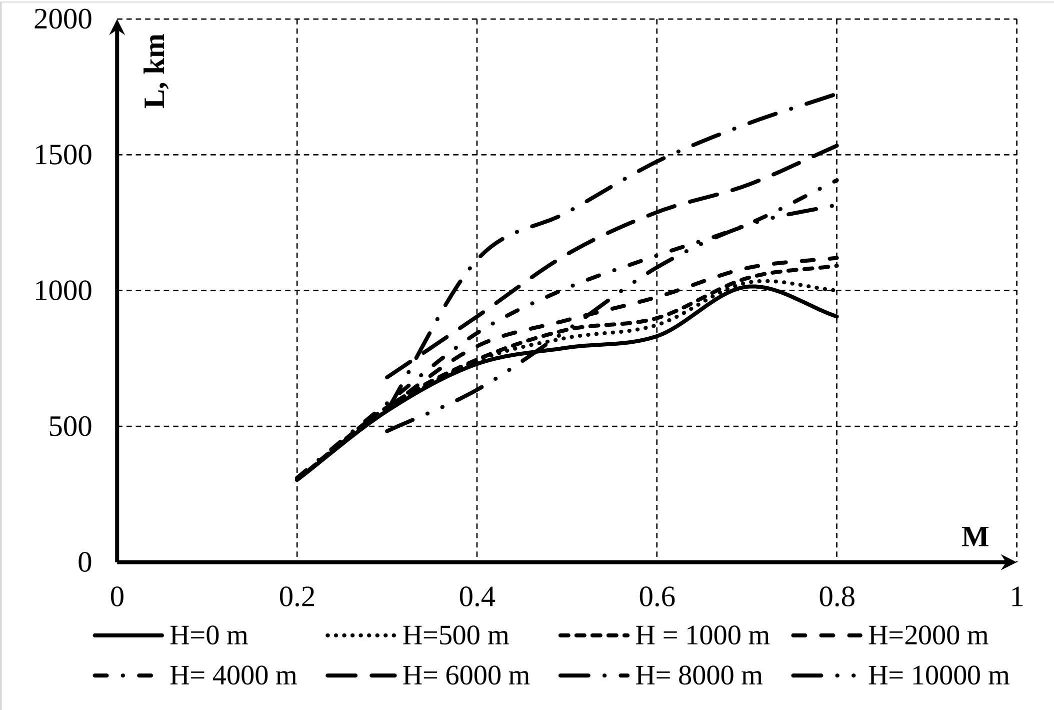


**Figure 3: Effect of altitude on the Range of the Aircraft**

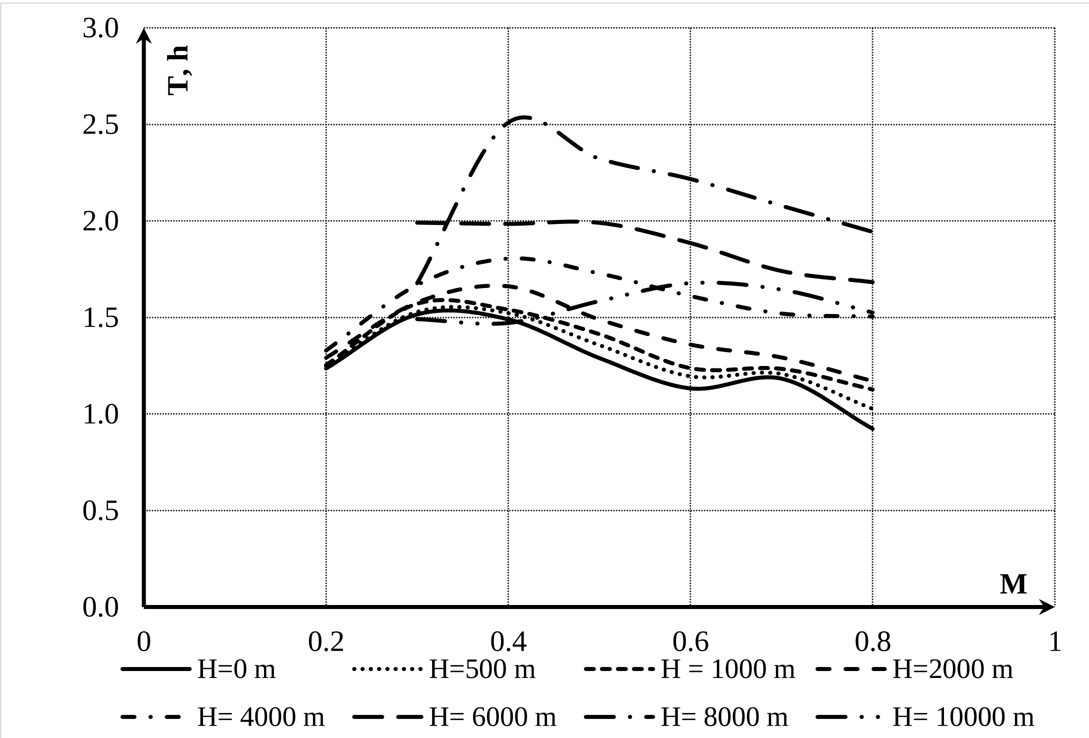


**Figure 4: Effect of altitude on the Flight Time of the Aircraft**

## CONCLUSION

Based on the calculation results and the graphs illustrating the effect of altitude on range and flight time, the following conclusions can be drawn:

- In the altitude range from 0 to 8000 meters, an increase in flight altitude corresponds to improvements in both range and flight duration. However, beyond 8000 meters, further increases in altitude result in reductions in these performance metrics;

- As flight speed increases, the aircraft’s range exhibits a positive correlation, while flight time initially increases before subsequently decreasing;

- When takeoff weight is increased due to the integration of external fuel tanks, and flight altitude is held constant, both range and flight duration are enhanced compared to configurations lacking external tanks.

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