LONGITUDINAL STABILITY OF A GLIDER IN RIGID TOW.

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INTRODUCTION

The problem of towing by means of a rope was treated analytically by many authors (Ref. 1, 2, 6, 7, and 9). In 1942, K. Petrikat and E. Pieruschka (Ref. 8) investigated the case of a winged container towed behind an aeroplane on a short stick. Eight years later, P. Mynarski, test pilot of the Glider Experimental Establishment in Bielsko (Poland), successfully started on the "Jezyk" glider with a short stiff tow behind the "CSS-13" plane.

In this paper, the analytical approach to the horizontal dynamic stability of a high performance glider towed behind an aeroplane is presented.

BASIC ASSUMPTIONS AND METHOD

An aeroplane and a towed glider are considered rigid bodies, and a tow--as the stiff weightless stick, with ball joints at both ends.

The following degrees of freedom of the system are taken into account in Fig. 1: pitching angles of the aeroplane and the glider, angle between the towing stick and vector of velocity, and horizontal as well as vertical displacements of the aeroplane. Five ordinary, second-order differential equations (Lagrange's) with constant coefficients are derived.

Eigen-values and eigen-vectors of the tenth order nonsymmetric matrix are found. On the base of the components of eigen-vectors, as well as coefficients of damping ξ and frequencies of oscillations η, the influence of constructional and piloting properties on the stability of the system is analyzed.

RESULTS OF CALCULATIONS AND CONCLUSIONS

The results of calculations are presented in Figs. 2 thru 9. The coefficients of damping ξ and frequencies of oscillations η are plotted against the velocity of towing V, angle β describing the position of the glider relative to the plane, length of the towing stick l_o, and distance k_{z1} between the towing hook of the glider and the center of gravity of the glider (Fig. 1).

The following modes of the motion of the system are found:

$\lambda_{1,2} = \xi_{1,2} \pm i\,\eta_{1,2}$ -weakly damped phugoid vertical displacements of the glider,

$\lambda_3 = \xi_3$; $\lambda_4 = \xi_4$

$\lambda_{3,4} = \xi_{3,4} \pm i\,\eta_{3,4}$ -heavily damped, pitching, aperiodic, or oscillating (with high frequency) motions of the glider,

$\lambda_5 = \xi_5$ -nondamped aperiodic pitching motions of the glider and the plane,

$\lambda_6 = \xi_6$ -damped aperiodic horizontal displacements of the glider and the plane,

$\lambda_{7,8} = \xi_{7,8} \pm i\,\eta_{7,8}$ -nondamped coupled pitching oscillations with high frequency of the whole system: the glider and the towing plane.

In Figs. 5, 6, and 7, the thick lines are related to the whole system: the glider and the towing plane, and the thin lines are related to the single plane in equivalent free flight.

In Figs. 2, 3, and 4, the influence of velocity of towing on the damping and frequencies of oscillations are presented for three positions of the glider relative to the towing plane:

lower $\left[\text{Fig. 2:}\ \beta_0 = 30^\circ\right]$,

normal $\left[\text{Fig. 3:}\ \beta_0 = 0^\circ\right]$, and

upper $\left[\text{Fig. 4:}\ \beta_0 = +30^\circ\right]$.

Increment of the velocity decreases the divergence of the coupled oscillations of the system $\xi_{7,8}$ (Figs. 2 and 3) and instability of the phugoid oscillations $\xi_{1,2}$ for the upper position (Fig. 4).

Stiff tow has a minor effect on the phugoid ($\xi_{1,2}$; $\eta_{1,2}$) and high frequency ($\xi_{3,4}$; $\eta_{3,4}$) oscillations, which are typical for the glider in free flight (Fig. 5).

For the whole range of velocities, the best results are obtained for the lower position of the glider relative to the plane. In the upper position, the instability of phugoid oscillations $\xi_{1,2}$ (Figs. 2 and 3) and small stabilizing effects on coupled oscillations $\xi_{7,8}$ are observed.

The length l_o of a stiff tow has a minor effect on stability at β_0 = const (Fig. 8).

The location k_{z1} of the towing hook at the front of the glider has a strong stabilizing effect on the aperiodic pitching motions ξ_5 and little destabilizing effect on the phugoid oscillations $\xi_{1,2}$ (Fig. 9). This result was easily predictable.

CONCLUSIONS

The results of the analysis performed for the particular glider and towing aeroplane show that towing is an unstable state of flight. This conclusion coincides with the earlier studies of stability of towed systems, as well as with the results of test flights.

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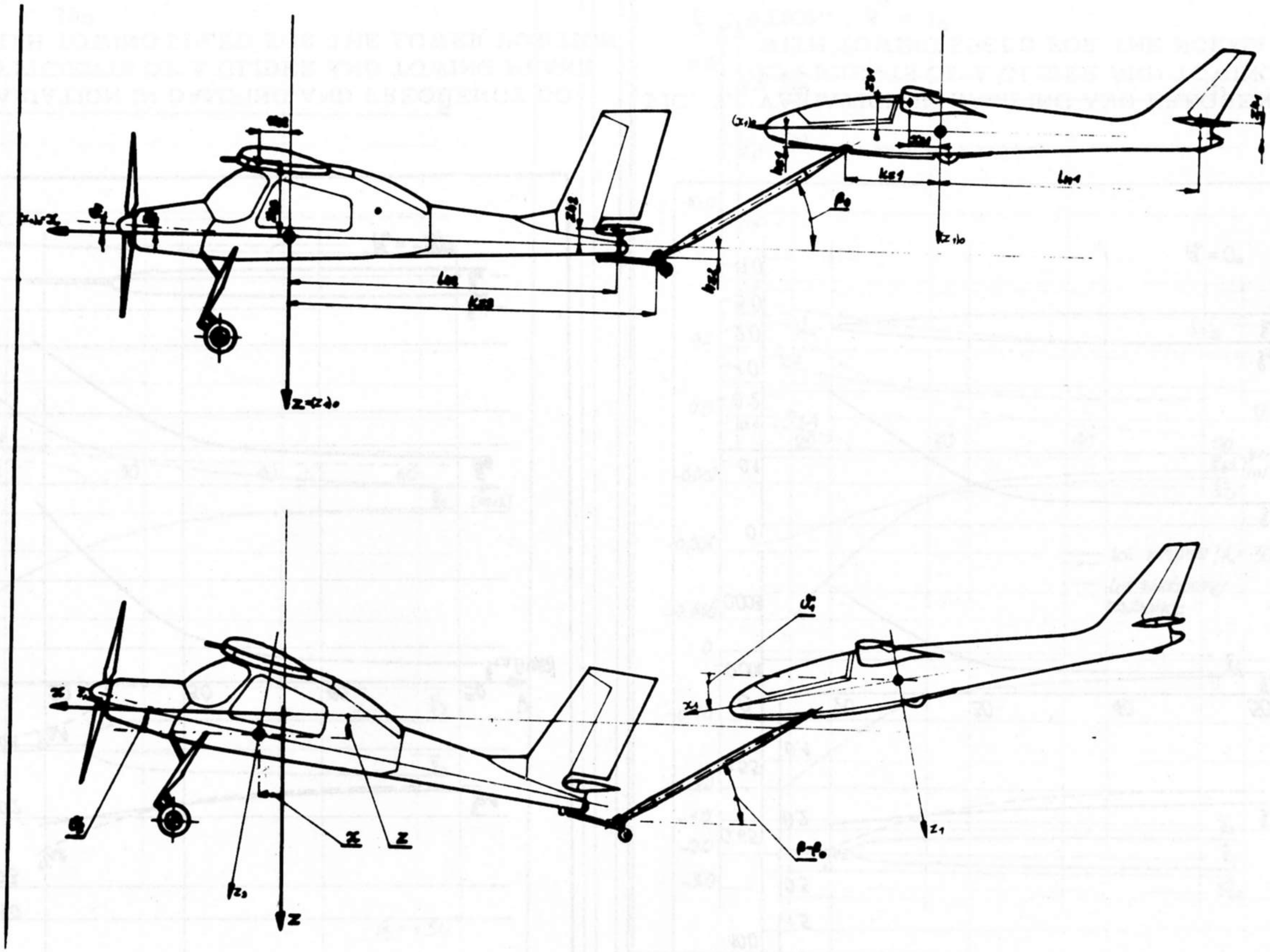

FIG. 1. VARIATION IN GLIDER POSITION CAUSED BY PERTURBATION RELATIVE TO STRAIGHT HORIZONTAL STEADY FLIGHT; INTERRELATIONS IN CO-ORDINATE SYSTEMS ADOPTED

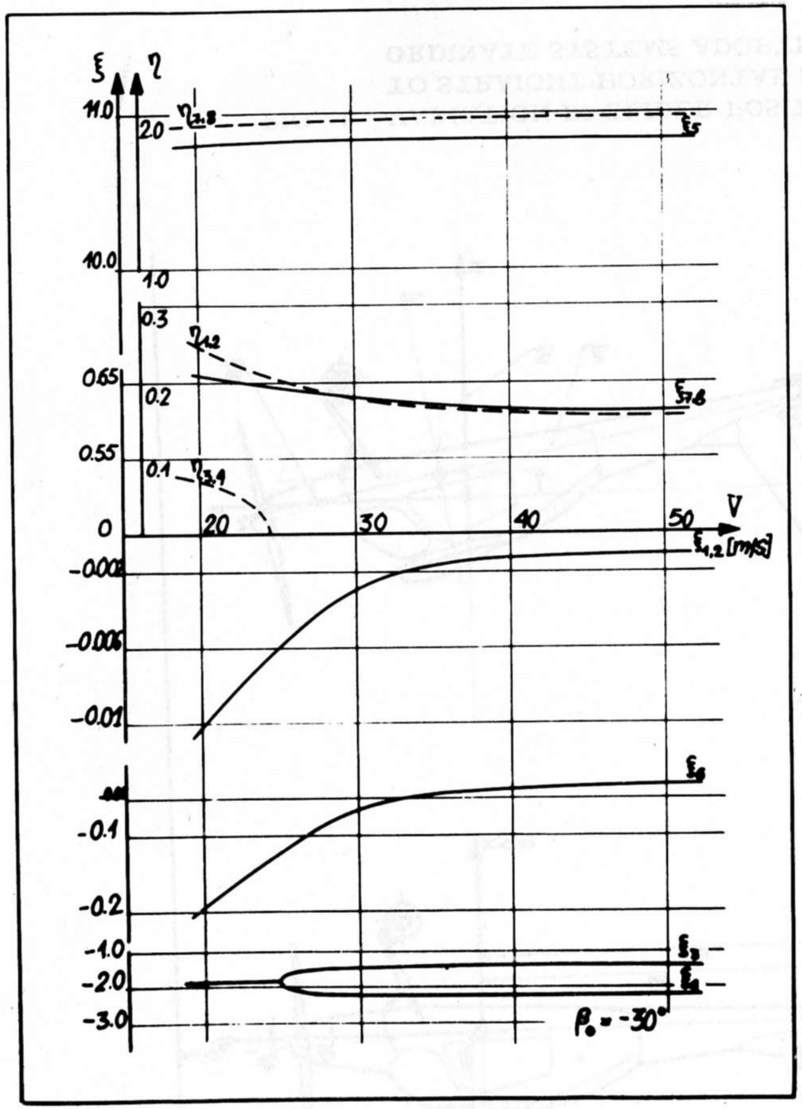

FIG. 2. VARIATION IN DAMPING AND FREQUENCY COEFFICIENTS OF A GLIDER AND TOWING PLANE WITH TOWING SPEED FOR THE LOWER POSITION $\beta_o = -30^o$

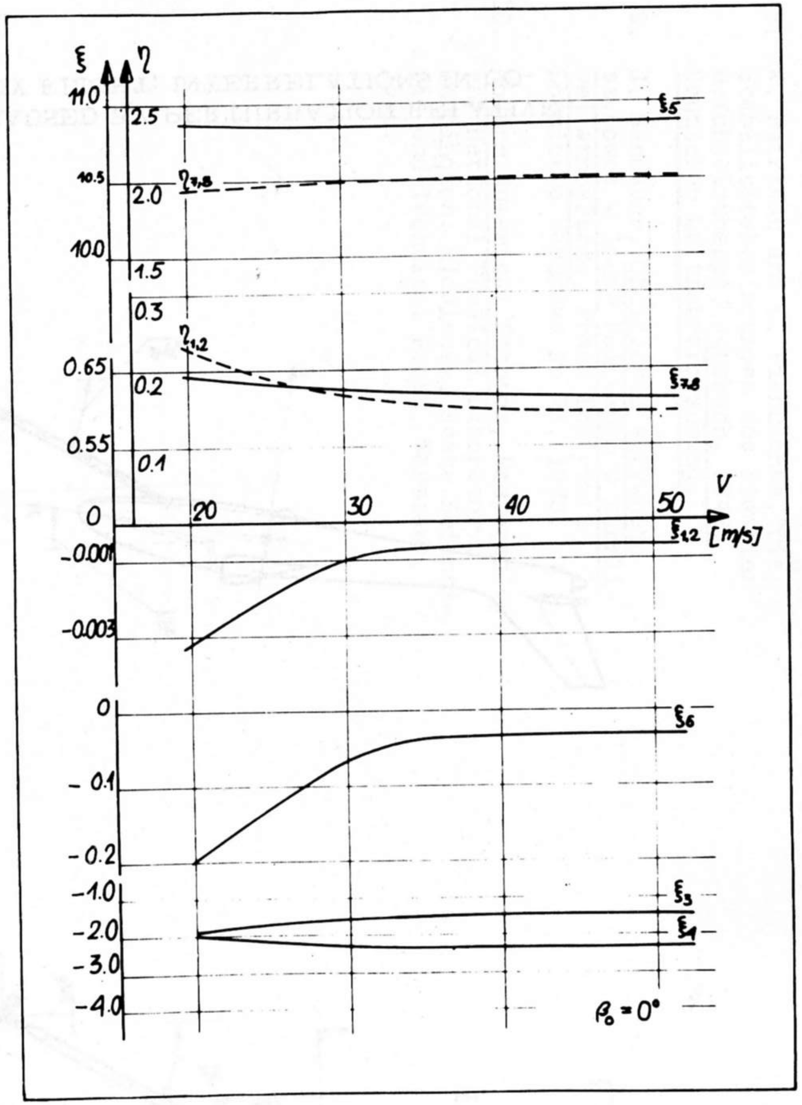

FIG. 3. VARIATION IN DAMPING AND FREQUENCY COEFFICIENTS OF A GLIDER AND TOWING PLANE WITH TOWING SPEED FOR THE NORMAL POSITION. $\beta_o = 0^o$

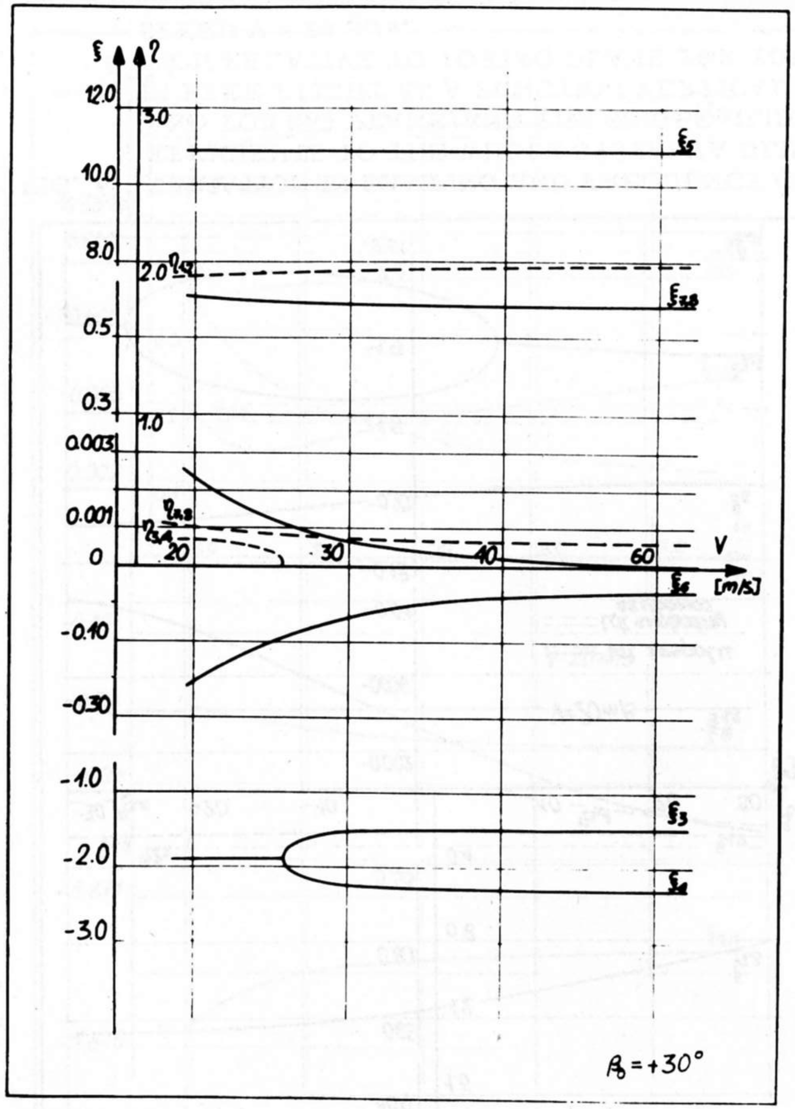

FIG. 4. VARIATION IN DAMPING AND FREQUENCY CO-EFFICIENTS OF A GLIDER AND TOWING PLANE WITH TOWING SPEED FOR THE UPPER POSITION $\beta_o = +30°$

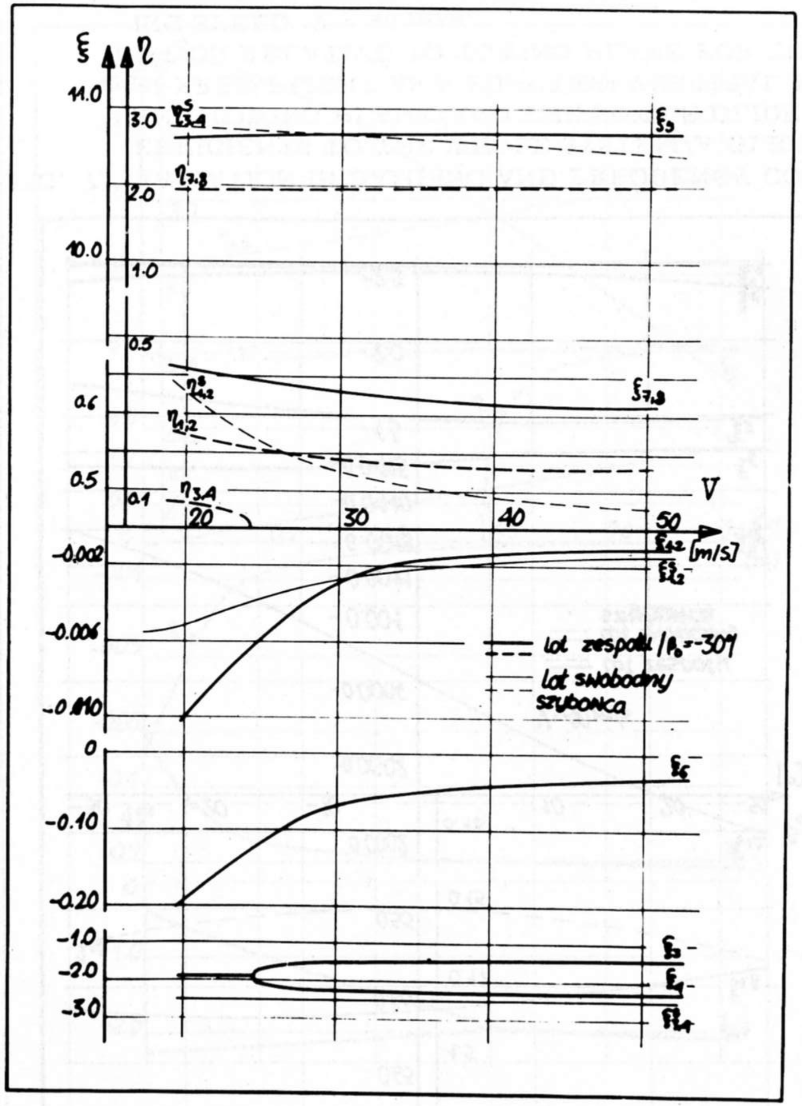

FIG. 5. VARIATION IN DAMPING AND FREQUENCY CO-EFFICIENTS TO THE WHOLE SYSTEM/A GLIDER AND TOWING PLANE/ AND THE SINGLE GLIDER IN FREE FLIGHT WITH TOWING SPEED FOR THE LOWER POSITION. $\beta_o = -30°$

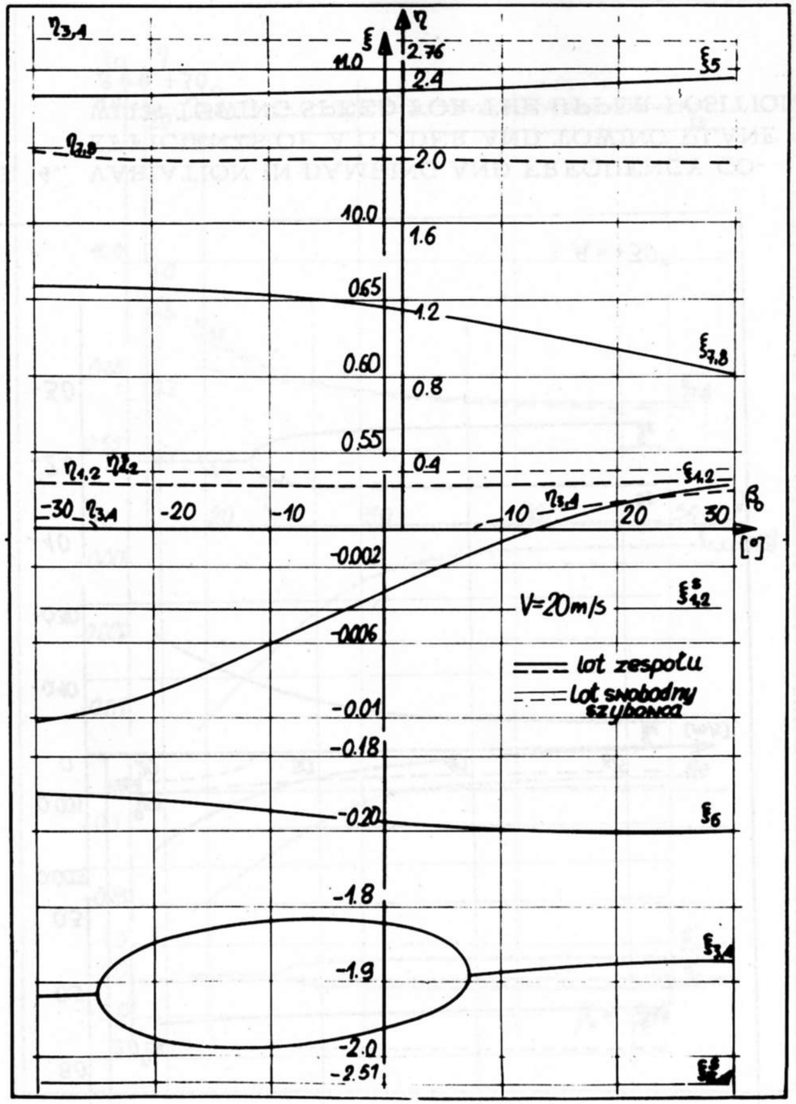

FIG. 6. VARIATION IN DAMPING AND FREQUENCY COEFFICIENTS TO THE WHOLE SYSTEM/A GLIDER AND TOWING PLANE/AND THE SINGLE GLIDER IN FREE FLIGHT AS A FUNCTION VERTICAL POSITION RELATIVE TO TOWING PLANE FOR TOWING SPEED V = 20 m/s.

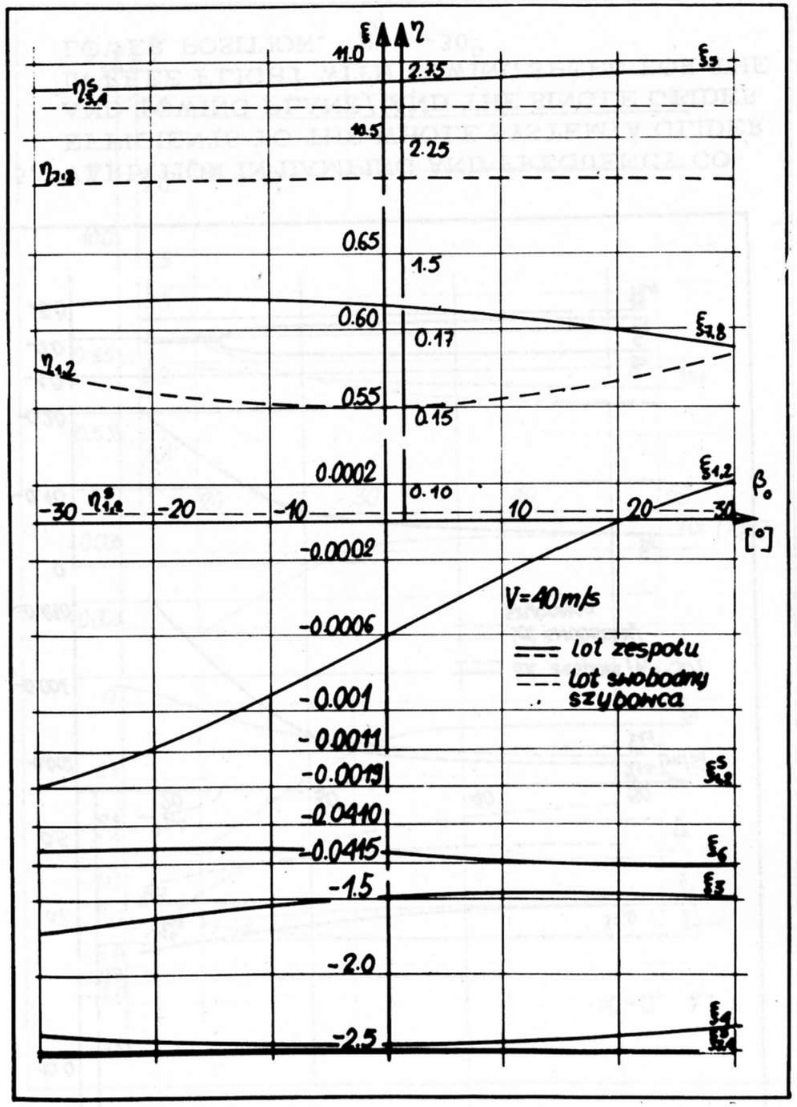

FIG. 7. VARIATION IN DAMPING AND FREQUENCY COEFFICIENTS TO THE WHOLE SYSTEM/A GLIDER AND TOWING PLANE/AND THE SINGLE GLIDER IN FREE FLIGHT AS A FUNCTION VERTICAL POSITION RELATIVE TO TOWING PLANE FOR TOWING SPEED V = 40 m/s.

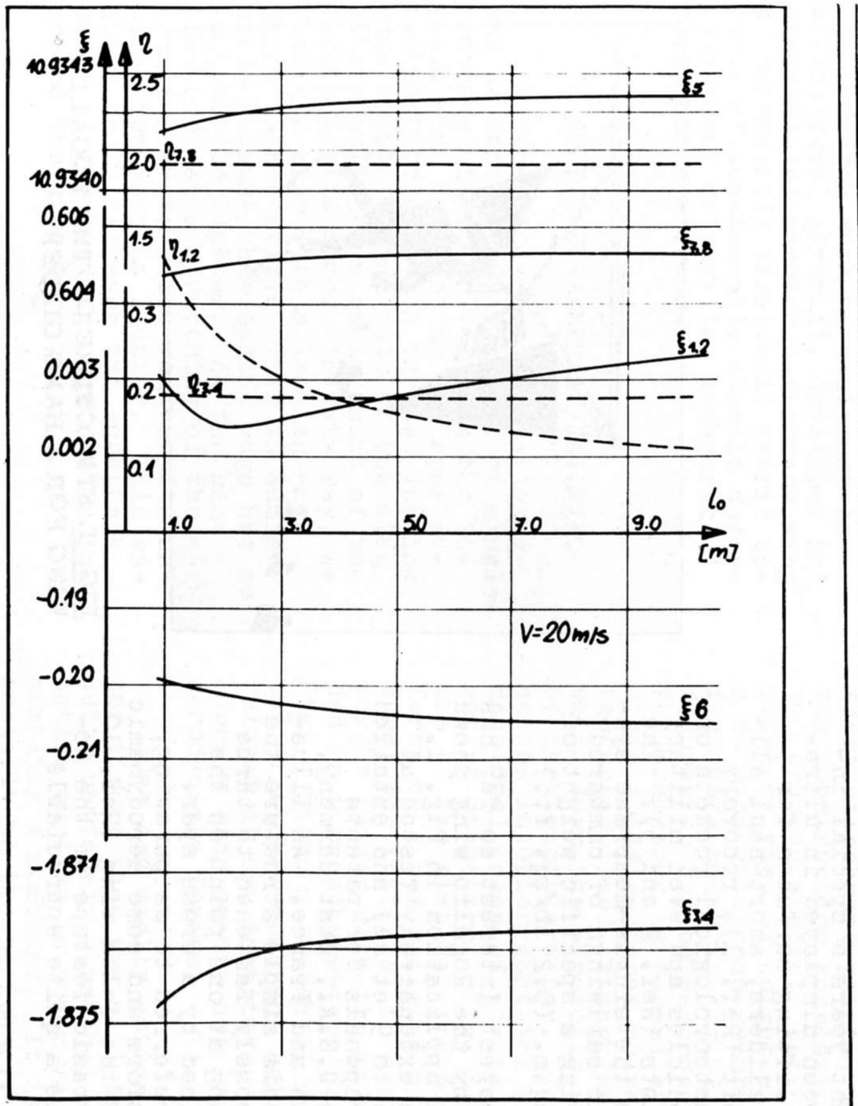

FIG. 8. VARIATION IN DAMPING AND FREQUENCY COEFFICIENTS OF A GLIDER AND TOWING PLANE WITH LENGTH OF A STIFF TOW FOR THE LOWER POSITION $\beta_o = -30^o$ AND TOWING SPEED V = 2- m/s.

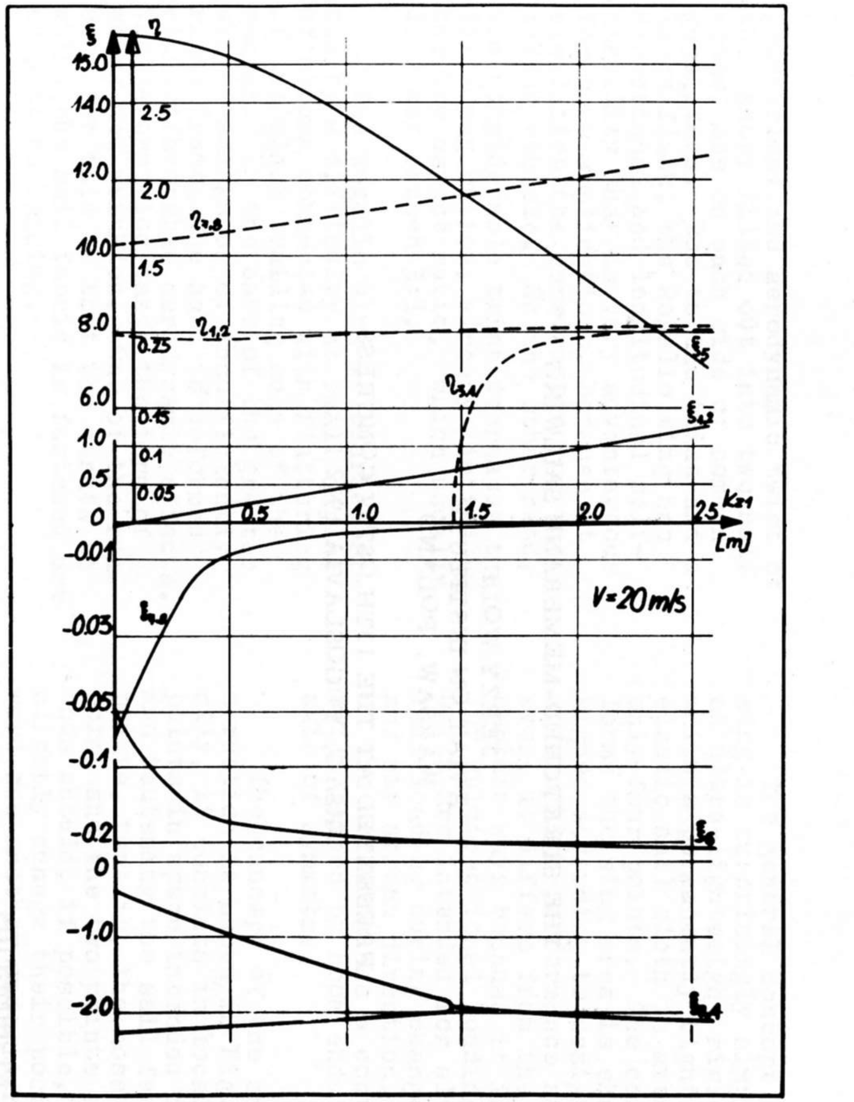

FIG. 9. VARIATION IN DAMPING AND FREQUENCY COEFFICIENTS OF A GLIDER AND TOWING PLANE AS A FUNCTION HORIZONTAL DISTANCE OF TOWING HOOK RELATIVE TO CENTER OF GRAVITY OF GLIDER FOR THE LOWER POSITION $\beta_o = -30^o$ and TOWING SPEED V = 20 m/s.