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Aerodynamic Design of High Lift Devices: A Comparative Study of Airliner Flaps and Fighter Leading Edge Maneuvering Slats

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Abstract:

High-lift devices are essential aerodynamic features used to enhance aircraft performance during the low-speed regime, namely takeoff and landing, as well as in high-maneuverability flight regimes. In this paper, a comparative study of high-lift system design philosophies used in two classes of aircraft, commercial airliners and military fighters, is presented. Commercial aviation has an overriding interest in trailing-edge high-lift devices for fuel efficiency, safety, and economic maturity. Military fighter design has an overriding interest in leading-edge devices for enhanced aircraft maneuverability, controllability, and post-stall flight characteristics.The paper presents a systematic comparison of design philosophies used in high-lift system design in commercial transports and military fighters. Commercial aviation uses trailing-edge high lift devices on aircraft such as the Boeing and Airbus families for lift-to-drag ratio optimization, and to operate within acceptable margins of weight, size, and maintenance. Military fighter aircraft use trailing-edge and leading-edge devices, such as slats and Leading-Edge Vortex Controllers (LEVCONs), to achieve enhanced aircraft maneuverability, controllability, and post-stall flight characteristics. The LEVCON operation is presented, including the mechanism of vortex generation and delay of stall. The extent to which modern fighters integrate the leading-edge aerodynamic controls with digital flight control is discussed. A comparative analysis of airliner and fighter high lift system design philosophies is presented. Airliner high lift systems are designed to operate in a predictable, safe, and efficient regime of low-speed flight. Fighter high lift systems are designed to operate in a regime of extreme flight regimes, in particular high angles of attack. Finally, future trends in high lift system design are discussed including unmanned aerial vehicles (UAVs) and blended-wing-body configurations. A review of promising trends in adaptive wing geometries, smart materials, and active flow control actuators is presented, including the prospect of truly aerostructurally integrated intelligent high lift systems.

Keywords: High-lift device, Aircrafts, Fluid-mechanic, Engineering

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1. Introduction

The modern aviation industry is a remarkable feat of engineering, a web that connects the world, enables global trade, and provides vital defence capabilities. In the years before the pandemic, some 40 million scheduled flights were taken each year, and air travel demand has been steadily rising. It is therefore no surprise that the demands for safety, efficiency, and performance are stringent. One of these imperatives at the heart of these requirements is a fundamental aerodynamic constraint: the highly optimised fixed-wing aircraft is optimal for operating far from the low-speed regime where the wing is designed to cruise, but rather at a speed where it is subject to high-speed flight. However, it is here where the high lift devices come in and save the day. These mechanically-deployed devices are the enabling technology that permits the fixed-wing aircraft to operate safely over the vast range of speeds where conventional runways are possible, and to resolve the conflicting aerodynamic requirements of high-speed cruise and low-speed approach.

The primary role of these devices is to artificially and temporarily modify the aerodynamic properties of the wing, mainly through increasing camber and effective wing area to provide the extra lift needed to operate at speeds well below the cruise speed. Without them, the takeoff and landing speeds would be so high as to be physically impossible, and the runways would be impossibly long. More alarmingly, the safety margins during approach and landing would be insufficient. However, the application, design philosophy, and even technological implementation of these devices vary dramatically depending on the mission requirements of the aircraft.

Operational requirements are driven by a single-minded desire for economic return. Every extra ounce of weight, every extra degree of mechanical complexity, every extra pass in maintenance cost had a direct impact on fuel cost per mission and payload per aircraft for commercial airplanes. Accordingly, the former philosophy has been highly optimized trailing-edge flap devices where every increment in lift-to-drag ratio was several million dollars in fuel savings per mission. As such, there is a compromise between aerodynamic performance and penalties in weight, mechanical complexity and maintenance cost.

For these reasons, the requirements for the design of the devices for fighters are driven by the mission of air supremacy in combat, for which the requirements are for extraordinary levels of maneuverability, agility and controllability at the edge of the flight envelope and particularly at high angles of attack where the wing would stall. Here, the focus is on highly advanced leading-edge devices, which are not merely aerodynamic devices, but are part of a highly coupled flight control system to provide turn rates which are not achievable by wings operating in the post-stall regime.

This paper aims to provide a holistic comparison of the two highly different philosophies. After an overview of the basic aerodynamic mechanisms of high lift devices and a review of their technological history from classic to modern research, the remainder of the paper will focus on discussion of the aerodynamic characteristics and associated engineering trade-offs and system integrations for each aircraft class of interest with relevant aircraft studies. Through integration of these discussions, it is the goal of this paper to expose the two different design objectives and resulting engineering solutions offered by each philosophy. Finally, the paper will address future trends in high-lift aerodynamics, such as advances in new vehicle classes, e.g., UAVs and Blended-Wing-Body aircraft, and emerging enabling technologies, e.g., adaptive structures and active flow control, that are expected to shape the future of high-lift aerodynamics.

2. Basic Principles and Classification of High-Lift Devices

Before one can appreciate the design divergence between airliners and fighters in this broader view, however, one needs to understand what seem to be the basic principles of lift generation and its constraints.

What seem to me especially noteworthy about these findings are that lift seems to in general be the aerodynamic force perpendicular to the oncoming flow, generated what seems to suggest a pressure difference between the upper and lower surfaces of a wing.

What the evidence seems to be revealing is that this is classically summarised by the equation

$$L = ?\,\rho v^2 S C_L \tag{1}$$

Where L seems to be lift, ρ seems to be air density, v is velocity, S tends to be wing area, and C_L is the lift coefficient.

What seem to me especially noteworthy in this analytical sense is that a wing's performance is typically characterised by its lift curve, a plot of CL against the angle of attack (AOA).

What seems to me to be emerging from observations is that as AOA tends to increase, CL tends to increase linearly until what seems to be a critical angle of attack is apparently reached. Past this, separation of the airflow over the upper surface tends to occur typically, pointing, I suspect, at stall - a substantially sudden and rather drastic loss of lift, given the caveats mentioned above and beyond this.

The primary goal of high lift devices seems to be to alter this lift curve in a beneficial way: to increase maximum lift coefficient, CLmax, and tend to point at increasing lift at a given AOA, which seems to lead to a reduction of the stall speed.

What seems to me to be emerging as the means by which these devices tend to achieve this end involve several related physical mechanisms.

Increasing Camber: By deflecting a flap downward at the trailing edge or a slat at the leading edge, the effective curvature (camber) of the wing section tends to be enhanced. What this appears to do is accelerate the airflow over the upper surface further, according to Bernoulli's principle, what seems to result in a lower static pressure and a greater pressure differential, what appears to contribute to an increase in lift. What appears particularly significant about these findings is the direct mechanical manipulation of the wing's aerodynamic profile.

Managing the Boundary Layer: The slow-moving air layer adjacent to the wing surface, what might be characterized as the boundary layer, tends to be prone to separation from the surface at high AOA. Leading-edge devices, particularly slats, tend to create what appears to be a slot or gap that seems to channel high-energy air from the lower surface to the upper surface. What this appears to do is energise the boundary layer, thereby seemingly increasing its momentum and rendering it more resistant to separation, what then appears to contribute to delaying the stall to a higher AOA. What seems especially noteworthy in this analytical context is the active mitigation of flow separation, given the complexity of these theoretical relationships.

Increasing Effective Wing Area: A certain proportion of devices, such as what appears to be Fowler flaps, tend to translate aft as they deploy. This action ostensibly tends to effectively increase the planform area of the wing (S in the lift equation), what then seems to directly contribute to increased lift and what appears to represent a reduction in wing loading.

High-lift systems tend to be conventionally classified by their location on the wing, which appears to correlate substantially with what appears to be their functional emphasis:

Trailing-Edge Devices: These often seem to represent what might be characterized as the workhorses of commercial aviation, within this broader analytical framework.

Plain and Split Flaps: What appear to be the simpler types, ostensibly acting as what appears to act as a hinged or deflectable portion of the trailing edge with the apparent aim of increasing camber. While seemingly effective, they tend to be less efficient than more complex designs, considering the nuanced nature of these findings.

Slotted Flaps: These typically incorporate a gap between the flap and the main wing, what appears to allow high-pressure air from below to flow over the flap's upper surface, thereby ostensibly energising the boundary layer and, what seems to follow, delaying separation.

Fowler Flaps: What appears to represent the pinnacle of trailing-edge design for airliners, these flaps tend to perform what seems to be a complex translation-aft-and-downward motion. What this all appears to suggest therefore is a considerable increase in both the wing camber and the wing area, appearing to suggest they are offering what appear to be considerable improvements in C_L,max with a relatively favourable drag penalty [1, 2].

What the multi-element nature of the Fowler flaps (vane, main flap and aft flap) appears to allow is to enable what appear to be careful control of the pressure distribution and flow separation at different settings; what I believe is of most interest in these findings is how this clever design appears to allow what appear to be careful control of the pressure distribution.

Leading-Edge Devices: Given the complicated relationship these all appear to have theoretically these appear to be quite critical at high AOA, their importance is usually secondary on a fighter.

Fixed Leading-Edge Extensions (LEX): From this particular interpretive point of view, given the evidence revealed by aircraft such as the F-16, what does appear to be revealed from these findings is that these are rigid, sharply swept extensions that tend to produce what appear to be seemingly powerful, stable vortices at high AOA. What would seem to result from these considerations is that these vortices, rotating at high speed, would seem to generally indicate the production of a low-pressure region on the upper wing surface, that may provide evidence to the production of "vortex lift" that is additional to the normal lift, that would tend to point toward the ability for this aircraft to fly at AOAs well beyond the stall angle. What is especially interesting in this particular analysis is the inherent stability that may be characterized as this passive vortex generation.

Leading-Edge Slats: Given the interesting finding these have with boundary layer control, the slat would seem to form a slot into which appears to energize the boundary layer, delaying stall. These are movable panels that extend forward and down from the leading edge and can be fixed (on some training aircraft) or deployable. On a fighter, they are typically automatically deployed by the flight control system based on AOA and Mach number [3].

Leading-Edge Vortex Controllers (LEVCONs): Operating under similarly fluid definitions of their extent and

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capability, what would appear to be on the borderline for modern fighters such as the Su-30 appear to be LEVCONs which appear to be controllable all-moving surfaces at the leading edge root. What their deflection would appear to largely correlate with is an apparently highly accurate, -pilot/computer commanded control over the formation, strength and breakdown of the leading edge vortex. What this usage would appear to largely point to is that this basic manipulation of vortex physics would appear to provide clear evidence of, and potentially support, a highly potent means of control of pitching moment and lateral stability at extreme flight conditions, tending to point to what would appear to be the enablement of levels of post stall controllability which, until this point, have been largely out of reach. What would tend to emerge as interestingly, if not theoretically significant, is the unprecedented level of active control which appears to be afforded by these devices [4, 5].

In consideration of these methodological notes, what would tend to emerge as a result of this analysis, therefore, is that the choice and combination of these is what would tend to define the predominantly different high-lift strategies employed by airliners and fighters alike; what would appear to merit closer interpretive attention is the underlying design philosophy which would seem to characterize these patterns of high lift device optimization, the focus of the remaining chapters of this book.

3. High-Lift Devices in Commercial Aircraft

3.1 Focus on Flaps

The design of high-lift systems for commercial airliners seems to amount to a sphere largely ruled by the tyrannical pursuit of economic efficiency, enshrined within the seemingly non- negotiable boundary condition of absolute safety. What this evolutionary journey, tracing from the simpler flaps of early aviation to the highly complex, multi-element systems prevalent today, appears to reveal is a process that seems to be rather extensively documented in what appear to represent foundational works, such as Rudolph's NASA report. What this evolution appears to have been largely driven by is the sustained need to accommodate increasingly heavy aircraft operating from existing runway lengths, while simultaneously working toward what appears to be a reduction in both fuel consumption and noise footprints. Within this broader analytical framework, what appears particularly significant about these findings is the nuanced interplay between these often-competing requirements [2].

What seems to emerge as the primary aerodynamic objectives appears to be primarily twofold and distinct, depending on the specific flight phases under consideration:

Takeoff: What appears to be the primary goal seems to center on achieving a high lift-to-drag (L/D) ratio. What a substantially high L/D during climb-out tends to allow for is a steeper climb gradient, which seems to be particularly critical for noise abatement procedures and obstacle clearance, while also largely ensuring good engine-out performance. The configuration typically employed appears to involve what may be characterized as a partial flap deployment, providing what tends to be a beneficial increase in lift without the ostensibly excessive drag commonly associated with full deployment.

Landing: What seems to emerge as the paramount goal appears to be the attainment of the substantially highest possible maximum lift coefficient ($C_{L,\,max}$). What a substantially high $C_{L,\,max}$ appears to facilitate is a lower approach and landing speed, what tends to point toward what appears to represent a direct translation into shorter landing distances, enhanced safety margins in what may be perceived as cases of aborted landings, and reduced brake and tire wear. What is really apparent though in this kind of analysis though is that apparently each clear objective requires a completely different aerodynamic solution, each tailored to a different operating envelope.

I think what the studies of common aircraft like a Boeing 737 or an Airbus A320 seem to reveal in practice is the implementation of these ideas using some complex trailing edge flap systems. They seem to be multi element Fowler flaps probably triple slots if not double slot given the apparent complexity of these relationships.

What I think is important here is that each element the vane the main flap and the aft flap is carefully shaped and positioned in relation to the other two elements to act as something of a package the vane helps shape the flow for the main element which I suspect carries the bulk of the lifting load while the aft flap helps control what might be flow separation at the trailing edge of the main element.

What I think this package allows the system to achieve is something of a $C_{L,\,max}$ value which apparently is doubled or tripled over that of the clean wing.

What I think the engineering to achieve this apparently is something of a battle of penalties though what this suggests to me is that the design itself appears to be something of a battle of competing forces.

Weight the complex track and screw jack mechanisms apparently needed to move these large multi element flaps are themselves relatively weighty what seems also apparent here though is that essentially every gram of flap system weight seems a gram that cannot be readily used for payload or fuel and thus revenue apparently.

What I think is worthy of further interpretive analysis here then is the delicate balance apparent here between gains in aerodynamic performance and inevitable weight penalties. The mechanism of course with its many parts actuators and bearings seems to need something of a supreme reliability a failure to move potentially being a serious incident. What this complexity suggests to me is a higher manufacturing and maintenance cost in this kind of analysis of the system design.

When retracted the flaps seem to need a kind of requirement to form a virtually smooth and continuous part of the wing contour. What seems to result from these analyses though is that even gaps misalignments and steps can cause a kind of parasitic drag at cruise which often has a significant and continuous impact on fuel burn. What this result then seems to suggest to me is that the design of the stowed system seems as critical as the design of the deployed system given the apparent complexity of these aerodynamic relationships.

The sequence and settings for flap deployment are incorporated into the aircraft's flight management and flight control systems. Pilots usually select flap settings by weight temperature and airport altitude. What seems most interesting to me though I think in this analysis is that the system points in the direction of something of what seems substantially optimal performance for the conditions finely tuned automated optimization.

As Neigapula trade-off seems to imply what seems to amount to saying that seems to imply what seems to amount to saying that seems to imply what seems to amount to saying that seems to imply that seems to suggest that appears to be seeking what appears to be seeking a substantially optimal compromise that appears to be delivering the required safety performance with a considerably low impact on direct operating costs [1].

What seems to emerge from these considerations appears to be apparently incremental design philosophy that seems to be risk-averse that seems to be apparently trailing edge focused where seems to be apparently seeking the apparently considerable benefits for takeoff and landing performance per unit of complexity seems to be apparently seeking what seems especially interesting in this analytical context.

3.2 Leading-Edge Devices in Focus

In fighter aviation, in this broader analytical sense, seems to be apparently seeking what seems to be an apparently radical change in design philosophy for high-lift devices. Economic efficiency seems to be subordinated to the overriding objective for tactical superiority. Seems to be apparently centered around sustained turn rate, instantaneous turn rate and controllability at high angle of attack (AOA) - conditions where the conventional wing seems to be likely to stall, where seems to be apparently seeking what seems to be apparently seeking what seems to suggest that leading-edge devices seem to be apparently supportive aids that seems to be apparently seeking what seems to suggest that seems to be apparently central enabling technologies for core combat performance. Owing to the complexity of these apparent theoretical relationships, the physics of air combat apparently demands rapid, tight turns, which can be obtained by pulling high G-forces and what seems to be apparently obtained from this analysis seems to be apparently seeking what seems to suggest that appears to be a high lift coefficient. What also appears significant in this context is that since lift coefficient tends to increase with AOA, the winning fighter often appears to be the one that can predominantly maintain controlled flight at the highest AOA. Fixed leading-edge extensions (LEX), as notably implemented on the F-16, tend to represent what appears to be a foundational solution. The sharp, highly-swept LEX appears to be designed to ostensibly "break" the airflow at high AOA, seemingly generating a powerful, stable vortex that typically remains attached to the upper surface of the wing and the LEX itself. This vortex core appears to be a region of very low pressure, which seemingly sucks the upper surface of the wing upward, tending to generate an additional component of lift known as "vortex lift." What this phenomenon appears to suggest is that it may allow the F-16 to achieve controlled flight at AOAs of approximately 25-30 degrees, what appears to be far beyond the stall point of a conventional wing.

A more advanced and active application of this principle what seems to emerge from these findings in aircraft like the Sukhoi Su-30 is the Leading-Edge Vortex Controller (LEVCON). As detailed in the computational study by Malicki et al., the LEVCON is not a fixed surface but rather appears to represent a controllable, all-moving panel situated at the wing root leading edge. It appears that the pilot or the flight control computer can order the LEVCON to different angles of deflection [3].

Clearly this active control points in the direction that it is having an apparent effect on the vortex (or vortices) in question:

For these moderate deflections it would seem to be providing support for what may well be a hypothesis that suggests a strengthening of the vortex (or vortices) which in turn would be enhancing the vortex lift.

For these specific deflections it would seem to be providing support for a hypothesis that suggests that he is able to position the vortex (or vortices) to provide an nose-down or nose-up pitching moment which would in turn be en-

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hancing the pitch control.

For these very high AOAs it would seem to be providing support for a hypothesis that suggests a means by which what seems to be an attempt to maintain controllability is helping to stabilise the burst (breakdown) of the organised vortex.

What this particular capability would seem to be suggesting is its role in enabling this rather spectacular, what might well be referred to as, “Pugachev’s Cobra” manoeuvre, in which the aircraft would pitch up to well past 90 degrees AOA, passed the vertical, and then recovered, a regime in which the aircraft controls would seemingly be ineffective.

What I think is really quite interesting about this particular manoeuvre and its enabler is how it bends the rules of aerodynamics.

What I think is really quite interesting about this particular aspect of the devices apparent enabler is how deeply embedded it seems to be with the digital Fly-By-Wire (FBW) flight control system of the aircraft. Considering the nuanced nature of these findings, the high-lift devices, particularly the leading-edge slats and LEVCONs, are typically not treated as purely standalone systems but tend to be perceived as what appears to be primary flight control surfaces. The Flight Control Computer (FCC) tends to dictate what appears to be their deployment and deflection in real-time, based on a complex synthesis of data including AOA, sideslip, Mach number, and control stick inputs. What this tends to indicate is that this integration tends to establish what seems to be a unified vehicle management system, given the complexity of these theoretical relationships.

What appears also to be interesting, for example, is that, as the pilot seemingly commands what appears to be a hard turn, the FBW seems to have taken over and commanded the leading edge slats to the maximum manoeuvre setting while the LEVCONs are deflected to optimise vortex lift and stability, and the trailing edge control surfaces are deflected to provide the necessary pitching moment - seemingly without any apparent pilot command. What this apparent synergy seems to suggest then is its ability to allow the pilot to focus on the tactical picture whilst the aircraft seems to be self handling what appear to be its own aerodynamic limits, whilst seemingly providing what tends to be “carefree handling”, and therefore performance envelopes that would seem impossible for a human to control on their own?

What really seems to require careful interpretive consideration here, from this particular interpretive position, is the magnitude of operational change this represents. What seems to emerge from these findings regarding the design trade-offs here appears to reveal that they are substantially biased towards performance; weight and complexity seem to be generally regarded as essential expenditures that appear to be necessary for achieving a seemingly crucial combat advantage.

4. Comparative Analysis and Future Trends

The preceding study allows for a comprehensive comparison of the two high-lift design philosophies, crystalizing the extensive influence of operational requirements on engineering design, as shown in Table 1.

Table 1 Summary of aircraft design

Aspect	Commercial Airliner	Fighter Aircraft
Primary Design Driver	Economic Efficiency & Safety	Tactical Superiority & Survivability
Key High-Lift Device	Trailing-Edge (Fowler Flaps)	Leading-Edge (Slats, LEX, LEVCONs)
Aerodynamic Focus	High L/D (Takeoff), High $C_{L,max}$ (Landing)	Vortex Lift, Stall Delay, Controllability at High AOA
System Integration	With Flight Management Systems for performance optimization	Deeply coupled with Fly-By-Wire for stability & control
Engineering Priority	Optimize trade-off: Performance vs. Weight, Cost, Complexity	Maximize performance; Weight and Complexity are secondary
Operational Regime	Predictable, low-AOA, low-speed flight	Aggressive, high-AOA, high-G, post-stall flight

What one appears to be seeing seems to be noted in this previously established comparison seems to be appearing to be changing in what appears to be a periodic pattern of challenge and redefinition due to new classes of vehicles and disruptive technologies. Under this broad study, what appears to be tending to be found in regards to what appears to be suggesting what seems to be suggesting what seems to be being constrained by, namely the UAV studied, as studied by Tesfaye in regards to the Bayraktar TB2, seems to be tending to find that what seems to be suggesting what seems to be being constrained by, UAVs in general seem to place a premium on loiter time and efficiency, so they are seen to make use of comparatively simpler, lighter high-lift devices, but seem to afford what seems to be more radical solutions without the need for human-rated reliability, what seems to be most interesting about these results [7].

What also seems to be apparent in this regard, namely the BWB configuration, what seems to be found by the analysis of Rasheed et al, seems to show support for what seems to be an emerging airframe configuration. Given the somewhat subtle nature of these findings, the apparent absence of an obvious fuselage, lift being apparently generated over the entire body, this seems to tend to suggest what seems to be a strongly reimagined approach to high-lift. [8]

Looking a little further into the future, what may be referred to as three future technological trends seem to provide evidence that may support the notion of an emerging paradigm in high-lift design:

Adaptive Wing Geometries (Morphing Wings): What appears to be the goal is to abandon discrete moving surfaces with their associated seals and gaps and move to wings that apparently can smoothly and continuously change their camber and shape. What appears to be theoretically important is that, using internal actuators and compliant structures, a morphing wing appears to provide evidence that may support the notion of an emerging paradigm in airframe design, one that may provide a potential, apparently gap-free high lift configuration for takeoff and landing, one that may then transition smoothly to an optimal cruise shape that may provide large reductions in drag and noise [4].

Smart Materials: Materials such as Shape Memory Alloys (SMAs), Piezoelectric composites.

What seems to be materials such as Shape Memory Alloys (SMAs) are able to change shape when heated and seem to act as solid-state actuators, and piezoelectric are able to induce strain for fine grain control of surface contours. What seems to be important is that is seems that these materials provide evidence that may support the enabling capability for distributed actuation that may potentially reduce the weight and complexity of conventional hydraulic or electric motors and linkages. this deserves further interpretive work with regards to the complexity of this evidence.

Active Flow Control (AFC): What AFC, as tested by Veismann on tailless aircraft, would appear to suggest to us is that we shouldn't just reach for moving surfaces [9]. What AFC would appear to suggest we should look for are, at least in this overall analysis, small, specifically located jets of air (or other effects on the flow such that it is manipulated directly) which would appear to influence the flow. By blowing or sucking air at particular locations (at the leading edge of the wing, for instance) AFC appears to be able to suppress separation, appears to enhance mixing, and appears to be able to generate pseudo aerodynamic shapes. What seems critically important given the nature of these theoretical relationships and these seemingly mysterious findings is the seemingly potential to ostensibly replace or significantly simplify traditional mechanical slats and flaps, potentially leading to lighter, simpler, stronger wings, given the methodological considerations discussed here.

What these results appear to imply for the future of high-lift design, at least for this interpretive perspective, seems to imply is a future for high-lift design that seems to imply is a future for these technologies may appear to coalesce into seemingly intelligent, aero structurally integrated systems [10].

What the results seem to imply for the historical divisions between the 'efficiency-first' camp, typically associated with airliners and the 'performance-first' camp, typically associated with fighters, may begin to blur.

What seems theoretically important for this analysis is a re-evaluation of these historical divisions.

What seems to follow from this analysis is that the next generation aircraft, whether civil or military, may tend to have wings that are not ostensibly structures with attached systems but seem to be sensing, thinking, morphing systems that tend to dynamically optimize what seems to be their shape for every second of the flight, that is, these aircraft may seem to be entering a whole new realm of aerodynamic efficiency and performance parameters, as interpreted in this paper, and what seems to warrant further interpretive consideration is a future-oriented paradigm toward adaptive integrated designs.

5. Conclusion

In what way did this paper appear to have examined in this wider study appear to have examined the aerodynamic design of high lift devices for commercial airliners and fighter aircraft.

What seems to the analysis seems to indicate results that may be hinting at is that the fundamental difference in requirements, the persistent pursuit of economic efficiency for civil transport and the unyielding requirement for tactical superiority in air battle seems to be leading to is two apparently different technological pathways and design philosophies. What seems to be particularly interesting to the analytical approach is the commercial airliner's apparent dedication to highly optimized multi-element trailing edge flaps seems to be leading to is a strong denial to the

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fighter aircraft's reliance on vortex generating, actively controlled leading edge devices seemingly in a digital flight control milieu.

What the journey may have started with, in Chapter 2, seems to have been a detailed presentation of the fundamentals of lift generation and stall, seemingly to provide the background for understanding, how, be it seemingly in different classes of devices, ranging from the area-adding Fowler flap over the vortex-generated LEVCON to the highly sophisticated wing- warping and even more, seemingly how they seemingly have been intent on doing, seemingly how they seemingly have been driving the development of trailing-edge flap systems seemingly into marvels of aerodynamic optimization. Here, what seems to merit further interpretative attention seems to be, that seemingly every design decision has been pitted against the weight, complexity and, lastly, the balance sheet of the airline. In contrast, what the journey in Chapter 4 seems to have been taken into seems to have been fighter country, if the demand for high manoeuvrability seems to have been suggesting what seems to have been growing the development which seems to have been here too rather sophisticated beyond even leading edge devices.

Not only seems to have carried out the comparative study of Chapter 5, given the subtleties of this evidence, these differences into what seem to be black and white classifications but seems to have taken the argument to a whole new dimension. Having explored the worlds of UAVs and BWB aircraft, and analysed what seem to be disruptive technologies such as morphing structures and active flow control, it seems to have been left with no doubt.

Therefore, what this series seems to be leading to is that the future of high lift design seems to be leading overwhelmingly predominantly away from the addition of individualized mechanical devices towards a new concept of the wing which seems to be more of a coherent intelligent adaptive system.

What this convergence seems to promise is that it seems to promise step-changes in performance and efficiency. This seems to make it seem, to bridge what seem to be theologically significant areas, which has seemed to have been the historical divide between the philosophies of civil and military aeronautical design and, consequently, opens what seem to be a whole new chapter in the science of flight.

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