Status Review of a Supersonically Biased Fighter Wing Design Study

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Results from a cooperative supersonically biased fighter wing design study between the National Aeronautics and Space Administration and the McDonnell Aircraft Company are summarized The study has been con ducted to explore the effects of supersonic aerodynamic performance, transonic maneuvering, low speed/high angle of-attack characteristics, and airframe system integration requirements on fighter aircraft wing design The approach adopted involves the theoretical and experimental investigation of four advanced aircraft con figurations which differ only in wing geometry. Supersonic and low-speed/high angle-of attack wind tunnel results have been obtained for 20 deg trapezoidal, 65 deg delta, 70/30-deg advanced cranked, and 70/66 deg advanced cranked-wing configurations The supersonic data show that the advanced cranked wings out perform the trapezoidal and delta wings at cruise and moderate lift conditions Low speed/high angle of attack results show that all wings have significant stability problems above an angle of attack of 20 deg Aircraft sizing analysis results show that the advanced cranked wing configurations are significantly lighter, based upon takeoff gross weight, than either the trapezoidal or the delta wings

Nomenclature

ALT	= altitude, ft
$A\!\!R$	= aspect ratio
b	= wing span
c	= local wing chord
$\bar{c}$	= mean aerodynamic chord
C_D	= drag coefficient
$C_{D_{min}}$	= minimum drag coefficient
C_L	= lift coefficient
C_m	= pitching-moment coefficient
C_{l_β}	= lateral-stability parameter
C_{n_β}	= directional stability parameter
FS	= full scale
$(L/D)_{max}$	= maximum lift to drag ratio
M	= Mach number
MS	= model scale
n_z	= load factor
R_N	= Reynolds number
SEP	= specific excess power
S_{REF}	= wing reference area
t	= thickness
TSFC	= thrust specific fuel consumption
x y,z	= Cartesian coordinate in streamwise, spanwise, and vertical directions, respectively
α	= angle of attack, deg
β	= angle of sideslip, deg
λ	= taper ratio

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Introduction

HISTORICALLY, fighter aircraft have been designed for efficient transonic cruise and maneuvering with no sustained supersonic cruise capability These configurations characteristically require partial afterburning to dash at supersonic speeds This has led to the common conception that a supersonic tactical aircraft is not a technologically or economically viable concept. However, advances in aerodynamics, structures, and propulsion systems since the mid-1960's suggest that these perceptions may no longer be valid [1 2]

Previous aircraft design studies have been limited in scope due to an approach which emphasized aerodynamic efficiency in one speed regime while significantly compromising the performance in others This has been especially true for supersonic aircraft designs.[3 5] These designs, though supersonically attractive, had highly cambered wings and fuselages tailored to a very specific fight condition Off design performance or evaluation criteria other than aerodynamics were not considered In an attempt to in corporate more pertinent criteria into the supersonic wing design process, a recent study[6] employed an F 16 fighter aircraft wind tunnel model This was a major improvement over previous efforts; however, considerations of overall mission performance, airframe weight, propulsion, or air frame integration were not addressed

The present research program draws from these previous efforts in developing a supersonic wing design approach applicable to fighter aircraft However, the merits of the wing design are judged not only on supersonic aerodynamic ef ficiency, but also on airframe low speed/high angle of attack stability, transonic maneuvering capability, and aircraft weight, as determined from aircraft sizing studies In pursuit of this goal, the program attempts to experimentally validate aerodynamic technologies developed during the Supersonic Transport/Supersonic Cruise Research (SST/SCR) era and adapt them to fighter aircraft To address these objectives, a cooperative effort between the National Aeronautics and Space Administration (NASA) and the McDonnell Aircraft

Company (MCAIR) was initiated in which the advanced supersonic wing design expertise at NASA was integrated with the design synthesis experience of MCAIR to define procedures for the design of an efficient transonic/supersonic fighter aircraft This paper reports the status of this design study

Technical Approach

The approach adopted for this study can be separated into three phases In the first phase, 16 configuration concepts differing only in wing planform shape were subjected to theoretical analysis to determine the aerodynamic characteristics and to provide estimates of the takeoff gross weight (TOGW). From this information, four configurations were selected for sizing to meet the requirements of a representative deep strike, supersonic cruise biased mission In this first phase, a 1990 level of aerodynamic, propulsion, and structural technology was assumed In the second phase of the study, wind tunnel models of the four configurations were used to experimentally validate the estimated aerodynamic performance, and a second sizing was performed using the experimentally acquired aerodynamic information From the aerodynamic performance and sizing results of the second phase, two configurations were selected for the wing camber design, which was the third phase of the study

Mission profiles which stress supersonic cruise capability with significant transonic performance were used in this wing-design study Defined in Fig 1 are the primary (A) and secondary (B) missions selected. Each mission is dominated by a supersonic cruise leg of 200 n mi Mission A is an air-to ground (ATG) profile and Mission B is an air to-air (ATA) profile. The major differences between the two profiles are the weapons loading, maneuver, and acceleration requirements In addition, both missions have a representative short takeoff and landing (STOL) requirement with a maximum field length of 1500 ft Operational ceilings of 50,000 ft have been assumed to eliminate the need for complex life support systems

The preliminary theoretical aerodynamics estimates assumed attainable levels of leading-edge suction at supersonic speeds and vortex flaps at subsonic and transonic speeds Weight estimates assumed advanced composites structures for both the fuselage and wing, and this resulted in a 10% reduction in fuselage weight and a 20% reduction in wing weight from a conventional all metal aircraft design The propulsion system consisted of two advanced technology afterburning turbojet engines with two dimensional converging diverging nozzles with thrust vectoring and reversing capability A turbojet engine was selected because of its efficiency at high altitude, high speed cruise

The four geometries selected for preliminary sizing were a 20 deg trapezoidal/45 deg horizontal tail combination, 65 deg delta (tailless), 70/30 deg crank (tailless), and a 70/66 deg crank (tailless) configuration Preliminary weight estimates are for uncambered wings with variable camber leading-edge devices for transonic maneuvering These devices included leading edge vortex flaps for the highly swept wings and simple rotating leading and trailing-edge flaps for the lower sweep wing As wing camber is defined during the third phase of the program, wing weight estimates will be updated

Pretest Sizing Results

Aircraft sizing analysis is performed with the MCAIR Computer Aided Design Evaluation (CADE)[7] code This method perturbs a reference input aircraft design until it meets the performance requirements The computer code, diagrammed in Fig 2, numerically models the airframe weight geometry, and aerodynamic performance for each component of a baseline aircraft Engine operating characteristics, performance, weight, and geometry are similarly modeled. For a given set of design conditions, mission profile, and performance requirements, the airframe components and engine characteristics are scaled and fuel requirements are assessed For this study, the sizing procedure was used to determine the minimum TOGW for each input aircraft configuration

Aerodynamic estimates were made using NASA and MCAIR analytical and empirical techniques Supersonic drag-due-to lift and leading-edge suction estimates were drawn from the Supersonic Design and Analysis System (SDAS).[8] Transonic maneuvering drag-due to lift estimates for the low and moderately swept wings with scheduled leading-edge, attached-flow flaps were developed using the extensive MCAIR data base on the F 18 wing. For the cranked wings, transonic drag due to-lift with vortex flaps was estimated using the method of Ref 9 Zero lift wave drag predictions were made with the method of Ref 10 for the fuselage and component interference contributions, and MCAIR empirical techniques were used for wing, fin, and boundary layer diverter contributions Skin friction calculations were made with the method of Ref 11 As a study ground rule, all aircraft were configured for neutral subsonic static stability at the reference center of gravity The neutral point location was determined from theoretical estimates obtained from Ref 9

The preliminary sizing results are shown in Fig 3 for the four selected configurations In addition to TOGW values, the planform reference area for each configuration is noted below the configuration sketch Results for Missions A and B indicate that the cranked wing, tailless concepts are competitive with the more conventional designs on the basis of TOGW It should be noted that the aircraft sizing results

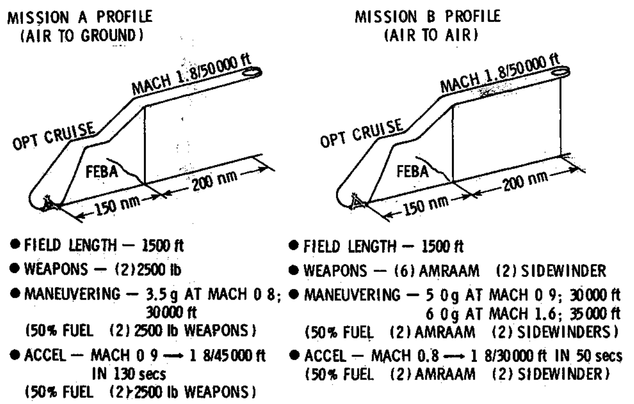

Fig 1 Mission and combat requirements selected for aircraft sizing analysis

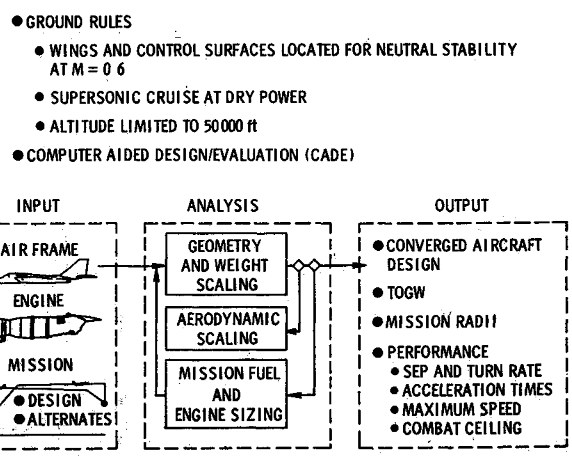

Fig. 2 Aircraft sizing ground rules and schematic of sizing procedure.

represent specific answers to a predefined mission, and slight alterations to mission requirements may have considerable impact on aircraft size and performance

Experimental Results

The basic wind tunnel model geometric characteristics are detailed in Fig 4 for the four selected configurations They vary extensively in wing area (due to the minimum gross weight sizing criteria), aspect ratio, and taper ratio The initial design validation consists of the supersonic and subsonic testing of the four selected flat wing configurations At supersonic speeds, the performance characteristics were investigated At subsonic speeds, the low speed/high angle of attack stability characteristics were investigated Transonic testing of all configurations has yet to be completed

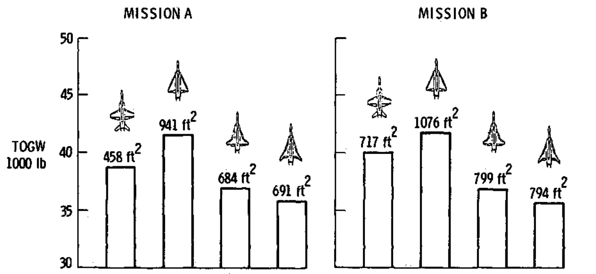

Fig 3 Theoretically based sizing results

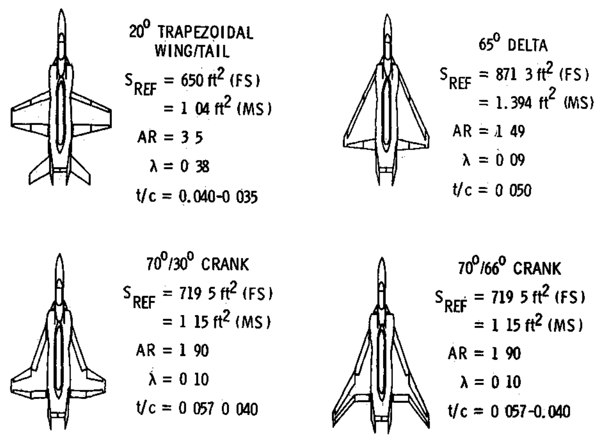

Fig 4 Details of the four fighter configurations under investigation

Supersonic Results

The preliminary supersonic wind tunnel testing was conducted in NASA Langley Research Center's Unitary Plan Wind Tunnel [12] The objective of this test was to verify the estimated supersonic aerodynamic characteristics of the four selected configurations and to compare the longitudinal and lateral directional aerodynamic characteristics of the two advanced cranked wing concepts to the two conventional designs

High speed experimental testing was performed over a Mach number range of 1 6 to 2 16 at angles of attack of 0 to 20 deg The test Reynolds number was 2×10^6/ft Both sideslip and control power conditions were tested The model consisted of a fighter fuselage with side mounted, flow through, half axisymmetric inlets The four wings were uncambered and varied in size, control surface size and location and airfoil section Test results for the four configurations are presented across the Mach number range with a special emphasis at the design condition of $M=1$ 80 Data presented are based upon a unit reference area S_{REF}, unit span b, and unit mean aerodynamic chord $\bar{c}$, due to the significant variation in planform geometry that existed between the study configurations

Presented in Fig 5 are the trimmed and untrimmed drag characteristics for the four selected configurations at $M=1$ 80 The untrimmed drag charcteristics at low lift show that both of the cranked wing geometries exhibited better performance than either the delta or the trapezoidal configuration At high values of lift, the reverse is true; both the delta and trapezoidal geometries have less drag then the cranked wings The observed reduction in aerodynamic performance at high values of lift was expected for the uncambered highly swept advanced cranked wings The degraded performance for the 70/66 deg cranked wing can be attributed to a strong spanwise flow region along the trailing edge which results in significant flow separation occurring at moderate angles of attack The trimmed drag characteristics show that both of the cranked wing configurations outperform the conventional designs at cruise (low lift) condition At high values of lift, the trapezoidal wing has the lowest drag The delta wing performance again exceeds that of the 70/30-deg cranked wing but not that of the 70/66 deg geometry

More insight into the effect that trailing edge separation has on the aerodynamics can be obtained by examining the longitudinal stability characteristics of the 70/66 deg cranked wing configuration in Fig 6 For the 70/66 deg cranked geometry, the separated flow condition which occurs at moderate values of lift results in a loss of lift and a break in the pitching moment curve These results emphasize the severity of the flow separation observed for the 70/66 deg cranked wing geometry; despite the separated flow, per

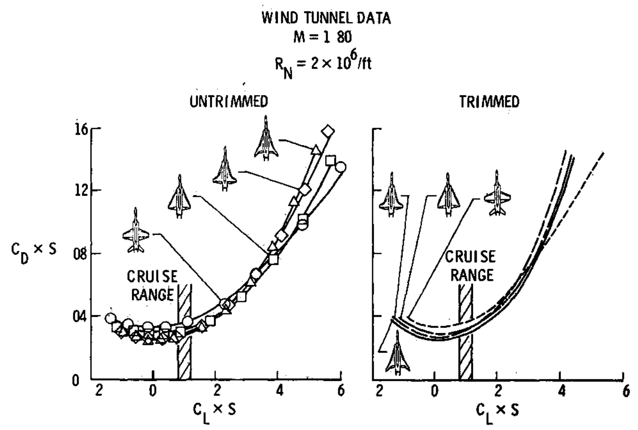

Fig 5 Effect of planform shape on experimentally measured supersonic drag characteristics

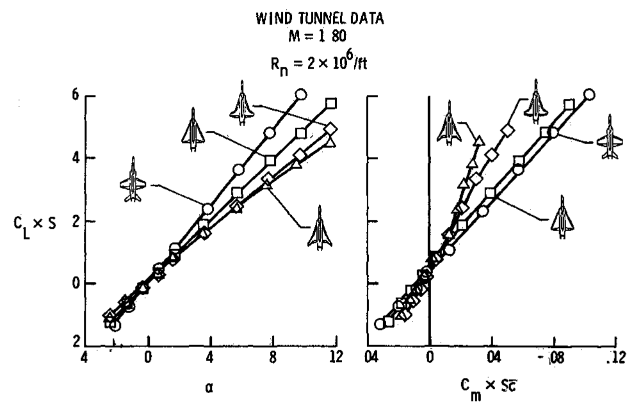

Fig 6 Effect of planform shape on experimentally measured supersonic lift and pitching-moment characteristics

formance levels for the 70/66 deg cranked wing configuration equal or exceed those of the other three planforms at cruise and moderate lift coefficients

Depicted in Fig 7 are the lateral directional stability characteristics of the four test geometries at a Mach number of 1.80 The data indicate that all geometries are stable both laterally and directionally at low angles of attack; however, the trapezoidal and cranked wing data show a significant reduction in directional stability with increasing angle of attack

In order to completely assess the relative merits of one design with another completely, the basic longitudinal characteristics at off-design conditions are investigated Presented in Figs 8 and 9 are the aerodynamic performance and longitudinal stability variations with Mach number for the four tested geometries. The variation of maximum lift to drag ratio, $(L/D)_{max}$, with Mach number and the value of lift at which $(L/D)_{max}$ occurs are shown in Fig 8 Similar values for the $M=1$ 80 trim condition are also shown Maximum untrimmed L/D is similar for all aircraft with values ranging from 5 0 to 5.3 at $M=1$ 80 These values compare favorably with an untrimmed $(L/D)_{max}$ of 4 5 for the F 15 and 5 5 for the F 16 wing redesign study.[6] The untrimmed data for the trapezoidal, delta, and 70/30-deg cranked wings show an 8% reduction in $(L/D)_{max}$ and a 20% reduction in the value of lift at which $(L/D)_{max}$ occurs from $M=1.6$ to 2 16. However, data for the 70/66-deg cranked wing reflect only 1 5% variation in $(L/D)_{max}$ from $M=1$ 6 to 2 16 Comparing untrimmed data to trimmed data shows that the 70/66 deg cranked wing is essentially at trimmed (C_L) at $(L/D)_{max}$ The tendency of the 70/66-deg planform to maintain a consistent performance at off design conditions is supportive of mission versatility

Shown in Fig 9 are the variations in lift-curve slope and longitudinal stability with Mach number. The data indicate that all geometries experience a similar reduction in lift-curve slope and a similar increase in longitudinal stability with increasing Mach number

Supersonic testing of the four uncambered wing geometries has been completed Results indicate that the 70/66 deg cranked-wing configuration is the most efficient at both design and off design conditions These aerodynamic results are significant, but a more meaningful measure of their worth could be reflected in the recalibration of the phase one theoretically based sizing incorporating the supersonic experimental data

Low-Speed/High-Alpha Results

Concurrent with the initial supersonic testing, a low speed, high-angle-of-attack experimental investigation was pursued on the four selected wing planforms in order to investigate basic stability characteristics.

Low speed/high alpha configuration and flat plate testing of the four selected configurations was conducted in the Langley 12 ft Low Speed Tunnel at a dynamic pressure of 4 psf and a Reynolds number of 0 743×10^6 The four planforms tested are shown in Fig 10 In all tests, a six component strain gage balance was used to measure the aerodynamic forces and moments For the wing alone tests, the balance was mounted below the wing and housed in an aerodynamic fairing. In wing body tests, a complete fuselage was incorporated which housed the balance internally The test angle of-attack range was 0 to 60 deg Flow angularity corrections were included in the data reduction Moment reference locations were chosen to coincide with the configuration neutral point For both wing-alone and wing body tests, the wings were simple flat plates with sharp leading and trailing edges For the wing-body tests, only the 70/30 deg and 70/66 deg planforms were investigated

The low-speed/high angle-of attack longitudinal stability characteristics of highly swept wings are dominated by leading edge vortex flow and the effects of vortex breakdown

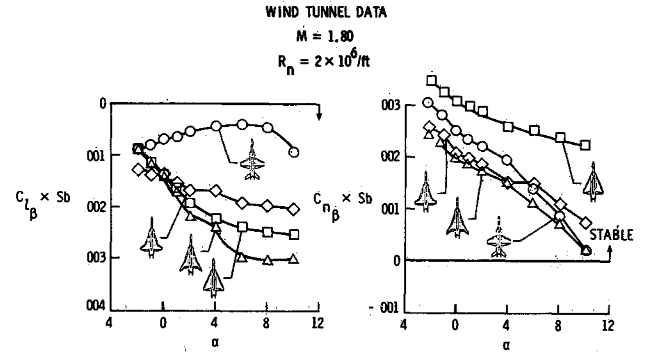

Fig. 7 Effect of planform shape on experimentally measured supersonic lateral directional stability characteristics.

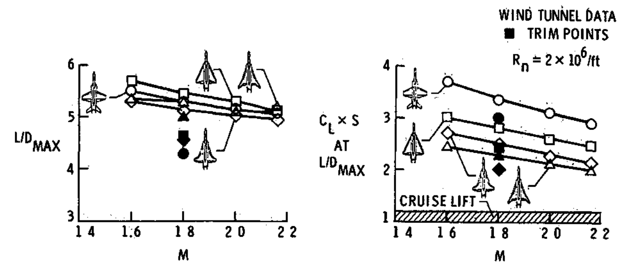

Fig 8 Variation in $(L/D)_{max}$ and the value of lift at $(L/D)_{max}$ with Mach number

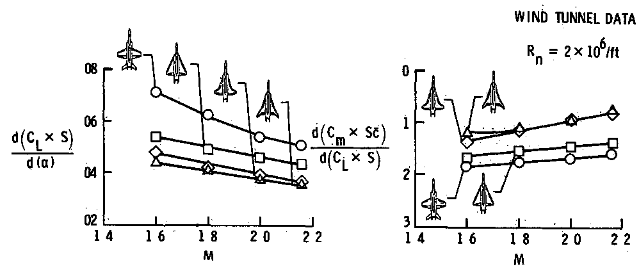

Fig. 9 Variations in lift curve slope and longitudinal stability with Mach number

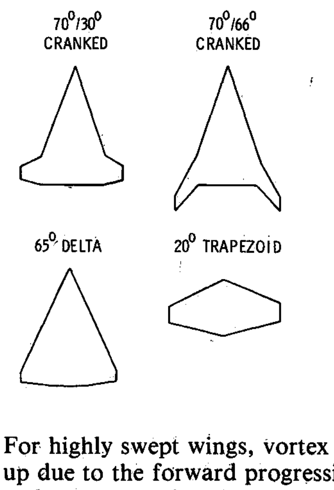

Fig 10 Low-speed/high angle of attack study planforms

For highly swept wings, vortex breakdown produces a pitch-up due to the forward progression of the vortex burst point, and consequently, the center of pressure, with increasing angle of attack This is demonstrated in the helium bubble flow visualization photographs of Fig 11 Figure 11a shows the 70/66 deg wing alone at $\alpha=12$ 5 deg with the vortex burst occurring at 0 $6x/l$ Figure 11b shows the same wing at $\alpha=25$ deg; here the burst point is much closer to the apex of the wing

Figure 12 shows the pitching moment data for all, the planforms tested The three highly swept wings exhibited the

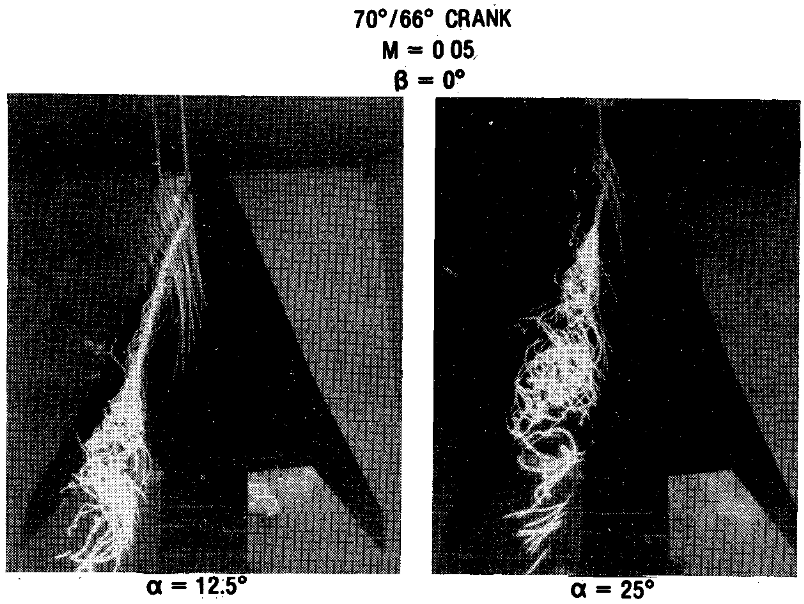

Fig. 11 Flow visualization photographs of sym metric vortex bursting

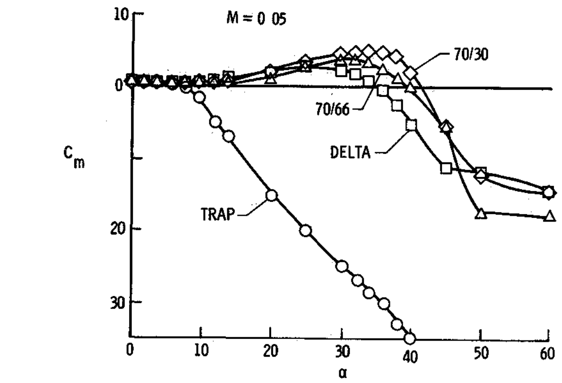

Fig 12 Experimentally measured, wing alone, pitching moment characteristics

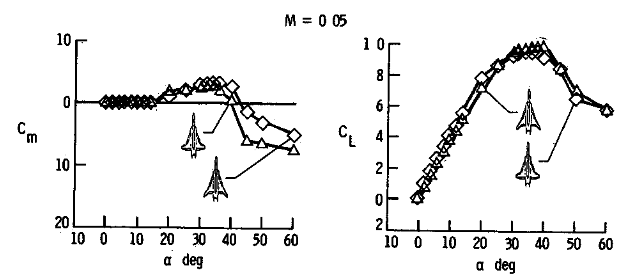

Fig 13 Experimentally measured, wing body, longitudinal aerody namic characteristics

pitch up characteristics typical of these configurations Although the level of pitching moment is different for each wing, the differences in the magnitude of the initial pitch-up are too small to discern, as is the angle of attack at which it occurs

Presented in Fig 13 are the pitching moment and lift curves for the 70/66-deg and 70/30-deg wing and fuselage con figurations Comparing these data with that of Fig 12 shows that the fuselage had very little effect on the pitching characteristics of these wings This indicates that the wing flow (probably the leading edge vortices) is the primary driver of the pitching moment

Based on these results, it is clear that improvements in the stability characteristics are needed Obtaining such im-

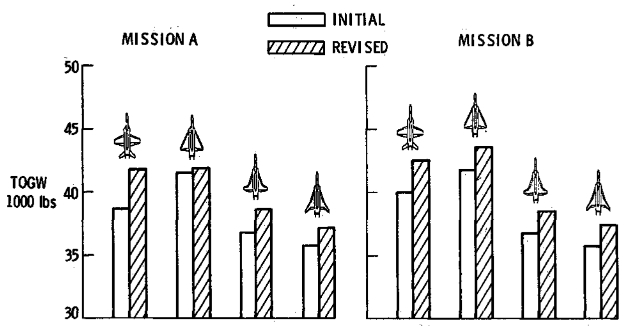

Fig 14 Revised sizing results based upon supersonic data

provements will require extensive modifications to the fuselage and vertical tails and possibly to the wing planform The effects of these changes on high speed performance will also need to be evaluated Serious consideration will have to be given to stability augmentation systems and thrust vec toring to achieve the desire handling qualities

Post-Test Sizing Results

The aerodynamic status of the full-scale aircraft was corrected to reflect only the supersonic wind tunnel data Data from the low speed high alpha testing does not affect these post test sizing results; however, configuration modifications implemented to correct low speed stability and control problems may have a large effect The revised sizing results are shown in Fig 14 for Missions A and B For both missions, all configurations experienced an increase in TOGW For Mission A, the trapezoidal wing shows the largest increase and the delta the smallest increase in TOGW Mission B results show all configurations undergoing the same increase in TOGW The Mission A and B results continued to identify the 70/66 deg cranked wing configuration as the best design

The three main drivers affecting the sized TOGW's are fuel load, engine size, and wing size The fuel load required is a function of the supersonic cruise efficiency, $M(L/D)_{\text{cruise}}$ /TSFC Forty percent of the total fuel load is consumed during the supersonic cruise legs which are the dominant mission segments for fuel sizing The sized fuel loads are shown in Fig 15 They are inversely proportional to the cruise efficiency factors as shown, with the 70/66 deg wing requiring the least total fuel The fuel distribution between

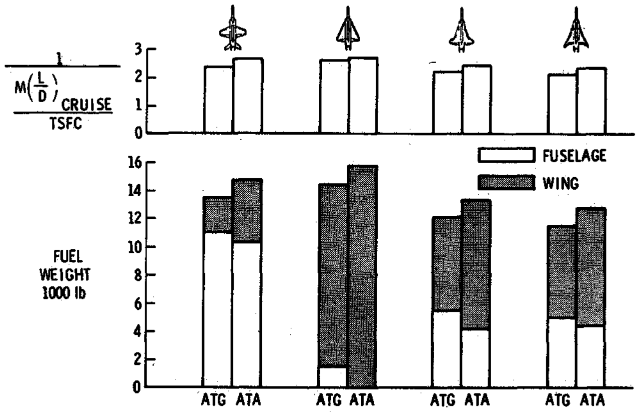

Fig 15 Sized fuel weights and supersonic cruise efficiency

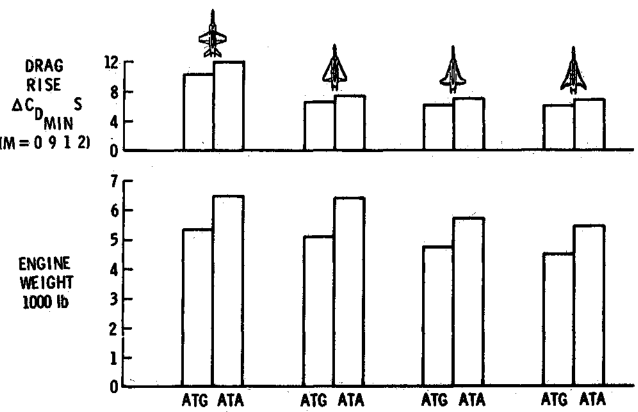

Fig 16 Sized engine weights and transonic drag rise

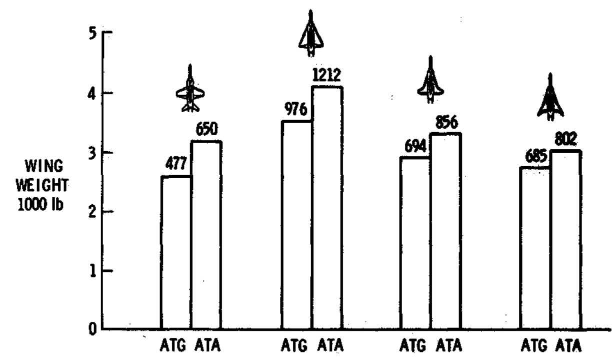

Fig 17 Sized wing area and weights

wing and fuselage is, in general, an indicator of fuselage weight and volume For example, the air-to-ground aircraft with the trapezoidal wing carries 80% of its fuel in the fuselage as compared to 43% for the 70/66-deg crankd-wing counterpart As a result, the trapezoidal wing aircraft fuselage is 20% heavier In each case, total capacity is determined by mission requirements

The engine size is influenced heavily by the acceleration requirement Therefore, the drag rise from Mach 0 90 to 1 20 is the major driver The sized engines are compared in Fig 16 and, as expected, they vary in relation to the drag rise severity which is also shown in Fig 16 These results again point to the advanced cranked wings as the optimum designs

The sized wing area and weights are shown in Fig 17 The effect of planform and wing thickness on wing construction is reflected in the wing weight per unit area Although the wing

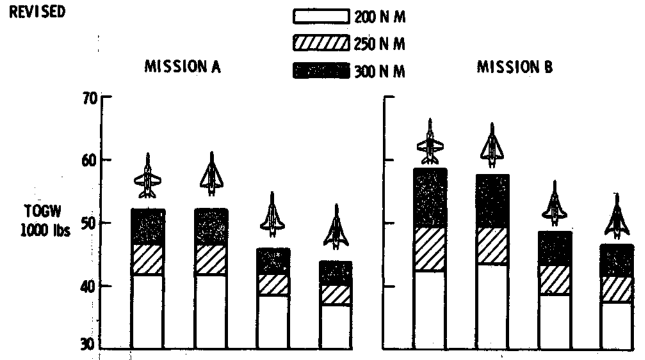

Fig 18 Effects of increasing the supersonic cruise leg on takeoff gross weight

areas vary significantly, from 477 to 976 ft^2 for the air-to-ground aircraft, the difference in wing weights is less than 1000 lb, with the delta-wing configuration sizing out the heaviest

The effects of increased supersonic range requirements on TOGW are presented in Fig 18 for both Mission A and B The values of supersonic range selected for this study were 200 (baseline), 250, and 300 n.mi Mission A results reflect a larger incremental increase in TOGW with increased range for the trapezoidal and delta configurations Results for Mission B indicate an even larger effect for the trapezoidal and delta-wing configurations This is due to the trim drag effects of the delta and trapezoidal wings which were more severe than the effects of the advanced cranked wings. These results can also be attributed to the zero-lift drag of each geometry which is lower for the highly swept, cranked planforms

Results from the supersonic wind tunnel-based sizing analysis indicate that the cranked-wing configurations remain competitive with either of the conventional designs for the selected missions

Design Enhancements

Results from the initial testing and sizing analysis phase of this study indicate that the cranked-wing configurations are the best candidates for future study Experimentally measured supersonic performance levels of the cranked wings meet or exceed those of the conventional designs, and their planform geometry allows for the application of a wide variety of new aerodynamic technologies In addition, low-speed experimental results have indicated that advanced cranked-wing configurations exhibit adequate stability characteristics at low to moderate angles of attack, and at high angles of attack existing technology will be applied in an attempt to improve the aerodynamics Supersonic and low-speed/high-alpha aerodynamic design enhancements and the predicted benefits of each are discussed in the following sections

Supersonic

Supersonically, the uncambered cranked planforms have shown adequate performance levels compared to the conventional designs at both design and off-design conditions. Weight estimates for the advanced cranked planform show a 10% reduction in TOGW compared to the trapezoidal and delta wings. Based upon these results, the two cranked planforms were selected for further design considerations in an effort to maximize supersonic aerodynamic performance This theoretical investigation will address supersonic area ruling in addition to several new supersonic design concepts: a new wing-camber design approach, leading-edge thrust, and vortex flaps

Traditionally, the first step in designing a supersonic aircraft is to optimize the zero-lift wave drag of the configuration by enforcing the supersonic area rule criteria [10] However, the guidelines of the current wing design study will not allow any modifications to the fuselage, wing positioning, or wing area These design constraints severely restrict the application of the far-field area rule methodology to this configuration However, by relaxing the restriction on fuselage modifications, an 8% reduction in zero lift drag and a 7% improvement in $(L/D)_{max}$ can be obtained for the 70/66 deg configuration, and by allowing modifications of the 70/66-deg wing geometry (e g , wing area, thickness) and positioning, an additional 2% reduction in zero-lift drag can be realized These theoretical estimates emphasize the importance of area ruling aircraft configured for supersonic flight; however, there are no plans to validate these predictions

Following the optimization of a configuration at zero lift, the second step is to optimize the wing camber and twist for a prescribed lift and moment. Selection of a wing design method or approach capable of modeling the complex fuselage flowfield of fighter configurations accurately was required Wing alone design procedures[13] have produced favorable results for wing-alone and supersonic transport-type configurations in which the near field interference effects of the various components can be neglected when compared to the wing aerodynamics In contrast, fighter-fuselage effects on the wing are significant, and application of these wing-alone methods to representative fighter aircraft resulted in extensive modification to the fuselage geometry Because of the limited scope of previous design methods and the increased attention to supersonically efficient fighter aircraft, the wing alone design methodology of Ref 13 was modified to include configuration-related loadings and surface ordinate constraints.[8] The configuration-related loadings account for fuselage upwash, fuselage buoyancy, and nacelle pressure fields Previous attempts to employ these effects in a fighter wing design study have had limited success, and attempts to apply the methodology in the present wing design study failed to provide a converged solution The failure of these attempts can be attributed to the inability of the methodology of Ref 8 to predict the fuselage alone aerodynamics and fuselage induced flowfield accurately

Because of this, a new wing-camber design approach has been defined Depicted in Fig 19 are the two basic components of this approach: PAN AIR[14] and SDAS [8] This new approach employs the PAN AIR code for computing fuselage characteristics and interference effects on the wing These PAN AIR-predicted effects are then incorporated into the SDAS wing optimization procedure as an aerodynamic loading Typical results from this PAN AIR/SDAS design approach are shown in Fig 20. Depicted in the figure are three representative span stations for the 70/66-deg cranked-wing configuration derived for a design lift coefficient of 0 10 and a Mach number of 1 80 For the combined PAN AIR/SDAS design, a solution was achieved for the 0 10 design-lift value; however, for the SDAS-only solution, the method failed to converge for the 0 10 design lift coefficient and, as a result, a value of 0 05 was used to obtain results for comparison Comparing the two solutions, we see that the SDAS only method produces significantly more twist and less camber than the PAN AIR/SDAS method These differences are due to the inability of the SDAS solution to predict the large favorable body on wing interference predicted by the PAN AIR code Shown in Fig 21 are the theoretical drag predictions of the two camber designs and the flat wing The performance of the SDAS design never exceeds that of the combined design or even the flat wing up to a C_L of 0.3 On the other hand, the combined method design provides im proved performance at the design condition ($C_L = 0$ 10) and at $(L/D)_{max}$ ($C_L = 0.21$) resulting in a 5 and 10% improvement in L/D, respectively These results emphasize that the SDAS-only design approach is not adequate for configurations with a large fuselage

In addition to the favorable benefits of cambering, two other aerodynamic enhancements are being investigated to improve the off-design, high-lift performance of cranked-wing designs further These are supersonic leading-edge thrust (attached-flow) and leading-edge vortex (separated-flow) effects The existence of leading-edge thrust on highly swept wings at supersonic speeds has been discussed in Refs 15 and 16 Recent developments in supersonic wing research have led to a review of leading-edge thrust as a possible mechanism for improving supersonic aircraft performance [17] These developments include the evolution of methods[18 20] for predicting thrust and experimental testing designed to show the effects of thrust on the aerodynamic characteristics [21]

Application of the attainable leading edge-thrust concept to the study configurations will be performed in accordance with the method of Ref 20 This method provides a quantitative means of selecting wing leading edge geometries which promote attached flow and desirable leading-edge thrust characteristics Theoretical estimates for the flat 70/66-deg

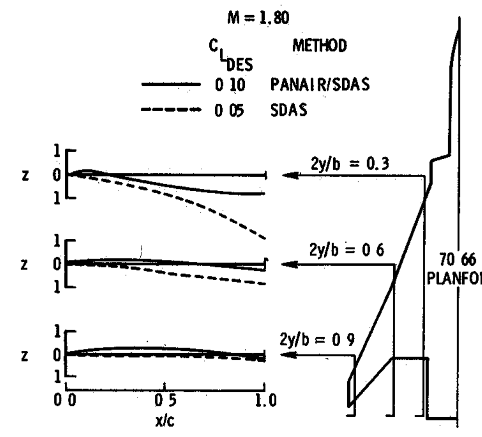

Fig 20 Comparison of wing cambers

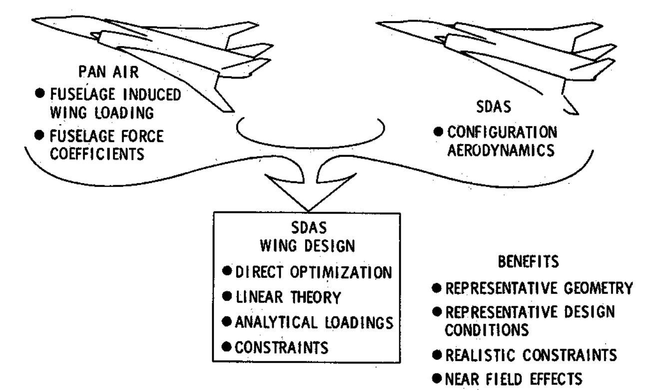

Fig. 19 Schematic of new wing design technique

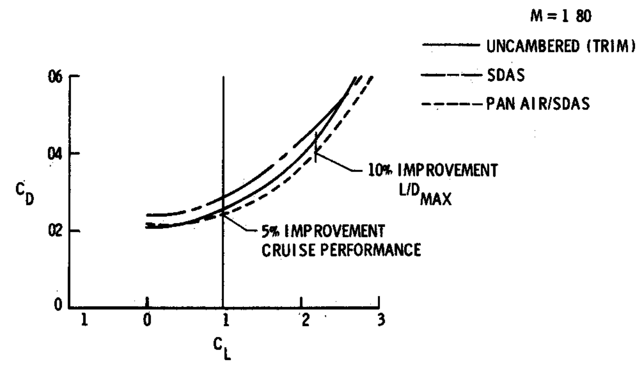

Fig 21 Comparison of wing design method drag polars

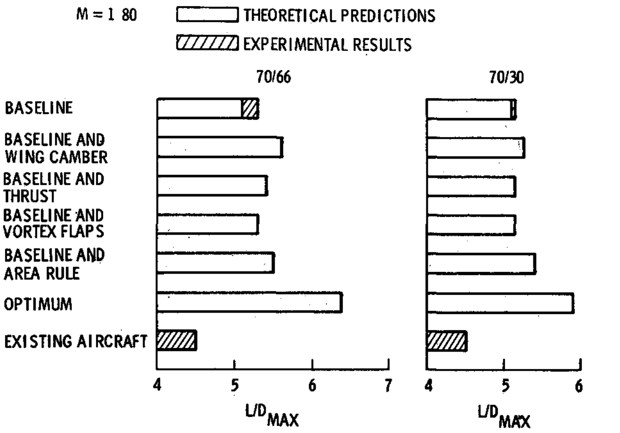

Fig 22 Theoretical estimates of the impact of several supersonic aerodynamic technologies on $(L/D)_{max}$

cranked wing planform indicate a 6% improvement in $(L/D)_{max}$ due to leading edge thrust

An alternative flow mechanism for obtaining efficient high lift is to employ a controlled leading edge vortex to improve the aerodynamics This approach has been extensively ad dressed by the transonic aerodynamic community;[22] however, the approach has not been explored at supersonic speeds Previous supersonic experimental investigations have failed to address performance benefits but concentrated on defining the separation characteristics at high supersonic speeds for developing an understanding of vortex effects on aerodynamic heating [23] Results from a recent study[24] have provided the much needed insight into leading edge vortex flow at supersonic speeds and have allowed a preliminary look at the available aerodynamic benefits from a controlled leading edge vortex Theoretically, the available methods[20 25] have the capability to model separated flows for predicting forces and moments. Theoretical estimates from Ref 20 indicate that a 4% improvement in maximum lift to drag ratio for the 70/66 deg wing is achievable

The impact of each of the assumed aerodynamic enhancements is summarized in Fig. 20 for both the 70/66 deg and 70/30 deg cranked wing configurations. Comparing the results for the two cranked-wing geometries reveals that the 70/66 deg geometry receives its largest benefit from wing camber, whereas the performance improvement for the 70/30 deg configuration is dominated by area ruling In general, the 70/66 deg wing receives greater benefits for all enhancements The application of the aerodynamic enhan cements to the 70/30 deg wing is restricted because of the supersonic leading edge of the 30 deg swept outboard panel which limits the use of wing camber, leading edge bluntness (thrust effects), and vortex flaps to the 70 deg inboard panel Combining all of the technologies in an optimum fashion the maximum theoretical lift to-drag ratio for the 70/66 deg wing is 6 4, and for the 70/30 deg wing, a value of 5 8 is achieved Comparing these results to the maximum untrimmed lift to drag ratio of existing aircraft (F 15) shows a 42% increase in performance for the 70/66 deg wing and a 31% increase for the 70/30 deg wing These theoretical estimates are extremely encouraging, and all of the enhancements, except area ruling will be validated experimentally

Low Speed/High Alpha

Initial low speed testing of the cranked wing configurations uncovered several stability problems that occurred at moderate to high angles of attack ($\alpha \geq 15$ deg) These destabilizing longitudinal and lateral directional charac teristics are due primarily to the movement of the vortex burst point over the wing In addition, at high angle of attack, the fuselage forebody sheds vortices which have been shown[26] to influence the lateral directional stability characteristics significantly An extensive experimental study has been initiated to investigate the effect of several geometry modifications on stability characteristics This study will look at the effects of vertical tail placement, forebody shaping, planform modifications, and leading edge devices Based upon these experimental results, appropriate modifications to the existing configurations will be made and estimates of changes in aerodynamic performance and TOGW will be determined

Conclusions

Results from a cooperative supersonically biased fighter wing design study between the National Aeronautics and Space Administration and the McDonnell Aircraft Company are summarized The tested wing geometries consisted of a trapezoidal wing, a delta wing, and two advanced wing designs (70/66 and 70/30 deg cranked wings) Initial weight estimates and sizing analysis based upon a supersonically dominated mission have been performed on all geometries The following list indicates the more significant findings of this ongoing cooperative research effort:

1) Weight estimates and sizing analysis results for the advanced cranked wing geometries indicate a 4000 lb reduction in TOGW compared to the more conventional designs

2) Supersonic performance levels of the cranked-wing configurations exceed those of the traditional designs at cruise conditions for both the trimmed and untrimmed case

3) Low speed/high alpha stability and control problems have been identified for the highly swept wings Major changes to fuselage shape and vertical tail size and placement are being investigated as possible solutions to these problems Various variable geometry devices will also be evaluated

4) Theoretical predictions suggest significant improvement in supersonic performance with the further application of existing aerodynamic technologies

5) A new supersonic wing design approach has been defined for fighter aircraft configurations; theoretical predictions look promising

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