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COMPUTATIONAL AERODYNAMIC DESIGN CONCEPTS FOR FUTURISTIC AIR COMBAT

S. C. Gupta
Institute of Armament Technology
Pune, India

Abstract

Advance aerodynamic software is used to arrive at the aerodynamic design concepts to meet the requirement of futuristic air combat. Aerodynamic cleanliness is aimed in the entire flight envelope. Technological feasible limits of various parameters are critically examined. Design concepts covered, include: 1) blend of high sustained load factor with linear acceleration in the plane of normal acceleration, 2) structurally suiting aerodynamic design, 3) mission adaptive profile, and 4) closely coupled canard.

I. Nomenclature

A = aspect ratio
b = semi-span
c = local chord
C_D = induced drag coefficient
C_L = lift coefficient
$C_{L\alpha}$ = lift curve slope/radian
I_{yy} = moment of inertia about lateral axis of the aircraft
M = Mach number
$m_{c.g.}$ = pitching moment about center of gravity
w = wing loading
x = chordwise coordinate
y = spanwise coordinate
α = angle of attack
$\dot{\gamma}$ = turning rate
$\ddot{\gamma}$ = rate of turn rate

II. Combat Requirement

In the present day war field scenario with the ECM/ECCM coverage and AWACS support, air combat is becoming increasingly complex. Infra-red (IR) and semi-active missiles have been developed in the past. Air to air missiles in the development include: 1) short range missiles (SRMs) with all aspect capability, and 2) medium range missiles (MRMs). These weapons lead to the requirement of new type of manoeuvres.(1,2,3) Feasible missile launch opportunity envelopes with various missiles are shown in Figure 1.

MRM is aimed at improving the supersonic combat effectiveness. High turn rate at supersonic speeds is restricted by high wave drag of symmetrical wings. Aerodynamic optimisation in this range of flight envelope is required for the effective use of MRMs. Direct lift control (DLC) benefit interchange between normal acceleration and linear acceleration in the plane of normal acceleration.(4) DLC is aimed at better firing opportunity.

Combat requirement with SRM is that of instantaneous manoeuvrability at subsonic speeds (refer Figure 2). Direct side force control (DSFC) is aimed at providing the side skid capability to the aircraft for better aiming opportunity and escape, epecially in the head-on situation. DLC-DSFC coordinated effort in a close combat for the SRM weapon system could provide, effective combat manoeuvrability for the entire range of aspect angles. Further, the aerodynamic characteristics expected during violent manoeuvres should be free from aerodynamic hysteresis.

The manoeuvre requirement can thus be placed in the following manner:

(a) Aerodynamically efficient wide flight envelope.
(b) High sustained manoeuvrability with in-reserve DLC.
(c) Large unsteady manoeuvrability with in-reserve DSFC.
(d) Least aerodynamic hysteresis and minimum control servo power expenditure.

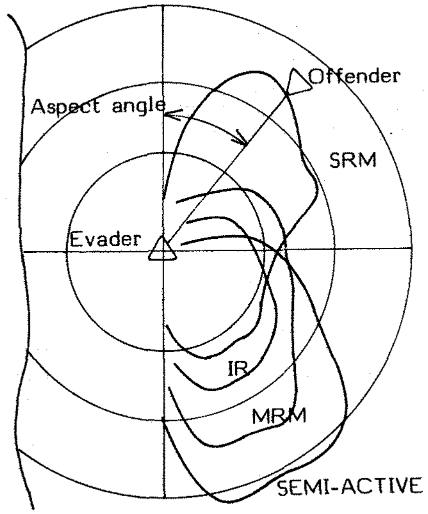


Figure 1. Missile Launch Opportunity Envelope

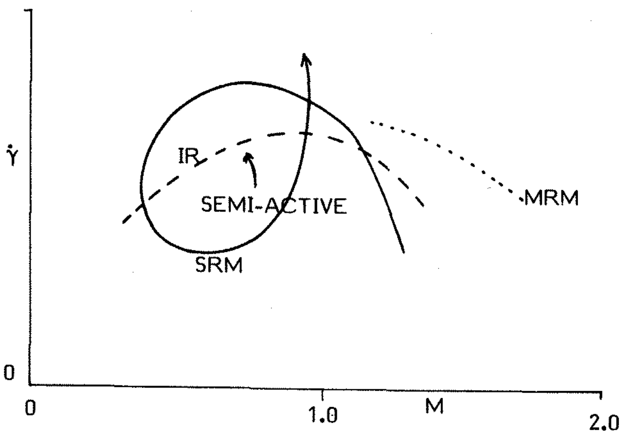


Figure 2. Manoeuvre Requirement with Various Missiles

III. Manoeuvrability

Speed, rate of climb, sustained turn rate and unsteady performance can be greatly increased through thrust-to-weight ratio (T/W). T/W of existing combat aircraft fall above 1.0. Increase in T/W ratio adversely affects cost and weight of the aircraft. T/W of 1.2 - 1.4 is reported to be the technological limit of feasibility in the energy - performance management(3). For the energy specified, maximum is required to be done to the aircraft configuration to achieve maximum possible manoeuvrability. There are two aspects of manoeuvrability, namely: 1) sustained steady, and 2) unsteady instantaneous.

Sustained Manoeuvres

Subsonic and transonic steady performance is required for IR/semi-active missile system. Performance capabilities that of new MRMs lead to the manoeuvre type combat in supersonic speed regime. Rate of turn and load factor are given as,

$$\dot{\gamma} \propto n, \quad n \propto [\, C_{L_\alpha} /w] \; \alpha \qquad (1)$$

Induced drag (D), *in the linear range* may be expressed as, $D = nW\alpha$. High sustained turn rate at any speed is possible through high load factor. High load factor can be attained through: 1) high value of lift curve slope, 2) high value of angle of attack, and 3) low wing loading. High value of angle of attack results in high induced drag. The angle of attack therefore, should be kept low. Thus, the choice of achieving high load factor lies in the ratio C_{L_α} /w. Lift curve slope depends upon the wing planform. Trapezoidal wing planform is good for subsonic *and transonic performance only*. Strake wing is good for high angles of attack subsonic performance. Forward sweep technology is not yet a much established subject. The choice thus, goes for a delta wing for its high performance in the supersonic domain.

Supersonic manoeuvre capability is possible through low aspect ratio delta wing. This is because of the low wave drag of deltas. Additionally, deltas have considerable potential for lift to drag (L/D) improvement. This is because the spanwise loading of deltas is far from being elliptic. Lift curve slope *of symmetrical delta wings of aspect ratio* 2-3 is generated through computer code 'WINGER' of reference 5. Effect of compressibility on lift curve slope is shown in Figure 3. High C_{L_α} planform of aspect ratio 3, suffers from large compressibility effects. Planform of aspect ratio 2 has low C_{L_α} and compressibility influence is marginal. Striking balance between the value of C_{L_α} and compressibility influence is considered. This results in choice of delta of 2.5 aspect ratio. This planform with leading edge sweep of 56° is considered for subsequent studies.

Wing loading is crucial parameter and is always linked with the sustained performance. Low wing loading is preferred to achieve high sustained turn rate. However, low wing loading results, increase in horizontal acceleration time and increase in aircraft empty equipped weight(6). Wing loading as high as 325 kg/m^2 and as low as 225 kg/m^2 are seen in certain designs. Present trend is in favour of lower wing loading. Technological limit of feasibility in this regard is brought out in reference 3. Wing loading in the range of 225-250 kg/m^2 is considered favorable in the present day fighter aircraft design.

With the consideration of C_{L_α} and w mentioned above, deltas are bound to build up fairly large angles of attack in the subsonic/transonic regime of speed. Deltas performance in the subsonic/transonic speed regime gets spoiled by the high induced drag. Deltas, therefore, require aerodynamic cleanliness in this flow regime. This is possible through mission adaptive profile (MAP).

DLC is aimed at improving missile launch opportunity envelope. A tail-less delta takes advantage from CCV (control configurated vehicle) technology. Flaps can be deflected according to required manoeuvrability, thus high lift can be generated keeping angle of attack low . Boosting DLC advantage is feasible through canard; wherein two point force application is aimed to blend normal acceleration and linear acceleration in the plane of normal acceleration. Closely coupled canard has the advantage of generating high maximum lift by inducing downwash on the main planform(7). Additionally, it helps supressing gust alleviation for a low wing loading planform.

Unsteady Manoeuvres

SRMs require instantaneous manoeuvre capability rather than sustained performance. Rate of turn rate is expressed by formula below:

$$\ddot{\gamma} = m_{c.g.}/I_{yy} \qquad (2)$$

Large rate of turn rate need be developed through large $m_{c.g.}$; which is feasible through canard control. Aircraft in combat with SRM operates close to maximum *lift boundary*. Canard is essential tool to produce high maximum usable lift.

DSFC substantially improves the head-on attack. DSFC can be provided through twin side force system, generated by a keel ahead of c.g. located underneath the fuselage and vertical tail fin surface. DSFC and DLC result in a type of skidding manoeuvre building up normal acceleration for escape. Additionally, mission adaptive directional stability may be developed through all moving keel.

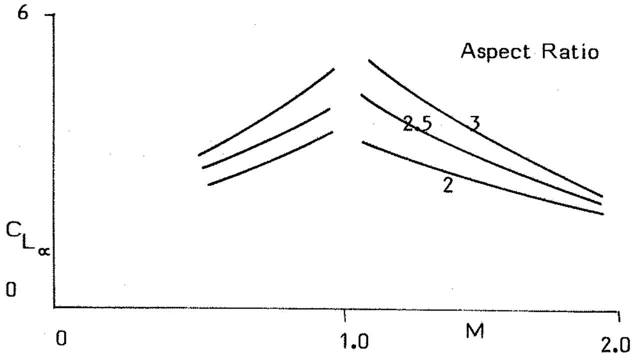


Figure 3. Lift Curve Slope of Delta Wings

IV. Aerodynamic Efficiency

Modern combat aircraft require optimal aerodynamic performance throughout the flight envelope. To achieve this, continuous variation in wing profile with variation in Mach number and angle of attack is essential . Since, it is not possible to vary the entire camber of wing in flight, some wing portion i.e. leading edge flap (LEF) and trailing edge flap (TEF) is considered free for deflection. LEF and TEF act as manoeuvring flaps for the optimal aerodynamic performance in flight. Optimum LEF and TEF deflections result in 'MAP'. Thus, the entire planform may be optimised for single design point (say, supersonic cruise to impart low altitude supersonic penetration capability to the aircraft). Off-design point operations can be achieved through 'MAP'.

Optimisation of Entire Planform

Computer code 'OPSGER' of reference-8 is applied to optimise flat plate delta of 2.5 aspect ratio. Lift alone constraint is considered in the optimisation. Wing root bending moment and pitching moment are allowed to vary in the optimisation process. Results are shown in Table 1. Advantage of optimisation deteriorates with increasing compressibility. Yet the optimisation need be done for the supersonic Mach numbers. This is because the supersonic drag levels are much higher in comparison to subsonic drag levels. Camber resulting from optimisation is shown in Figures 4a & 4b. Conical camber has large spanwise gradients (refer Figure 4b) and suggests a structurally unsound design.

Basic delta is therefore, modified. A crank-crop-delta is envisaged out of the basic delta, keeping aspect ratio, wing area, span and root chord unaltered. Crank location is arbitrarily selected. Computer code 'OPSGER' of reference 8 is applied to optimise such a flat plate, crank-crop-delta of aspect ratio 2.5. Lift alone constraint is considered in the optimisation exercise. Wing root bending moment and pitching moment are allowed to vary in the optimisation process. Results are shown in Table 2. Camber resulting from optimisation is shown in Figures 5a & 5b. Spanwise variation of conical camber of crank-crop-delta is much lesser in comparison to that of delta wing (refer Figures 4b & 5b). This suggests crank-crop-delta as the ideal choice for structurally sound design. However, slight degradation in the optimisation effort appears in case of crank-crop-delta (refer Table 1 & Table 2).

Aircraft in the supersonic manoeuvre operates at low angles of attack. Slopes of the optimal camber are small at low angles of attack. The entire planform could be aeroelastically tailored to generate such optimal shapes. With the advent of composite materials, such a feature is becoming feasible.

M	C_L	C_D		% Drag Reduction
		Flat Plate	Optimal Profile	
0.5	.196	.0137	.0048	64.96
0.75	.216	.0151	.0059	61.60
1.25	.242	.0169	.0097	42.60

TABLE 1. Drag Levels. Delta Wing, A = 2.5, α = 4°

M	C_L	C_D		% Drag Reduction
		Flat Plate	Optimal Profile	
0.5	.199	.0139	.0057	58.99
0.75	.222	.0155	.0071	54.19
1.25	.260	.0182	.0139	23.62

TABLE 2. Drag Levels. Crank-Crop-Delta Wing, A = 2.5, α = 4°

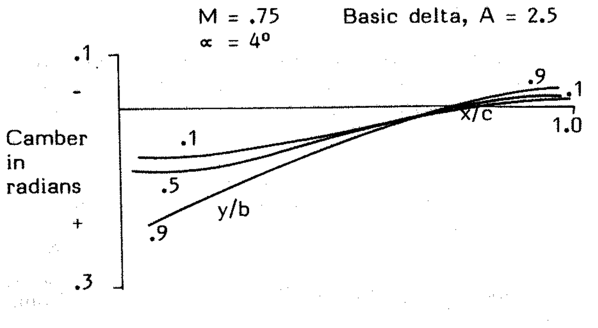


Figure 4a. Chordwise Slopes of the Optimal Profile

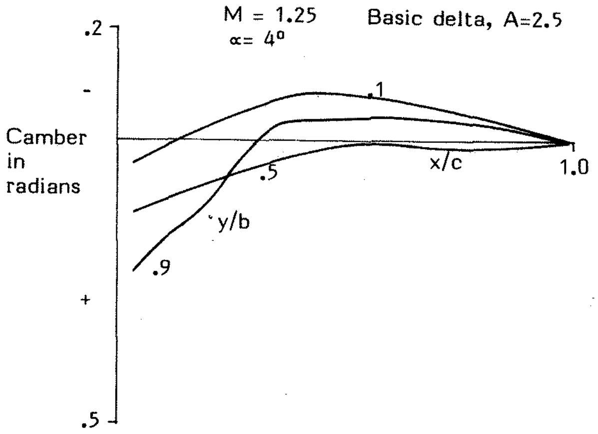
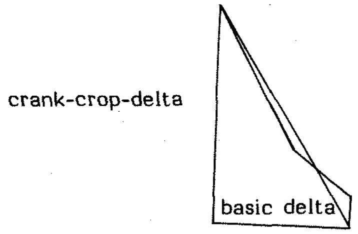


Figure 4b. Chordwise Slopes of the Optimal Profile



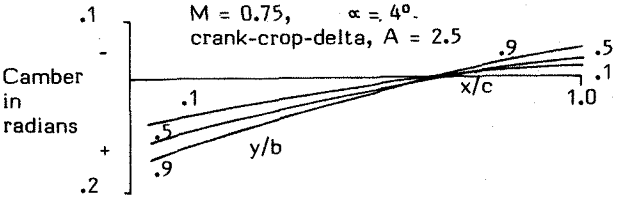


Figure 5a. Chordwise Slopes of the Optimal Profile

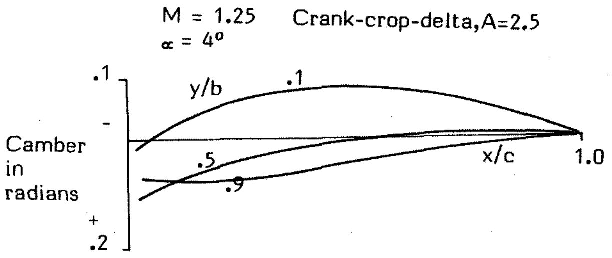


Figure 5b. Chordwise Slopes of the Optimal Profile

Mission Adaptive Profile

At the subsonic manoeuvre, aircraft operates at high angles of attack. Optimal camber required are large; and this demand cannot be met through aeroelastic tailoring. Certain advantage from aeroelastic tailoring may however, be gained. Thus, the requirement of variation of entire wing profile with variation in angle of attack cannot be met. The optimisation task is vested upon 'MAP'. 'MAP' is essentially an optimisation exercise aimed to determine LEF and TEF deflections that will satisfy the condition of minimum drag under the constraint of lift and camber of the remaining portion of the planform. Computer code of reference 9, 'GENMAP' is applied to delta and crank-crop-delta, under consideration. Flat plate model is taken. 35% of local wing chord is taken to form LEF and 15% of local wing chord is taken to form TEF. 'MAP' is applied, subject to constraint of lift. Wing root bending moment and pitching moment are allowed to vary in the process of mission adaption. Resulting camber distribution in both the cases, for subsonic flow regime is shown in Figure 6. Spanwise variation in LEF camber is nearly constant from root to tip for the case of crank-crop-delta in comparison to delta. This suggest suitability of a crank-crop-delta against a delta for the mission adaption.

Impact of 'MAP' on drag reduction is shown in Figure 7. Large gain in load factor development through 'MAP' is broughtout in reference 9. 'MAP' efficiency deteriorates at supersonic speeds. Therefore, it could be best used for subsonic flow. 'MAP' is required to be programmed as a function of Mach number and angle of attack.

LEF plays the lead role in the 'MAP' effort. TEF plays the negligible role. LEF deflections at higher angle of attack are large. 'MAP' workload could be reduced by the aeroelastic tailoring of the complete planform.

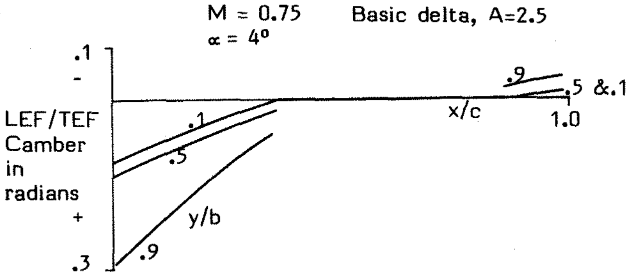


Figure 6a. 'MAP' Slopes

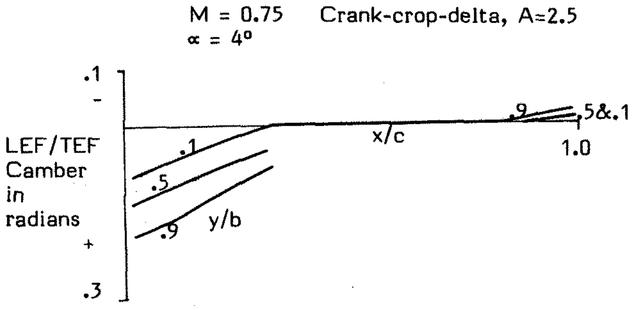


Figure 6b. 'MAP' Slopes

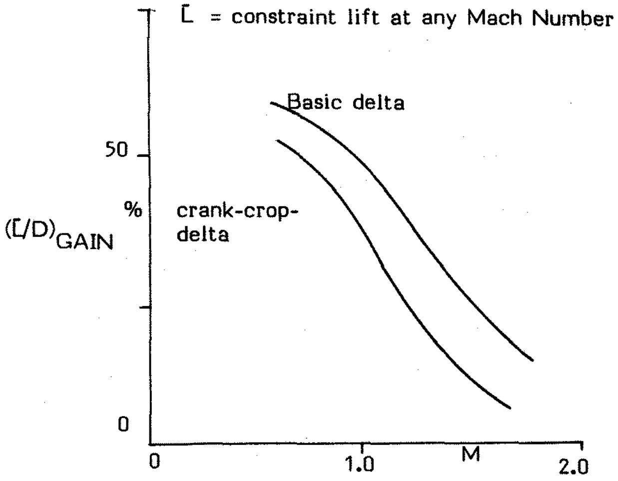


Figure 7. Drag Reduction Comparison

V. Conclusions

Manoeuvre demand for various missiles is broughtout. Aircraft performance expectation are wide for wide range of weapon system. Advance aerodynamic software is used to generate data. Data is analysed to arrive at design concepts, aimed at meeting the performance expectation of the futuristic air combat.

Conically cambered, crank-crop-delta, optimised for supersonic cruise is considered as an ideal choice of lifting planform. Mission adaption through LEF and TEF blend is aimed at providing efficient manoeuvre performance in the subsonic flow regime. Closely coupled canard merits over non-canard configuration. Importance of direct lift control and direct side force control is imperative in the most modern air combat.

VI. Acknowledgements

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