HIGH-LIFT SYSTEMS FOR ENHANCED TAKEOFF PERFORMANCE

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Abstract

This study aims to exploit wing leading edge devices customarily designed for low noise during landing, to achieve higher airplane performance for takeoff. High-lift geometries that incorporate slat cove fillers which can be obtained by conventional mechanical systems or morphing structures have been considered. A systematic aerodynamic analysis procedure was used to arrive at several promising configurations. Optional mechanical systems are presented. The aerodynamic design of new wing leading edge shapes is obtained from a robust Computational Fluid Dynamics procedure. Acoustic benefits are qualitatively established through the evaluation of the computed flow fields.

1 Introduction

Noise reduction in airport environments has become an area of high priority in the aerospace transport industry. During takeoff, approach and landing noise is generated by the engines and various airframe components. With the advent of high bypass ratio engines significant reduction in engine noise has been achieved in recent years. Consequently, other noise sources have become more critical, with greater focus now being placed on techniques of airframe noise reduction. A major component of airframe noise is the high-lift system, which contributes significantly to the total noise during approach and landing when the engines operate at low power setting. In particular, slotted leading edge slats produce high noise levels at these conditions. Several studies have demonstrated the effectiveness of slat cove fillers in reducing this noise source. While these investigations have led to a potential solution to this environmental problem, the structural complexity and increased weight present a set of system integration challenges for the airframe manufacturers. The question of whether slat cove fillers are economically viable for flight worthy systems is therefore still outstanding. Since the incentive to develop technologies which result in higher airplane performance is very high, this study is aimed at identifying additional advantages of slat fillers, particularly enhanced performance during takeoff. The current analysis shows that at takeoff conditions properly designed slat fillers result in substantial reduction in drag. Consequently, an increase in takeoff lift-to-drag ratio (L/D) results in larger airplane payload, shorter runway, longer range or smaller engines (or combinations thereof). Smaller engines have direct implications to airplane weight, fuel consumption and eco-friendliness.

Boeing has developed a systematic approach for the development of leading edge concepts under the NASA Multi-Objective Leading Edge Concepts program [1]. That study led to the development of several slat cove fillers with improved noise characteristics at landing without compromising landing stall. A similar procedure is applied in the current study to develop cove filler configurations. These fillers are then evaluated for takeoff conditions where the slats are in the sealed position. This step is followed by employing new concepts of slat integration for the purpose of achieving even higher performance at takeoff. The performance improvement at takeoff combined with the noise reduction at landing makes the slat cove filler a practical technology, broadening its appeal for future airplanes from both the economical and environmental perspectives.

In the following sections the design approach used for the development of the low drag and reduced noise cove fillers will be described. The computational process that is used to facilitate the design will be briefly reviewed. The analyses leading up to several viable candidate fillers will be presented in the context of two different, but representative high-lift systems. The paper will conclude with a discussion on practical airframe integration and optional mechanical systems.

2 Design Strategy

2.1 Approach

This study focuses on enhanced airplane takeoff performance that can be realized by slat cove fillers which are customarily designed for low noise during landing. The overall design strategy consists of a two step process, whereby candidate low noise configurations are first developed for the landing condition, followed by a design which targets takeoff performance.

The objective of the first step is to develop viable slat cove fillers for reducing the noise associated with conventional slotted leading-edge structures without compromising the stall characteristics at landing. A systematic approach based on wing section analysis is employed in order to obtain cove filler shapes with reduced noise for the condition corresponding to nominal landing operation, with lift equal or greater than that of the baseline section. Additionally, $C_{L\ Max}$ should be no lower than the baseline value. This step is further described in Reference [1].

The low noise cove fillers are then subjected to an aerodynamic analysis at representative takeoff conditions. Generally, the evaluation can be performed either for sealed or extended slat positions, which are both commonly used during takeoff. The current design uses the sealed slat detent. If further geometrical modifications are employed in order to enhance takeoff performance, the analysis is followed up with a subsequent assessment at the landing conditions.

2.2 High Lift Configurations

The design strategy is applied to two multi-element high-lift systems.

The Energy Efficient Transport (EET) wing section developed by NASA was selected as the first baseline configuration [2]. This high-lift system is shown in Figure 1 for the extended (slotted) and the sealed slat positions. It consists of a slat, wing and flap elements. The EET configuration with the slotted slat was optimized experimentally for maximum lift and extensively tested in the Low Turbulence Pressure Tunnel (LTPT). This high Reynolds number wind tunnel was designed to produce high fidelity flows at close to full-scale conditions. In the study of the EET section the flap is held at the same deflection for both the takeoff and landing positions.

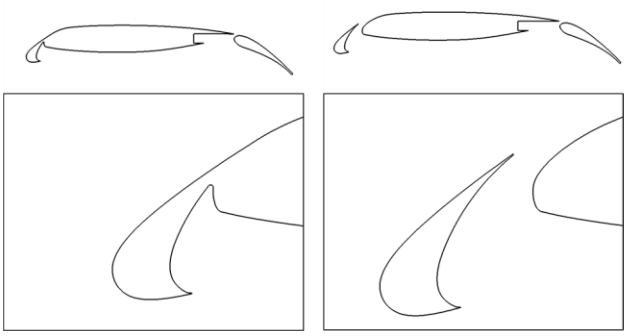

Fig. 1. EET Section

The second high-lift system represents a conventional multi-element wing and is also evaluated at representative full scale flight conditions. This system is referred to as Configuration B, and its LE is shown in Figure 2. The study of Configuration B employs different flap deflections for the takeoff and landing conditions.

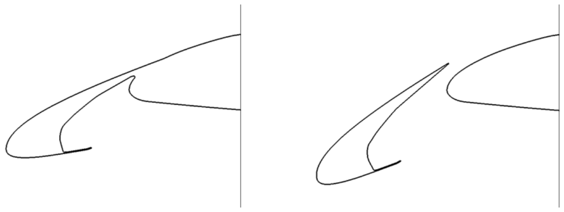

Fig. 2. Configuration B

3 Numerical Procedure

3.1 Computational Process

The numerical tool is a modified OVERFLOW code originally developed by NASA [3] and it forms the core process of Boeing's transport aircraft CFD methodology. OVERFLOW employs the Reynolds Averaged Navier-Stokes (RANS) formulation using overset grid systems. A second order upwind differencing scheme and the Spalart-Allmaras turbulence model have been employed for all the simulations. Fully turbulent flows are considered. The grid systems for the EET airfoil are presented in Figure 3 for the sealed and the slotted slat positions. It consists of eight overset blocks with approximately 325,000 points. C-type meshes around the respective leading edges of individual elements are used. Cap grid systems of C-type are also used around the blunt trailing edges of the flap and main wing element to ensure numerical stability for high Reynolds Number flows at maximum lift. The grid spacing perpendicular to the surface produces a y+ ~ 1 for the Reynolds Number considered here. Very fine mesh resolution is used in order to accurately represent the flow in the slat cove region for facilitating future acoustic analyses.

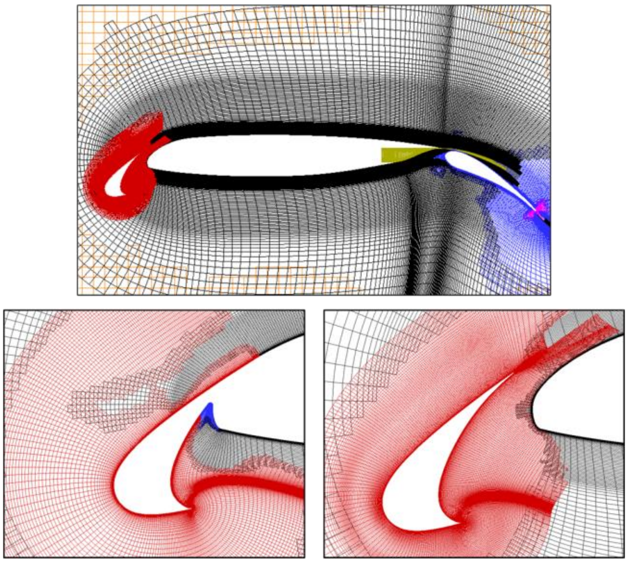

Fig. 3. Grid System for the EET Section

3.2 Validation

The numerical tool has been validated extensively for numerous high-lift applications. Pertaining to the current study, the validation for the EET configuration will be briefly discussed here. Further details are provided in Reference [1].

Free air calculations were performed for the landing configuration over a range of angles-of-attack for a free stream Mach number of 0.2 and Reynolds Number, RN, of 9 million based on cruise airfoil chord length. The experimental data from Reference [2] is used for validation. The lift curves in Figure 4 indicate very good agreement between the experimental data and the simulations in the linear range. Although there are notable discrepancies near the maximum lift condition, the numerical predictions are acceptable in the context of this study and the CFD tool is adequate for high-lift design at the nominal condition and at maximum lift. This is a particularly valid assumption when used on a comparative basis in order to establish relative merits.

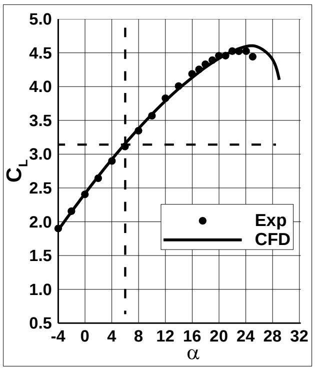

Fig. 4. Validation at the Nominal Landing Condition

3.3 Flow Physics

Flow progression with increased airfoil incidence illustrating high-lift characteristics of the slotted slat EET airfoil is described by total pressure flow fields in Figure 5. At the nominal landing condition the flow is well behaved over the three elements. However, flow recirculation occurs in the slat cove region, which is considered a major source of noise. At maximum lift (α=24°) the flow is still fully attached, but larger losses are evident at the

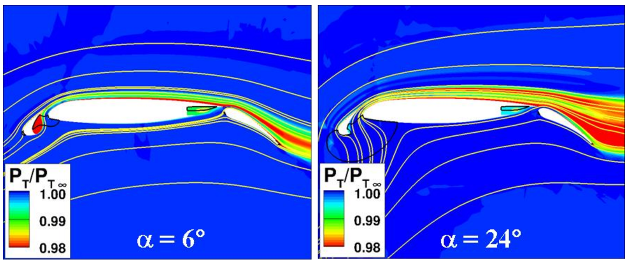

Fig. 5. Flow Characteristics of the EET Section

main element and the flap, where stronger interactions between the various viscous layers takes place. Interestingly, flow separation at the slat has been eliminated due to the higher global circulation at this lift level whereby the stagnation point on the main element has moved downstream. From an aerodynamic stand point turning of the flow at the flap is degraded due to adverse pressure gradients the slat and main element wakes experience as they pass through the suction peak on the flap. Flow quality further deteriorates at start of stall (beyond α=24°) where de-cambering of the streamlines leads to off surface separation at the flap, resulting in reduced lift.

3.4 Design Conditions

From an operational standpoint, stall speed is a determinant of landing field length. Generally, a slower approach speed will result in a shorter field length, and the landing approach speed can be no slower than 1.23 times the 1G stall speed. This determines the lift coefficient corresponding to landing approach, also referred to as nominal landing condition. $C_{L\ Max}$ is the lift coefficient at the 1G stall speed, which is measured during flight test. Therefore modified leading edges with reduced noise at landing approach must be evaluated at $C_{L\ Max}$ to ensure that there is no change to the stall speed. Similarly, at takeoff the V2 speed can be no slower than 1.13 times the 1G stall speed.

In the current analytical study of the EET section, the lift coefficient during landing approach is 3.15 based on the estimated $C_{L\ Max}$. This lift coefficient corresponds to α=6°, which is indicated by the dashed lines in the lift curves. This angle of attack is also used as the nominal takeoff condition.

4 Design Analysis

4.1.1 Design ground rules

Several ground rules have been adopted for the development of candidate configurations. The cruise mold lines have been preserved in order to limit the scope of the analysis to high-lift conditions. The force coefficients are referenced to the cruise wing section chord length. The designs are limited to LE modifications. No optimization of slat or flap in terms of gap or overhang was performed since the study focuses on identifying gross effects. Therefore the aerodynamic performance of final candidates should be considered conservative. The numerical analyses use similar grids for the respective baseline and the new geometries in order to ensure minimal differences in discretization errors.

4.1.2 Slat cove filler

Generally during landing when the slat is extended, the flow recirculation which occurs in the cove region and the channel flow between the slat and the main wing element are major sources of noise. Cove fillers are designed to eliminate the shedding of the wake off the slat and maintain good flow quality in the gap. Experiments conducted by NASA and Boeing [4], EADS [5] and JAXA [6] demonstrate that meaningful reduction in noise levels can be obtained, depending on filler types and implementation. Although cove fillers are advantageous from an acoustics perspective, they represent a challenge with respect to structural integration. Fillers require morphing structures since they are not easily retractable due to the limited space between slat and main wing element.

4.1.3 Slat cove design

The filler design follows the strategy developed in Reference [1] where only the landing noise problem was consider. The process starts with the flow solution obtained for the slotted slat baseline airfoil at a given α (hence dubbed α-filler). The boundary of the separation pocket in the slat cove is then used to define the shape of the initial filler. The solution obtained for this slat filler is analyzed and a refined version of the filler is devised in a subsequent step. The latter step is crucial for improving flow quality in the channel between slat and main element and it has implications for both acoustics and aerodynamic performance.

4.2 EET Configuration

Details of the flow patterns in the LE region at the nominal takeoff and landing slat positions are shown in Figure 6, together with the lift and L/D curves. The flow fields are described by vorticity contours, regions of flow reversal (regions of negative streamwise velocity component are denoted by thin black lines) and select streamlines. Since the flap deflection is the same for both conditions, the sealed slat results in lower drag in the linear lift range, but also lower maximum lift. Qualitative assessment of noise is implied from the computed flow fields where wake intensity is used as proxy of potential noise generation mechanism. The noise source at landing is underscored by the strong vortex shedding off the lower slat trailing edge.

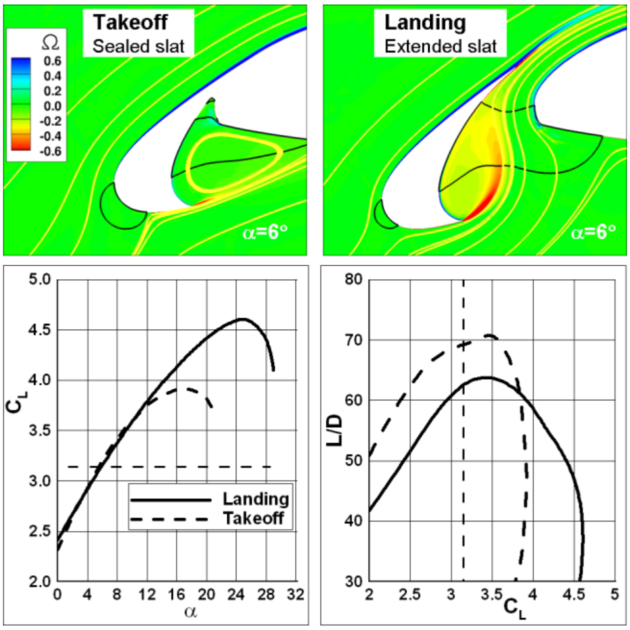

Fig. 6. Flow Characteristics of the EET Section

A note on the calculated drag is in order. Since the forces are based on two-dimensional simulations, the induced drag is not accounted for since this component is an artifact of flow past finite wings. Slat cove fillers directly impact the profile drag, but in a general 3D implementation it can also be integrated to tune the wing span load in order to minimize the induced drag component during takeoff.

An assessment of takeoff performance of two of the low-noise cove fillers developed in Reference [1] is performed next. Fillers 2bα12 and 2b-mod11 are shown in Figure 7. Filler 2bα12 was obtained from the baseline flow at α=12º according to the process described in 4.1.3. Details on the development of the less intrusive 2b-mod11 are given in [1]. Figure 8 presents the flow characteristics due to the fillers for the landing and takeoff slat positions. At the landing condition both cove fillers prevent the formation of the wake off the lower side of the slat, with commensurate implications to acoustics characteristics. At the takeoff condition the flow recirculation pocket is significantly reduced relative to the baseline configuration, resulting in reduced drag. In particular, 2bα12 produces an increase of 6.6% in L/D at the nominal condition. The lift curves of the respective baseline flows are by and large preserved, up to stall and beyond. At low angles-of-attack (below 2°) the flow on the lower surface of slat fillers tends to separate due to the small LE radius. However, we believe this can be relatively easy to fix by re-contouring of the surface in order to produce larger LE radius.

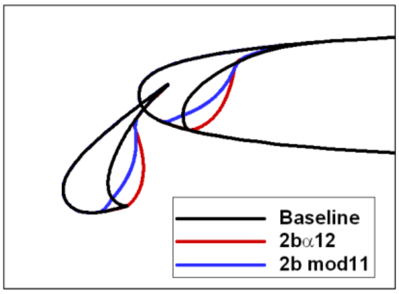

Fig. 7. Low-Noise Cove Fillers for EET in Stowed and Deployed Positions

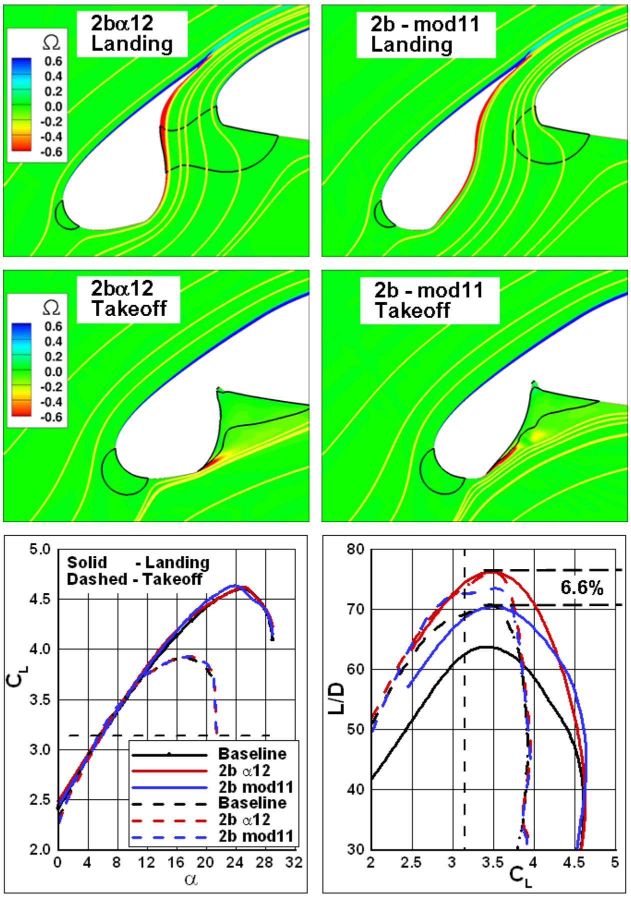

Fig. 8. Flow Characteristics of the EET Cove Fillers

4.3 Configuration B

4.3.1 α-Fillers

A set of α cove fillers for low noise characteristics are first developed by using the separating streamlines for the baseline landing configurations for a set of angles of attack; 0, 6º and 12º. These fillers are denoted 2bα00, 2bα06 and 2bα12, respectively. This is followed by a contour smoothing procedure in order to further improve upon the flow quality in the channel flow between the slat and the main wing element and thereby further attenuate noise. The fillers are then evaluated for their performance during takeoff in the sealed slat mode. The flow fields obtained with the fillers are then compared with the baseline flows at the respective landing and takeoff nominal conditions. Figure 9a shows the normalized total pressure contours for α=0º at landing and α=10º at takeoff. Figure 9b presents the lift and L/D curves. All slat fillers produce lift curves which are very similar to the original airfoil at both the landing and takeoff conditions. However, the smallest filler 2bα12 is not acceptable since it results in shedding of a wake from the lower side of the slat at landing, potentially a noise generation source. At takeoff all the fillers result in smaller flow recirculation pockets and lower drag compared to the baseline sealed slat. The improved L/D at the nominal takeoff condition is significant, with up to an increase of 11.7% for the largest 2bα00 filler.

4.3.2 Optional Fillers

Figure 10 shows the two candidate fillers in the stowed and deployed positions for takeoff and landing. It can be inferred that filler size is a very important parameter in regard to mechanization of the slat system. Obviously, smaller fillers are more advantageous since they

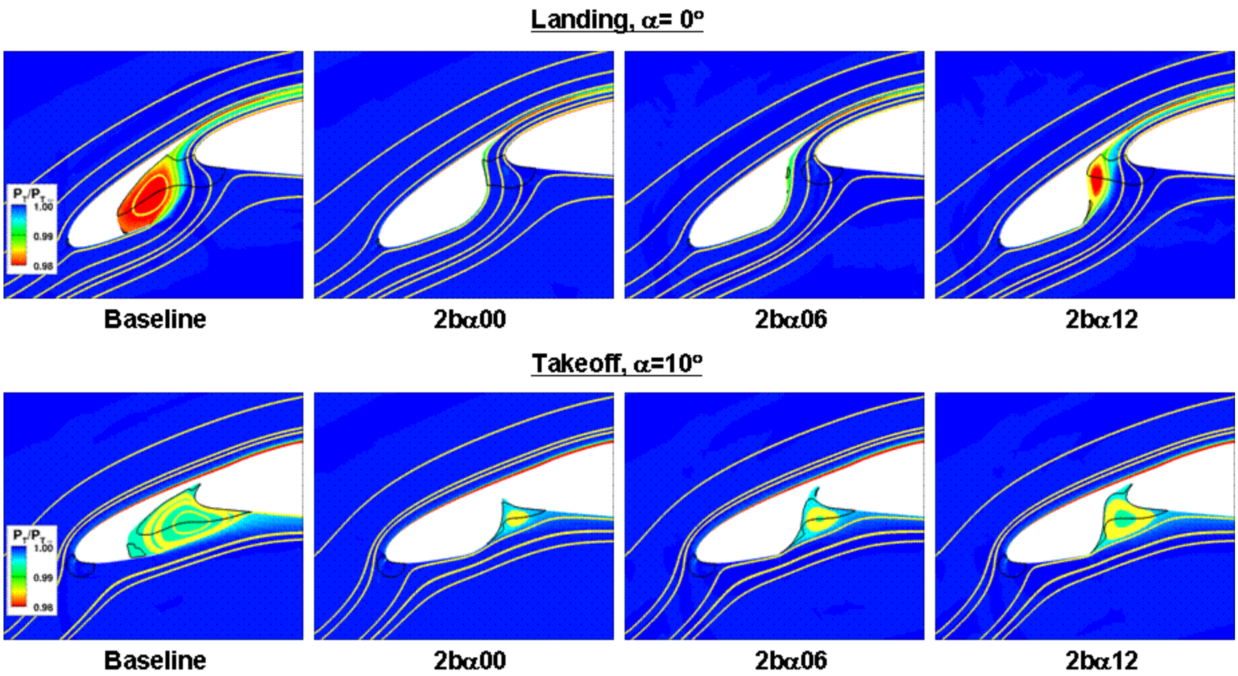

Fig. 9a. Flow Fields of Configuration 2 and Slat Fillers at the Nominal Landing and Takeoff Conditions

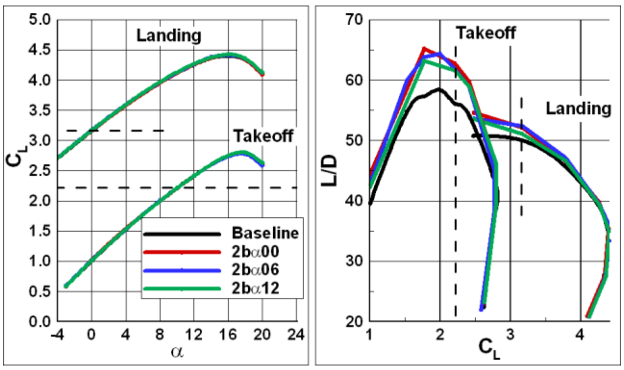

Fig. 9b. Characteristics of Config 2 α-Fillers

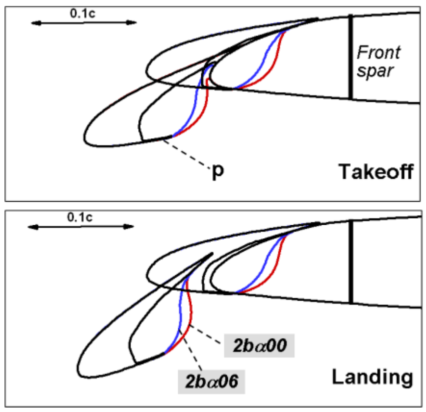

Fig. 10. α-Fillers in Stowed and Deployed Positions

will require less structural slat morphing to accommodate retraction.

In order to reduce the size of the cove fillers it is instructive to explore other variants. Optional filler shapes can be obtained by removing the fixed panel at the bottom of the slat (marked p in Figure 10). This will produce smaller recirculation regions inside the cove. The process used for defining the α–filler contours by tracking the separation streamlines at a given flow incidence results in a new family of smaller fillers denoted Mod3. Obviously, both of these fillers will require a small deployable element on the lower surface so that the cruise mold line is preserved when the slat is retracted.

Figure 11a shows the flow characteristics for Mod3 and its α-filler variants. At the landing condition the difference in the flow fields between the 2bα00 and its Mod3 counterpart are hardly noticeable since the separation streamline off Mod3 is closely aligned with the panel p of the original slat. The differences are more pronounced for the smaller fillers. In particular, Mod3 2bα12 shows reduced vorticity in the cove relative to 2bα12, even though from noise considerations both of these fillers are deemed

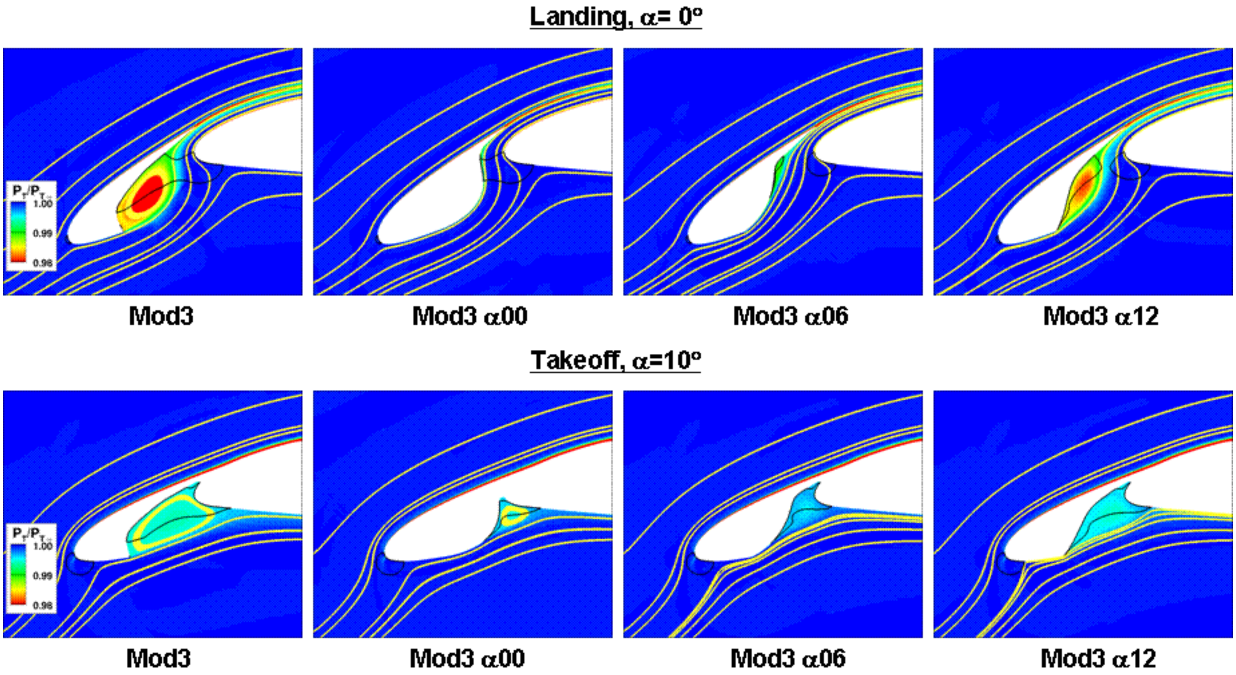

Fig. 11a. Flow Fields of Configuration 2 and Mod3 Fillers at the Nominal Landing and Takeoff Conditions

unacceptable. At takeoff the smaller Mod3 fillers have a significant impact on the flow structure relative to the baseline slat. The smaller fillers Mod3 α06 and α12 are very effective in streamlining of the flow with very small recirculation pockets confined to the area where the slat and main element are connected. This results in lower drag, consistent with the L/D improvements shown in Figure 11b. No degradation in nominal lift and stall margins are incurred with any of the Mod3 α-fillers. The advantage of the Mod3 geometry with respect to the amount of slat overlap with the main wing element can be easily seen from the overlay of the α06 pair in Figure 12. Relative to 2bα06, the Mod3 slat shape reduces the amount of overlap by about 50%, with major implications to structural integration.

4.3.3 Non-Intrusive Fillers

The integration of slat fillers poses an integration issue since they are not easily retractable due to the presence of the main wing element. At this point it is instructive to explore alternative methods of cove filler integration. Specifically, the question of whether outright elimination of slat/main-element overlap is possible at all, at least from the aerodynamic and noise aspects which are the focus in this stage of the investigation. The elimination of slat/main-wing overlap potentially allows for

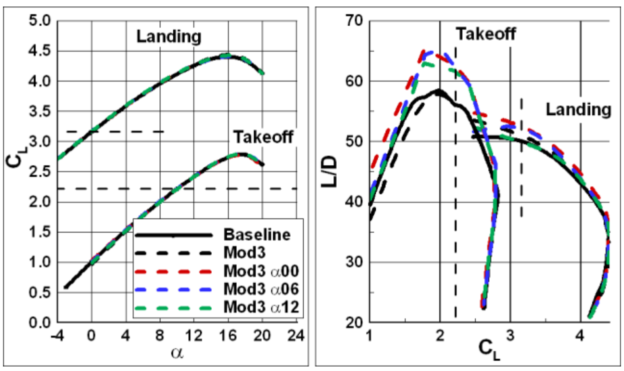

Fig. 11b. Characteristics of Config 2 Mod3 Fillers

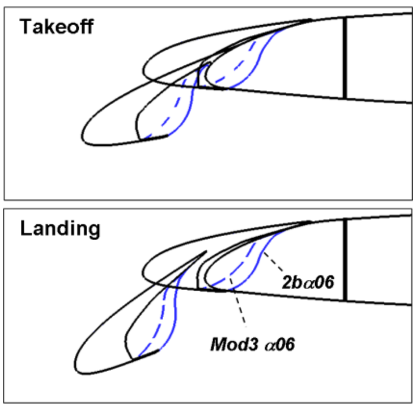

Fig. 12. 2bα06 and Mod3 α06 Fillers

use of rigid structures, which are attractive because of their relative ease of integration. Inspection of Figure 12 indicates that non-intrusive systems might be achievable by reshaping the front part of the main element. In the following analysis non-intrusive systems of both the 2bα06 and Mod3 α06 fillers are considered.

Consider the smaller filler Mod3 α06 which requires a moderate change in the forward portion of the main wing element. Its non-intrusive counterpart is dubbed Mod3 α06 m1. The analysis starts with the definition of a shortened front of the wing element that accommodates the slat in the stowed position as indicated in Figure 13. Here too, the cruise mold line is preserved. This new segment blends smoothly with the original main element contour by matching the geometrical slope. The

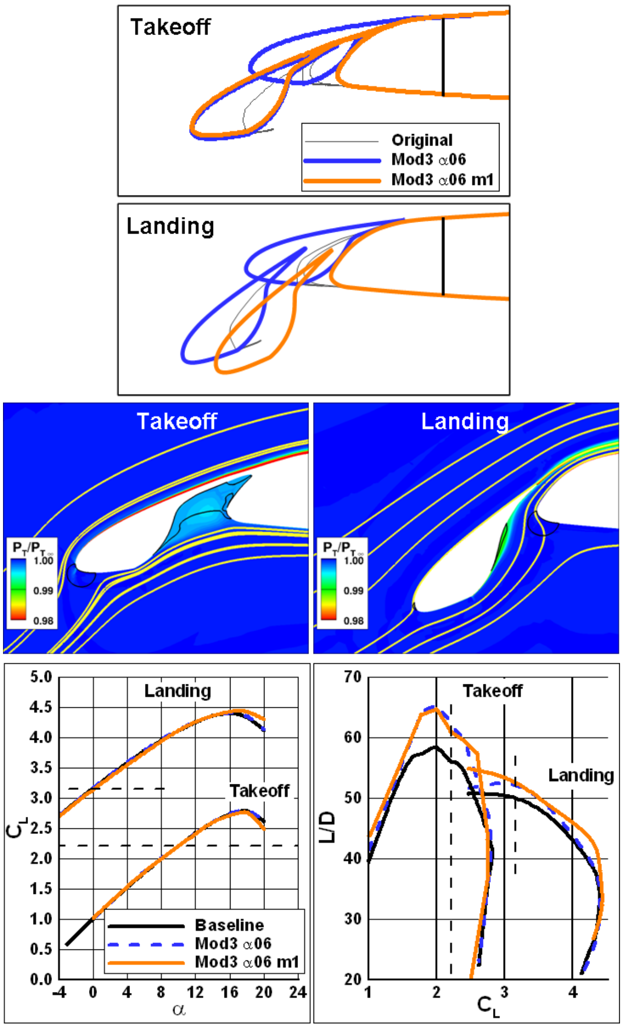

Fig. 13. Mod3 α06 m1

new main element is short by 3% of the cruise chord length. Therefore, a special skin panel needs to be used to effectively obtain a sealed slat at takeoff. The panel could be deployed from within the slat. The panel is defined such that the sealed section contour is smooth. The new slat is at a slightly higher location to ensure a continuous geometry. The chord length at the takeoff condition is identical to that of the baseline airfoil. Preserving the chord length is necessary in order to attain the required lift over the range of angles of attack.

Special attention must be given to the channel flow between the slat and the main element for the extended slat at landing. This is critical since the relative position of the slat is a major determinant of $C_{L\ Max}$. The slat of Mod3 α06 m1 is moved closer towards the new main element and it is at a slightly larger deflection than that of the baseline. This ensures identical cross sectional channel exit area. Consequently, the flow quality in the channel is very similar to that of Mod3 06.

The results in Figure 13 indicate that the non-intrusive Mod3 α06 m1 produces very good flow characteristics from both the acoustic and the aerodynamic performance aspects (to be compared with the respective flow fields in Figure 11a). Overall, this filler's performance is very similar to that of the Mod3 α06 filler. Especially noteworthy is that the reduced extended airfoil chord of Mod3 α06 m1 at the landing configuration does not adversely impact the overall lift.

It is noted that the final definition of Mod3 a06 m1 was obtained with about three design steps for each of the takeoff and landing conditions. It is conceivable that better performance can be achieved by refining the slat filler shape and the main element contour, and by optimizing the slat detent. However, this is beyond the scope of the current investigation. The intent of this particular part of the study is to identify alternate potential ways of integrating slat cove fillers and assess overall noise and aerodynamic attributes.

A more aggressive re-contouring of the main element is considered next for the larger 2bα06 slat filler. Considerations similar to those used for the design of the non-intrusive Mod3 variant are adopted for developing the non-intrusive 2bα06 m2 version. Here too, the important factors affecting the aerodynamic performance are the chord length of the sealed slat configuration at takeoff and the channel flow between the slat and main element at landing. This main element is shorter than the baseline by about 4.7% of the chord length. This case is presented in Figure 14. The flow fields of 2bα06 m2 should be compared with the 2bα06 total pressure contours in Figure 9a. Interestingly, 2ba06 m2 lift curves are very similar to those of the baseline and the 2bα06 filler. However, at the nominal takeoff condition 2bα06 m2 has elevated drag level relative to 2bα06. Nevertheless, since the overall maximum values of L/D of the two fillers are quite comparable, it is possible that a redesign of 2bα06 m2 might produce better L/D at the nominal condition.

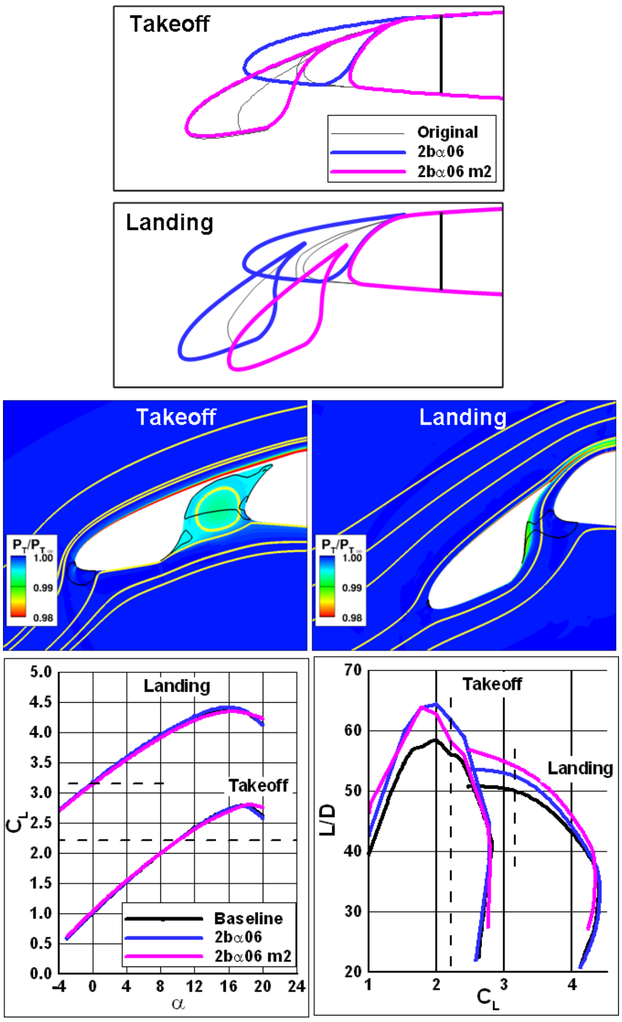

Fig. 14. 2bα06 m2

4.3.4 Candidate Fillers

The current study helped identify concepts of low-noise and low-drag wing leading edge devices. Several slat cove filler shapes have been systematically developed such that their lift characteristics at the nominal takeoff and landing conditions are equivalent to those of the baseline section. Stall attributes are also similar to the baseline. A comparative summary of sectional aerodynamic forces of promising slat candidates is presented in Figure 15. They are all based on the α06 family of fillers. The smaller Mod3 variants obtained by removing the panel from the lower side of the slat are also included. The intrusive subset includes an overlap region of slat and main element when the high-lift system is retracted. The non-intrusive variations are used in conjunction with smaller main wing element in order to accommodate the slats in the stowed position.

Check marks indicate that the lift is higher by at least 0.99 times the respective baseline value (i.e., no more than 1% off the baseline). Lower noise levels relative to the baseline as inferred from the computed flow fields are also check marked. The four candidate configurations result in improved L/D at takeoff. Generally, the smaller Mod3 fillers produce higher L/D due to the streamlining on the lower slat surface and the ensuing smaller recirculation pockets. Degradation in L/D is realized with the non-intrusive shorter main element sections, particularly in the case of the larger filler.

		Intrusive		*Non-Intrusive*	
		Large filler 2bα06	*Small filler Mod3 α06*	*Large filler 2bα06 m2*	*Small filler Mod3 α06 m1*
Landing					
	Noise	✓	✓	✓	✓
	C_L	✓	✓	✓	✓
	$C_{L\,Max}$	✓	✓	✓	✓
Takeoff					
	L/D	*10.20%*	*11.10%*	*5.40%*	*8.70%*
	C_L	✓	✓	✓	✓
	$C_{L\,Max}$	✓	✓	✓	✓

Fig. 15. Candidate Slat Fillers

5 Mechanical Systems

The implementation of slat fillers is a critical element in the design of practical high-lift systems. Both short term options using state of the art mechanical systems and long term solutions based on morphing structures can be considered for the integration of slat fillers. The latter will require significant advances in adaptive structures in conjunction with skin technology.

Several concepts utilizing morphing structures for the integration of slat fillers have recently been developed. Reference [7] uses an expandable element placed in the slat cove. When the slat is stowed the displacement element is contracted and fits between slat and main wing. During high-lift operations pressurized air from the engine is used to inflate the expandable element, which fills out the slat cove and produces the cove filler. Another approach employs an n-stable surface which forms slat filler with the aid of an actuator device [8]. In essence both of these concepts use structural morphing of the slat filler.

The current study considers an alternate implementation which employs a rigid slat/filler structure in conjunction with a morphing structure of the main element. Moveable skin panels in the front of the main wing element are used to allow retraction of the slat when the high lift system is stowed. During high lift operations the moveable panels and the slat are simultaneously deployed. Figure 16a shows one possible embodiment of the 2b mod11 slat filler of the EET section. Also shown is a conventional system in which slat detent is obtained by a set of levers, linkages and gears. The slat deployment mechanism employs rotary actuators which are activated by a system of torque tubes and gearboxes. The rotary actuator turns the pinion gear which moves the slat main track. The main track is attached to the slat through a system of connecting elements. Slat extent is obtained by the movement of the main track members in response to counterclockwise turning of the pinion gears.

The slat filler mechanism is similar to that of the conventional system. The difference is in the main wing element, whose front part consists of a moveable panel which is connected to a linear actuator. As the slat extends partially the actuator pushes the moveable panel upstream until the panel reaches its full extent position. At this position the moveable panel and the fixed wing part form a smooth and continuous main wing element. The slat main track further moves upstream until full slat extent is obtained. Retraction of the slat is obtained in reverse order by turning of the pinion gear in the clockwise direction. Slat retraction is synchronized with the downstream movement of the panel until reaching the stowed position. Figure 16b describes the slat deployment mechanism by tracking the motion of all moveable panels through a set of snapshots. The sealed configuration at takeoff is obtained in a similar fashion.

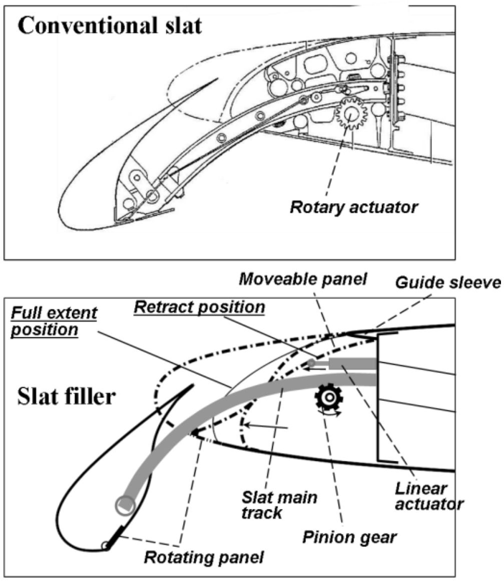

Fig. 16a. Mechanical System for the EET 2b mod11 Slat Filler at Landing

A mechanical system for the non-intrusive slat filler Mod3 α06 m1 of Configuration 2 is presented next. Since no morphing structures are needed for either the slat or the main element, this system provides a very simple mechanical solution for the incorporation of slat fillers. In fact, the slat detent mechanism is similar to that of a conventional system (similar

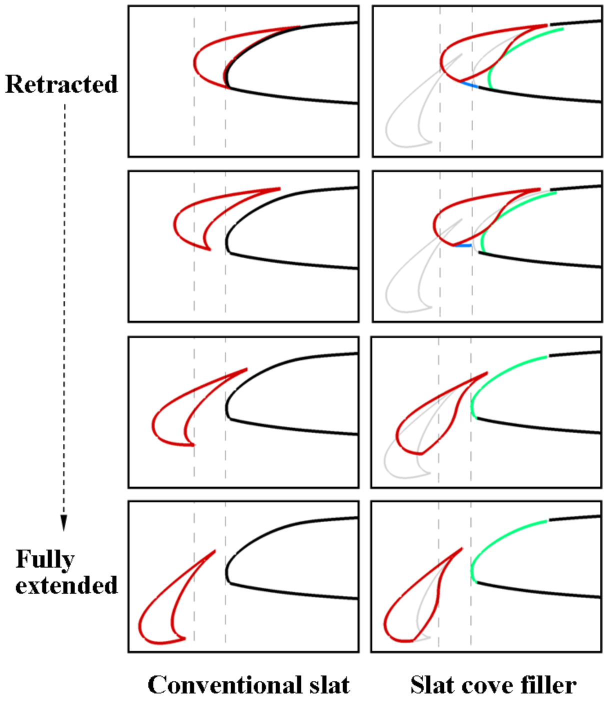

Fig. 16b. Slat Extent Motion

to the conventional slat shown for EET in Figure 16a). Figure 17 describes the system when fully deployed at takeoff and at landing. Because the wing element is shorter, however, an extendable skin panel is used to effectively create the sealed slat position during takeoff. The moveable panel is nested in the slat. The panel is attached to a set of tracks on its underside. The slat contains a rotary actuator which turns a pinion gear. The pinion gear is in contact with the tracks of the extendable panel. At takeoff the actuator turns clockwise in synchronization with the slat deployment mechanism and it extends the moveable panel to from the sealed configuration. During landing the panel remains in the retracted position within the slat.

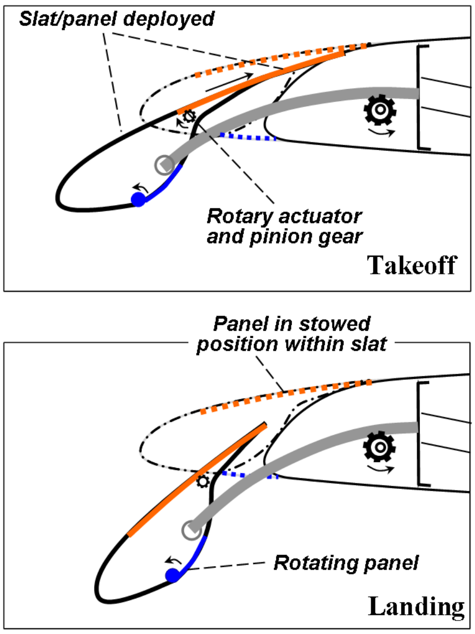

Fig. 17. Mechanical System of Config. 2 with the Non-Intrusive Slat Filler Mod3 α06 m1

In order to preserve cruise mold surface when the system is retracted a hinged panel is placed in the lower side of the slat. The rotating panel is activated during takeoff and landing by a rotary actuator; counter clockwise when slat is deployed and clockwise when it is retracted.

6 Conclusions

An initial study to explore expanded usage of slat cove fillers beyond their original intent of noise reduction is presented. The investigation focuses on slat fillers with high takeoff capability, and implications to the concomitant improvement in airplane performance. The combined low-drag low-noise devices are very attractive, with major ramifications for future airplanes from both the economical and environmental perspectives.

The aerodynamic characteristics of candidate high-lift concepts were assessed for wing sectional geometries. Geometrical modifications were confined to slat modifications without altering the cruise mold lines. The study focused on identifying gross effects and therefore the aerodynamic performance of potential concepts should be considered conservative. It is conceivable that further improvement for both takeoff and landing can be realized by subsequent optimization through geometrical refinements and control of gap and overhang for both slat and flap elements. Clearly, an assessment of the leading edge devices into more representative full wing configurations is required. Moreover, an experimental validation is needed to accurately establish potential aerodynamic and acoustic benefits of slat cove fillers for realistic configurations.

While the results obtained for some of the promising slat fillers are encouraging, a practical implementation requires a careful trade study of numerous design parameters within a multidisciplinary framework. With regard to structural integration, the prospects of implementation of intrusive slat fillers (with slat/wing overlap) will depend on technological advances in the areas of mechanical systems or morphing structures. Alternatively, the non-intrusive devices (with no slat/wing overlap) potentially avoid the structural complexities of their intrusive counterparts.

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