PROPELLER - AIRFRAME AERODYNAMIC INTERFERENCE ON TWIN ENGINE AIRCRAFT

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Abstract

Rational integration of the propulsion system–airframe allows quite obviously improve the full economizing of propeller aircraft and to arise safety of the take-off and landing modes. The article presents the series of experimental results, got during the low-speed wind tunnel testing of some typical configurations of twin engine aircraft. It's shown here quite substantial airframe influence on effectiveness and normal force of air propellers and also influence of propellers streams on lift, drag and longitudinal static stability. On the basis of got data indexes of aerodynamic perfection for examined configurations of twin engine aircraft have been determined. The most potential flight range may be realized with the traditional configuration with engines on the wing and pulling propellers. The best take-off and landing performances are achieved while engines were installed on pylons at the tail of the fuselage.

Nomenclature

V_∞, q_∞ - undisturbed air speed and dynamic pressure;
C_L - lift coefficient;
C_D - drag coefficient;
C_m - pitching moment coefficient;
T - thrust (axial component);
T_y - propeller normal force;
P - power;
ρ - air density;
n_s - propeller angular velocity, rev/s;
α - angle of attack, deg;
η - propeller efficiency;
λ - advance ratio ($\lambda = \dfrac{V_\infty}{n_s D}$);
B - relative thrust of propeller ($B = \dfrac{4T}{\pi D^2 q_\infty}$);
α_x - thrust coefficient ($\alpha_x = \dfrac{T}{\rho n_s^2 D^4}$);
β_x - power coefficient ($\beta_x = \dfrac{P}{\rho n_s^3 D^5}$);
α_y - normal force coefficient ($\alpha_y = \dfrac{T_y}{\rho n_s^2 D^4}$);
α_y^α - normal force coefficient due to angle of attack, deg^{-1};
$\bar{X}_F$ - dimensionless aerodynamic focus position relative mean aerodynamic chord nose;
$\bar{X}_{c.g.}$ - dimensionless center of gravity position relative mean aerodynamic chord nose;
δ_f - flap deflection angle, deg;
HS-F - Horizontal Stabilizer position – on the Fuselage;
HS-T - Horizontal Stabilizer position – T – tail unit (above the fin).

Introduction

Nowadays all over the world it's developed and serviced the great amount of twin engine aircrafts, using different versions of power plant position.

The most widespread version at the present time is one with engines on the wing and pulling propellers. Sometimes engines with pushing propellers are installed on pylons in the tail of the fuselage. Aircrafts with engines on the wing and pushing propellers are also known. The variety of power plant different positioning on twin engine aircraft is connected with the variety of tasks which are carried out by these mentioned aircrafts and also with absence of correct assessments for effectiveness of used variants. How should we choose engine's position to intensify merits and to weaken lacks of aircraft configuration or in other words speaking to provide positive aerodynamic interference?

Researches of this problem have been held for many years. However, the effectiveness of different engine's positions for twin engine aircraft hasn't been still assessed. The closest with this work’s goal investigation are the Williams, Johnson and Yip study of the twin engine aircraft model with three different variants of engine's positions [1]. But in this study there aren’t data of aerodynamic drag, lift to drag ratio and also effectiveness of propellers, operating in the airframe constitution.

Analyzing of the longitudinal stability, effects due to propeller's stream and normal force on focus location haven’t been separated.

In a whole that study, done at the highest technical level (in comparison with earlier ones) doesn’t allow to make any conclusions regarding the perfection of considered variants.

The aim of present work was experimental research of major propeller-airframe aerodynamic interference in typical configurations of twin engine aircraft and comparing assessment of the effectiveness in taken versions in cruise and take-off modes.

Model of Twin Engine Aircraft

The subject of research was a parametric model of twin engine aircraft (Fig.1). Engine's nacelles were installed on the model in three positions, providing examination of typical versions for twin engine aircraft. Horizontal stabilizer was installed in two typical positions: on the fuselage and T-typely above the fin. The series of propeller's blades have been chosen according to the range of flying speed for the regarding types of aircraft. Transition stimulators were installed on all models' surfaces.

After preparing the model, several series of balance and visual tests were carried out. The aim was “adjusting” of all tested versions and the improvement of local aerodynamics. Through of these tests results the vortex generators on the engine's nacelle were chosen together with the fairing in adjoining of nacelle with the wing were installed. These undertakings allowed to prevent flow separation on the wing and to linearize the major aerodynamic characteristics at subcritical range of angle of attack. “Adjusting” took place also in propeller: an angle for propeller's blades had been choosing, which provided the best efficiency at cruise mode.

Tests Equipment

The major series of wind tunnel tests was carried out with using of “disconnecting” power plant scheme (Fig.2). The model was fixed on the external electromechanical balance by wire suspension. In empty-bodied nacelle with a gap, which excluded mechanical contact, electrical engine with power 12 kW was installed, and there was propeller on it’s shaft. The engine was fixed on the holder of a strain-gage balance, which was installed on a special following-up system, providing the stable mutual position of the model and engine while the angle of attack was changing during testing.

Used scheme of testing with "disconnecting" power plant, allowed to measure aerodynamic loads, which were on the model and loads, produced with the propeller, simultaneously but separately and with the high accuracy.

Tests Conditions

Testing of the model has been conducted in the low-speed wind tunnel T-203 SibNIA with open test section 2.33 by 4.0 m. A speed was 40…60 m\sec, which corresponds to Re number $(0.7…1.0)\cdot 10^6$, determined through the mean aerodynamic chord of the wing. Re number of the propeller, determined with the chord of blade, which is away from the rotation axis in a distance of 75% of propeller radius, was $0.3\cdot 10^6$ during the cruise mode.

The necessity of correct comparing the results of wind tunnel tests of model's different versions determined some limits, which were satisfied during the testing. Comparison of aerodynamic characteristics through the investigated configurations was done at the following parameters:

- Re, M number – idem;
- idem (fixed) position of the laminar-turbulent transition lines;
- idem lift coefficient at
  cruise mode – $C_{L.cruise} = 0.5$;
  take-off mode - $\tilde{N}_{L.lim}$, corresponding to the speed which was 10% more than stalling speed;
- idem the static stability: $\frac{\partial C_m}{\partial C_L} = -0.1$, determined at $C_L = 0.5$ and zero relative thrust of the propellers.

The last condition was satisfied with the definite choosing of center of gravity position. Relative propellers thrust at cruise mode was taken from the equality of thrust and drag in horizontal flight. At take-off mode the relative thrust was taken according to statistic B=1.5.

It is known when air compression doesn't influence a lot, similitude of aerodynamic loads on a propeller and kinematic similitude in its stream for wind tunnel model and full-scale are provided with equality of relative thrust and advance ratio - a specific form of Strouhal number. Idem Re number for all compared propellers allowed to satisfy with the only criteria – relative propeller thrust and to determine changing of aerodynamic characteristics as a function of this parameter.

In used approach, each series of testing contained two stages. At the first stage aerodynamic coefficient (C_{int}) were determined for the model with the imitator of power plant – nacelles and propeller's spinners (without blades) were done solid together with the model. At the second stage testing of model with operational propellers was conducted and the increments of aerodynamic coefficients vs. relative thrust were determined. After this the increments were summed with the coefficients C_{int}.

In the testing with the operational propellers the following parameters was measured: axial thrust, normal force, reactive moment and propeller's angular velocity. With these measured loads thrust, power and normal force propeller's coefficients, relative thrust and efficiency of propellers were calculated.

Tests Results and Analysis

Propeller

Aerodynamic characteristics of propeller depend on its position on an aircraft. Exactly speaking they depend on kinematic parameters of flow field, which is formed with plane components in the propeller's position (Fig. 3). Pulling propeller, which is streamed with uniform flow, has the highest efficiency.

Effectiveness of the propeller turned out to be lower in the 2 configuration. Its maximum efficiency was 10% less. The reason of such big difference is strong nonuniformity of the flow, which streamed the propeller in this case.

Propeller's efficiency in the 3 configuration was lower than in the traditional one, but the difference wasn't so big.

When the propeller operates in the dawnwash flow the force appears in the plane of rotation. This force, called “normal” is proportional to the angle of attack. The normal force magnitude of the propeller is very low in comparison with a lifting force of an airplane.

But when it acts in a long distance from the center of gravity, it can influence a lot on the aerodynamic focus position of an aircraft, so on the parameters of the longitudinal stability.

As the test results showed, the magnitude of normal force coefficient at fixed relative thrust can be quite exactly approximated with the linear function of angle of attack.

With this reason we can consider of the derivative of normal force coefficient due to angle of attack as the validate estimation, which characterize propeller normal force in the subcritical angle of attack range, and use it for the parameters of longitudinal stability calculation. Normal force coefficient depends on the real angle of attack of propeller axis, so it has the highest magnitude in the 1 configuration.

Downwash of the wing decreases of the normal force: more in the 2 configuration and less in the 3 one.

Airframe

Operational propellers influence on the lifting ability of configurations – derivative $C_{L\alpha}$ and coefficient $C_{L\,max}$ are raising as soon as coefficient B is increasing, especially while the flap is deflected (Fig. 4).

It’s necessary to pay attention on increasing of $C_{L\,max}$ in the 2 configuration, where the wing is not washed with propeller's streams. The main reason here is the reduction of positive pressure gradient on the wing due to the suction of the propellers.

Propeller's streams and suction of operational propellers influence on the aerodynamic drag: coefficients $C_{D\,min}$ increasing similarly in the 1 and the 2 configurations and less in the 3 one.

The maximum magnitude of the lift to drag ratio is decreasing due to the relative thrust. The most reduction is in the 1 configuration and the smallest one is in the 3.

Propeller's streams effects on the aerodynamic focus position. In fig. 5 changes of the focus coordinate vs. B coefficient for three configurations are given in cruise and take-off modes. In the 1 configuration the influence of propeller's streams is promoted of focus displacement ahead. This displacement depends on the position of horizontal stabilizer a little. The main reason here is increasing of downwash flow by the wing at the tail unit.

In the second configuration the horizontal stabilizer at the fuselage is blown with the propeller's streams, but in T-type unit isn’t. This fact has an effect on focus displacement. Effectiveness of blown stabilizer is raising and focus of the model “goes” back. In T-type unit the influence of increasing downwash dominates and focus moves ahead.

In the 3 configuration the propeller's stream influence on focus position is not revealed.

Normal force of the propellers, allocated in front of the center of gravity (as in the 1 configuration) reduces of the longitudinal stability. If propellers are allocated behind the center of gravity so does in the 2 and the 3 configuration the propeller's normal force moves the aerodynamic focus back and degree of longitudinal stability increase.

Mutual influence of propeller's streams and normal force leads to total loss of longitudinal stability on take-off modes in the 1 configuration. It leads to raising of longitudinal stability in the 2 configuration with the horizontal stabilizer on the fuselage, so that to increasing of trimmed losses of lifting force and lift to drag ratio.

In the 2 and the 3 configurations with T-type tail unit, propellers operation doesn't influence a lot on stability changing.

For correct account of trimmed losses and comparing effectiveness of the configurations the new center of gravity position and respective parameters of longitudinal stability was determined for all possible flight modes. The new center of gravity position was chosen on some compromise between providing safety of take-off mode and most reduction of losses in cruise flight.

General Efficiency

The following characteristics of cruising mode are given in the table: lift to drag ratio with taking into account all of losses, requiring cruise relative thrust, efficiency of propellers operating in a constitution of aircraft and potential flight range (range by Breguet).

Comparing got data it’s easy to see that the most perfect in cruise mode is traditional configuration with pulling propellers. The best take-off and landing characteristics – the highest lift coefficient, effectiveness of high lift devices, take-off lift to drag ratio and biggest thrust excess for acceleration and climbing are realized in the 3 configuration, having “clear”, not shadowed with nacelles, wing.

Configuration		Cruise mode				Take-off mode		
		$\left(\frac{L}{D}\right)$ (trimmed condition)	B (trimmed condition)	η	$\bar{L}$	$C_{L.\lim}$	$\left(\frac{L}{D}\right)$ (trimmed condition)	$B_{TO} - B_{HF}$
HS-F	**1**	10,7	0,151	0,77	1.0	1,2	7,8	1,00
	2	10,1	0,161	0,67	0.82	1,2	8,5	1,04
HS-T	**1**	10,6	0,152	0,77	1.0	1,2	8,2	1,02
	2	9,9	0,164	0,67	0.80	1,2	9,2	1,07
	3	10,6	0,152	0,73	0.94	1,3	9,9	1,07

Conclusions

1. Substantial influence of propellers position on twin engine aircraft was exposed. The biggest propeller's efficiency is realized in traditional configuration with pulling propellers, operating in uniform flow. When engines are located on the pylons the propeller's efficiency is lower a little. Pulling propellers allocated behind the trailing edge of the wing operate with the worst effectiveness.

2. Influence of the propellers on aerodynamic characteristics is seen in its raising of lifting ability, raising of aerodynamic drag and reduction of lift to drag ratio.

Influence of propellers on an aircraft static longitudinal stability is determined with two dominating factors: propeller's streams interference and normal force of propellers. The magnitude of normal force depends on kinematic parameters of flow field, formed with airframe elements. In configurations, where propellers operate in downwash flow, their normal force coefficient is less than the same coefficient of a separate propeller. Minimal unfavorable influence on static longitudinal stability has place in configurations where horizontal stabilizer is not blown.

3. Comparing assessments of potential flight range for typical configurations of twin engine aircraft were got. The most potential flight range is achieved on aircraft with traditional engine position on a wing and pulling propellers. However much better take-off and landing characteristics may be achieved on the configuration with “clear” wing. The worst effective in cruise flight is the configuration with engines on a wing and pulling propellers. Its potential flight range is only 80% of the range with traditional configuration.

References

[1] Williams K.J., Johnson J.L. and Yip L.P. *Some Aerodynamic Considerations for Advanced Aircraft Configurations.* AIAA Paper 84-0562.

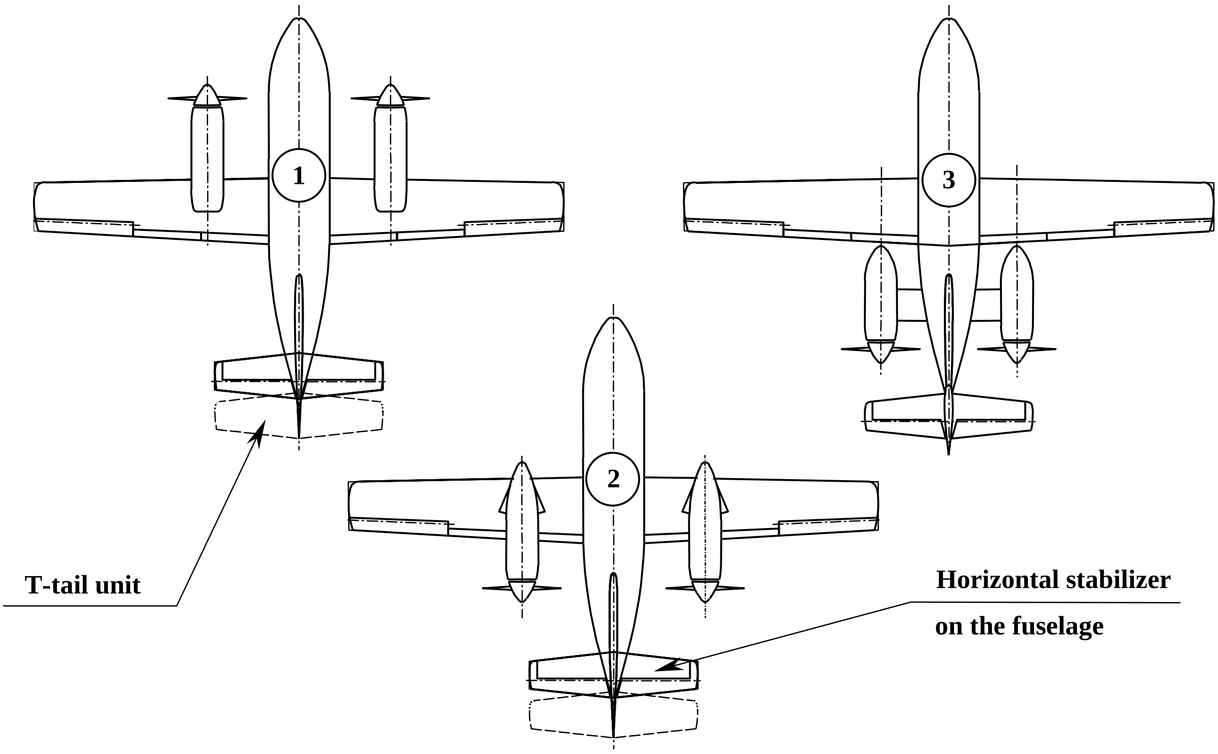

Fig.1. Versions of model's configuration

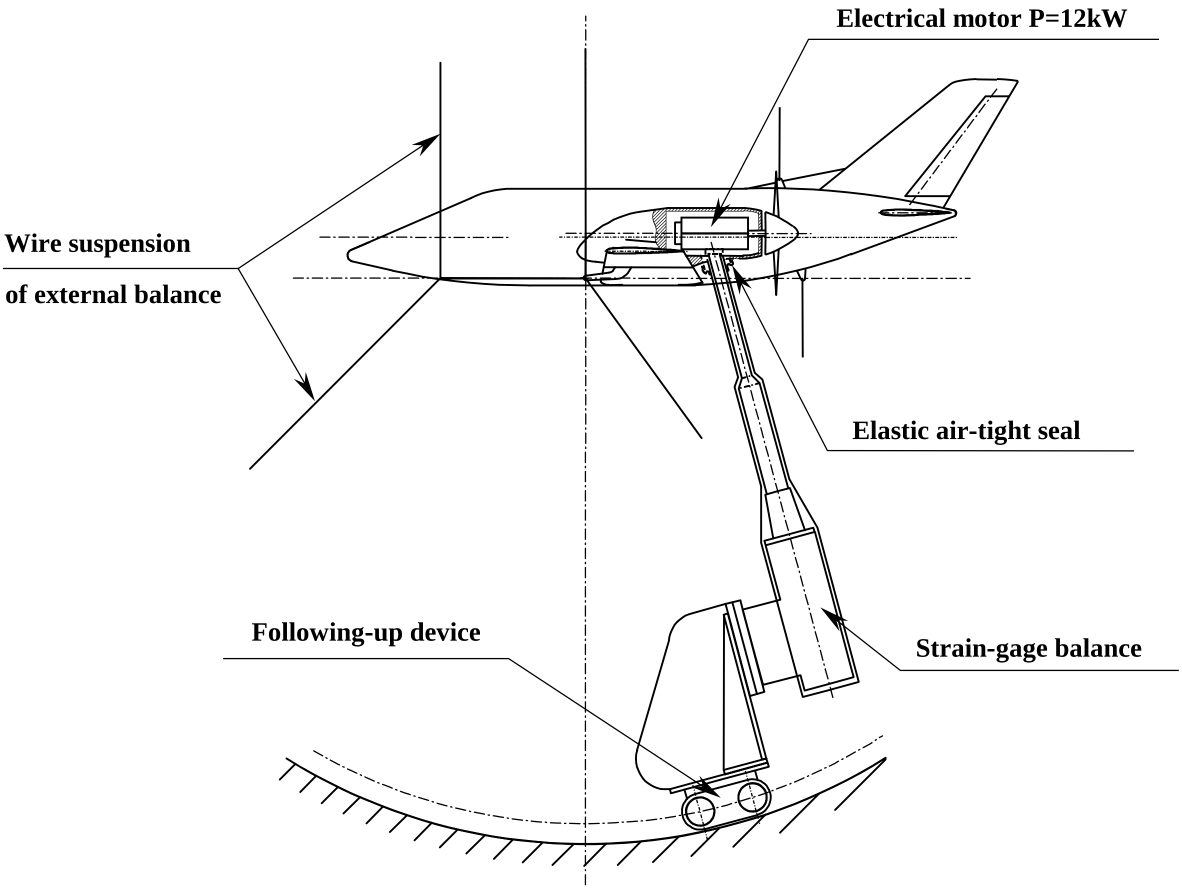

Fig.2. Structure of testing rig

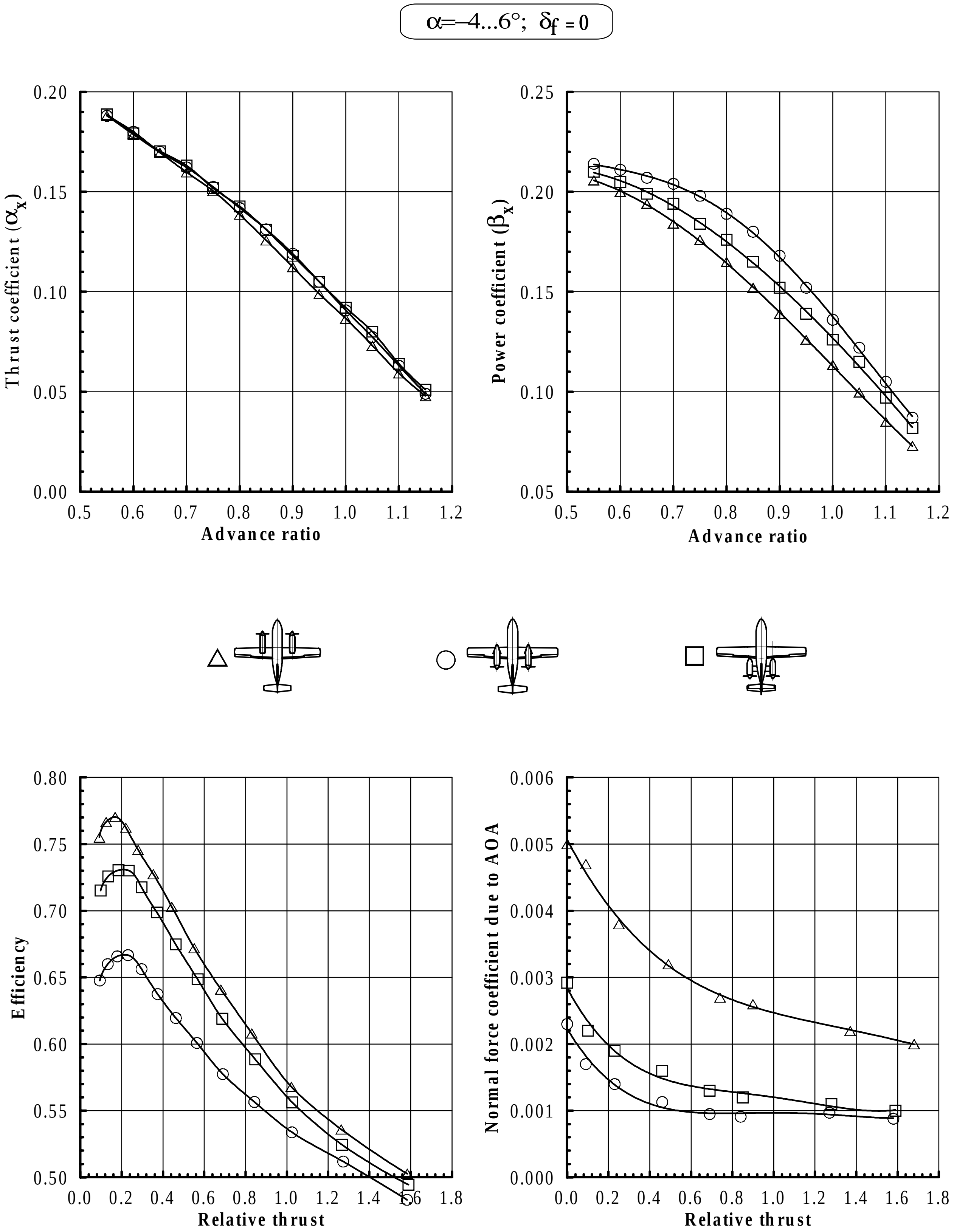

Fig.3. Propeller characteristics

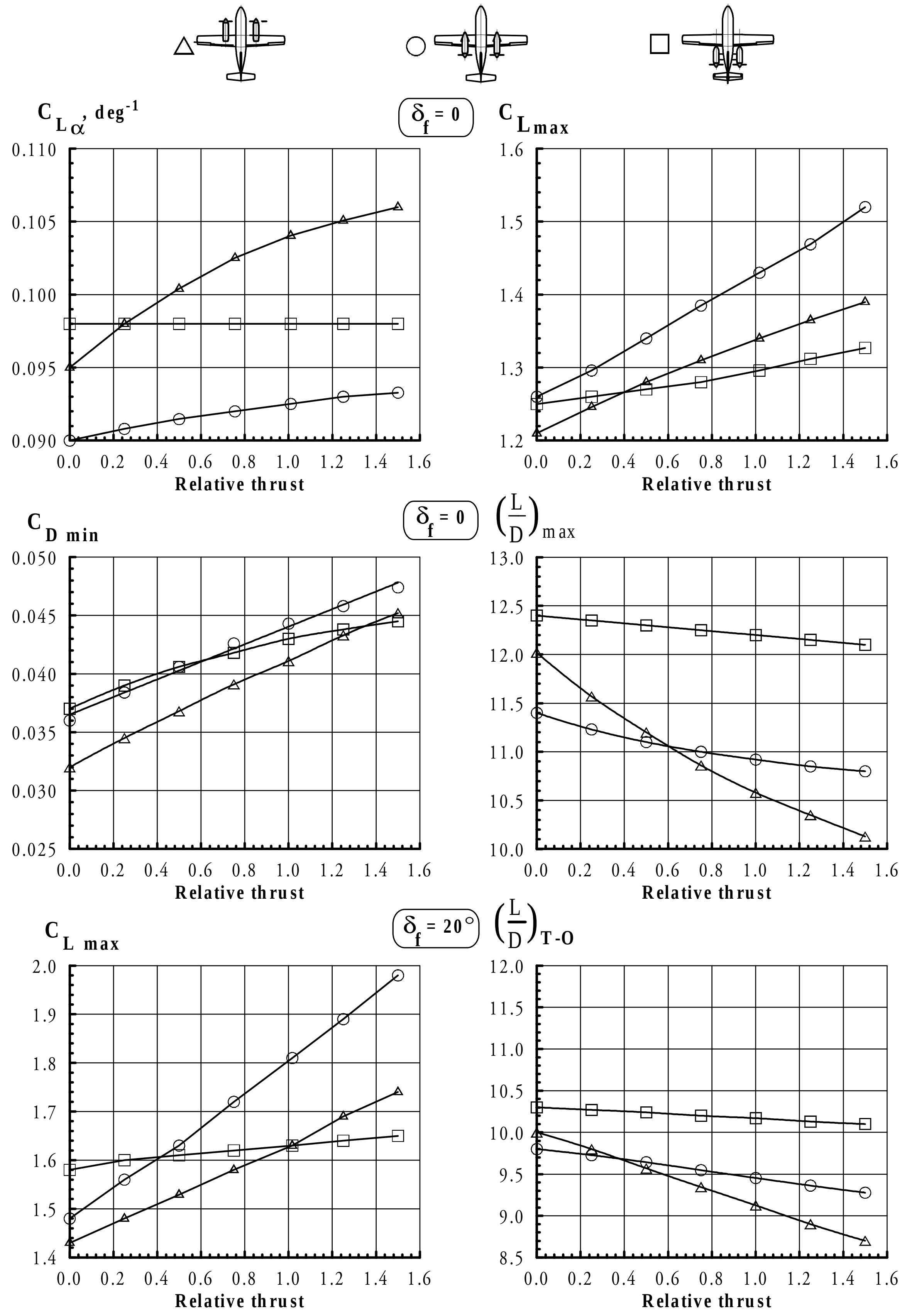

Fig.4. Propeller streams influence on the airframe aerodynamics (T-tail unit, trimmed losses aren't taking into account)

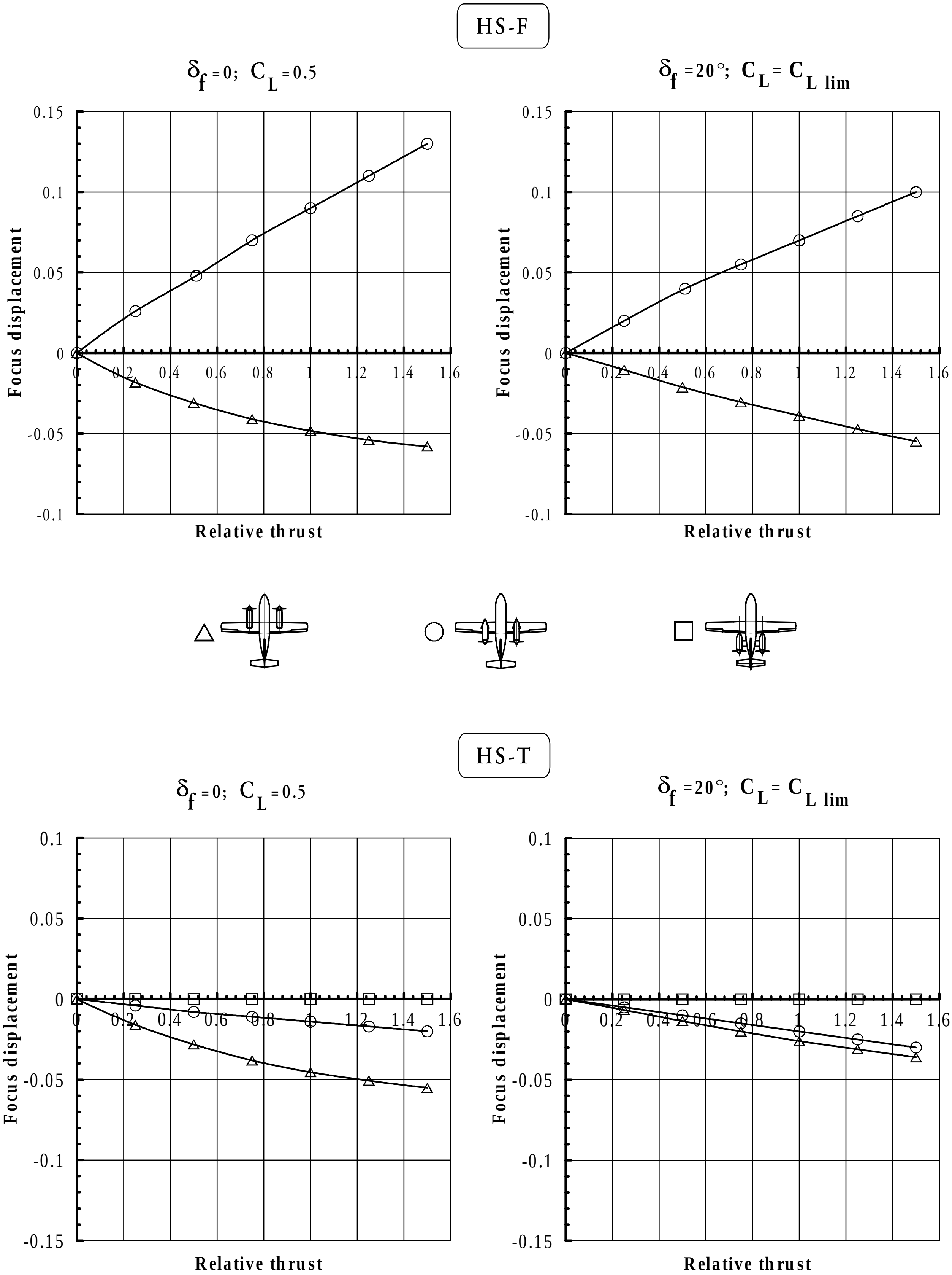

Fig. 5. Aerodynamic focus displacement due to propeller streams

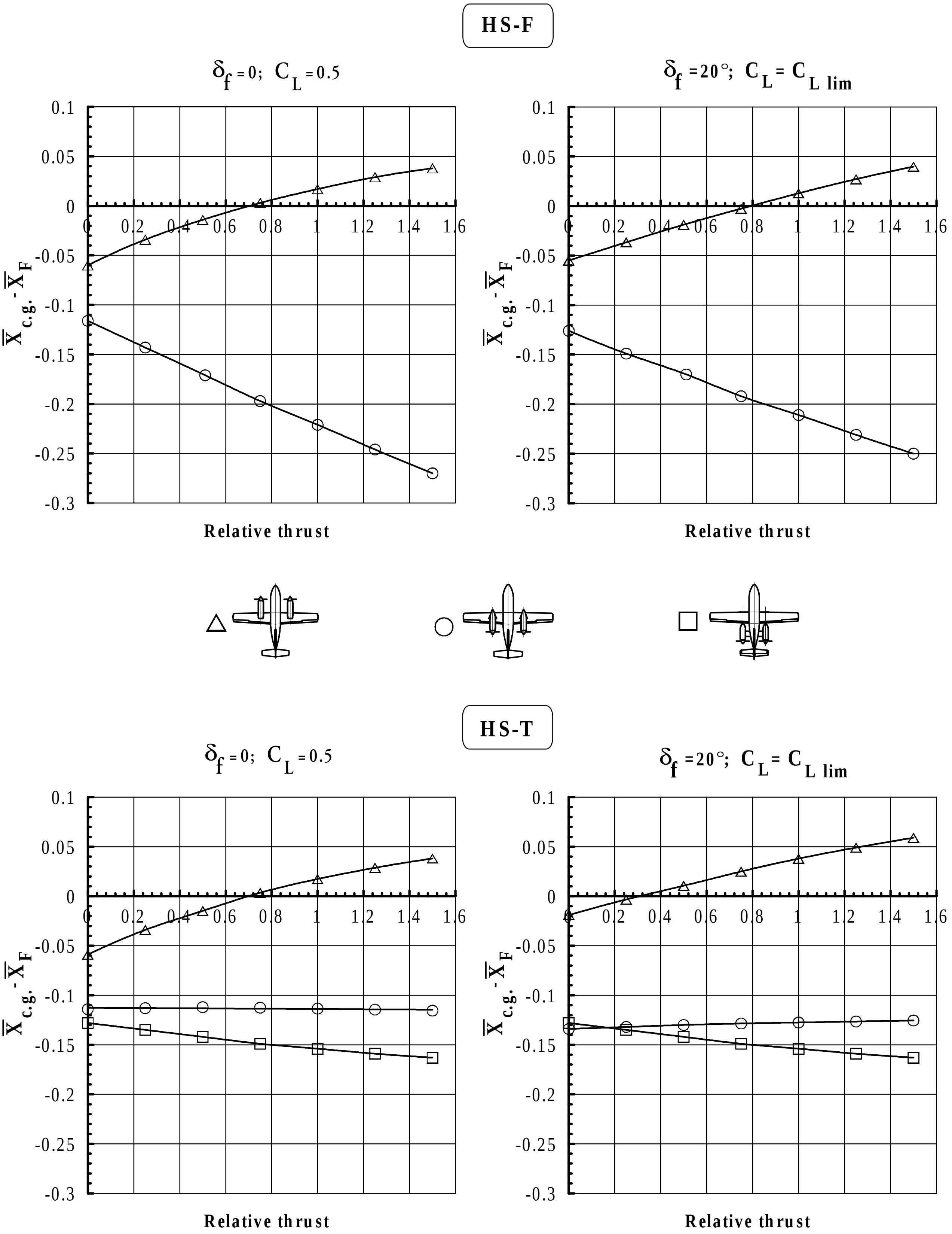

Fig.6. Disturbance of static longitudinal stability due to propeller streams and normal force