

Assessment of Longitudinal Static Stability and Trim Characteristics of the Il-76 Aircraft Throughout a Wide Range of Altitudes and Speeds

Vinh Long Mai^{#1}, Van Quyen Dinh^{#2}, Tat Dat Dong^{#3}, Viet Tuan Luu^{#4}

[#] Faculty of Aircraft - Engines, Air Force Officer's College, Khanh Hoa, Viet Nam

¹maivinhlong1992@gmail.com

Abstract – The aerodynamic characteristics of the Il-76 heavy transporter are evaluated in this paper, with a notable emphasis on longitudinal stability and balance across diverse flight levels. Through comprehensive calculations of the Il-76's static margin and requisite trim angles, the study identifies the critical relationship between flight speed and control surface response. A significant part of the discussion concentrates on the Il-76's sensitivity to transonic flow effects, where air compressibility triggers a shift in the aircraft's focal point. In conclusion, the present work demonstrates that the stability of the Il-76 undergoes non-linear transitions at higher Mach numbers, a phenomenon dictated by the specialized geometry of its lifting surfaces.

Keywords: Il-76, flight dynamics, longitudinal static stability, aerodynamic center (focus) by angle of attack, trim diagram, elevator, Mach number.

I. INTRODUCTION

The operational safety of the Il-76 heavy transport aircraft depends fundamentally on its longitudinal stability and control effectiveness. Given its role as a high-capacity subsonic transporter operating in heterogeneous flight regimes, the Il-76 must exhibit strong self-restoring tendencies when encountering atmospheric perturbations. This paper evaluates the aircraft's static stability margins to ensure its center-of-gravity remains within certified limits. By computing the longitudinal flight parameters of the Il-76, this work provides a detailed analysis of its trim characteristics, specifically focusing on the relationship between elevator input and airspeed at different flight levels.

II. METHODOLOGY

This section describes the conceptual framework and the computational algorithm used to determine the flight characteristics of the Il-76 aircraft. The investigation is based on the methods of classical flight dynamics and the aerodynamics of subsonic aircraft.

Fundamental foundations for evaluating longitudinal static stability

The mathematical model of longitudinal static stability with respect to the angle of attack (normal load factor) is based on determining the relative positions of the center of mass and the aerodynamic center (focus) of the aircraft. The degree of stability ($m_z^{c_y}$) was calculated as the difference between the relative center-of-gravity position of the aircraft and its aerodynamic center:

$$m_z^{c_y} = \bar{x}_T - \bar{x}_F, \quad (1)$$

where:

$\bar{x}_T = x_T/b_A$ - is the relative distance from the aircraft's moment reference center to its center of mass (assumed to be 0.3);

$\bar{x}_F = x_F/b_A$ - is the relative position of the aircraft's aerodynamic center (focus) with respect to the angle of attack, which depends on the Mach number (M);

b_A - is the value of the aircraft's mean aerodynamic chord (MAC).

Algorithm for determining equilibrium characteristics

To determine the trim conditions for the aircraft in steady-state level flight at specified altitudes, the method of solving the moment equation relative to the transverse axis is employed. The required elevator deflection angle (φ_{bal}) (in radians) is calculated using the following approximate formula:

$$\varphi_{bal} = -\frac{1}{m_z^\varphi} (m_{z_0} + m_z^{c_y} \cdot c_{y_{\alpha LF}}), \quad (2)$$

where:

m_z^φ - derivative of the longitudinal moment coefficient with respect to the elevator deflection angle;

m_{z_0} - is the gradient of the longitudinal moment coefficient with respect to the elevator deflection angle;

$c_{y_{\alpha LF}}$ - lift coefficient required to maintain level flight at a specified altitude and speed.

The calculations were performed for altitudes of 3,000 m, 4,000 m, 6,000 m, and 8,000 m within a Mach number range from 0.4 to 0.85.

III. RESULTS AND DISCUSSION

Stability analysis

Based on the calculation results, a graphical dependence is plotted (Fig. 1).

Based on the outcomes, it was found that as the Mach number increases up to 0.75, the $m_z^{c_y}$ value varies from -0.286 to -0.245. This indicates that as the speed approaches $M = 0.75$, the aircraft aerodynamic center (focus) shifts toward the leading edge, which formally increases the stability margin within this range. However, with a further increase in speed ($M > 0.8$), a degradation in stability is observed due to the onset of shock-wave compression and flow separation, which is confirmed by a sharp change in the

value to -0.364 at $M = 0.85$.

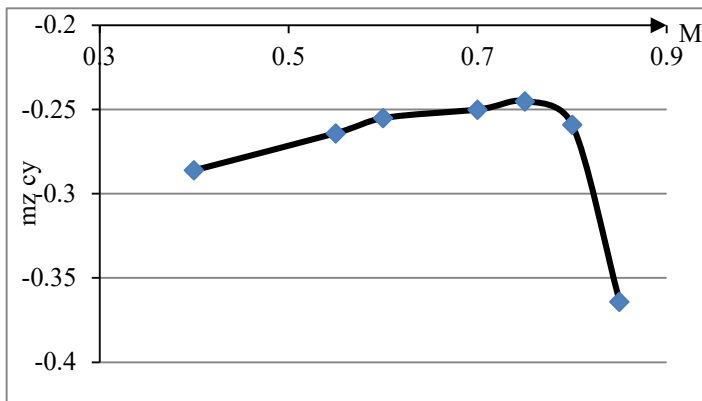


Fig. 1. Longitudinal static stability margin as a function of Mach number

Based on the calculation results, balancing diagrams are constructed (Fig. 2).

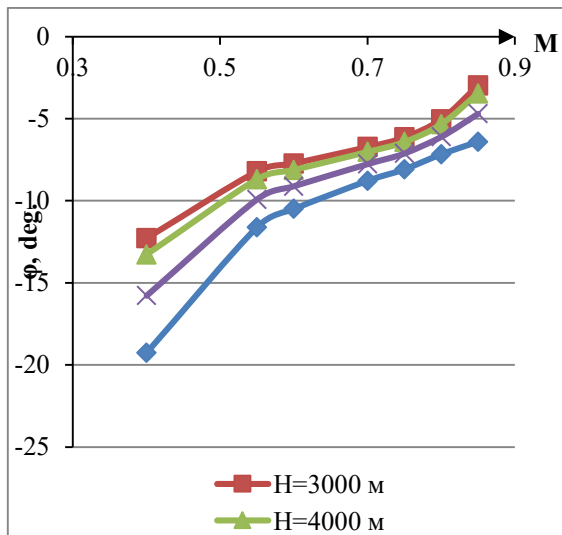


Fig. 2. Balancing diagrams (Elevator control curves in level flight)

Balancing characteristics

Analysis of the trim diagrams (Figure 2) reveals the following patterns:

1. Effect of speed: As the Mach number increases, the required upward elevator deflection angle (negative values) decreases in magnitude. For example, at an altitude of 3,000 m and $M = 0.4$, the deflection angle is -12.273° , whereas at $M = 0.85$, it decreases to -2.973° .

2. Effect of altitude: As flight altitude increases, air density drops, necessitating higher lift coefficients ($c_{y\alpha_{LF}}$) to support the aircraft's weight. This results in the need for more significant elevator deflections to maintain trim. At an altitude of 8,000 m and $M = 0.4$, the required deflection angle reaches -19.255° .

IV. CONCLUSION

This computational analysis provides a comprehensive evaluation of the Il-76 heavy transport aircraft's longitudinal stability and trim characteristics. The findings demonstrate

that the aircraft maintains a robust static stability margin across the investigated flight envelope, ensuring reliable self-restoration capabilities. Notably, the identified non-linear shifts in the aerodynamic center - specifically the forward migration up to $M = 0.75$ and the subsequent rearward shift at $M > 0.8$ - validate the significant impact of transonic flow and air compressibility on this specific airframe. Furthermore, the established trim diagrams quantify the critical relationship between altitude-dependent air density and required elevator authority. These results offer a precise technical framework for assessing the Il-76 maneuverability and can be instrumental in optimizing flight safety protocols under high-altitude, high-speed conditions.

REFERENCES

- [1] Zhukova A.Y., *Flight Dynamics of Transport Aircraft*. - Moscow: Transport, 1996.
- [2] Krivel S.M., *Calculation of Flight Performance and Aerobatic Characteristics of an Aircraft*. - Irkutsk: IVVAIU (VI), 2006.
- [3] Vereshchinov D.V., *The Il-76 Aircraft. Aerodynamics and Flight Dynamics*. - Irkutsk: IVAI, 2002.