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ANALYTICAL AND EXPERIMENTAL INVESTIGATIONS OF AN IMPROVED AERODYNAMIC ORBITER CONFIGURATION

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Abstract

The results of analytical and experimental investigations of an improved aerodynamic orbiter configuration version are presented for a multipurpose aerospace system being developed at the Scientific Production Association "Molnia" based on the subsonic aircraft-launcher An-225 (Mria).

The main objective of these investigations is to evaluate modification techniques of the baseline orbiter version which provide for an increased hypersonic L/D and, consequently, improved aerospace system performance.

Based on the results obtained, a modification of the baseline orbiter version is suggested. According to the predictions, this modification provides for an increase in its maximum hypersonic L/D by 14% to 27% in the descent flight envelope and, consequently, in the lateral range of the modified orbiter by 2000 km, i.e., from Z=4200 km for the baseline version to Z=6200 km for the modified version. This improves the aerospace system performance extending the inclination range of the serviceable orbits and the network of landing airfields. It is shown that the weight of the combined thermal protection system is twice as less as the thermal radiation protection.

The TsAGI wind tunnel test results for schematized models of the hypersonic vehicle GLA-5 are used to estimate the aerodynamic characteristics of the modified orbiter at sub,- trans,- super,- and hypersonic velocities. The calculations and experimental investigations are conducted as concerns the choice of the orbiter's thermal protection. The weight of the combined thermal protection system is shown to be half as much as that of the radiation thermal protection system.

Introduction

The progress in aerospace engineering has motivated the development of some aerospace systems based on the subsonic aircraft-launcher. An example of similar systems is a multipurpose aerospace system MAKS being developed at the SPA "Molnia" based on the aircraft-launcher An-225(1-3). The system involves an orbiter with an external fuel tank. The improved performance of the MAKS implying an increased lateral range and, consequently, an extension of serviceable orbit inclinations and of the network of landing airfields, as well as a reduced time in orbit before descent dictates the application of such aerodynamic configurations of the orbiter that provide a higher L/D-ratio.

Many publications are devoted to the choice of aerodynamic configurations at hypersonic velocities, among which domestic investigations(4-8) as concerns aerodynamic designing of a hypersonic vehicle and its components with a high L/D-ratio are worth noting.

The objective of the present study is confined to an attempt to define the configuration of an orbiter with a high hypersonic L/D-ratio proceeding from the existing prototype for which the orbiter of the multipurpose aerospace system MAKS is chosen(3).

The modification implying an increase in the baseline vehicle length in proportion to a coefficient and a decrease in the wing aspect ratio in proportion to the same coefficient can serve as a practical approach allowing a reduction in the aerodynamic drag and, accordingly, a rise in the L/D-ratio of the orbiter with its retained or slightly increased weight. An additional condition of such a modification is the retention of the orbiter engine compartment sizes. Note also that a similar modification makes it possible to retain the lifting surface and the volume of the vehicle and to increase the sweep of the body and wing leading edges. As a result, the wave drag and viscosity-induced drag reduce.

Another important condition governing the configuration of the orbiter is the requirement for its landing characteristics. The arrangement of sustained liquid-propellant rocket engines on the orbiter results in an increase in the relative body base area by 18% to 20% and, accordingly, in a considerable rise in the drag and in a reduction in the maximum L/D-ratio. In view of the fact that the orbiter landing is accomplished with inoperative engines, the attainment of an acceptable maximum L/D-ratio at landing regimes is gaining in importance.

The above-outlined approach was applied to choose a modification of the baseline orbiter version proposed by PSA "Molnia" for the multipurpose aerospace system MAKS based on the subsonic aircraft-launcher An-225 (Mria).

Aerodynamic characteristics at hypersonic velocities, orbiter descent trajectories. Choice of a modified orbiter version and thermal protection system.

The calculated aerodynamic characteristics of the baseline and modified orbiter versions were analyzed by applying the engineering package of applied programs. The version developed by the SPA "Molnia" for a multipurpose aerospace system (Fig. 1a(3)) was assumed as a baseline version.

Fig.2 presents calculated maximum L/D-ratios as a function of similarity parameter M/√Re for the baseline and modified orbiter versions at different modification coefficients .

The analysis of these curves shows that a considerable increase in the maximum hypersonic L/D-ratio is attained when the orbiter length is increased by a factor of 1.2 and the wing aspect ratio is decreased in the same proportion (Fig. 1,b). As stated above, a similar modification leads to an increase in the sweep of the body and wing side edges, thus reducing the wave drag and viscosity-induced drag. Besides, the wave drag in this case can be reduced additionally due to smaller body and wing edge bluntness radii.

The maximum L/D-ratio of this orbiter modification in the range of similarity parameter M/√Re under study increases by 13% to 27% (Fig.2).

The calculated aerodynamic characteristics of this orbiter modification were used to determine the lateral gliding range according to the program developed by E.N. Dudar and Yu. V. Shiranov. The gliding trajectory parameters were evaluated for the following initial conditions:

H_0=100 km; V_0=7.85 km/s; $\gamma_0=60^0$;$\theta= 0.9^0$; G/S =300kg/m^2

The orbiter angle of attack for the entire glide trajectory was controlled according to the law $\alpha = \alpha_{(L/D)max}$. The gliding trajectory parameters were calculated up to the altitude H=20 km.

The results of these calculations are given in Fig. 3 in the form of dependences L,Z =f(t) and Tw, =f(t) for the baseline and modified orbiter versions.

It follows from these dependences that the side range of the modified orbiter version increases up to Z=6200 km as compared with the lateral range of Z=4200 km for the baseline version (Fig. 3).

The rise in the maximum L/D-ratio is followed by an increased flight time resulting in a proportional increase in the integral heat flux absorbed by the orbiter coating and, respectively, in the heat protection system weight. For the payload weight to be retained under these conditions, the heat protection system weight must be reduced by applying either new more effective heat-protecting materials or new heat protection techniques.

Two thermal protection systems for the modified orbiter version aree considered. They are, first, the radiation heat protection in which the heat reduction is provided basically due to radiation from the external surface, and, second, the combined heat protection in which heat radiation and absorption by the external heat-protecting layer is supplemented by energy absorption while evaporating the cooling agent from the internal side. Evaporation is proceeds into the cavity, and the vapors are removed through special orifices.

In the external heat protection layer, the nonlinear equation for heat productivity was solved.

The american material Li-900 (γ =144 kg/m ^{3}) which is similar to the domestic material TZMK is considered as an external heat-protection shell. The cooling agent is water, the open ratio of the tapping point is $2x10^{-4}$, the orbiter coating is made from 2mm-thick duraluminium. The initial mass of the cooling agent is taken to be equal to the mass of the external heat protection system so that the total heat protection system weight be minimum. The initial heat protection system temperature is T=300 K. The temperature field on the orbiter surface is assumed to be unvaried, while the absolute surface temperatures change along the trajectory in proportion to the temperature at a critical body nose point (Fig. 3).

Proceeding from the calculation results, a minimum (with an accuracy to 1mm) thickness of the external thermal-protection layer is determined when the coating temperature does not exceed 100^0 C. It follows from the calculation that the weight of the combined thermal protection system of the modified orbiter version is almost 2 times less than the weight of the radiation protection system. Thus, the combined thermal protection system is a very promising approach for a hypersonic vehicle with a high L/D-ratio.

To verify the calculated aerodynamic characteristics of the modified orbiter version, schematized parametric models of the GLA-5 orbiter (Fig.4) were designed and manufactured. These models were investigated in the hypersonic wind tunnels TsAGI T-120M, T121, IT-1V and IT-2M. The schematized GLA-2 model with the fuselage having a delta planform and triangular cross sections was served as a baseline model. A wing and a tail were installed in the fuselage afterbody the sized of which were taken the same in both models. The relative radii of the forebodies and the fuselage side edges of the GLA-5 model corresponded to the baseline (II version, r_n=0.0146, r_{le}=0.0146 to 0.0086) and advanced I versions (r_n=r_{le}=0.0048) of the orbiter. The model was investigated with three versions of wings having different leading edge sweeps (χ_w =60° to 68°) and different relative outboard wing areas of S_w/S_F=0.42 to 0.50.

The bluntness radii for the wing leading edges were chosen with due consideration of variations in the sweep based on the calculations.

The study program suggested obtaining the data on main characteristics, longitudinal static stability and effectiveness of the control surfaces (elevons and fuselage flap), as well as the preliminary experimental data on the lateral static stability of the GLA-5 models.

The main flow parameters, angles of attack, sideslip angles, control surface deflection angles and characteristic geometric parameters of the GLA-5 model are summarized in the following table.

Flow parameters, test conditions and geometric model parameters

Parameters	Wind tunnels			
	T-120M	T-121	IT-1V	IT-2M
Flow parameters				
Mach number M	~8	4-8	12.2-14.9	18.7-19.5
Reynolds number Re*	$(0.34...2.51)10^6$	$(1.4\text{-}...1.19)10^6$	$(0.77...2.2)10^5$	$(1.4...7.5)10^4$
Stagnation pressure Po,Mpa	1.0-12.0	0.3-5.1	1.6-8.0	4.0-30.0
Stagnation temperature,To,K	613-773	293-723	850-876	2200-2500
Test gas	air	air	nitrogen	nitrogen
Angle ranges				
Angle of attack α** grad	-6-+21	-6-+21	-8-+21	-8-+28
Sideslip angle β grad	0	0 and 4	-8-+28	-8-+28
Control surface deflection ranges				
Ailerons δ_e grad	(0+-20)	0	0	0
Fuselage flap δ_F grad	(0+-10)	0	0	0
Characteristic geometric parameters				
Fuselage planform area S_F,m^2				
1 version (corresponds to advanced orbiter version)	0.002095	0.002095	0.002095	0.002095
II version (corresponds to baseline orbiter version)	0.00215	0.00215	0.00215	0.00215
Fuselage length L_F,m (I and II versions)	0.1038	0.1038	0.1038	0.1038
Fuselage span l_F,m(I and II versions)	0.0295	0.0295	0.0295	0.0295

* The Reynolds numbers are based on fuselage length.

** The angles of attack are measured from the upper fuselage surface.

Fig.5 shows maximum L/D-ratio versus similarity parameter $M/\sqrt{Re}$ obtained in testing the GLA-2 and GLA-5 models. It is seen that the modification of schematized models enables required maximum L/D-ratio increments and required values of (L/D)max to be attained over the whole test range of the similarity parameter $M/\sqrt{Re}$ which corresponds to the orbiter descent regimes.

As an example, Fig. 6 presents the dependences C_L, L/D, Cm=f(α) for the GLA-5 model with different wing and body versions corresponding to the advanced orbiter version at M=8, $Re=(1.00...1.19)10^6$. For comparison, the dependences C_D L/D, Cm=(α) for the baseline schematized GLA-2 model are also given.

Fig.7 demonstrates the dependences L/D, Cm=f(α) for this model with one of the wing versions ($\chi=68^o$, $S_w/S_F=0.419$) and the fuselage corresponding to the baseline orbiter version at M=18.7 to 19.5, $Re=(1.4...7.5)10^4$.

The analysis of the dependences $C_L=f(\alpha)$ in Fig.6 reveals that the lift coefficients decrease in the test range of angles of attack for the proposed orbiter modification. To reduce the difference in the lift coefficients of the baseline and modified orbiter versions it is reasonable to increase slightly (up to 10%) the relative outboard wings area which is also desirable to provide more aft (characteristic of vehicles of the class under consideration) c.g. positions at hypersonic velocities and the longitudinal static stability at subsonic velocities. According to the test data for the schematized GLA-5 model, self-balancing of the modified orbiter version at angles of attack close to $\alpha=\alpha_{(L/D)max}$ can be attained by an adequate choice of the c.g. position, the relative areas of the outboard wings and their locations along the fuselage length (Fig.6). A reduction in the bluntness radius of the nose and the fuselage leading edges (from 250-150mm to 80mm for the full-scale model) can result in an additional rise in the maximum L/D-ratio by ~0.1 (Fig.6).

At hypersonic velocities, the viscosity effect decreases considerably the maximum orbiter L/D-ratio (Fig.7). Variations in the Reynolds numbers from $Re\cong 10^6$ to $Re\cong 10^4$ result in a reduction in the maximum orbiter L/D-ratio three times from 3 to 1.

Assessment of aerodynamic characteristics of the modified orbiter version at sub-, trans- and hypersonic velocities

It is inferred from the calculations carried out that the maximum L/D-ratio of the modified orbiter version will not exceed 4.0-4.4 at landing velocities because of a relatively great fuselage base section area ($F_b/S_F=17\%$).

As means of increasing the maximum L/D-ratio of the modified orbiter version at landing regimes, it is possible to apply:

1) deflecting the body flap upward to the base region;

2) tapering the afterbody at small angles of the generatrix;

3) increasing the relative outboard wing areas within 10% which is also desirable, as mentioned above, for hypersonic velocities;

4) by-passing the air from the wheel well to the base region.

The above-outlined means were tried in studying the aerodynamic configuration of the base orbiter version.

The capability of obtaining the acceptable aerodynamic characteristics of the modified orbiter version at transonic and supersonic velocities is confirmed by the test results of the large-scale GLA-5 model in the T-114 wind tunnel of TsAGI at M=0.6…4.0 and $Re=2.3x10^6$ …$4.9x10^6$.

It is obvious from the dependences $(L/D)_{max}$, Cm_{CN}, Cm(α =0), $C_{L\alpha}$,$C_D(\alpha=0)$, $C_L(\alpha=0)=f(M)$ in Fig. 8 that the GLA-5 model with a swept wing $\chi=64.3^o$, $S_w/S_F=0.485$ features the most favorable lifting properties. This model is characterized by a rather high maximum L/D-ratio and its longitudinal static stability for a specified c.g.position retains over the whole test Mach number range.

Conclusions

1. The orbiter modification is suggested which allows the hypersonic L/D-ratio to be increased by 13-27% during the reentry, as compared with the baseline orbiter version, over the test range of the parameter $M/\sqrt{Re}$. This capability of increasing the hypersonic L/D-ratio is confirmed by the test results obtained for the schematized orbiter models in the TsAGI T-120M, T121, IT-1V, IT-2M wind tunnels at M=4.0...19,5, $Re=2.5x10^6$ ...$1.4x10^4$.

The results of testing the GLA-5 model in the T-114 wind tunnel (M=0.6...4.0, $Re=2.3x10^6...4.9x10^6$) verified the capability of obtaining acceptable L/D-ratios of the modified orbiter version at sub-, trans and supersonic velocities.

2. It is shown that under the same initial conditions accepted for the calculation of the glide trajectory, the lateral flight range of the modified orbiter version increases by Z=2000km, as compared with the baseline version, to be Z= 6200km. A similar increase in the orbiter lateral range improves considerably the aerospace system performance as concerns the extension of the inclination range for the serviceable orbits and of the airfields network for landing the orbiter, as well as the reduction in the holding time on the orbit before reentry.

3. The investigations of the combined thermal protection system on the modified orbiter show that this approach is very promising for a hypersonic vehicle of a great L/D-ratio.

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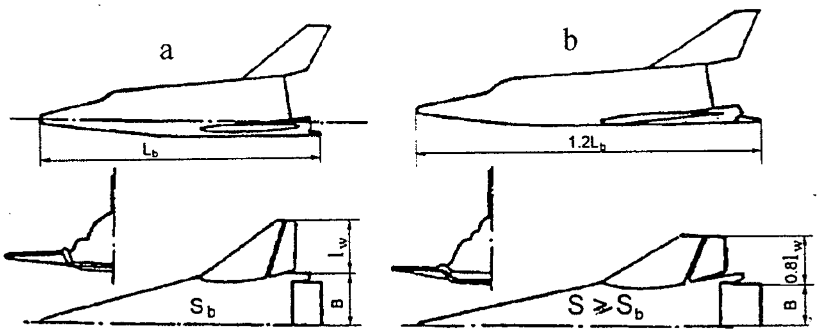


Fig.1 Orbiter configuration: a– baseline, b– modified

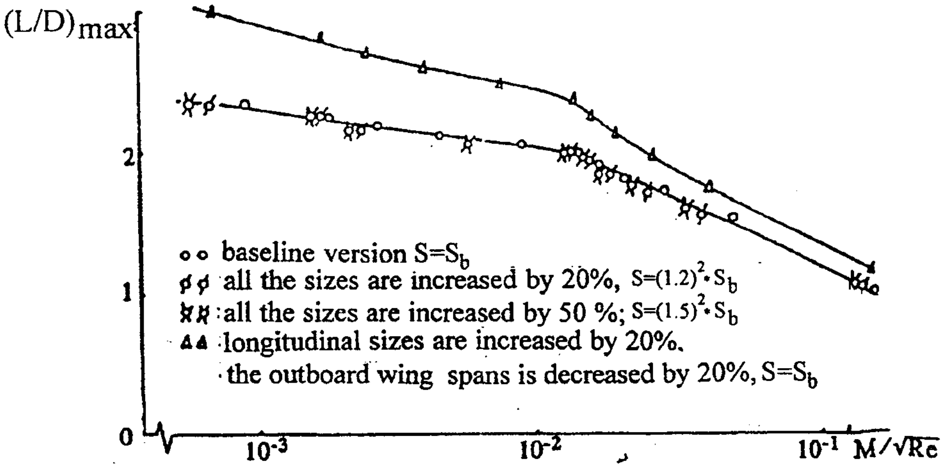


Fig. 2 Maximum L/D-ratio vs similarity parameter for the baseline and modified orbiter versions

H_0=100km; V_0=7,84km/s; γ_0=60°; θ=0,9°; $\frac{G}{S}$=300 kg/m^2

Control of angle of attack by law $\alpha=\alpha_{(L/D)\max}$

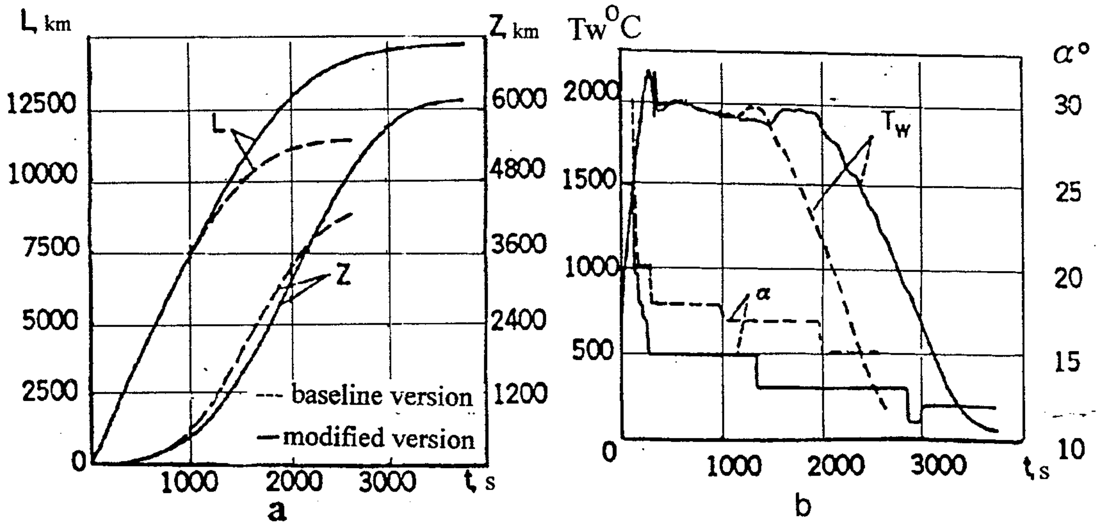
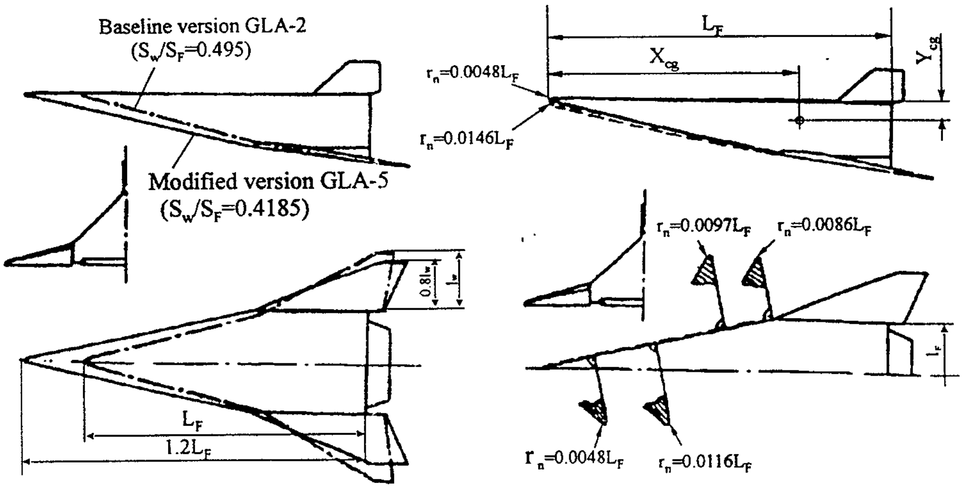


Fig.3 Trajectory parameter vs time for the baseline and modified orbiter versions during the reentry: a – longitudinal and lateral flight range; b– temperatures at the critical body nose point and angles of attack.



a

I version $r_n=r_{le}=0.0048L_F$
II version $r_n=0.0146L_F$, r_{le} =var.

b

Fig. 4. Schematized orbiter models; a - GLA-2 and GLA-5;
b - modified GLA -5 versions.

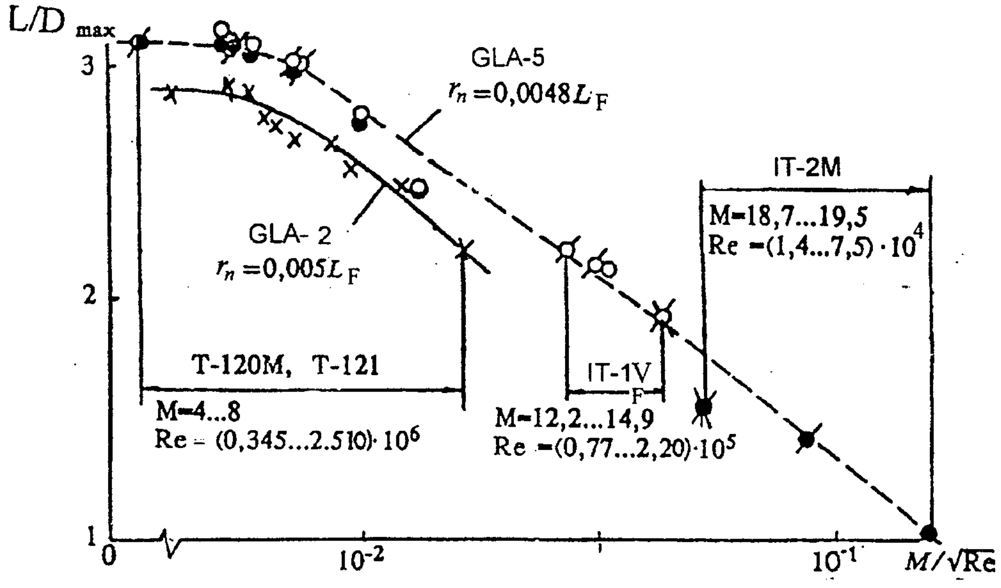


Fig.5 Maximum L/D-ratio vs similarity parameter $M/\sqrt{Re}$ for the GLA-2 and GLA-5 models

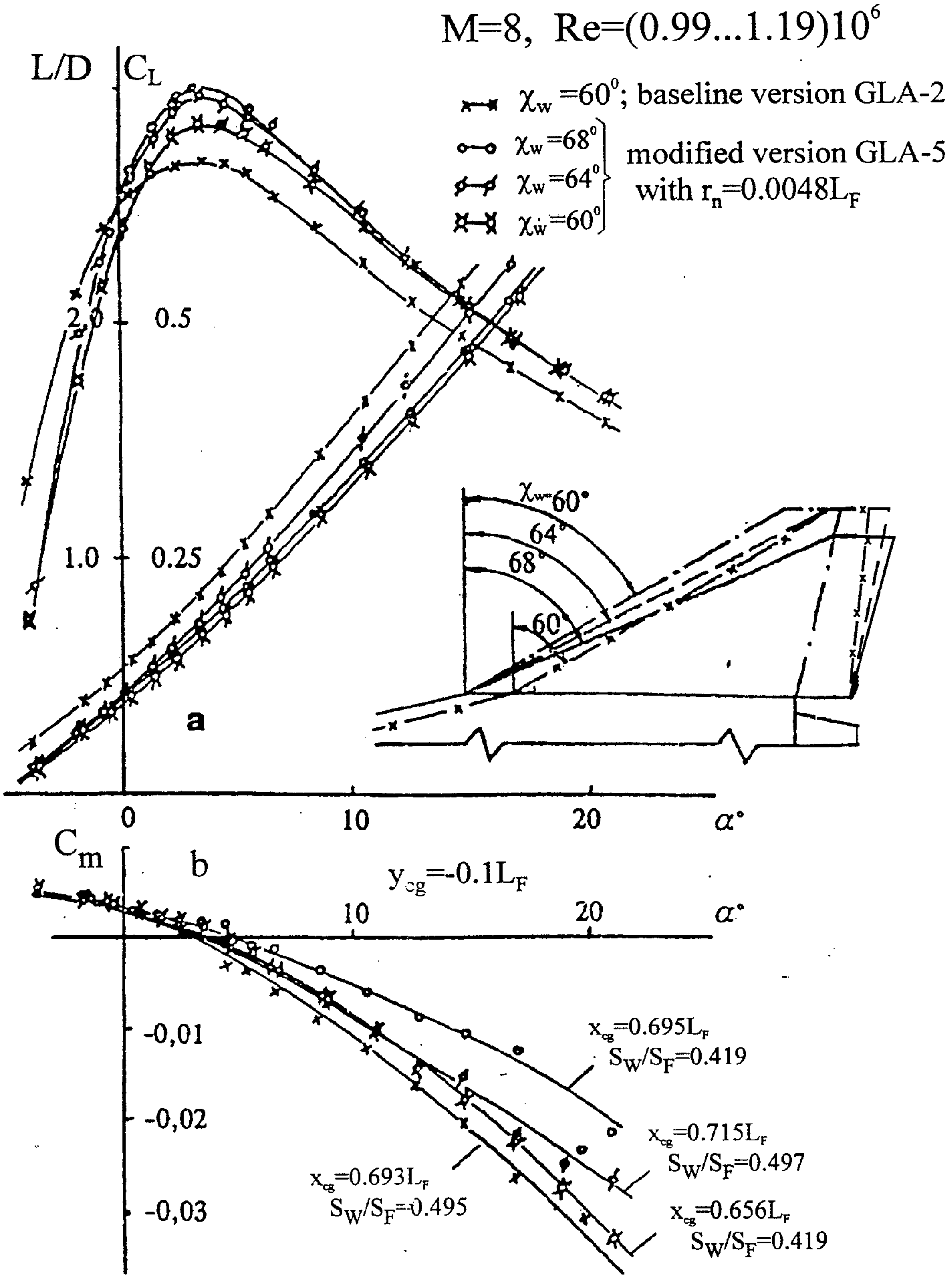


Fig. 6. Aerodynamic characteristics vs angle of attack for GLA-2 and GLA-5 models with different wing version χ=60°- 68° and the body of the advanced version.

a - lift coefficient and L/D - ratio
b - pitching moment coefficient

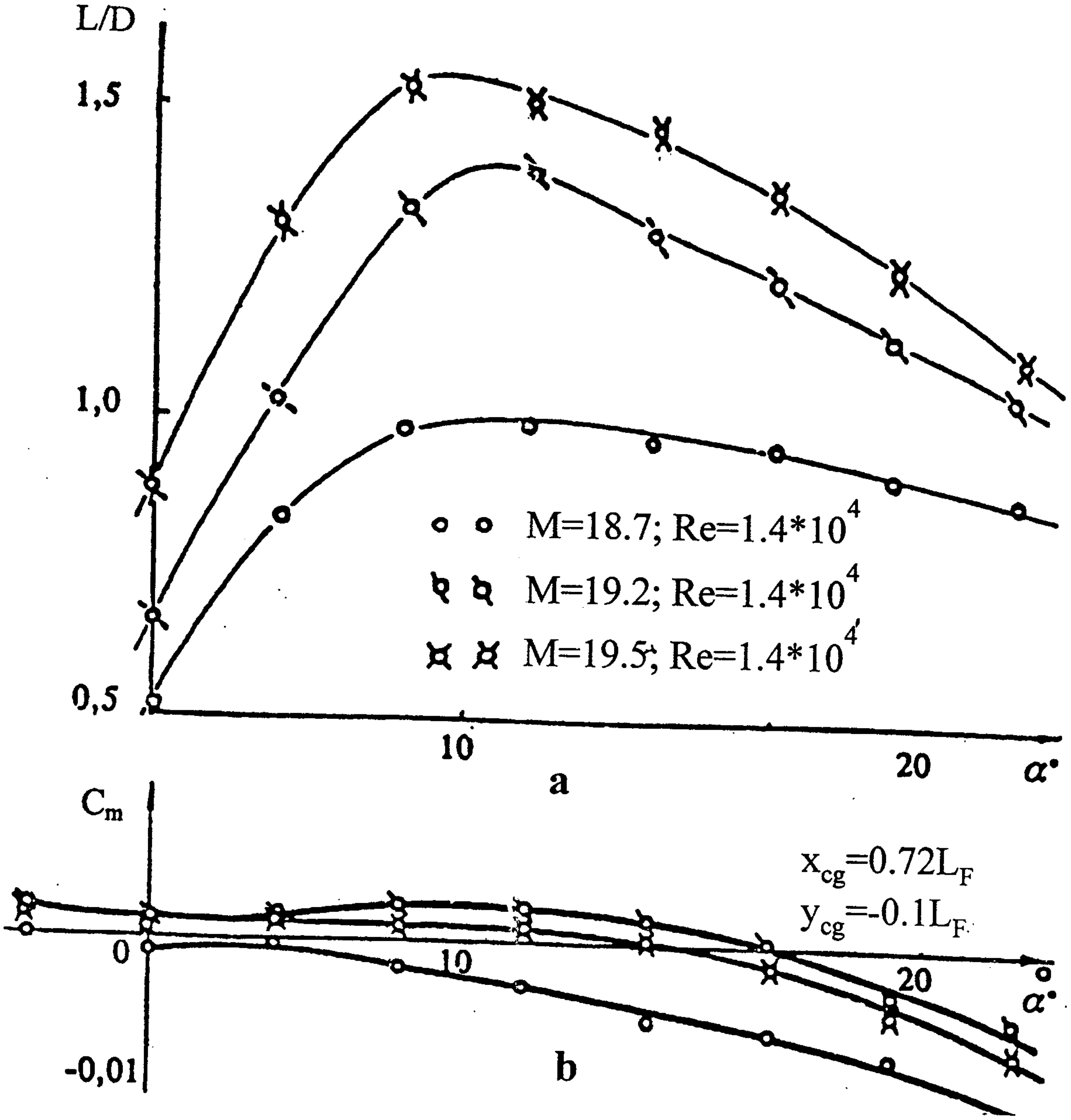


Fig. 7. Aerodynamic characteristics vs angle of attack for GLA-5 model with the body of the baseline version and the wing $\chi_W = 68^o$ at M=18.7-19.5

a - lift coefficient and L/D - ratio
b - pitching moment coefficient

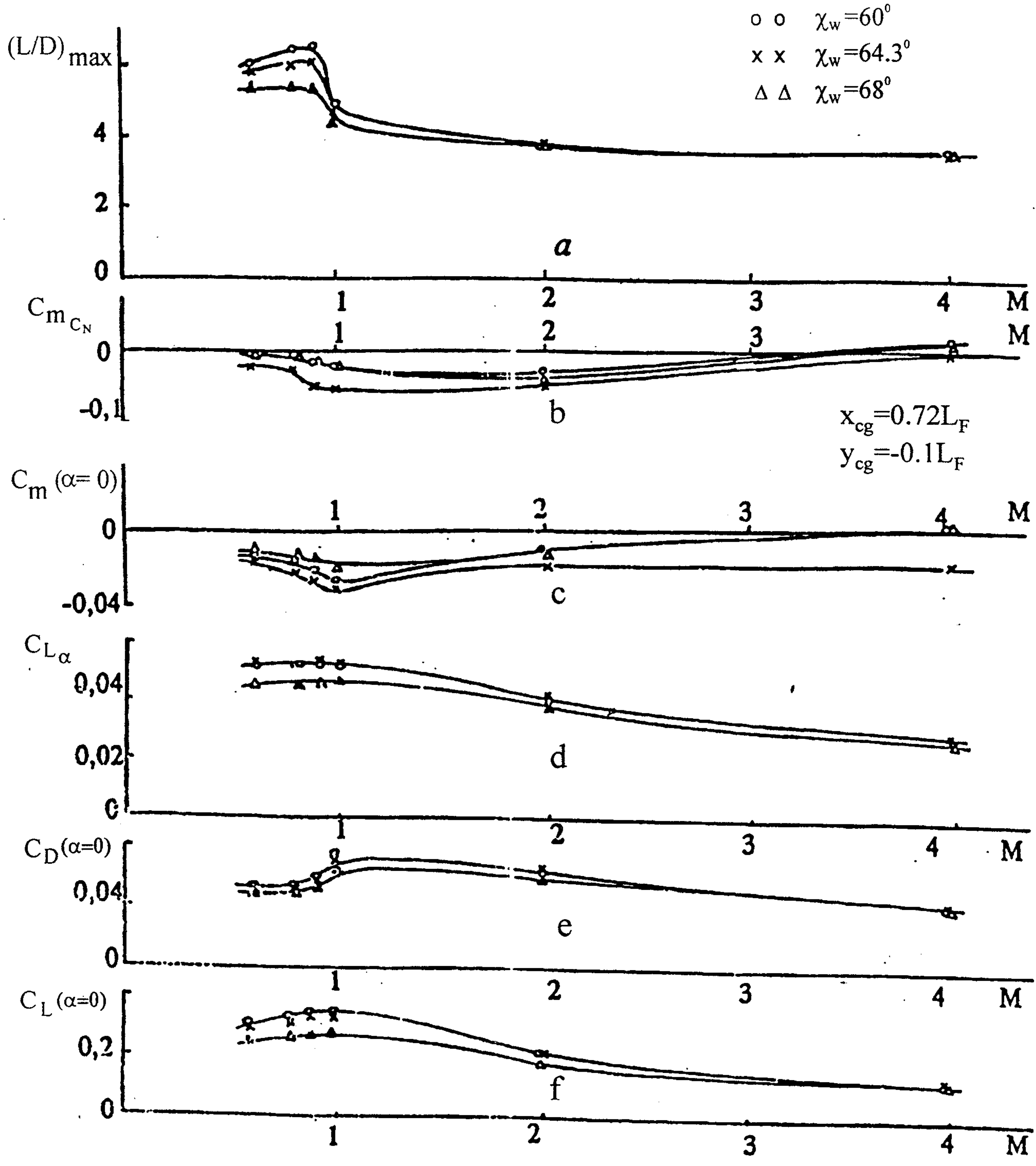


Fig.8 . Aerodynamic characteristics vs Mach number fot the GLA-5 with different wing version χ_w=60°- 68° and the body of the advanced version.

a - maximum L/D-ratio; b - longitudinal static stability coefficient; c - pitching moment coefficient at zero angle of attack; d - lift derivative with respect to angle of attack; e - drag at zero angle of attack f - lift coefficient at zero angle of attack.