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RESEARCH ARTICLE

Viability of an Oblique Wing in Commercial Flight: Performance, Design, and Barriers to Implementation

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ABSTRACT: An oblique wing offers improved aerodynamic performance at a wide range of airspeeds, but it comes with a complex design as well as logistical and experimental barriers. By assessing the oblique wing's viability in commercial flight, the potential of the concept can be proved, giving the go-ahead for further exploration. This paper explores the viability, examining how the oblique wing compares to other wings in commercial flight, as well as some limitations that it faces. The working thesis of this paper is that the oblique wing offers a more efficient aerodynamic performance across a wide range, but suffers from stability issues and design limitations that make it difficult to control. This thesis will mainly be explored through experimental data (NASA AD-1, wind tunnel testing) and design solutions for oblique wings.

KEYWORDS: Aerospace Engineering, Aerodynamics, Aircraft Design, Oblique Wing, Commercial Flight, Stability and Control, Implementation Barriers.

Introduction

The oblique wing presents in its design and capabilities a promising alternative to conventional wing configurations like variable sweep wings and swept wings.[1] This is due to its ability to shift its wing position in accordance with its airspeed, reducing drag at high speeds like a swept wing but still maintaining aerodynamic performance at low speeds.[2] However, any regular variable sweep wing could also accomplish this–what differentiates the oblique wing even further is that the design complexity is much lower. A variable sweep wing has two pivot points that must withstand many forces, whereas an oblique wing has one pivot point that only has to withstand one. Its experimental advantages over these conventional wing designs have prompted research into its viability in supersonic commercial flight, where it may address challenges previous attempts have faced.[3,4]

However, there are some issues that come up when utilizing oblique wings, like control difficulties and instability caused by an uneven distribution of forces.[5-7] Furthermore, creating a design solution for an oblique wing commercial aircraft is difficult, as there are many more factors to consider than when creating a design for a conventional wing commercial aircraft, like configuration, structure, materials, aircraft dynamics, and more. However, there has been little to no research or testing into the field since the AD-1 tests of the 70s and 80s.[8,9] This research paper will explore the benefits and drawbacks of an oblique wing in commercial flight as well as the challenges that dissuade further design, testing, and implementation.

Through this, the paper can clarify the performance of oblique wings in commercial flight in comparison to conventional wing types, as well as the issues preventing the practical application of an oblique wing. By identifying these aspects, this paper aims to assess the viability of the oblique wing in future commercial flight.

Based on aerodynamic theory and past experimental data, the working thesis of this paper is that an oblique wing aerodynamically outperforms a standard wing at transonic speeds, bringing with it, however, several significant challenges, like stability, maintenance, and logistical issues such as cost and risk. This will be explored in three body sections. The first section is on the performance of an oblique wing in comparison to standard wing types. The second section is on the design challenges presented by an oblique wing, how the other design components of an aircraft would be affected by the presence of an oblique wing, and potential design solutions for oblique-wing commercial aircraft. The third examines the logistical and commercial barriers that are preventing the implementation of oblique wings in commercial flight.

Aerodynamic Performance of Oblique Wings

In this section, there will be an introduction to oblique wings, their history, and an analysis of their aerodynamics. This section will focus on explaining the aerodynamic forces of oblique wings and comparing them to those of conventional wing designs.

In order to assess how viable oblique wings are in commercial flight, one of the most important factors is aerodynamic capabilities. Forces like lift, drag, and wave drag at different speeds are what distinguish an oblique wing's capabilities from those of swept or variable sweep wings. Using both theoretical and experimental data, this section will compare the performance of the three wings.

1.1. Oblique Wing:

An oblique wing is, in essence, a variable sweep wing that features a single pivot. This single pivot allows for either side

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of the wing to achieve a high sweep angle, with the test aircraft reaching up to a 60-degree sweep.[10]

What separates this wing type from a conventional swept-wing is its ability to fluidly shift configuration and sweep angle in accordance with airspeed and Mach number. What separates it even further from a regular variable sweep wing is its single pivot point, which causes the wing to undergo fewer forces and less stress.[10]

1.2. History of the Oblique Wing:

In 1942, the chief engineer of the Aircraft Manufacturing Department of Blohm and Voss (BuV] Shipworks, Richard Vogt, proposed the P202, a radical new jet fighter design in the midst of World War II. The design featured a fighter plane that had a "straight, pivoted variable-sweep wing…"[11] The plane would take off and land with the wing at a 0 degree sweep position, but at high speeds it would pivot and reach up to a 35 degree sweep, becoming an oblique wing. However, Vogt's proposal would stay just that–a proposal. The P202 never made it past the conceptual stage, not even receiving an aircraft designation from the German Air Ministry.[11]

After the conclusion of World War II, Vogt was brought to the US through Operation Paperclip, a secret United States intelligence program that employed thousands of engineers and scientists from Nazi Germany.[12]

From there, the concept of the oblique wing was revitalized by NASA aeronautical engineer Robert T. Jones. Before this, Jones had "independently identified the benefits of swept-back wings for high-speed aircraft, regarded as one of the most important discoveries in the history of aerodynamics".[13] He also contributed heavily to concepts like aircraft-piloting control schemes for improved safety.

His work on the oblique wing began in 1945, when, at the NASA Ames Research Center in California, Jones began a multitude of analytical and wind tunnel studies. These studies indicated that a transport-sized oblique-wing aircraft would have distinctly better aerodynamic performance than a more conventional-winged aircraft at speeds up to Mach 1.4.[8]

With these discoveries, the concept of an oblique wing garnered more attention at NASA. This led to the creation of the NASA Oblique Wing, an uncrewed propeller oblique wing aircraft.[11] After obtaining this physical proof-of-concept, NASA designed and built the AD-1, the tests of which were conducted from 1979 to 1982.[11]

Since the AD-1 program, however, all physical testing for oblique wing aircraft has ceased, and only conceptual work has progressed.[8]

1.3. Lift Force of an Oblique Wing:

When looking at the oblique wing, its appearance and asymmetrical shape make it seem as if any aircraft sporting such a wing would corkscrew at any nonzero sweep angle. However, this is not the case, as the principles of lift generation still apply to the oblique wing and mostly disregard the shape.[9]

An oblique wing's asymmetrical shape, while causing asymmetrical lift distribution, still applies lift across its entire body. Similarly to conventional wing types, as long as the angle-of-attack remains positive, so too does the lift generated by the wing.

The concept that the oblique wing (and other variable sweep wings) are built around is that, according to the sweep angle of the wing, an aircraft can undergo variable amounts of lift, with the Coefficient of Lift (CL) decreasing rapidly as the sweep angle increases. A variable sweep wing is built to address the fact that with swept-back, delta, or straight wings, a plane is set on a configuration favoring either a specific speed or a wide range of speeds. In the former case, the wing performs poorly at speeds outside the targeted range, and in the latter, the wing performs at a mediocre level across a wide range. With a variable-sweep wing, you can achieve the positives of targeting a specific speed while avoiding the drawbacks of being locked into a configuration by shifting the sweep angle and modifying the generated lift.[15]

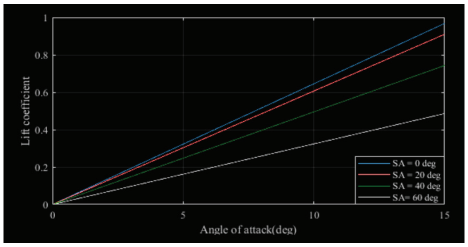

Figure 1: Sweep Angle vs Coefficient of Lift. This figure shows that as the sweep angle increases, the coefficient of lift significantly decreases, highlighting why oblique-wing aircraft display versatility across a wide range of speeds (Rahman *et al.*,).[16]

This effect can be seen in Figure 1, where the coefficient of lift (CL) decreases while the sweep angle increases in an oblique wing, starting at 1 for an AOA of 15 degrees, and at the maximum 60-degree sweep angle, the CL drops to 0.5. Due to the fixed nature of conventional wing configurations, the CL stays constant, which is why the oblique wing is more versatile. This can be seen in the delta wing–the high sweep angle leads to stellar performance at supersonic speeds, and this performance is reflected in the dominating presence of delta wings in modern interceptors and stealth jets of today.[1] However, these high-performance aircraft scrape by at lower speeds with their low lift coefficients. While the delta wing design works for its intended purpose, when taking into consideration the size and transonic speed of the average commercial aircraft, having insufficient lift at lower speeds can have more impactful consequences.[17]

$$L = Cl \text{ x } r \text{ x } \frac{V^2}{2} \text{ x } A$$

$$\text{Lift} = \text{coefficient x density x } \frac{\text{velocity squared}}{\text{two}} \text{ x wing area}$$

Figure 2: This figure presents the standard lift equation (NASA, n.d.).[17]

When analyzing the equation that gives us lift, it becomes apparent that the only variable that can be "tuned" mid-flight without causing any fatal stability errors is the surface area of the wing exposed to the airflow.

So, by changing the sweep angle of the wing and therefore modifying the CL, an oblique wing aircraft can tweak the amount of lift needed midflight, a process that can be automated, such as in the F-14 Tomcat.

Another important quality of an oblique wing is its asymmetrical shape. As mentioned prior, the oblique wing's asymmetrical shape creates a respective asymmetrical distribution of lift.

This is due to an oblique wing having a higher local angle of attack in the side that is swept forward, and a lower angle of attack in the side that is swept back. This difference in angle of attack results in higher lift on the side that is swept forward, and lower lift on the side that is swept back. Through this, the center of lift gets shifted towards the forward-swept side in such a way that rolling and yawing moments are created, making the plane less stable, with a twitchier and jerkier flight path. [18]

1.4. Drag Force of an Oblique Wing:

Similar to the lift force an oblique wing experiences, the drag force is also impacted in multiple ways by the asymmetrical shape.

One of the most distinct ways that drag is influenced by an oblique wing's design is a significant reduction in wave drag.

Wave drag is a type of aerodynamic drag caused by shock waves that form when an aircraft begins to approach and exceed the speed of sound. The increased air pressure and energy loss caused by these shockwaves cause a sudden increase in drag and a reduction in efficiency at transonic and supersonic speeds.[1]

Table 1: This table shows how induced drag decreases as sweep angle increases at 300 meters/second (Adapted from Zandsalimy, 2021).[19]

Λ (Degrees)	Total Induced Drag
0	0.0164236
30	0.0164083
45	0.0163848
60	0.0163361

By pivoting the wing such that the leading edge aligns closer to the direction of the airflow and shock waves, an oblique wing delays shock formation and minimizes the effect of these shocks. This effect can be seen in Table 1.

This allows for a smoother airflow transition and directly causes a reduction in wave drag. In Figure 3, we can see the induced drag of an oblique wing as the sweep angle changes.

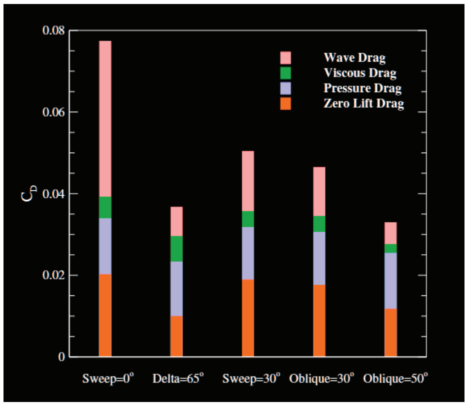

Figure 3: Drag components of different wing configurations at Mach 0.9. This figure demonstrates how the lowest total drag is found in an oblique wing at a 50-degree sweep (Zandsalimy).[19]

In Figure 3, we can see that the oblique wing, at a sweep of 50 degrees, has a significantly lower CD than every other wing configuration at Mach 0.9. As an aircraft with a conventional wing approaches the speed of sound, the drag begins to spike sharply. However, with an oblique-wing aircraft, the drag is mitigated by the shifting sweep angle as the airspeed approaches Mach 1. This reduction in wave drag is a direct advantage over conventional wing types in aerodynamics.[7]

Figure 3 is also helpful in that it objectively defines the Coefficient of Drag (CD) difference between the different wing configurations. In terms of CD, an oblique wing swept at 50 degrees has an advantage over all other wing types, even those tuned for high-speed low-drag performance like the delta wing. While it does fall short in terms of pressure drag and zero lift drag to the delta wing, the oblique wings overall improved drag performance as well as the ability to change sweep angle according to airspeed puts it, relative to the drag of other wing configurations, as the prominent design.

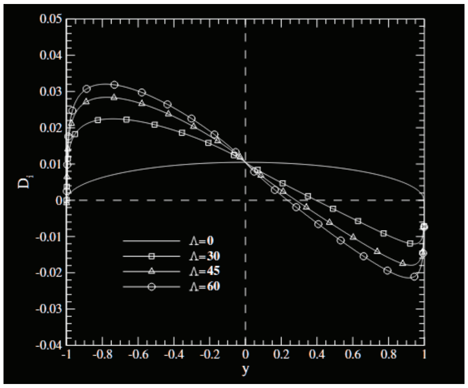

Figure 4: Induced drag distribution across the span of an oblique wing at 300 m/s. This figure illustrates the asymmetrical nature of drag distribution on an oblique wing, explaining the yawing moments an oblique-wing aircraft experiences (Zandsalimy, 2021).[19]

Just like how an oblique-wing aircraft experiences asymmetrical lift, it too undergoes asymmetrical drag. The aircraft experiences this drag at different levels across the span of the wing.

The forward-swept part of an oblique wing, due to increased lift and complex flow patterns, undergoes increased drag as well, and the back-swept part undergoes decreased drag. This can be confirmed in Figure 3, where the drag difference between the sides of the wing can get up to as much as ~0.054.[19]

This drag difference is what creates the yawing moments that are one of the causes of an oblique-wing aircraft's instability.

1.5. Comparison to Conventional Wings:

Throughout this section, both the lift and drag forces of an oblique wing have been explored, and the oblique wing's unique qualities and how they affect these forces cause key differences in its aerodynamic performance in comparison to conventional wing types.

In Figure 1, we can clearly see that where other wing types stay at a constant amount of lift (due to a constant sweep angle), the oblique wing shifts its sweep angle to adjust the lift needed according to the airspeed.[15]

In Figure 4, the fact that this nonzero sweep angle can cause an imbalance in drag that forces rolling and yawing moments

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can be observed. These moments require a counteraction for the aircraft to maintain its course.[20, 21]

In Figure 3, we can see that due to the oblique wing's unique shape, it has a lower drag coefficient than other wing types (hence less drag), which allows for a smoother performance at transonic speeds.[1, 7]

Overall, the oblique wing presents clear advantages in aerodynamic adaptability, with the fluid sweep angle allowing for peak performance across a wide range of airspeeds. This puts it above other wing types in terms of pure aerodynamic efficiency. However, it also experiences significant instability and control issues due to the imbalance in lift and drag forces caused by the innate asymmetrical shape of the wing.

■ Design Challenges of an Oblique Wing

This section will explore the challenges presented by the oblique wing in terms of design. Oblique wings have never been tried and tested in a commercial setting, so when creating a design solution for an oblique wing aircraft, there is no precedent and many different avenues to explore.

2.1. Oblique Wing Aircraft Designs:

After establishing what an oblique wing actually is in the first section, it is now important to explore what it would look like on an aircraft.

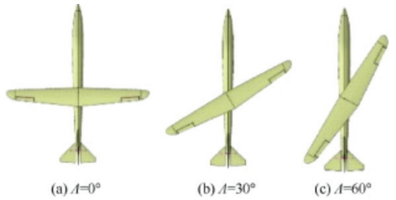
(a) $\Lambda=0°$ (b) $\Lambda=30°$ (c) $\Lambda=60°$

Figure 5: Visualization of an Oblique-Wing Aircraft. This figure illustrates how the oblique wing rotates around its single pivot and what different sweep angles look like on an oblique-wing aircraft. (Yue *et al.*)[14]

In Figure 5, it is shown that the oblique wing typically sits around the midspan of the plane and rotates around that point. This design uses a conventional configuration, with a fuselage and the wing being two separate parts of the aircraft.[19]

Another proposed design solution is an oblique all-wing aircraft. This type of airplane would consist solely of a wing, with all control surfaces, engines, and cabin space being contained in one structure.[3]

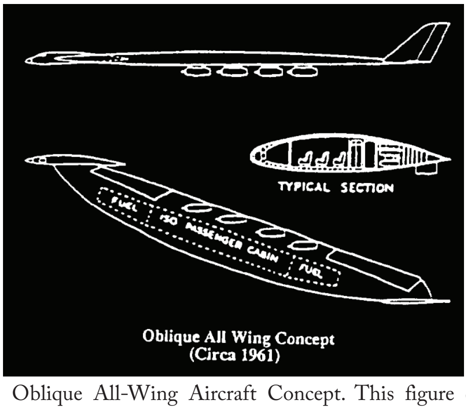

Figure 6: Oblique All-Wing Aircraft Concept. This figure depicts the conceptual layout of an aircraft designed with the fuselage doubling as an oblique wing (Galloway *et al.*).[8]

Figure 6 showcases the proposed design for an oblique all-wing (OAW). As pictured, everything from cabin space to control surfaces and turbines is all on the same structure, the body of the aircraft. In this design solution, the aircraft assumes a gentler sweep angle for takeoff and landing, and then rotates to a higher sweep angle for cruising. It does this by rotating everything on the aircraft, from engines to the rudder, as seen in Figure 6.

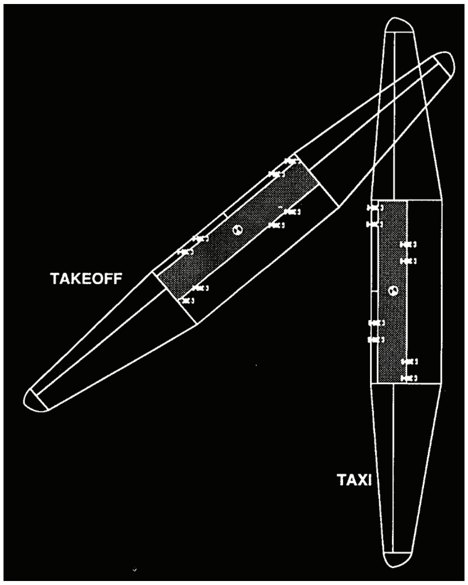

Figure 7: Alternative Oblique All-Wing Aircraft Concept. This figure is an alternative concept for the oblique all-wing aircraft seen in Figure 6, offering a more conventional configuration and design (Waters *et al.*).[22]

In Figure 7, an alternative design can be seen, where the aircraft consists of a single wing, and through rotation of engines and wheels, can change its sweep angle. What differs here is that there is no distinct pilot cabin, and the plane resembles a conventional design to a higher degree.

These two designs are both viable solutions to creating an oblique-wing commercial aircraft, and as such, will both be covered in this section.

2.2. Structural Integration & Airframe Modification:

Having an oblique wing alters many key aspects of an aircraft's design, and even with the same aircraft, just swapping out the wing can make the new design stray from the old by a significant amount.

For example, when the Vought F-8 Crusader was being considered for oblique wing testing, there were many aspects to take into consideration, like wing placement, angle, and pivot mechanism, as seen in the study conducted by Koltko *et al.* in 1975.

The first issue that comes up is that of the pivot–due to the single-pivot design of an oblique wing, a significant amount of stress is placed upon that pivot, whereas in a normal variable-sweep wing design, there are two pivots to take the brunt of the force.[18]

In order to address this problem, the researchers at Vought Systems considered two paths forward, considered two paths forward: a turntable concept and a cantilevered post bearing concept.[23]

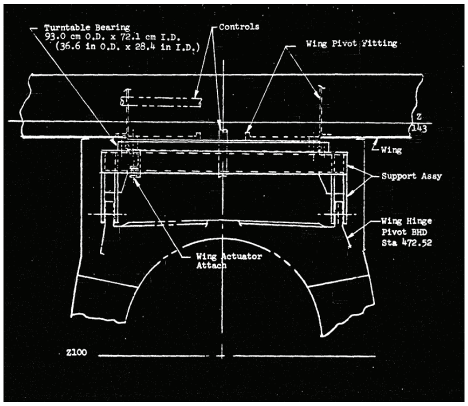

Figure 8a: Turntable concept. This figure presents the turntable pivot mechanism, the preferred design for an oblique-wing pivot (Koltko *et al.*).[23]

In Figure 8a, the turntable concept is displayed. It had many benefits that ultimately led to Vought picking it as their primary choice over the cantilever concept.[18] Some of these benefits include structurally superior wing load paths into the fuselage, a smaller wing pivot actuator, and a minimal size, allowing more room for controls and routing from the fuselage through the center of the wing.

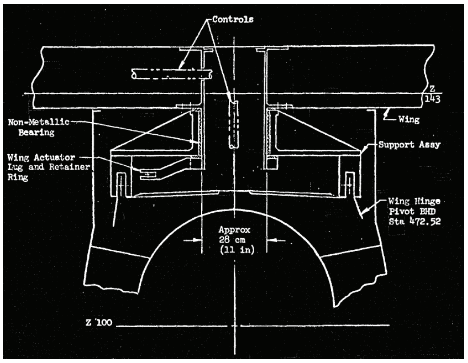

Figure 8b: Cantilever post concept. This figure depicts the cantilever post pivot concept, which was discarded due to poor distribution of load (Koltko *et al.*).[23]

The cantilevered post bearing concept, while still being viable, had a few key drawbacks that led to the turntable concept being picked, such as undesirable load paths and little to no structural redundancy. In Figure 8b, the cantilever concept is shown.

The concepts and principles explored by the researchers at Vought Systems scale to transport and commercial aircraft, and are actually more critical as the pivot mechanism would have to withstand more force and stress.[3]

In the case of the F-8, the researchers determined that there would need to be little to no change to the actual airframe, as the oblique replaced the F-8 wing fairly simply. All that was needed to be done was to take the wings off, cover up the holes, and attach and hook up the oblique wing.[23]

In the case of a commercial aircraft, if using the conventional airframe, the case is similar, just on a larger scale. Many transport aircraft feature high-set wings, so taking them off and replacing them with an oblique wing would be just as simple a process as with the F-8.[18]

2.3. Weight & Balance Considerations:

For a conventional aircraft, and even aircraft sporting variable-sweep wings, the balance of the aircraft is constant or predictably and controllably shifting. However, in the case of an oblique wing, its asymmetric shape as well as force distribution (see 1.3 and 1.4) cause the center of lift to shift relative to the center of gravity, requiring exact and constant control to maintain level flight.[5,9]

The center of balance for the oblique wing is far more volatile than that of other configurations, and hence the importance of the aircraft being able to manage those shifts due to imbalance.[5,18]

Beyond intricate control, keeping in mind the placement of passenger and cargo space is important for maintaining a manageable center of gravity in a commercial oblique-wing aircraft.

In Figure 6, the design shows a cross-section of the aircraft, where the cabin space and cargo areas are clearly defined.[3] A format like this is conducive to a balanced commercial oblique all-wing aircraft, because even as the engines and control surfaces change their orientation, the center of gravity remains the same, allowing for a sweep that does not cause pitching, rolling, and yawing moments.[24]

2.4. Control Solutions:

As explained, an oblique wing's asymmetrical geometry causes complex aerodynamic moments that make stability and control far more difficult to maintain than in conventional aircraft.[18] Furthermore, the uneven distribution of lift, as well as induced drag, causes coupling moments, where if the plane pitches, it rolls, or if it rolls, it yaws, and so on.

At transonic speeds, these coupling moments are exacerbated by the sensitivity of the controls as airspeed increases.[1,7]

At high sweep angles, however, normal control surfaces may be insufficient, and so a fly-by-wire system is preferred. Fly-by-wire is, in essence, a computer that makes rapid, micro corrections to the control surfaces of an aircraft that allow for the plane to fly level, even if the plane is inherently unstable.[10, 24] This fly-by-wire system can even correct for the many coupling moments produced by the asymmetrical design of an oblique wing, which is why it is an optimal control solution.

■ Barriers to Implementation

In this section, the paper explores what logistical and commercial barriers hold back the oblique wing from being further explored as a concept, much less becoming implemented on a wider level. These issues span from regulatory to financial in nature.

3.1. Logistical Barriers:

For an oblique wing aircraft, no matter what the configuration is, the point stands that the variable sweep element of the wing remains, meaning a constant and high level of stress is placed on a single pivot.[18] This pivot, no matter how efficient or effective the design, would need regular and attentive maintenance, increasing upkeep and production costs.

To add to the issue of complex parts, oblique-wing aircraft are nowhere near popular, and if they were introduced to commercial flight, it would take focused effort over an extended period of time to set up a strong supply chain.[3] In the initial years, there would likely be a shortage of repair parts.

Finally, due to the complex nature of an oblique-wing aircraft, airlines would need highly trained pilots, engineers, and technicians to maintain even a few planes, much less an entire fleet.[3,7]

3.2. Regulation & Certification Issues:

Current FAA and EASA regulations are built around symmetric wing designs, meaning that radical asymmetrical configurations like oblique wings would require entirely new standards and certification protocols.[5]

The asymmetry of an oblique wing, as already established, can complicate aerodynamic characteristics such as stall speed, controllability with and without fly-by-wire, and structural integrity.[1] These factors could lengthen the certification process by many years, deterring further development.

Furthermore, there is no precedent for an asymmetric-wing aircraft in any commercial sense, increasing both cost and perceived risk for manufacturers.

3.3 Market and Economic Viability:

The main holdup that overshadows other barriers is that, for the last half-century, existing aircraft designs and configurations have worked reliably and economically.[10] Current designs maximize what is economically important and operate efficiently at subsonic speeds, where drag is minimized, and fuel economy is highest.[1]

Even if the barrier of supersonic flight's fuel inefficiency is overcome, there still stand market and economic obstacles. Airlines often focus on a "family" of aircraft, and introducing an oblique-wing aircraft would require unique crew training and maintenance. Public perception also matters, since if passengers believe the design is unsafe or unstable, acceptance could become a major hurdle.

3.4. Summary:

The main logistical and commercial barriers holding back further development of oblique wing aircraft in commercial flight are regulatory hurdles due to a lack of precedent, increased manufacturing and maintenance complexity, and economic uncertainty caused by the risks and perception of asymmetrical wings. Despite these obstacles, however, new opportunities for the concept can be made through advances in control systems and materials. If these logistical and regulatory challenges were resolved, the oblique wing could make a resurgence as a viable option for commercial flight, but until then, it will remain a research subject dependent on constant innovation and exploration.

■ Conclusion

The thesis explored in this paper is that an oblique wing aerodynamically outperforms a conventional wing design, but brings with this performance a host of challenges in stability, control, market and economic barriers, and overall a lack of commercial feasibility.

The paper first explored the aerodynamic characteristics of the oblique wing concept, including lift and drag performance at transonic speeds and asymmetrical force distribution. This section demonstrated that while the oblique wing does introduce some problems with stability, it also achieves a lower drag and maintains lift more effectively than other conventional wing configurations.

Next, the discussion shifted to the various design challenges and solutions surrounding the oblique wing, analyzing how such a design could become structurally and technically viable. Finally, the logistical and commercial barriers preventing the adoption of the oblique wing concept were presented, such as regulatory uncertainty, complexity of manufacturing, and the lack of an incentive in the market.

Despite these challenges, however, advances in computational modeling and control systems could make future implementation of the oblique wing concept viable and more feasible. Future research should have a focus on computational fluid dynamics and wind tunnel testing in order to gain a clearer understanding of aerodynamic stability across a range of sweep angles. Further exploration into lightweight composite materials could reduce the weight of the oblique wing structure while increasing durability and efficiency of the single-pivot mechanism. On top of this, improvements in fly-by-wire technology and control systems may mitigate the stability issues caused by the asymmetrical shape of the wing that limit the concept's viability in commercial flight.

These developments hold promise for the oblique wing and also carry broader implications for the overall field of aerospace engineering. The advancement of adaptive aerodynamic design and further research on oblique wings could serve as the base for next-generation aircraft, allowing the designs to achieve higher fuel efficiency and lower emissions. Additionally, collaboration between the disciplines of materials science, avionics, and aerodynamics could transform the oblique wing from an experimental concept to a feasible component of sustainable transonic flight.

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