

A WING DESIGN METHODOLOGY FOR LOW-BOOM  
LOW-DRAG CONCEPTUAL SUPERSONIC BUSINESS JET

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**A new methodology for designing the wings of a low-boom low-drag conceptual aircraft is proposed. The primary objective of this work is to develop an automated integrated framework to design the wing of a supersonic commercial jet. The work focuses on the design of the aircraft wing geometry, specifically the wing planform, camber, and twist. The wing is designed to achieve a lift distribution which supports low boom performance while maintaining high aerodynamic performance.**

**The wing planform is parameterized to maintain design flexibility while limiting the number of design variables. It is necessary for the designer to be able to inject knowledge-based design decisions into the process. To allow this, the parameterization scheme maintains a level of flexibility for the designer to inject knowledge-based design decisions into to the design process.**

**This methodology addresses two important issues during the conceptual design phase: maintenance of high aerodynamic performance and design for low sonic boom impact. This research successfully shows that optimization techniques can be applied which emulate the designer's manual process.**

**The preliminary results indicate that small meaningful changes to the wing planform yield significant modifications to the equivalent area due to lift which is beneficial to low-boom performance**

**Nomenclature**

$A_e$	= Equivalent area
$C_l/C_d$	= Ratio of coefficient of lift to coefficient of drag
$M$	= Mach number
$P$	= Pressure
$S_j$	= Internal wing control points
$X_e$	= Equivalent length
$Z$	= Wing camber surface vertical location relative to airfoil section leading edge
$Z_i$	= Wing corner control points
$dX$	= Range of equivalent area distribution
$dA$	= Change in equivalent area
$u$	= Normalized wing span vertical dir.
$v$	= Normalized wing span horizontal dir.
$\Delta\alpha$	= Change in quantity $\alpha$

**Introduction**

The desire for increased air speeds has led to supersonic flight. However, the pressure disturbance incurred during supersonic flight results in a ground sonic boom. In a general sense, the sonic boom phenomenon can be described as a sudden increase in the ambient pressure due to the

shock waves that are generated from an aircraft traveling at supersonic speeds. Figure 1 illustrates an aircraft traveling through the atmosphere and the resulting ground boom signature. The sonic boom is of concern since it may cause general impacts on the environment and human comfort. The sonic boom contains high and low frequencies which may cause damage to structures and produce significant audible noise perceived by humans and animals. The impact is of such concern that supersonic flight is restricted to overseas flight. Thus, for unrestricted commercial supersonic flight to be obtainable, research must be conducted which is able mitigate the sonic boom while maintaining high aerodynamic performance.

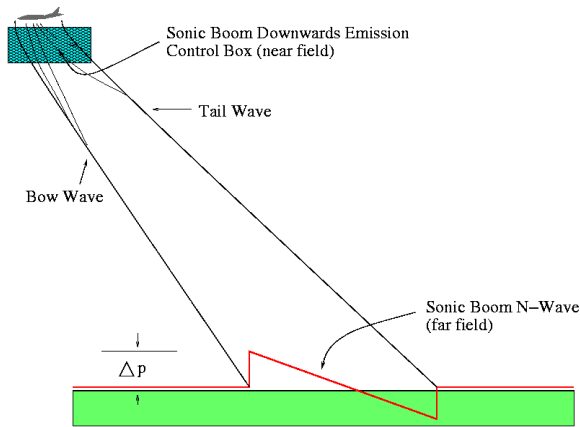
The pressure field generated by an aircraft is shown in Figure 2 at different points as it propagates towards the ground. Near the aircraft, pressure fluctuations arise

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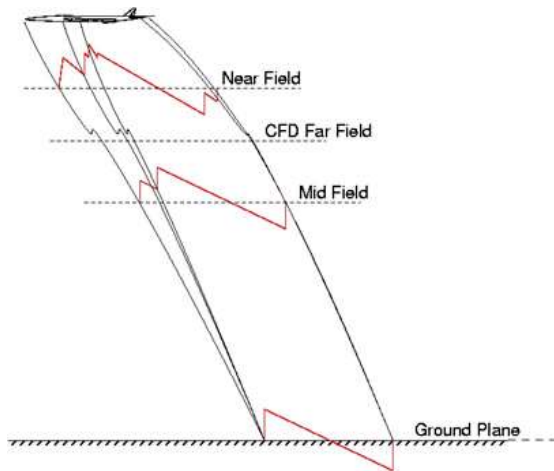
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**Figure 1 – Supersonic aircraft in flight with resulting ground sonic boom signature**



**Figure 2 – Progression of pressure distribution through atmosphere**

from the shock and expansion waves emanating from the aircraft. Near the nose of the aircraft, a large pressure increase results from the initial bow shock. Shock from the leading edge of the wing, nacelles, and tail also generate increases in pressure. Aft of the aircraft, the pressure recovers to the ambient pressure.

As the pressure propagates to the mid-field region differences in the local speed of sound, due to pressure gradients, cause the wave-fronts to coalesce. There are still some observable fluctuations in the pressure signature indicative of the near-field pressure signature. However, most

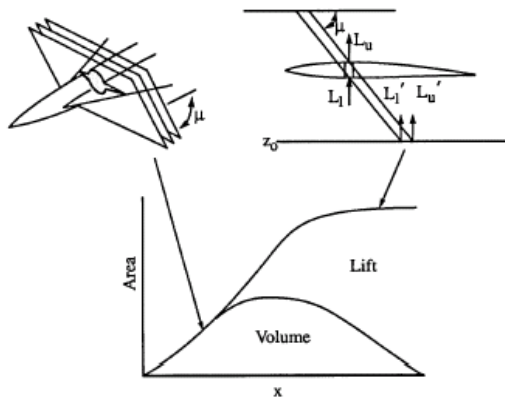
minor pressure fluctuations begin to blend into the existing signature.

Far from the aircraft, the wave-fronts propagate and eventually coalesce to generate a steady sonic boom signature. The major wave-fronts have coalesced towards either the front or the rear shocks of the pressure signature. The ground sonic boom signature is usually in the form of an N-wave. However, it was found that through vehicle shaping techniques, the shape of the sonic boom signature can be manipulated.

The far-field pressure signature is of particular importance to the design of aircraft since it represents the impact on the structures and people on the ground. The impact of the sonic boom at the ground can be measured in several ways. One method of determining the impact of the sonic boom is the overpressure. The overpressure is the pressure rise over the ambient pressure at the ground. However, sound intensity can vary from person to person. Thus, the impact of the sonic boom can be measured quantitatively any sort of metric such as sound pressure level (SPL) or perceived noise level (PNL). These metrics of sound measurement attempt to quantify the boom intensity and its impact on human comfort. Mitigation of the sonic boom impact can be achieved through careful aircraft design. Aircraft designs with long slender fuselage sections and blended wing-body concepts have shown that the sonic boom overpressure can be reduced.

Aircraft shaping techniques<sup>1-3</sup> are based on sonic boom theory<sup>4-27</sup> which formulates a relationship between the geometry of the aircraft and the ground sonic boom signature. The geometry of the aircraft configuration is represented by equivalent bodies of revolution with area distribution, which represents the volume and lift contributions of the aircraft to the near-field pressure distribution, as shown in Figure 3. The volume and lift contributions

are largely modified through shaping of the aircraft's fuselage and wing geometry, respectively. The sonic boom theory and sonic boom minimization theory will be described in detail in the next section.



**Figure 3 – Representation of the aircraft geometry via equivalent bodies of revolution**

The reduction of the sonic boom impact is not a trivial issue. Although there are known techniques<sup>28</sup> which will aide in reducing the overpressure or increase the rise time of the sonic boom, the aircraft performance must also be maintained such that the overall aircraft design leads to a practical aircraft. A balance must be achieved generate an aircraft design with reasonable aerodynamic performance and low sonic boom impact.

The primary objective of this work is to present a unique method to design the wing geometry of a conceptual supersonic aircraft configuration. The wing geometry is designed to provide high aerodynamic performance that also supports low boom performance. This work presents a synthesis between knowledge-based design and numerical optimization.

This work facilitates the larger goal of designing a feasible low-boom, low-drag supersonic conceptual aircraft. The wing geometry is first designed to achieve a favorable lift distribution with the highest level of aerodynamic performance. The

fuselage is then shaped to achieve low-boom characteristics. This process is highly coupled where the modification of the fuselage or wing geometry will affect the other. Thus, it is important to develop an efficient and systematic integration of the wing and fuselage design process.

The research utilizes an inverse design method<sup>13,29</sup> which starts with some desirable or theoretical performance characteristic and seeks to modify the shape to meet this. In the case of supersonic aircraft design, sonic boom theory provides theoretical area distributions for minimum boom signatures. The conceptual aircraft configuration is modified such that the design's total equivalent area distribution matches the target equivalent area distribution as closely as possible. This process can continue in an iterative process until a sufficient degree of matching is achieved.

The wing geometry is critical to the aerodynamic performance of the aircraft. However, the importance of the wing design is further exemplified when the sonic boom signature is considered. Determination of the wing geometry is the first critical step in the design of a conceptual supersonic commercial aircraft.

According to linear acoustic theory,<sup>7,8,12-15</sup> the asymptotic, far-field approximation of the near-field pressure disturbance of any lifting body can be decomposed into equivalent bodies of revolutions which generate the same pressure disturbance. The equivalent bodies of revolution represent the configuration's volume and lift contributions to the near-field pressure disturbance. The total equivalent area distribution of any feasible aircraft should match the theoretical equivalent area distribution in order to achieve the predicted theoretical sonic boom signature on the ground. Thus, the design of the wing geometry should produce a lift

distribution which will not adversely affect the total distribution. It is important to recognize this relationship between the design of the wing to the overall aircraft design.

#### **Research Methodology**

The conceptual design phase provides the designer with a high level of design freedom. It is in this phase of the design process where the conceptual design is highly dependent upon the designer's knowledge. However, to explore many conceptual designs, it is necessary to integrate the designer's knowledge and creativity with computational speed.

This design methodology recognizes the inherent value of the designer's knowledge and creativity in the conceptual design. Even a sketch on the back of a napkin, an eye-ball approximation, or a detailed design are based on years of experience which accounts for weights, size, volume, structure, performance, stability, etc. It is possible, however unlikely, that a computer program may one day be developed which would be able to simulate the infinite number of design choices required in the conceptual design phase. Until then, the designer must be considered an integral part of the design process.

A large gap exists in the current design process. Low-boom theory provides a fundamental guide for which aircraft geometries should be designed. The theory decomposes the aircraft into equivalent bodies of revolution, one for the volume and lift of the aircraft. Volumetric shaping techniques, although not trivial, are known and have been used to shape the fuselage of the aircraft to obtain favorable volume distribution for low-boom characteristics. However, wing shaping techniques to obtain favorable lift distributions have largely relied upon manual design iterations and are usually dependent upon trial-and-error results. This design method provides the designer with an environment in which the

wing geometry can be modified with the intent of achieving a desirable lift distribution.

This design methodology builds off of the designer's creativity and intuitive design choices. This process is intended to aid the designer in incorporating design changes to the initial conceptual design. The optimization routine allows the designer to search through consecutive small scale design which is meant to simulate the manual design iterations by a designer. Through this unique process feasible wing designs are generated which maintain suitable levels of aerodynamic performance and are suited to low-boom shaping techniques.

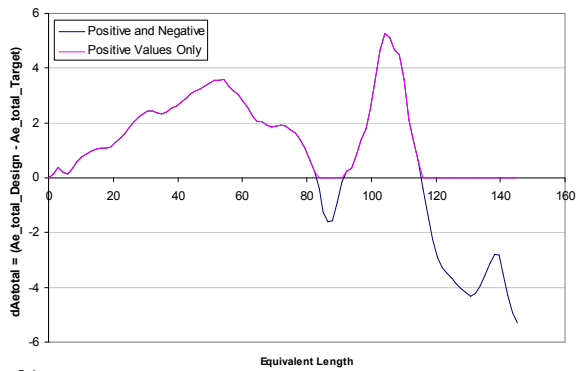
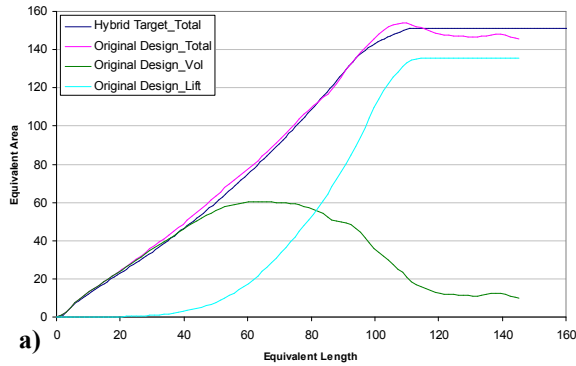
The remainder of this section will be organized in the following manner. First, the inverse design method will be described. Next, the software and a list of programs will be described which allows designer interaction and generates aerodynamic and boom analysis. The wing geometry design scheme will then be described. Lastly, a short description of the optimization scheme will be given.

#### ***Inverse Design***

Normally, design methods follow a direct design method which modifies the design until a set of criteria are met. There are no models or guides that determine whether the "perfect" design has been achieved. However, inverse design methods modify the design to achieve some theoretically "perfect" design. In the context of supersonic aircraft design, the boom minimization theory provides theoretical equivalent area distributions or near-field pressure distributions for minimizing the sonic boom impact. Figure 4(a) compares the design and theoretical equivalent area distribution. In this figure, the theoretical target is generated by the HYBRID2DP program. The design equivalent area distribution is generated by

the boom analysis program, PBOOM. The mismatch between the design and theoretical total equivalent area distribution is shown in Figure 4(b). The aircraft geometry is modified to minimize or reduce this mismatch.

The inverse design method has been used in the conceptual design of supersonic aircraft. Specifically, the aircraft fuselage is shaped using this method. The target equivalent area distribution is defined and compared to the design equivalent area distribution. The fuselage radius distribution is modified using a fuselage modification tool, BOSS. This tool can modify the fuselage shape to reduce the mismatch between the design and theoretical equivalent area distribution. This method can even be used to generate wing-body conceptual design which matches the theoretical equivalent area distribution within some degree of tolerance. However,

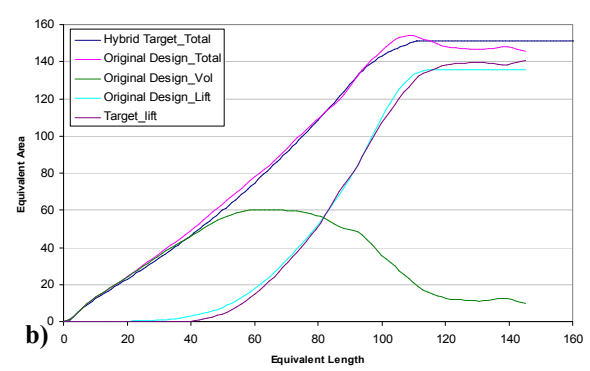
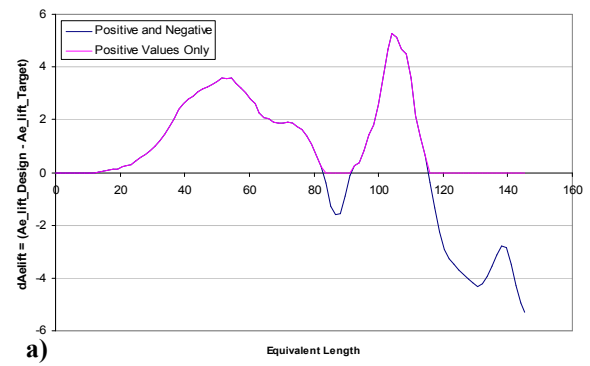


**b)** Figure 4 – a) Comparison of the design and theoretical equivalent area distribution b) Difference between the design and theoretical total equivalent area distribution

there has yet to be any complete feasible conceptual design with fuselage, wings, nacelles, etc. which matches any theoretical distribution.

The challenge that this research seeks to address is how to design the wing geometry such that the aerodynamic performance is preserved and the lift distribution is modified to allow low-boom shaping techniques to be successfully employed.

Figure 5(a) includes a target lift distribution that is generated by  $(Ae_{lift})_{Target} = (Ae_{total})_{Target} - (Ae_{vol})_{Design}$ . The gap distribution between the design and target lift distribution is shown in Figure 5(b). The objective is to design the wing geometry to minimize or reduce this mismatch without unacceptable loss to aerodynamic performance.

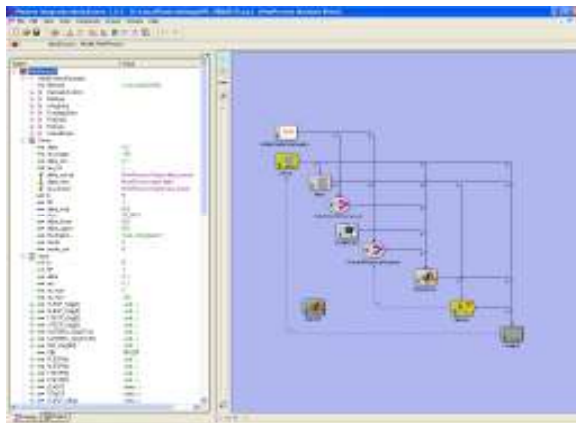


**a)** Figure 5 – a) Comparison of design and target equivalent area due to lift distribution b) Difference between the design and target equivalent area due to lift distribution

### **ModelCenter**

Currently, the aircraft analysis and design tools and process described herein are being conducted and developed within the ModelCenter framework, a commercially available software package developed by Phoenix Integration, Inc.<sup>30</sup> ModelCenter provides the engineer with an environment where multidisciplinary analysis codes can be integrated with visual connections between the components. Data transfer between codes is conducted by linking file input and output parameters between each component. ModelCenter has built-in trade study and design exploration tools, which further enhances the aircraft design process. The ModelCenter integration of conceptual design and analysis tools is described in more detail in the final section of this report.

This research will be conducted using pre-existing legacy codes within a modern design environment. Legacy codes such as AWAVE, ADRAG, PBOOM, etc have been developed in the past to aid in the design of subsonic and supersonic aircraft. ModelCenter is a design tool which allows parametric studies and analysis to be conducted in an integrated environment. Other codes may be developed and integrated through this environment to aid in the design of the SBJ. Figure 6 shows a screenshot of the existing ModelCenter

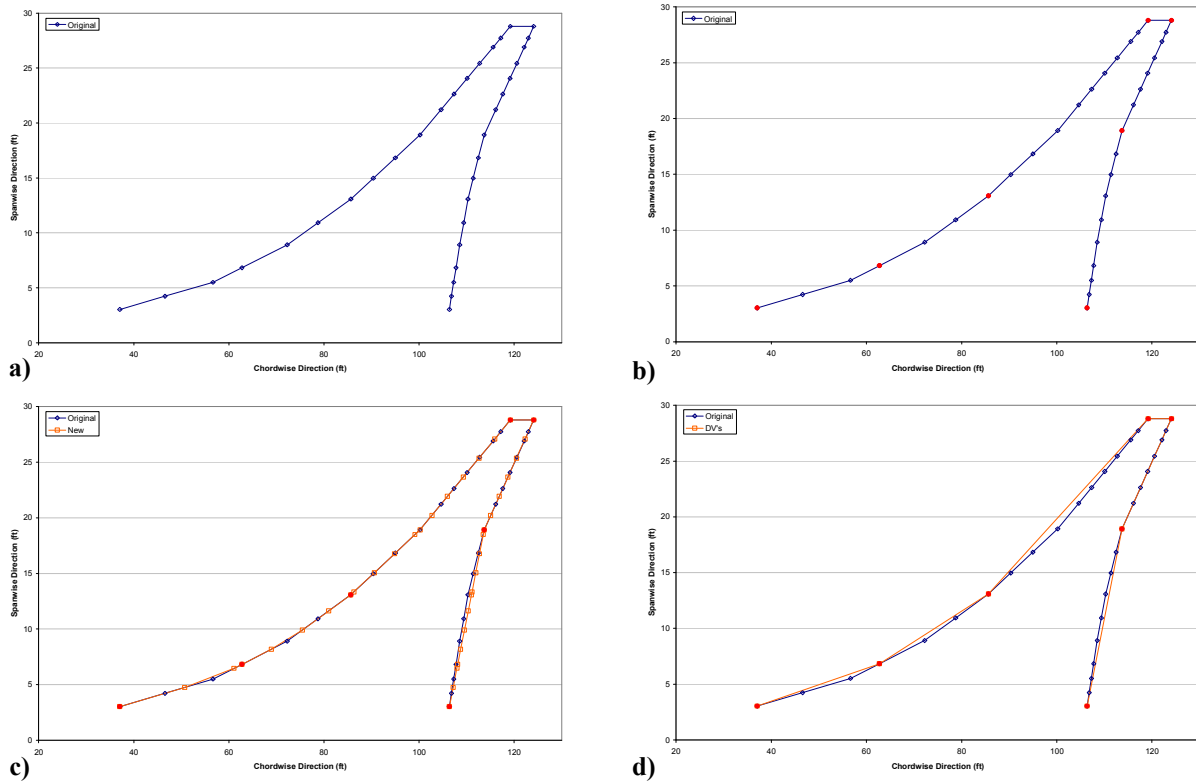


**Figure 6 – Screenshot of ModelCenter**

program that is being used to design and analyze the conceptual design.

### **Planform Design**

The wing geometry is designed in several steps. A knowledge-based wing planform is shown in Figure 7(a). The planform geometry can be parameterized such that each leading edge and trailing edge location can be modified. However, this would involve a large number of design variables and would prove to be computationally expensive. Instead, the planform shape is defined using only critical points using two breakpoints for the leading edge, one breakpoint for the trailing edge, and the three corner points of the planform as indicated in Figure 7(b). The leading and trailing edge break points require the definition of six design variables, one pair of x-y coordinates for each break point. The remaining three design variables are based on the x coordinate of the planform's root trailing edge location and the wing tip's leading and trailing edge location. The wing root's leading edge position is held constant. The breakpoints can be chosen by the designer or by using the natural breakpoints, where the change in sweep angle is the greatest. This produces a linear piecewise continuous planform that captures much of the planform's original geometry, as shown in Figure 7(c). The leading edge curvature of the original planform represents the designer's knowledge and experience of its aerodynamic and low-boom performance. Therefore, it must be accounted for in the definition of the new planform shape. To recapture this shape, a linear elastic scheme is used to define the interim points between the break point locations. The original planform's trailing edge is fairly linear. So the new planform's trailing edge shape was assumed to maintain a linear shape for simplicity. However, the same linear elastic scheme could be applied to the trailing edge if so desired. Thus, using only nine design

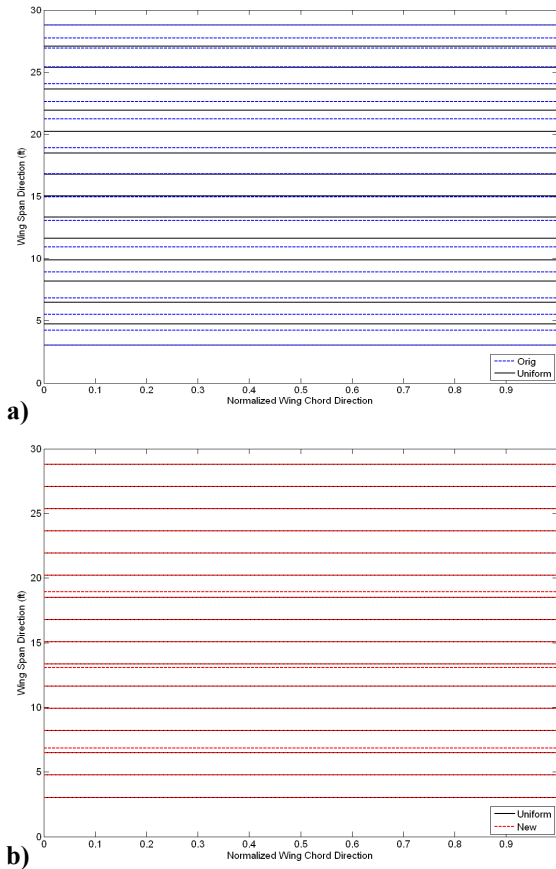


**Figure 7 – a) Original designer-generated planform and airfoil station definition b) User defined design variables based on original wing geometry c) Comparison of original and new linear planform based on user-defined design variables with linear leading edge d) Comparison of the original and new planform based on user defined design variables with non-linear leading edge**

variables, the new planform shape, Figure 7(d), is generated which is a reasonable approximation of the original design.

Some note must be made about the method by which the wing's airfoil station locations are defined. The original planform's airfoil stations are defined at irregular spanwise intervals, which is shown in Figure 8(a). It was determined that a systematic method to define the spanwise airfoil locations was necessary for 2 reasons. First, it is important to maintain continuity between the aerodynamic performance results and the changes in the planform design. Second, the spanwise resolution of the wing's airfoil stations must be sufficient such that the camber surface could be properly designed. For these reasons, the spanwise airfoil locations were defined using a combination of uniformly distributed

airfoil stations and those defined at each of the three break points. The original and uniformly distributed airfoil station locations are compared in Figure 8(a). The new planform is defined by a maximum of 19 airfoil stations: 1 at each of the chord and root location, 1 at each of the three break points, and 14 locations that are uniformly distributed between the root and chord airfoil stations. A maximum of 19 airfoil stations was used due to the limitation of the analysis program, PBOOM, but is more than sufficient. Many prior wing geometries were defined using only 17 total spanwise airfoil stations. Using this scheme, the 2 concerns above are addressed. The uniformly distributed airfoil locations and airfoil locations due to the break points are shown in Figure 8(b).



**Figure 8 – Airfoil station location scheme. a) Original vs 16 uniformly distributed airfoil station locations. b) 16 uniformly distributed airfoils and airfoil station locations due to break points.**

The uniqueness of this methodology lies in the methodology in which new planform geometry is designed. The planform is modified based on two assumptions. First, it is assumed that the baseline planform incorporates a level of knowledge-based design and reflects a design that provides a level of confidence in its overall ability to satisfy many design requirements and constraints. Second, it is assumed that large variations from the baseline are less desirable than small ones. That is, as planform modifications deviate further and further from the baseline planform, the reliability of the final planform design becomes less reliable since unintended design considerations replace the knowledge-based design considerations. In

other words, a larger level of risk is associated with planform geometries which vary greatly from the baseline as compared to those which deviate by lesser amounts. The validation of this method is discussed below in the results.

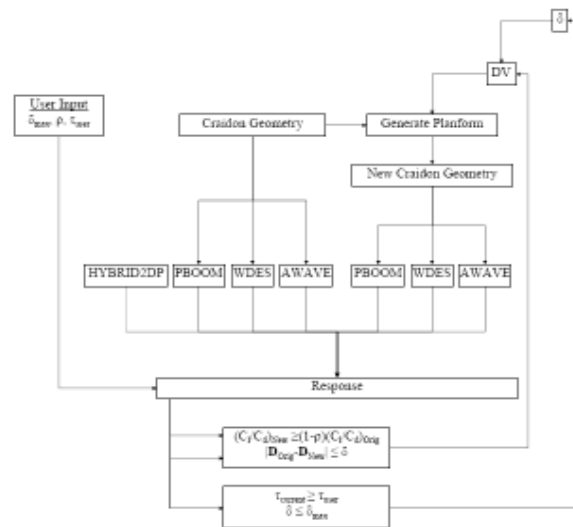
### **Camber and Twist Design**

Once the wing planform is generated, the camber and twist is designed using WDES. This program determines the least amount of wing camber and twist needed to achieve a desired level of  $c_l$ . Usually, the wing is designed to achieve a  $c_l$  of 0.1 for an angle of attack between  $0^\circ$  and  $\sim 3^\circ$ . WDES works on a lifting line principle where candidate camber surfaces are superposed to achieve desirable camber and twist. A complete description of the program can be found in Refs. 29, 31, and 32.

### **Optimization**

The design methodology uses two optimization algorithms to search through the design space. A flow chart is shown in Figure 9 which illustrates the necessary inputs from the designer and the decision processes.

The inner optimization routine uses a gradient-based search method to determine the optimal set of design variables which



**Figure 9 – Flowchart of design methodology**

minimizes the gap between the design and target lift distribution which was shown above in Figure 5(b). The optimization algorithm is fully described in Ref. 33. The optimization problem is described by EQ. 1- EQ. 4. The objective function is based only on the positive difference between the design and target lift distribution. In this manner, emphasis will be placed on designs which produce the most amount of gap reduction. The design variables are those described above. The first constraint is meant to maintain the aerodynamic performance of the aircraft within some user defined penalty,  $\rho$ . The second constraint controls the size of the design space through which the optimization algorithm is allowed to search. The  $\delta$  value is controlled by the outer search algorithm which is described next.

The outer optimization problem, described by EQ. 5 – EQ. 8 is a simple search algorithm which controls the  $\delta$  value which defines the size of the search space

for the inner optimization algorithm. Recall, that one of the driving philosophies of this design methodology is that as the design deviates further from original baseline, the confidence in the design decreases and the risk associated with accepting the design increases. Therefore, objective function is based on value of allowed change in the each design variable. The  $\delta$  is also the design variable. The first constraint ensures that the optimization algorithm does not go wild by limiting the delta value to a user-defined maximum allowed change in the design variables. The second constraint is meant to control the  $\delta$  value supplied to the inner optimization problem.  $\tau$  is the percent gap reduction rate that has been achieved as a result of the design changes made by the inner optimization loop. The gap reduction is constrained by a user-defined value,  $\tau_{user}$ . The interaction between the inner and outer optimization problem is described below.

The solution to the inner optimization problem is non-unique. Many

Objective Function:	$\min[F(\bar{D}_{new})] = \min \left[ \int_{x_{e,start}}^{x_{e,end}} \left\{ \frac{1}{2} \left[ (A_e^{lift} - A_e^{lift}) + (A_e^{lift} - A_e^{lift}) \right] \right\} \right]$	EQ. 1
Design Variables:	$\bar{D}_{new} = \{x \text{ and } y \text{ coordinates of the leading and trailing edge break point locations} - 6 \text{ design variables}$ $x \text{ coordinate of the wing tip leading edge location} - 1 \text{ design variable}$ $x \text{ coordinate of the wing tip and root chord trailing edge location} - 2 \text{ design variables}\}$	EQ. 2
Constraints:	$\left( \frac{C_l}{C_d} \right)_{New} \geq (1 - \rho) \left( \frac{C_l}{C_d} \right)_{Orig}$ $ \bar{D}_o - \bar{D}_{new}  \leq \delta$	EQ. 3 EQ. 4
Objective Function:	$\min \left  \bar{D}_o - \bar{D}_{new} \right  = \min[\delta]$	EQ. 5
Design Variables:	$\delta$	EQ. 6
Constraints:	$0 \leq \delta \leq \delta_{max}$ $\tau_{user} - \varepsilon \leq \tau \leq \tau_{user} + \varepsilon$	EQ. 7 EQ. 8

designs may exist which can solve the inner optimization problem. There are several methods by which a solution could be found. One method is to define a very large design space and search the entire design space for a solution. This is referred to here as the “one-shot” method. This is usually employed by many design methods and may generate great objective function values but the designs generated are usually infeasible.

An alternate method is emphasized in this design methodology which controls the  $\delta$  value by stepping in increments,  $\delta_{step}$ . The  $\delta$  value will increase towards  $\delta_{max}$  by increments of  $\delta_{step}$ . This step-by-step process will continue until  $\delta_{max}$  is reached or until the tolerance constraint is satisfied. If  $\tau > \tau_{user} + \epsilon$ , the  $\delta$  value is reduced until the gap reduction is achieved or comes as close as possible.

The final solution will thus be dependent upon the value of  $\delta_{max}$ ,  $\delta_{step}$ ,  $\tau_{user}$ , and  $\rho$  provided by the designer. This method gives the designer a unique process by which design trades can be made between the amount of change incurred to the original planform design, the amount of gap reduction achieved, and the amount of loss in aerodynamic performance.

#### **Current Research Results**

The design of a supersonic commercial aircraft requires a complex process which modifies the geometry of the aircraft such that the summation of the equivalent area due to volume and lift matches the total target equivalent area distribution as closely as possible. The first step of the process requires the definition of the wing geometry to define the lift distribution. The designer can define an arbitrary target lift distribution or use the existing or arbitrary volume to define the target lift distribution through the equation,  $(A_e)_{lift}^{target} = (A_e)_{total}^{target} - (A_e)_{volume}^{actual}$ . In this manner, the wing geometry can be modified

to reduce the gap between the design and target lift distribution.

An example case is highlighted in Figure 10(a)-(d) which shows the equivalent area distribution, the gap distribution of the total equivalent area, the gap distribution for the lift distribution, and the wing planform. Figure 10 (a) shows the target, original, and optimal equivalent area distributions. The target total equivalent area distribution is defined using sonic boom minimization theory. The original and optimal design volume and lift distribution are also shown. As can be seen, there is some mismatch between the design and target equivalent area distributions. The target lift distribution was defined by using the suggested equation above. The mismatch from the target for the original and optimal total equivalent area distribution is shown in Figure 10 (b). The mismatch from the target for the original and optimal equivalent area distribution due to lift is shown in Figure 10 (c). The original and optimal wing shape is shown in Figure 10 (d). Using the wing shaping methodology proposed in this research the mismatch between the target and design lift distribution was achieved. The design variables are constrained to a maximum value and the solution represents the optimal planform that provides the most reduction in the gap distribution. The results illustrate that small changes in the original planform geometry can be made which reduces the gap between the design and target lift distribution.

#### **Future Research**

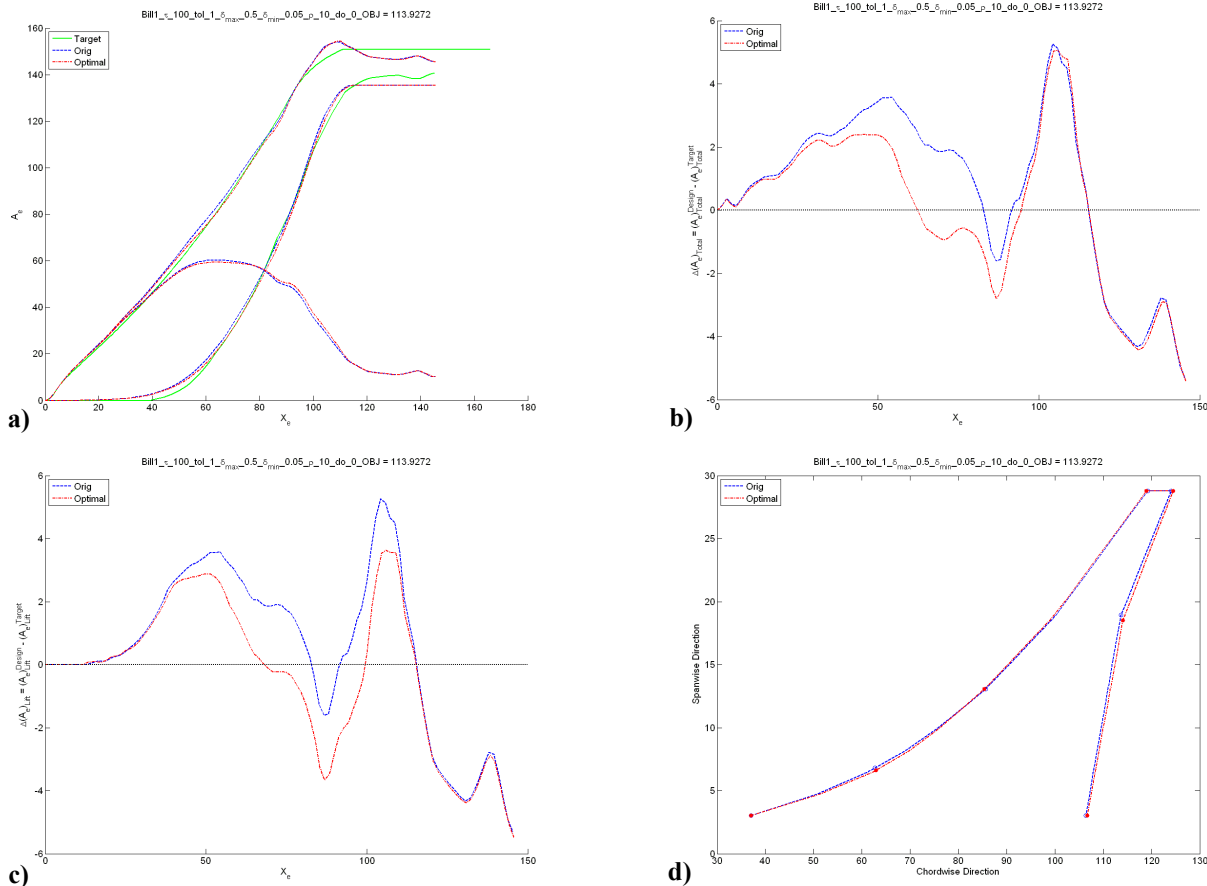
Thus far, this research has primarily involved several studies which seek to understand the relationship between the equivalent area distributions and the sonic boom signature. In addition, much effort has been invested into the generation of a new methodology for wing design with the intent to reduce the gap between the design and target lift distribution. The results seek to provide the designer with the information

and capability to generate feasible design concepts. The design process described in this research relies upon the design knowledge provided by the designer. However, the process provides a useful capability to the designer by replacing much of the time-consuming manual iterations with an efficient optimization routine. In addition, the design process ensures that any changes to the wing design produce the greatest amount of benefit by reducing the gap between the design and target lift distribution.

Other work to be done involves refining and defining the characteristics and behavior of the wing design methodology. This involves extensive verification and validation of the design process. To be

successfully integrated into the entire conceptual design process, the designer must have full confidence and understanding of the relationship between the necessary inputs and outputs. There are several issues that need to be quantified.

The choice of the initial design variables are decided by the user. Currently, the design variables are related to the corner points of the wing planform as well as two locations on the leading edge and one location on the trailing edge. The spanwise location of the leading edge and trailing edge should be closely tied to the natural breakpoints of the wing planform. This is usually an eye-ball approximation. However, a sensitivity analysis should be conducted that quantifies the effect of the



**Figure 10 – Compare Original and Optimized a) Equivalent area distribution, b)  $(\Delta Ae)_{total} = (Ae_{total})_{Target} - (Ae_{total})$ , c)  $(\Delta Ae)_{lift} = (Ae_{lift})_{Target} - (Ae_{lift})$ , d) Planform shape with design variable locations. Optimization parameters:  $\delta_{max} = 0.5, \delta_{step} = 0.05, \tau_{user} =, \rho_{user} = 10\%$ .**

spanwise location on the ability of the process to reduce the gap between the design and target lift distribution.

The sensitivity of the gap reduction to the step size,  $\delta_{\min}$ , should also be quantified. The designer or user should be provided with some guidelines as to what  $\delta_{\min}$  values should be used to obtain a high level of gap reduction with feasible results. The  $\delta_{\min}$  value affects the solution to the optimization routine. Essentially, the  $\delta_{\min}$  value determines the size of design space through which the optimizer searches through. From experience the design space is very nonlinear and there are many local minima. Finding an optimal solution is highly dependent upon the size of the design space.

Possible future work on this research involves expanding the practicality and functionality of the design methodology. One area for expansion is to limit the amount of change that is incurred to the volume distribution as a result of the changes in the wing geometry. It is easier to match the total equivalent area distribution through volume shaping techniques than through lift shaping techniques. The lift distribution is modified so that there is added volume for fuselage shaping techniques to match the total target equivalent area distribution. However, if the changes in the wing geometry cause an adverse effect on the volume distribution, then there is no net gain in volume. Also, low-speed performance is as important during the conceptual design phase as cruise performance and low-boom. One important metric for low-speed performance is wing area. A designer knows fairly well whether an aircraft has sufficient low-speed performance by gauging the amount of wing area. Therefore, any changes in the wing geometry should not adversely affect the wing area. Control parameters should be

implemented into the design process to maintain a certain degree of wing area.

The above issues will be conducted with the higher level of priority given to the issues mentioned first to the least amount of priority given to those mentioned last. This is mainly due to the time constraint that exists. However, every issue must be addressed to be able to successfully integrate the wing design methodology into the entire conceptual design process.

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