Projected Advantage of an Oblique Wing Design on a Fleet Air Defense Mission

C. D. Wiler* and S. N. White†
Rockwell International Corporation, El Segundo, California

A review of performance aerodynamics is presented which leads to the conclusion that variable wing geometry is an efficient method of satisfying multidesign point mission requirements. Of the two variable-geometry approaches, the oblique wing is identified as having potential advantages over symmetric-sweep designs on fighter missions with subsonic loiter and supersonic dash requirements. A design comparison study is reported which showed a 17% reduction in takeoff weight for the oblique wing or a 29% mission performance advantage at the same gross weight. With other associated technologies now well in hand, the oblique wing concept is shown to offer considerable promise as the second generation of variable wing sweep.

Introduction

THE oblique wing concept first appeared in the literature during the late 1940s in publications by R. T. Jones of NASA Ames Research Center.[1,2] At the time, industry was following simple sweep theory, which suggests that wing sweep should be high enough that the wing leading edge is behind the Mach angle for supersonic flight. In principle, this is accomplished as effectively with a forward-swept wing as an aft-swept wing. Early designs, such as the F-86 fighter aircraft, effectively utilized fixed sweep. The concept of variable sweep was not tested for several years and did not appear on operational airplanes such as the F-111 and F-14 until more than 20 years later. Oblique wings were not considered for these early developments because of concern that the forward-swept panel would have a structural divergence problem similar to that accurately predicted for fixed symmetric forward-swept wing designs. Dynamic studies in the early 1970s established that classical divergence does not exist for an oblique wing, as the aircraft is free to roll in order to relieve the divergent load on the forward wing.[3,4] This rolling tendency must in itself be controlled and, at least in the static sense, requires a stronger wing design than would otherwise be the case. The introduction of composite materials into aircraft structures has made it possible to design efficiently for the unique characteristics of the oblique wing. With the design problems better understood, it appeared worthwhile several years ago to reexamine where the oblique wing might best be applied. One opportunity appears in missions requiring both outstanding loiter performance and supersonic dash. To appreciate the application of this unique design, we will first review some of the fundamentals of subsonic and supersonic performance aerodynamics.

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*Program Manager, Advanced Concepts; North American Aircraft Operations.

†Supervisor, Advanced Systems Aerodynamics, North American Aircraft Operations.

The Requirement for Variable-Geometry Design

The conficts of efficient supersonic and subsonic flight impose differing requirements on the aircraft design. Table 1 illustrates a number of desired characteristics (high lift, maneuverability, efficient high-speed cruise, and satisfactory ride qualities), which result in the differing wing planform and loading characteristics shown. A fundamental requirement for all aircraft is high lift to reduce takeoff and landing speeds. Ideally, the solution would be an unswept wing of low wing loading. Figure 1a illustrates the loss in lift with increasing sweep. Wing loading can be modified on a given planform by the use of flaps, which effectively increase the area of the wing. Maneuverability also requires high lift but at higher speeds, and the use of flaps as normally considered is not practical. Wing sweeps for these conditions may be low to high, depending on the speed of the maneuver condition (Fig. 1b). In a high-speed cruise flight condition (Fig. 1c), wing sweeps are kept high to minimize C_{D_0}, which is the dominant drag term for supersonic cruise. Wing loading is also high to minimize the total drag, for reasons described later. Ride quality is a special characteristic required on low-altitude high-speed missions and typically results in a requirement for high wing sweep to minimize the lift-curve slope and high wing loading to minimize the response to gust-induced lift forces. Figure 1d compares relative ride qualities with sweep. It is the combination of these requirements for high lift and maneuverability at low speeds vs those for high efficiency at high speed (and in some applications good ride qualities) that has been a major influencing factor in the design of variable-geometry aircraft.

The starting point for any successful design is always inherently good drag characteristics for the proposed mission. Subsonically, the basic elements of drag include a geometry term (zero lift drag) and lift term (drag-due-to-lift), see Fig. 2. The geometry term is dominated by skin-friction drag, a viscous interaction between the aircraft's surface and the surrounding air. The lift term is due primarily to the vortex wake left behind the aircraft (the cost of producing lift). Reducing these drags generally requires a reduction in wetted area and an increase in span. High aspect ratio and low sweep planforms are an obvious choice for good subsonic performance.

Supersonically, two wave drag terms are added to the subsonic drag terms. These wave drag terms also consist of a geometry and a lift term. Figure 2 compares these drag factors to their subsonic counterparts. The geometry term is due primarily to volume and is shown to be a strong function of length. The wave drag-due-to-lift term is in the same form as the subsonic vortex drag; only a length term replaces the span term of the vortex drag. Where wetted area and span are the primary subsonic variables, volume and length or fineness ratio are the primary supersonic variables for efficient cruise.

Low total aircraft drag therefore requires low wetted area to minimize skin-friction drag, large span to minimize vortex drag, and small volume with long length to minimize wave drag.

When both efficient subsonic cruise and either supersonic cruise or penetration ride qualities reach equal importance, a compromise solution must be found, as for the B-1B aircraft shown in Fig. 3. Here the requirements for high lift, good range, and penetration ride qualities have been satisfied by a design sweeping the wing symmetrically from 15-67.5 deg aft, as in the designs utilized on the F-14 and the F-111. These aircraft are all very effective solutions to their design problems and were limited only by the technology available during their design.

Some of the problems found in the symmetric designs are listed below.

1) Aerodynamic center shift with sweep and Mach number results in increased trim drag and fuselage and tail loads.

2) Wing seals and fairings result in increased volume and mechanical complexity.

3) Wing carry-through structure results in increased weight and design compromises.

The problem of aerodynamic center shift is familiar: large aerodynamic center shifts cause problems with trim drag. As the wing centroid is moved aft due to sweep, the aerodynamic center must move with it. There is also the natural phenomenon of the aerodynamic center shifting aft in the transition from subsonic to supersonic speeds. These effects combine to present a large range of trim requirements difficult to satisfy without paying a large trim drag penalty somewhere in the flight envelope.

Wing seals, movable fairings, and wing carry-through structures present many design problems. Seals and fairings are not only mechanically difficult to design but add to aircraft drag by requiring volume to accommodate them. In one example, part of the wing trailing edge must be stowed inside the fuselage in the aft-sweep position. Provision for this intrusion increases fuselage cross-sectional area, with resulting increases in wetted area and volume. The wing carry-through structure, which takes the load from two widely separated pivots, adds to the weight of the structure and severely limits what can be accommodated in this area of the fuselage. This presents a challenge to the designer, who would prefer to have such expendables as weapons located in this area.

The operational success of the designs mentioned shows that these problems have been overcome to a reasonable extent and that the advantages of variable sweep far outweigh the disadvantages of the specific mechanization. What will be shown in the remaining discussion is an alternate method of configuring a variable-geometry aircraft that shows promise in fulfilling several mission requirements.

Oblique wings are second-generation variable-geometry systems that use a single, centrally located pivot resulting in equal but opposite changes in sweep between the two wing panels (Fig. 4). This single-pivot arrangement produces a greater change in wingspan when compared to conventional symmetric configurations in that the full span of the wing leading and trailing edges is swept. This sweeping of the total wing helps reduce the "root" effects on the critical upper surface of the wing, giving a larger span of wing that can produce efficient flow.

Figure 5 compares the effective geometries of oblique and symmetric variable sweeps. Assuming equal low-speed performance (which requires equal spans and wetted areas), the oblique wing provides a substantial increase in length when swept. For equal volumes, this will greatly reduce the wave drag terms associated with supersonic flight. The increase in fineness ratio over a similar symmetric variable sweep becomes more pronounced as the dual pivots of the symmetric design move outboard from the illustrated centerline case. Outboard pivots are a method commonly used to reduce aerodynamic center shift. Addition of a fuselage to the above comparison will show the oblique concept to have a smoother area distribution, with a lower maximum cross-sectional area, especially at low Mach numbers. This illustrates the basic wave drag advantages of oblique wing configurations. In summary, for equal subsonic performance, oblique wings provide (through their greater geometric variation) a higher fineness ratio than symmetric variable-sweep designs, resulting in substantially increased supersonic performance potential.

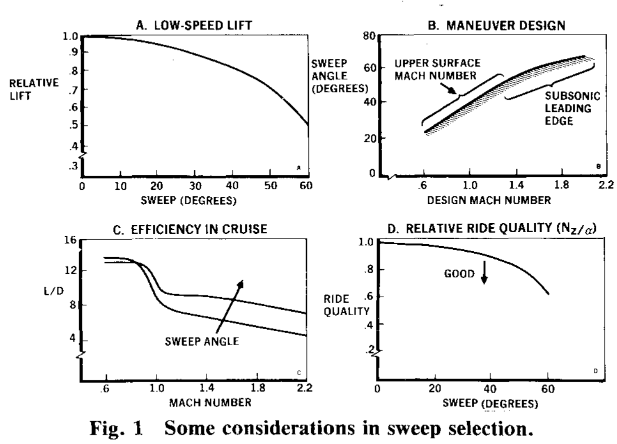

Fig. 1 Some considerations in sweep selection.

Table 1 Basic low-speed vs high-speed sweep trades

Desired characteristic	Wing sweep	Wing loading
High lift	Low	Low
Maneuver	Low to moderate	Low
High speed	High	High
Ride quality	High	High

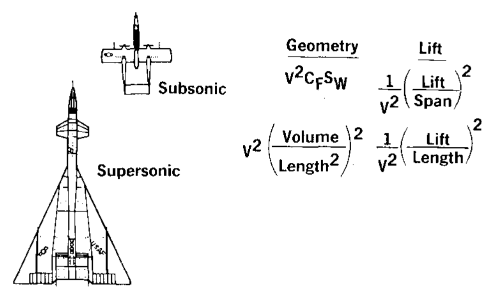

Fig. 2 Drag variables.

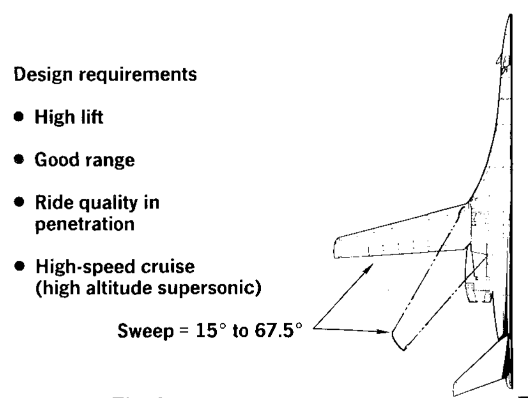

Fig. 3 A conventional solution.

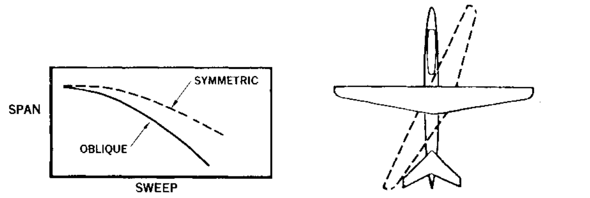

Fig. 4 An oblique wing is a simpler form of variable-geometry device.

Table 2 Comparison of technologies

Technology	Symmetric sweep design	Oblique wing design
Oblique wing		Yes
Advanced propulsion (parametric—both optimized)	Yes	Yes
Advanced weapons/avionics (10 missiles)	Yes	Yes
Advanced materials, including composite wing	Yes	Yes

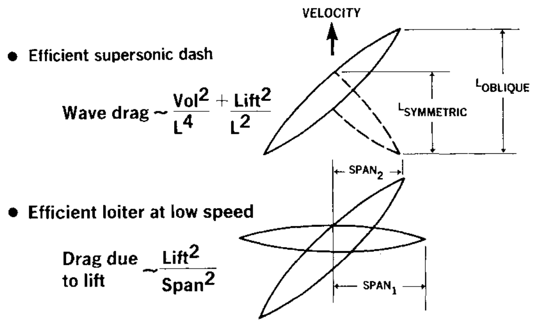

Fig. 5 Oblique wing features.

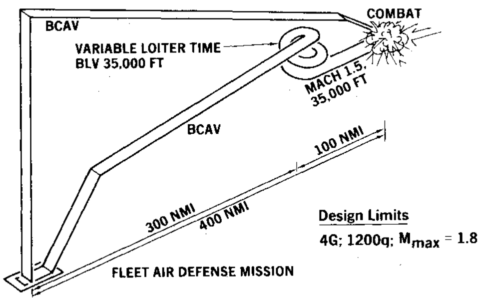

Fig. 7 Comparison mission.

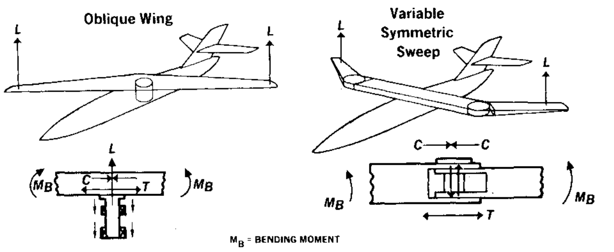

Fig. 6 Comparison of pivot point loads.

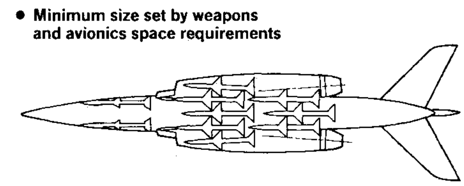

Fig. 8 Common fuselage.

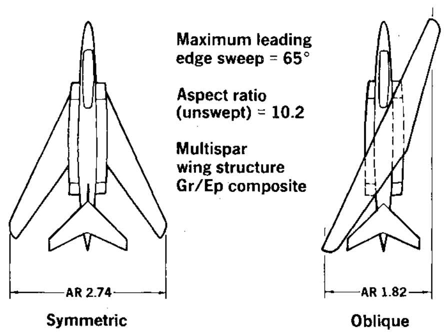

Fig. 9 Planform comparison.

A symmetric sweep design will always be burdened by the need for dual pivots. Figure 6 shows that all the lift on the wings is concentrated at the pivots, which must transmit the load as a combination of shear, bending, and torsion. The structural designer would like to have a substantial box structure holding these pivots. As noted, however, the configuration designer would prefer to be able to put expendables in this area. The limitation, then, is the ability to carry the loads across the bottom of the fuselage. By contrast, the oblique wing resolves bending moments within its own structure and transmits only lift (shear) through the pivot when symmetrically loaded. Unsymmetric loads due to maneuvers or off-design trim conditions are minor compared to the total loads in the pivots for the variable symmetric-sweep wing.

Design Comparisons

With these inherent advantages of an oblique wing design established, a direct comparison of the two designs on a common mission can be made. The mission chosen will emphasize the efficient loiter capabilities of the oblique wing design combined with a supersonic dash to a combat condition. We chose a hypothetical fleet air defense mission (Fig. 7), in which the aircraft takes off from a carrier, cruises at the most efficient condition to a station 300 n. mi. out, and loiters until a dash is required to a combat location 100 n. mi. away. Following this, the aircraft returns at best cruise altitude and velocity to the carrier. Loiter time is 3 h for the baseline mission. The ground rules chosen for this study, in addition to the common mission, were that design criteria would be the same and common technologies would be utilized for both aircraft. The only difference in technology between the two designs (Table 2) is the oblique wing itself. Both aircraft utilized advanced propulsion systems optimized using a parametric deck to satisfy the design requirements. Both aircraft carried the same weapons and avionics suites, including 10 air-to-air missiles, and utilized advanced materials wherever required, including composite wings. The fuselage design (Fig. 8) was common to both aircraft because of the avionics systems and the large number of missiles required. As shown in Fig. 8, the missiles occupy most of the available space on the underbody of the twin-engine design.

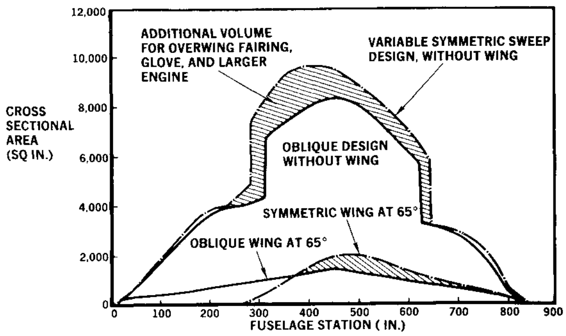

Fig. 10 Volume distributions.

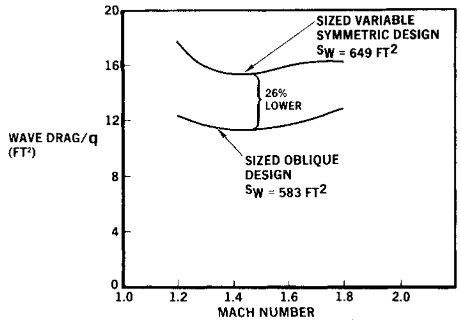

Fig. 11 Wave drag comparison.

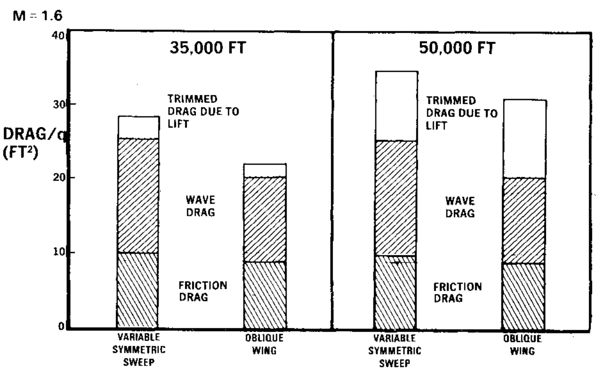

Fig. 12 Drag buildup.

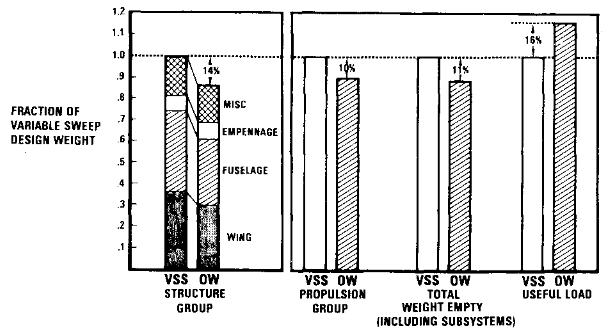

Fig. 13 Component weight comparison.

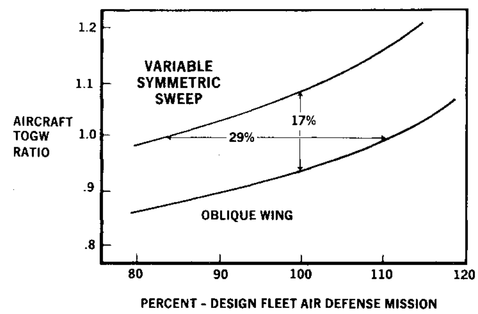

Fig. 14 Mission trades.

The two wing planforms are compared in Fig. 9. Maximum leading-edge sweep was set at 65 deg, and an aspect ratio of 10.2 was chosen to maximize the loiter efficiency. These were chosen as a starting point because NASA obtained a large body of wind tunnel data on this planform in the early 1970s.[5,6] Further studies confirmed that the aspect ratio could be higher for mission efficiency but is limited by maximum span considerations for carrier operations. The difference in effective aspect ratio in the swept condition between the symmetric and oblique wing designs is shown in Fig. 9. The symmetric design has a minimum aspect ratio for supersonic flight of 2.74; the oblique wing, 1.82. Volume distributions are compared in Fig. 10 for the final-sized aircraft. The oblique wing design exhibits much less volume at the center of the aircraft. There is an overall increase in total volume on the symmetric design due to the larger wing resulting from the sizing, the overwing fairing required to close out the pivots, the glove required for aerodynamic trim, and the larger engines required because of the less efficient design. The result of this volume distribution is illustrated in Fig. 11. The area of the wing on the sized symmetric aft-sweep design is 649 ft^2 compared to 583 ft^2 on the oblique wing. Wave drag is approximately 26% lower at the supersonic dash Mach number of 1.5. Taking all the drag factors into consideration at Mach 1.6, there is a substantial decrease at both 35,000 and 50,000 ft for the oblique wing (Fig. 12). This is approximately an 11-21% decrease in drag and results from all three components: friction drag (because the aircraft itself is smaller and more efficient), wave drag, and trimmed drag due to lift (because of the minimized effects of aerodynamic center shift).

In carrier applications, takeoff gross weight can be severely limited. Therefore, a valuable comparison is the useful load at a constant takeoff gross weight representative of maximum good design practice. Illustrated in Fig. 13 is a buildup by component of the two designs at a constant gross weight. Once again, it is apparent that the oblique wing design weights are superior and that the total for the structure group is 14% lower than that for the symmetric design. Because of the greater efficiency due to lower drags, the propulsion group is approximately 10% lighter than the symmetric design; and the total weight empty for the oblique wing design is 11% lower than that of the conventional design, accounting for subsystems and other miscellaneous weights that are approximately the same for both designs. This decrease of 11% in weight empty results in an increased useful load of 16% for the oblique wing design, where useful load includes fuel and weapons as well as the crew. The result of these weight and performance advantages is shown nondimensionally in Fig. 14. The 100% design mission is the 400-mile radius mission shown in Fig. 7. In scaling the radius, the cruise legs and the supersonic dash are scaled by the same percentage. The aircraft takeoff gross weight ratio compares to the design weight used in Fig. 13. The advantage of oblique wings can be used in either of two ways: 1) for a constant mission there can be a 17% gross weight reduction for the oblique wing design, or 2) if maximum design takeoff gross weight is limited because of carrier compatibility considerations, a 29% greater mission radius can be achieved with the oblique wing design.

For a more severe (longer) mission, the variable-sweep design becomes heavier more rapidly than the oblique wing design, so that these differences are accentuated. Because of such constraints in the naval application as landing speeds and launch weight limits, the point is rapidly approached where a more stringent requirement cannot be satisfied with a variable aft-sweep design. A greater operating radius would require the introduction of major new technologies into the aft-sweep design before those same technologies would be needed for an oblique wing.

Summary and Conclusions

The present study examined only one particular application for an oblique wing. Although the results of the study cannot be generalized to other cases, certain fundamental axioms of the oblique wing vs variable aft-sweep comparison described above, generally apply. An oblique wing will always have an advantage where large span is required with high fineness ratio. This results in high subsonic lift-to-drag ratios and higher supersonic lift-to-drag ratios. Although these aspects were not specifically discussed here, the study confirmed the supposition that there would be much lower design pivot loads for the oblique wing. The single pivot, with symmetric loading, results in lower pivot loads, lower wing actuator loads due to the balanced aerodynamic forces, and lower aft fuselage loads due to the reduced trim problem. Obviously, there is a lower parts count for the oblique wing design: the single pivot is less complex than the two required for the aft-sweep design. In addition to the pivot, the requirements are minimized for overwing fairings and gloves to satisfy aerodynamic trim and drag problems.

The advantage of oblique wings to the configuration designer is obvious. The problem of providing for the wing in the swept position has been considerably simplified. There is no requirement for internal storage of the trailing edge of the wing. The single pivot, with its lower loads, has also resulted in a considerably simpler structure in the area of the center of gravity, allowing the designer much more flexibility in the carriage of advanced weapons in other design applications. Furthermore, for carrier-based designs, the centerline pivot results in a more compact planform for deck storage.

The performance advantages of oblique wings in a particular application have been discussed in this paper. These potential advantages will not be realized, however, until a number of related technologies are developed. Foremost among these is the control system architecture to handle complex structural dynamics and cross-coupled aircraft responses while presenting the crew with the feel of a conventional airplane.

Beyond the purely technical considerations, the pilot community will have to be conditioned to accept configurations unlike anything in their experience. This acceptance will be most easily gained by a thorough research program, one consisting of ground-based simulations and flight tests under conditions representative of anticipated operational requirements. Such a program is now planned by NASA as the Oblique Wing Research Aircraft, using the Ames/Dryden digital fly-by-wire F-8C testbed aircraft. First flight is planned for January 1989, with a flight test program expected to cover speeds to Mach 1.6 and altitudes to 50,000 ft.

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