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SOME CONSIDERATIONS ON FORMS OF AERODYNAMICS SURFACES USED FOR NAVAL MISSILES

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Abstract: *Authors' formulas for avoiding critical situations are given, which occur on the aerodynamic surfaces of naval missiles. The sweepback or front angle of wing is now related to critical Mach line and a different method for computing this angle is used. These formulas were successfully applied in new wings computing, based on the missile wings.*
Keywords*: aerodynamic surface, naval missile, sweep-back angle, leading edge, trailing edge, flow.*

1. INTRODUCTION

In aircrafts and some missiles design, the wings, empennages and/or ailerons represent the main aerodynamics components on which depends the (aerodynamic and dynamic) behavior of the object during flight [1][2]. The projections of aerodynamic surfaces on a plain parallel with their median plain or on a reference plain have usually simple geometric forms (rectangle, trapeze or triangle) based more on constructive reasons than functional ones. But, for some naval missiles complex forms of wings, empennages and ailerons (generated by a sequence of complex curves) are used too [3]. The main form and geometric characteristics of the wing and the other surfaces are mainly established on aerodynamics considerations so that the wings, ailerons and empennages to assure the necessary characteristics of flight between the speed limits established for naval missiles [4].

Theoretical and experimental aerodynamics studies established that there are many regimes and domains of air flow around wings, empennages and ailerons [5][6][7]. Special problems are made by the turbulent flow which diminishes the efficiency of commands for air frame, induces vibrations in mechanical systems and supplemental forces which appear and act on naval missile etc. [8][9][10]. Even in subsonic flight (compressible), on wings, empennages and ailerons surfaces appear local supersonic flow and turbulences which become more important when speed rise to transonic regime [11][12].

One of the most important problems in design of air frame is represented by the reduction of efficient surface realized by appearance of turbulence and shock waves on wings, empennages and ailerons. The main method used since '40 is represented by use of boundary angle for forms of aerodynamic surfaces. Later, have been used special devices as: shock wave breakers, apices, disks, vortex generators, spoilers etc. these expensive constructive elements are used rather for commercial aircrafts than for singular or limited use flight vehicles [11][13][14].

The most used forms on plane of wings, empennages and ailerons are those generated through straight lines (rectangle, trapezoidal and triangular or "delta"). These forms have the advantage of being easy to make with enough precision demanded by design. In subsonic compressible flight is often meat the trapezoidal form. This form and its versions will be analyzed further.

The geometric elements of form on plane (Fig. 1.1) which will be used for calculation are: wing surface S_{ar}, root wing chord c_0, tip wing chord $c_e = c_{50}$, span b, sweepback angle of leading edge χ_0, sweepback angle of trailing edge χ_{100}.

The element which determines the orientation in plane of the aerodynamic surfaces is the sweepback angle χ. Usually, the reference definition of sweepback angle is between the perpendicular line on longitudinal axe of the naval missile and one of edges (fig. 1.2). The recommended values are 0^o … 20^o for subsonic incompressible regime and 20^o … 40^o for subsonic compressible and transonic flight regimes.

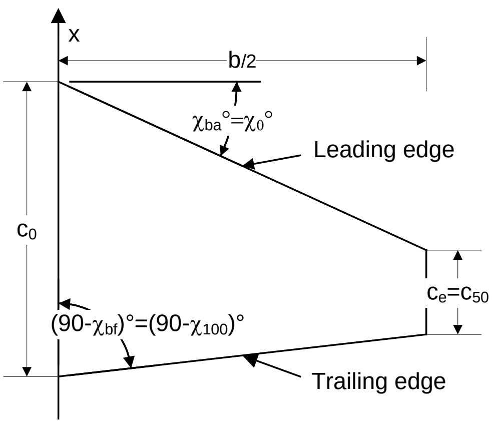


Fig. 1.1. Topview of a wing (planform)

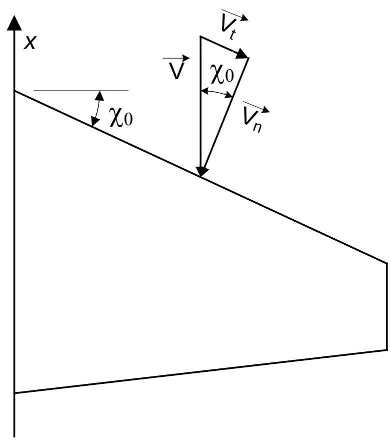


Fig. 1.2. Critical speed derivation

For subsonic compressible and transonic flight regimes, the wing having sweepback angle represents an effective way to delay the detachments induces by the shock waves on wing, in boundary layer and in air flow (the cases of appearance of disturbances phenomena, turbulence, vortexes, boundary layer detachment and rise of friction). This is the way to obtain a much better behavior of the wing and an appreciable delay of the moment of appearance of critical speed corresponding to critic Mach number, $M_{cr,}$ and normal component of speed, $\overrightarrow{V_n}$.

In accordance with Fig. 1.2, it can be writing:

$$M_{cr} = \frac{\left(M_{cr}\right)_{\chi=0}}{\cos(\chi)} \quad \text{or} \quad \chi_0 = \arccos\left[\frac{\left(M_{cr}\right)_{\chi=0}}{M_\infty}\right]. \qquad (1.1)$$

In the case of missiles having supersonic flight, the wing, empennages or ailerons with sweepback angle with rounding front edge, for M < $1/\cos(\chi_0)$ assure the reduction of drag force. But, χ_0 must not exceed the value $70^\circ 31' 43''$, because is necessary to maintain a sufficient minim surface of the wing.

2. A NEW GENERAL METHOD FOR CALCULATING THE SWEEPBACK ANGLE OF WING

Starting for now is presented a new method for determination of sweepback angles of wings, empennages or ailerons edges starting from the position of supersonic flow on aerodynamic profiles for subsonic compressible or transonic flight speed, for some symmetric profiles NACA type (0006, 0009, 63-006, 63-009, 64-006, 64- 009, 65-006, 65-009, 65-009, 65-006, 65-009). Analysis is made taking into account the determinations presented in NACA Report No. 824 – Summary of Airfoil Data [15] and a comparison of efficiency of profiles adapted to high speed of flight is presented.

Starting from some simple geometric relations, for $r = c_e/c_0$, $0 \le r \le 1$, the following relations between sweepback angles of the wings, χ_0, χ_{100} and $\chi_{\varepsilon\ max}$, considering the speed positions as in fig. 1.3, on maxim thickness:

$$\tan(\chi_0) + \tan(\chi_{100}) = 2\frac{c_0}{b}(1-r); \qquad (1.2)$$

$$\tan(\chi_0) + \tan(\chi_{100}) = 4\frac{S_{ar}}{b^2}\frac{1-r}{1+r}; \qquad (1.3)$$

$$\tan(\chi_0) + \tan(\chi_{100}) = \frac{4}{\lambda}\frac{1-r}{1+r}. \qquad (1.4)$$

Because the analyzed profiles do not have the same coordinate of maximum thickness, $\chi_{\varepsilon\ max}$, the sweepback angle as a function of those of line of maximum thickness, $\chi_{\varepsilon\ max}$, determined for M_{cr}, is:

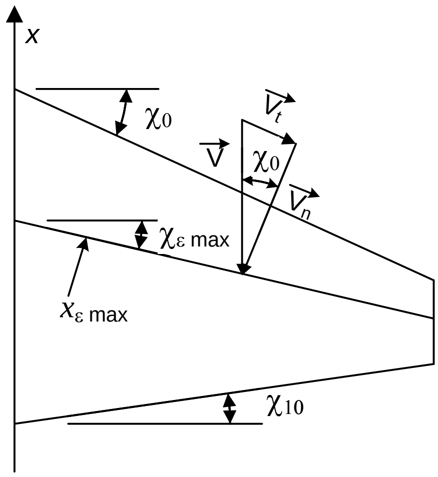


Fig. 1.3. The derivation method

$$\chi_0 = \arctan\left[\tan(\chi_{\varepsilon\max}) - 2\frac{c_0}{b}(1-r)x_{\varepsilon\max}\right]; \qquad (1.5)$$

$$\chi_0 = \arctan\left[\tan(\chi_{\varepsilon\max}) - 4\frac{S_{ar}}{b^2}\frac{1-r}{1+r}x_{\varepsilon\max}\right]; \qquad (1.6)$$

$$\chi_0 = \arctan\left[\tan(\chi_{\varepsilon\max}) - \frac{4}{\lambda}\frac{1-r}{1+r}x_{\varepsilon\max}\right], \qquad (1.7)$$

respectively,

$$\chi_{100} = \arctan\left[2\frac{c_0}{b}(1-r)(1+x_{\varepsilon\max}) - \tan(\chi_{\varepsilon\max})\right]; \qquad (1.8)$$

$$\chi_{100} = \arctan\left[4\frac{S_{ar}}{b^2}\frac{1-r}{1+r}(1+x_{\varepsilon\max}) - \tan(\chi_{\varepsilon\max})\right]; \qquad (1.9)$$

$$\chi_{100} = \arctan\left[\frac{4}{\lambda}\frac{1-r}{1+r}\left(1+x_{\varepsilon\max}\right)-\tan\left(\chi_{\varepsilon\max}\right)\right]. \quad (1.10)$$

But, to establish the optimum value of sweepback angle must take into account the fact that simultaneously with its rise the slope of lift curve decreases and this fact has important consequences on rise the missile to flight altitude and soaring to target. So, the choice of sweepback angle is a complex problem and very important one because of great implications on flight performances and quality of missile.

. Because the angles χ_0 and χ_{100} are connected with the flow speed on wing profile and along the wing, they become dependent on profile thickness. For some classic NACA symmetric profiles, which are characteristic for naval missile wings, for *r* = 0.146, $\lambda = 1.185$, and $M_\infty = 0.94$, from Rel. (1.5) … (1.10) are obtained the results in Tab. 1.

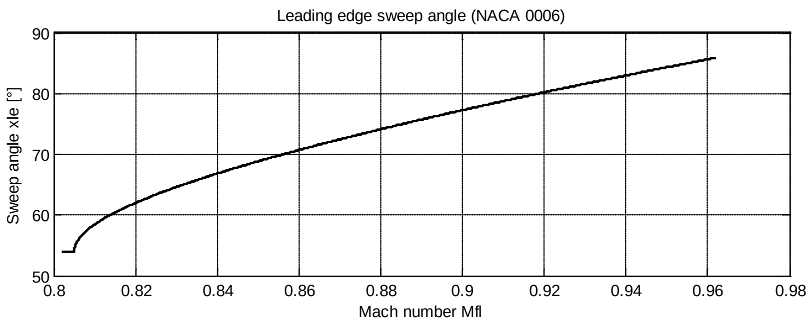
Tab.1. Critical characteristics of analyzed profiles

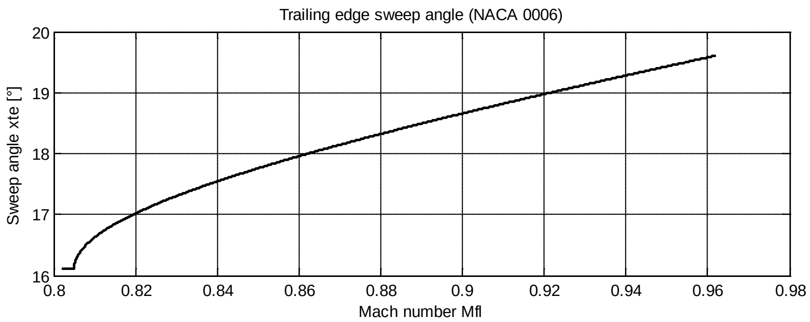
Profile	M_{cr}	$\chi_0\ [^\circ]$	$\chi_{100}[^\circ]$
0006	0.805	57.75	13.71
0009	0.766	60.01	13.25
63-006	0.834	57.97	13.67
63-009	0.780	61.02	13.04
64-006	0.836	59.03	13.45
64-009	0.785	61.76	12.87
65-006	0.838	60.02	13.25
65-009	0.790	62.47	12.71
66-006	0.840	61.30	12.79
66-009	0.795	63.43	12.49

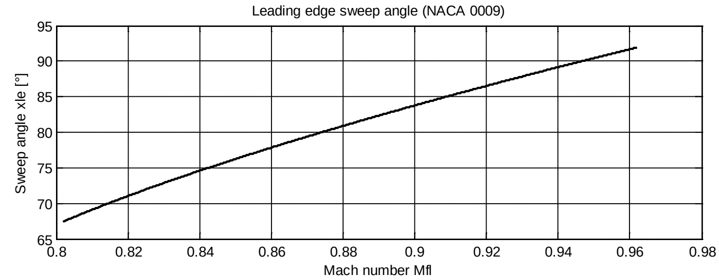
The variations of sweepback angles of wings, empennages and ailerons of naval missiles are presented for an aerodynamic surface having *r* = 0.146 and characteristics of profiles in references presented in list.

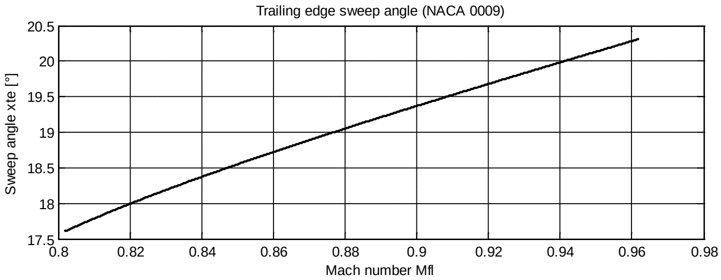
It is seen that the thick profiles (profiles having relative thickness of 6%) are "somewhat indifferent" in first speed domain. The variation of sweepback of leading edge is almost constant until approximate *M* = 0.8. For grater Mach numbers appears a rapid rise of sweepback angle of leading edge, followed of almost linear rise of the angle for the relative speed regime which remain. This is the explanation of the fact that critic Mach number of these profiles is placed in domain 0.805 – 0.840.

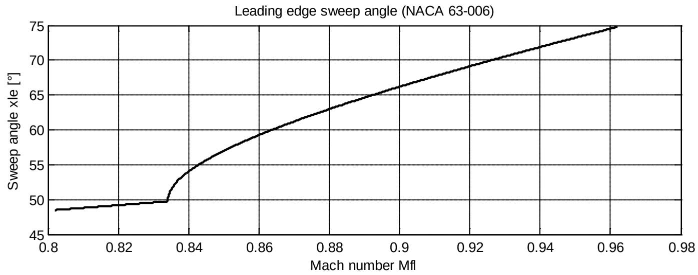
Also, results that the NACA profiles 0006 and 0009 asses limits in use for relative speed over *M* = 0.86.

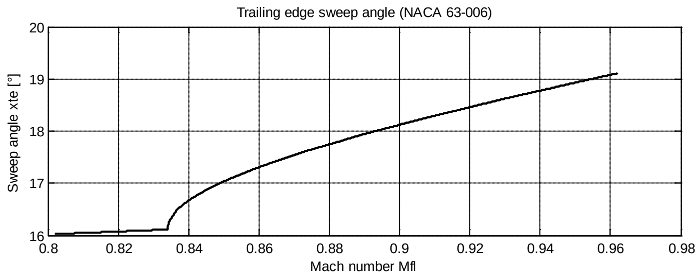





Leading edge sweep angle (NACA 0009)
Sweep angle xle [°]
Mach number Mfl


Trailing edge sweep angle (NACA 0009)
Sweep angle xte [°]
Mach number Mfl


Leading edge sweep angle (NACA 63-006)
Sweep angle xle [°]
Mach number Mfl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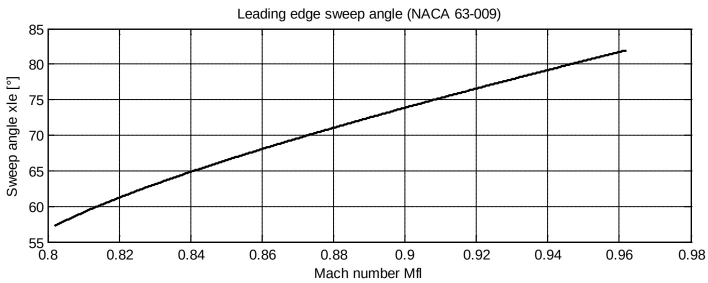
Sweep angle xte [°]
Mach number Mfl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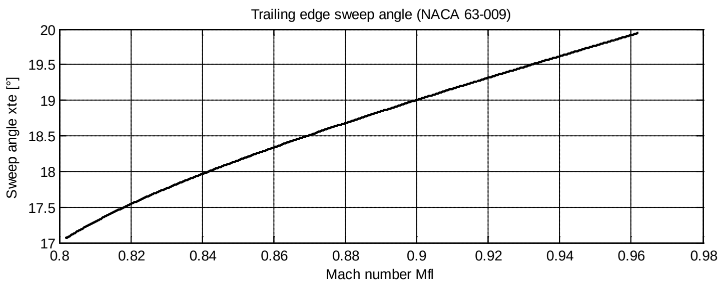
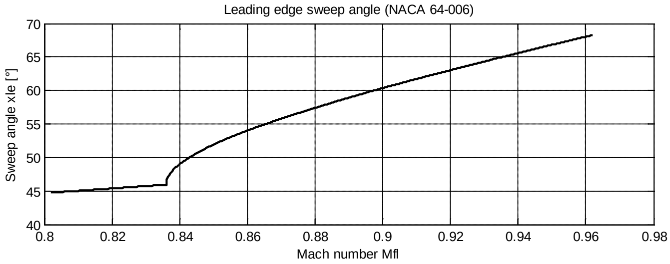
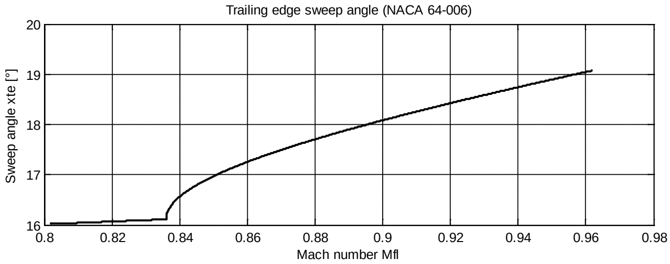
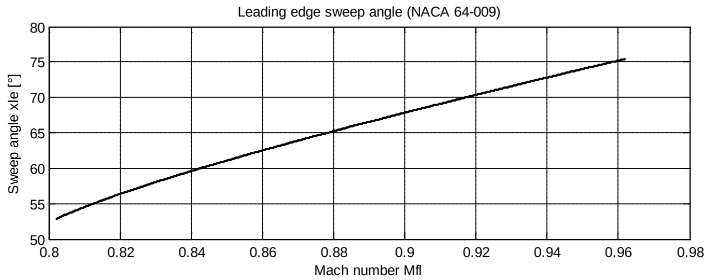
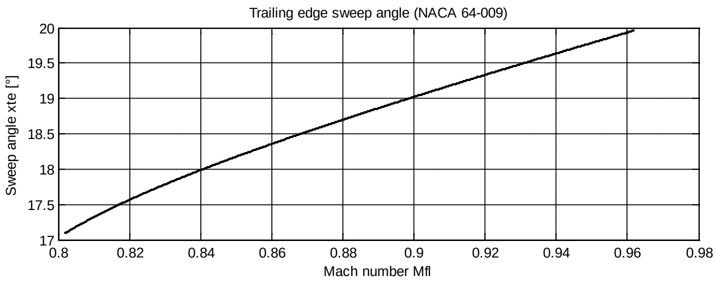
Sweep angle xle [°]
Mach number Mfl

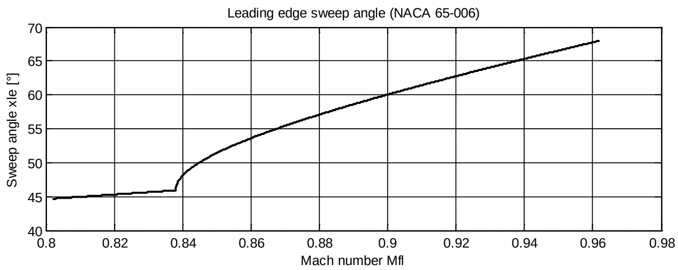

Trailing edge sweep angle (NACA 63-009)
Sweep angle xte [°]
Mach number Mfl


Leading edge sweep angle (NACA 64-006)
Sweep angle xle [°]
70
65
60
55
50
45
40
0.8 0.82 0.84 0.86 0.88 0.9 0.92 0.94 0.96 0.98
Mach number Mfl


Trailing edge sweep angle (NACA 64-006)
Sweep angle xte [°]
20
19
18
17
16
0.8 0.82 0.84 0.86 0.88 0.9 0.92 0.94 0.96 0.98
Mach number Mfl


Leading edge sweep angle (NACA 64-009)
Sweep angle xle [°]
80
75
70
65
60
55
50
0.8 0.82 0.84 0.86 0.88 0.9 0.92 0.94 0.96 0.98
Mach number Mfl


Trailing edge sweep angle (NACA 64-009)
Sweep angle xte [°]
20
19.5
19
18.5
18
17.5
17
0.8 0.82 0.84 0.86 0.88 0.9 0.92 0.94 0.96 0.98
Mach number Mfl


Leading edge sweep angle (NACA 65-006)
Sweep angle xle [°]
70
65
60
55
50
45
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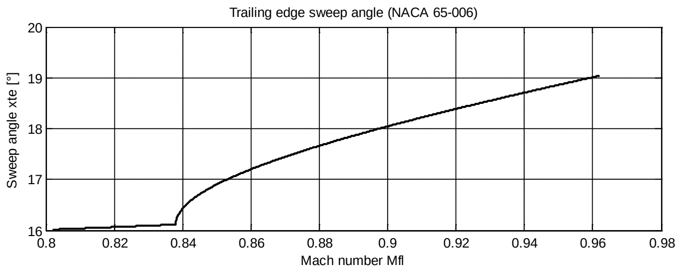
0.8 0.82 0.84 0.86 0.88 0.9 0.92 0.94 0.96 0.98
Mach number Mfl


Trailing edge sweep angle (NACA 65-006)
Sweep angle xte [°]
20
19
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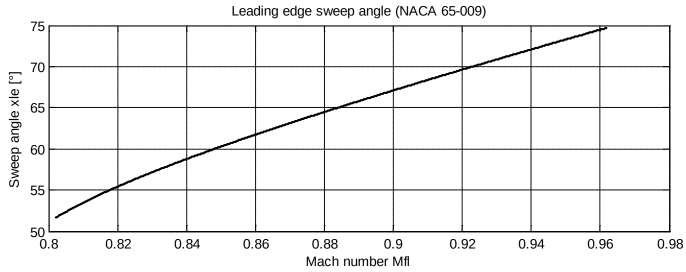
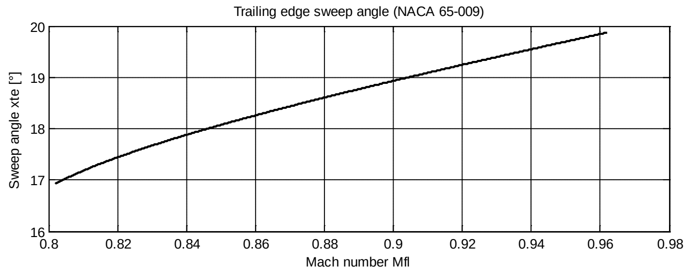
16
0.8 0.82 0.84 0.86 0.88 0.9 0.92 0.94 0.96 0.98
Mach number Mfl


Leading edge sweep angle (NACA 65-009)
Sweep angle xle [°]
75
70
65
60
55
50
0.8 0.82 0.84 0.86 0.88 0.9 0.92 0.94 0.96 0.98
Mach number Mfl


Trailing edge sweep angle (NACA 65-009)
Sweep angle xte [°]
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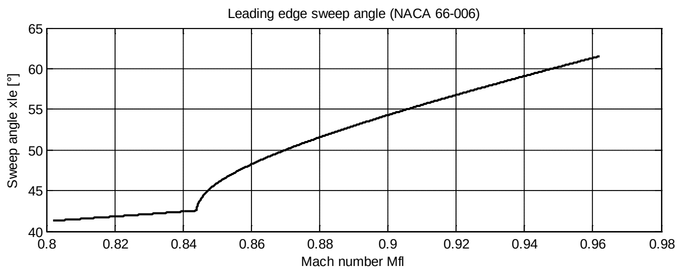
16
0.8 0.82 0.84 0.86 0.88 0.9 0.92 0.94 0.96 0.98
Mach number Mfl


Leading edge sweep angle (NACA 66-006)
Sweep angle xle [°]
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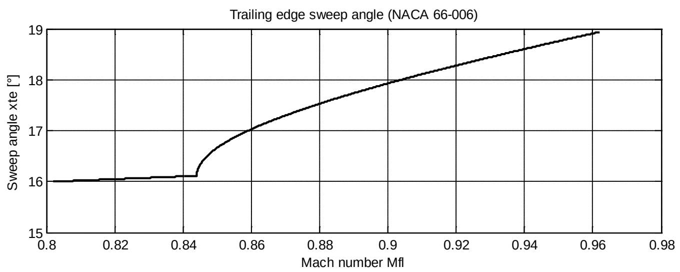
40
0.8 0.82 0.84 0.86 0.88 0.9 0.92 0.94 0.96 0.98
Mach number Mfl


Trailing edge sweep angle (NACA 66-006)
Sweep angle xte [°]
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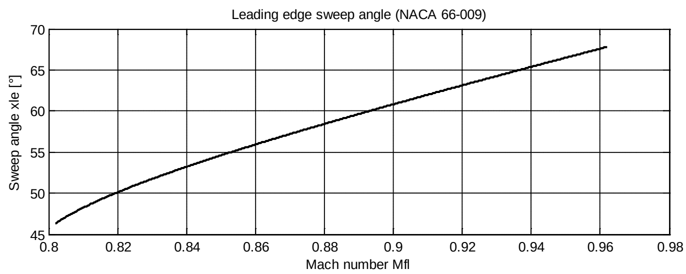
18
17
16
15
0.8 0.82 0.84 0.86 0.88 0.9 0.92 0.94 0.96 0.98
Mach number Mfl


Leading edge sweep angle (NACA 66-009)
Sweep angle xle [°]
70
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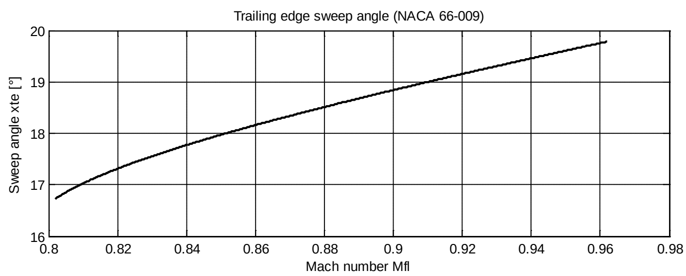
0.8 0.82 0.84 0.86 0.88 0.9 0.92 0.94 0.96 0.98
Mach number Mfl


Trailing edge sweep angle (NACA 66-009)
Sweep angle xte [°]
20
19
18
17
16
0.8 0.82 0.84 0.86 0.88 0.9 0.92 0.94 0.96 0.98
Mach number Mfl

The profiles having relative thickness of 9% are “more sensitive” because the values of critic Mach number are placed in domain 0.766 – 0.795. So, the variation of sweepback angles of the aerodynamic surfaces edges appears since the beginning of the (flight) domain considered for calculus.

But, taking into account that shock wave start to form and manifest for the same relative flight speed, the influence of these is more evident in the case of these profiles.

The critic Mach number continues to diminish when relative thickness of profiles rises, but the profiles having relative thickness greater are not used for wings, empennages and/or ailerons of naval rockets.

Starting from those presented until now, is evident that simultaneous with diminishing the values of critic Mach number raise the influence of drag force because of earlier appearance of supersonic flow on wings, empennages and/or ailerons surfaces.

Also, it is reveals an accentuated rise of sweepback angles in comparison with results presented in references about aircraft design for flight speed specific naval missiles which operate until now.

As a first conclusion must underline that the profiles with small thickness are very useful for design and construction of wings, empennages or ailerons of naval missiles, and those having greater thickness are useful for construction of apexes or shock wave breakers.

3. CONCLUDING REMARKS

Rel. (1.5) … (1.10) represents a new point of view on calculation of wings for naval missile which differs from those in references.

The variation of sweepback angles for thick profiles, with relative thickness of 6%, is relatively small until M = 0.8. But, after this value of Mach number appears a rapid rise of sweepback angle of leading edge, followed by almost linear rise of the value of this angle in the last part of speed domain. Also it is seen that profiles NACA 0006 and 0009 assess limitations for their use for relative speed over M = 0.86.

For the profiles having relative thickness of 9%, the variation of sweepback angle of the edges of aerodynamic surfaces begin to manifest starting from values under M = 0.8, and the influence is much more evident for this profiles. Also is observed a rise of these angles more accentuated in comparison with references data for design of airplanes, for speeds specific actual operational naval missiles.

As a general conclusion appears that the thick profiles are useful for wings, empennages and ailerons, and those with greater thickness are useful for apexes and shock wave breakers.

The values of sweepback angles presented in Tab. 1 are confirmed (verified) by the real models of naval missiles, and sweepback angle of leading edge can rich limiting value of 70°31′43″, which is characteristic for subsonic flight speed.

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