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A Quick Method for Evaluating the Merits of a Proposed Low Sonic Boom Concept

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Summary

The characteristics of a proposed low-boom aircraft concept cannot be adequately assessed unless it is given an extensive, time-consuming, mission-performance, and sonic-boom analyses. So, it would be useful to have a method for performing a quick first-order sonic-boom and mission-range analysis. The evaluation method outlined in this report has the attributes of being both fast and reasonably accurate. It can also be used as a design tool to estimate the sonic-boom ground overpressures, mission range, and beginning-cruise weight of a new low-boom concept during the first stages of preliminary design.

Introduction

New aeronautical programs and initiatives often attract unsolicited conceptual aircraft design proposals. The merits of these concepts need to be quickly evaluated to avoid giving it an unnecessary and time-consuming performance analysis. These preliminary evaluation methods must be trustworthy, even though they might be empirical or based on first-order theory. In this report, a simple method is described for making such an initial evaluation of a proposed concept's mission and sonic-boom performance; a method that would provide quick preliminary results for judging whether an extensive analysis of the proposal was warranted. It is based on two computer codes that require a modest amount of input. Their numerical output is easily interpreted to provide information about the concept's mission and low-boom characteristics so that its merits can be assessed. A computer listing of both codes is in Appendices, and sample cases are presented to demonstrate how this method is used.

Nomenclature

C_L	cruise lift coefficient
GRF	ground reflection factor, between 1.8 and 2.0, usually 1.9
h	beginning-cruise altitude, ft
l_e	effective length of the concept, ft
L/D	cruise-averaged lift/drag ratio
M	Mach number
Δp	nose-shock overpressure on ground, psf
SFC	cruise-averaged specific fuel consumption, $lb_{fuel}/lb_{thrust}/hr$
W_{BC}	beginning-cruise weight, lb
W_E	empty weight, lb
$W_{F,RES}$	weight of reserve fuel, lb
W_{GTO}	gross takeoff weight, lb

y_f	“nose bluntness” length, ft
ξ	distance from nose to start of “ramp”, ft
λ	distance from nose to end of positive section of the F-function, ft

Evaluation of a Low-Boom Concept’s Merits

Since the concept must meet a specified ground overpressure constraint as well as a mission constraint, the evaluation is begun with one of several low-boom minimization codes, references 1 to 4. The main difference between the four low/reduced-boom codes is the shape of the configuration’s forebody, derived from a low-boom F-function, and the corresponding volume and lift equivalent areas. All of these codes are based on Whitham theory, reference 5, and are used to calculate a low-boom pressure signature shape to meet a desired overpressure level from Mach number, beginning-cruise weight, and beginning-cruise altitude inputs. These codes can also be used iteratively to obtain estimates of beginning-cruise weights and/or altitudes of a concept that will generate a specified low-boom pressure signature shape and overpressure at a specified Mach number. In either of these two modes, the effective length of the concept and the cruise Mach number is held constant. Obviously, the effective length or the beginning-cruise altitude can also be varied if their variations with beginning-cruise weight are desired.

Once the low/reduced-boom codes have been used to calculate a desired overpressure from the beginning-cruise weight and altitude, a preliminary weight estimation code, such as the one described in reference 6, would be used to obtain a second set of necessary weight data. With this code, gross takeoff weight, beginning-cruise weight, empty weight, and mission fuel weight are estimated from range, engine performance, aerodynamic characteristics, payload, climb/descent parameters, and technology level parameters. It can also be used to iterate gross takeoff, empty, and mission fuel weights from a previously calculated beginning-cruise weight.

Together, these codes and the interpretations of their output are used to form a judgement about the stated merits of a particular proposal. Since these are empirical and first-order codes, there is some degree of flexibility in the judgement to accept or reject a proposal. In the following sections, each of the tools in the evaluation method are described in more detail. Then, sample cases are presented to demonstrate its application.

Low-Boom Beginning Cruise Weights, Altitudes, and Ground Overpressures

Ground overpressures are determined mainly by cruise Mach number, beginning-cruise weight, beginning-cruise altitude, pressure signature shape, and effective length although several other parameters also affect the result. Several methods, references 1 to 4, are available which can provide estimates of low-boom ground overpressures from this list of inputs:

(1) Cruise Mach number,
(2) Estimated beginning-cruise weight,
(3) Estimated beginning-cruise altitude,
(4) Ground reflection factor,
(5) Effective length of concept,
(6) “Nose-bluntness” length,

(7) Specification of “flat-top” or “ramp” pressure signature,

(8) Distance where the F-function “ramp”, if any, begins,

(9) Type of stratified atmosphere,

(10) Nose-shock strength (estimated), and

(11) Nose-shock/tail-shock strength ratio.

In this report, the method described in reference 4 is used.

Many, if not most, of these inputs are either specified in the proposal, implied by the mission to be performed, or can be estimated from the geometry of similar concepts. For example, item (1) is a mission parameter usually specified, but it can be set by class of aircraft.

Item (2) usually is specified, but it could be estimated by an iterative process from items (3) through (11).

Item (3) is part of either the mission requirements or the concept’s description. If it is not listed or specified, it could be the altitude for which the engine functions at a high level of efficiency at cruise thrust. It could also be estimated, along with item (2), to meet a required beginning-cruise overpressure. If Items (2) and (3) are not specified, then the evaluation must be halted until the required data is given.

Item (4) is usually given values that range from 1.8 to the ideal maximum of 2.0. A value of 1.9 is often used, and will be used in the sample cases.

Item (5) is usually part of the concept’s description, but it could be obtained from the beginning-cruise parameters. It could be equal to the overall length if no other information is available.

Items (6) and (8) may be part of the concept’s geometry description. If not, they can be estimated from information in reference 2, or from reports on previously designed low-boom concepts.

Item (7) should be part of the concept’s description, but may be omitted because it is part of the contractor’s proprietary design method. If unspecified, it can be given a value of zero (“flat-top” F-function and pressure signature, figure 1) which is the most conservative value. It can also be assigned several non-zero values up to a maximum of 1.0 (“ramp” F-function and pressure signature, figure 2) to determine the weight sensitivity of the concept across a range of “ramp” values. Should this second option be used, item (8) will require a value that is equal to, or larger than, the value of item (6).

Item (9) can be described by any one of the model standard-day atmosphere tables.

The overpressure, item (10), is an input quantity that serves as an initial value in the calculation procedure. As an output that is very dependent on items (1), (2), (3), and (5), it is the overpressure measured under the flight path at beginning of cruise generated by a concept with the estimated beginning-cruise weight.

Tail-shock strength, item (11), is usually the same as the nose shock. However, if the aft-end geometry of the concept has components or features with low-fineness ratio boattailing, the value of the ratio in item (11) can be made different than 1.0.

By iterating the beginning-cruise weight, item (2), beginning-cruise altitude, item (3), or the effective length, item (5), an overpressure equal to the desired level can be obtained. Beginning-cruise altitude and effective length could be changed and the procedure repeated until a matrix of beginning-cruise weights and effective lengths versus beginning-cruise altitudes are found for a given ground overpressure. These capabilities are useful in initiating a low-boom design.

One general trend observed is that an increase in effective length permits an increase in beginning-cruise weight for a specified overpressure and beginning-cruise altitude. Another equally important trend is that an increase in the beginning-cruise altitude leads to a decrease in allowable beginning-cruise weight for a specified ground overpressure, a specified pressure signature shape, and an effective length. These trends link beginning-cruise weights and altitudes to overpressures in ways critical to overall design success.

Preliminary Mission Weights

The estimated beginning-cruise weight is used to calculate a preliminary set of mission performance data from a mission range-weight estimation code such as the one described in reference 6. This first-order method is based on the weights and ranges of real and conceptual High Speed Civil Transport (HSCT) vehicles; those with ranges of 3500 to 6500 nmi, that carry 100 to 300 passengers, and that cruise at Mach numbers of 1.5 to 3.0. The inputs are:

(1) Cruise Mach number,
(2) Mission range,
(3) Number of passengers,
(4) Averaged cruise Lift/Drag ratio,
(5) Averaged cruise Specific Fuel Consumption (SFC),
(6) Estimated ratio of W_{BC}/W_{GTO} ,
(7) Estimated weight of fuel required for descent and landing,
(8) Estimated ratio of $W_{F,RES}/W_{GTO}$,
(9) Estimated ratio of W_{GTO}/W_{E} ,
(10) Estimated range to takeoff, climb, and accelerate to cruise,
(11) Estimated range to descend and land,
(12) Weight of payload,
(13) Wing area
(14) Number of crew

Most of these inputs are mission requirements (items (1), (2), (3), (12), and (14)), characteristics of similar real or conceptual aircraft - items (4), (5), (6), (7), and (13) - or those that can be estimated from previous designs of supersonic-cruise aircraft and concepts - items (4), (5), (6), (7), (8), (9), (10), and (11). Thus, if the proposed concept description does not provide one or more of these inputs, there are sources that can provide suitable initial values.

One of the key inputs is item (6) which relates the gross takeoff and the beginning-cruise weights. Another is item (9) which relates the gross takeoff and empty weights. Figure 3 (figure 2 from reference 6) can be a guide for selecting a value for item (9) if these weights are not provided. However, it must be remembered that there is a range between optimistic and pessimistic estimates to be factored into the judgement of an input value, and the data for figure (2) in reference 6 was obtained from large, long-range aircraft and concepts. Varying the value of item (9) will provide a matrix of empty, beginning-cruise, and gross takeoff weights which can be compared with the same parameters of similar concepts. The beginning-cruise weight calculated with this code should be very close to that obtained from the low-boom code. These comparisons can then be used to determine which combination of beginning-cruise weights, beginning-cruise altitudes, and empty weights - for a specified ground overpressure - are possible and plausible on a potential concept.

After the primary mission weights have been estimated, the wing loading and lift coefficient for the beginning-cruise weight and altitude should be calculated for comparison with values from similar sized concepts. Previous low-boom research concepts, references 7 to 10, have had beginning-cruise wing loadings of from 50 to 70 psf. Most of them had lift/drag ratios that reached a maximum in the $C_L = 0.11$ to 0.13 range, although they usually cruised at a C_L that was closer to the values in lower end of this range. The concepts were 250 to 300 passenger HSCT-sized vehicles, so their beginning-cruise lift/drag ratios would be higher than those on the smaller Supersonic Business Jet (SBJ) concepts. So only the wing loading and cruise C_L data for the proposed concept should be obtained from these larger long-range concepts. The cruise lift/ drag ratios should be compared with those from similar-sized concepts.

After the evaluation has been completed, the calculated results are compiled and compared with the predictions claimed in the proposal. These comparisons as well as the characteristics of previous concepts are guides in judging the mission capabilities and low-boom potential of the proposed configuration. If the preliminary data looked promising, a much more thorough evaluation of mission and low-boom performance would be warranted and could be initiated.

This method could also be used to initiate a preliminary design of a low-boom concept. In that situation, the purpose would be the exploration of design boundaries rather than the determination of possible design merit. Results from such an exploration could then be used to suggest avenues and options which lead more quickly and surely to a successful design.

In the next section, the evaluation method is demonstrated by applying it to three hypothetical proposals. Results from the calculations are outlined and discussed to demonstrate the capabilities of the method. Usually three-view sketches accompany the proposal. However, in this report, no three-view sketches are provided since they would reflect biased design preferences.

Sample Cases

Three hypothetical low-boom concept proposals will be evaluated to demonstrate the applicability of the method. All three are SBJ concepts because, at the moment, this class of vehicle is thought to be the most likely candidate for an acceptable supersonic-cruise vehicle for flight over the continental United States or Europe. These data will be common to all the concepts:

(1) gross takeoff weights in the 100,000 lb class;

(2) crew of 2 and a payload of 10 passengers;

(3) cruise Mach numbers between 1.6 and 2.0;

(4) overall lengths of about 100 ft;

(5) desired overpressures on the ground under the flight path and at start of cruise of 0.5 psf or less; and

(6) low/reduced sonic- boom-shaped pressure signatures.

Since SBJ concepts have been studied in the past, a matrix of aerodynamic and propulsion characteristics is on record. Lift/drag ratios in the 6.5 to 7.5 range have been found at cruise lift conditions, so for the concept in each sample case, an average lift/drag ratio of 7.0 will be used. Although this might appear to be an easily attained value, low-boom concepts acquire many incremental drag penalties as the configuration geometry is tailored to generate a specific shaped pressure signature. Jet engines used on previously designed SBJs had supersonic-cruise SFCs which depended on their particular speed range and thrust rating. In the sample cases of this report, supersonic-cruise SFCs are either 1.2 or 1.25 lb / lb / hr, very conservative preliminary-design values, especially for cruise Mach numbers in the range of 1.6 to 1.8. At Mach numbers in the range of 1.8 to 2.0, these cruise-averaged SFCs are conservative but not excessively high. The beginning-cruise weight fraction, W_{BC}/W_{GTO}, is assumed to have a typical value of 0.9, which is an approximate and a conservative value similar to that found on several previous SBJ concepts.

Case No. 1

An SBJ concept with these mission range and sonic-boom performance characteristics was proposed:

- Cruise Mach number of 1.6,
- Mission range of 5000 nmi,
- 10 passengers and a crew of 2,
- Ground overpressure of 0.30 psf at start of cruise,
- Gross takeoff weight of 90,000 lb,
- Empty weight of 31,000 lb.
- Overall length of 100 ft,
- Beginning-cruise altitude of 45,000 ft,
- “Flat-top” F-function and pressure signature.

These parameters are eight of the eleven input data needed to estimate the beginning-cruise weight of a concept that will generate only 0.30 psf on the ground under the flight path. The rest will have to be supplied by the proposal writer or be estimated by the evaluator.

Cruise Mach number was item (1) on the list given in the section on *Low-Boom Beginning Cruise Weights And Altitudes.* Item (2) was varied until the desired overpressure is the same as the output results of items (10) and (11). Item (3) was 45,000 ft. Item (4) was set to a value of 1.9; item (5) is usually less than the overall length, but the overall length of 100 ft was used. Item (6) will be set by the degree of nose bluntness needed to keep the nose apex angle well behind the Mach angle. Item (7) was set by designating a “flat-top” F-function and pressure signature. Item (8) was not needed because a “flattop” signature was desired, but it was arbitrarily set equal to y_f. Item (9) was a standard-day stratified atmosphere, item (10) was the result iterated to get 0.30 psf, and item (11) was set to 1.0 for equal nose and tail shock strengths.

For convenience, the conical-nose “flat-top” F-function in reference 4 (see Appendix A) was used to obtain an equivalent area distribution and a beginning-cruise weight at cruise altitude for the specified 0.30 psf ground overpressure. This F-function is shown in figure 1, and was calculated with the following data as inputs:

$M = 1.6$ “Flat-Top” Signature Standard Day Atmosphere

$h = 45{,}000$ ft $W_{BC} = 0.9 * W_{GTO} = 81{,}000$ lb GRF = 1.9

$y_f = 4$ ft $l_e = 100$ ft $\Delta p = 0.30$ psf

Calculated results indicated that for $h = 45{,}000$ ft, the desired beginning-cruise overpressure of $\Delta p = 0.30$ psf could be obtained if $W_{BC} = 46{,}815$ lb rather than the 81,000 lb estimated in the proposal. Other y_f values could have been used, or the beginning-cruise altitude could have been decreased, but the beginning-cruise weight would not have increased enough to come close to 81,000 lb. Decreasing W_{BC}/W_{GTO} would have helped the concept meet the desired low-boom requirement. This does not usually provide a practical solution, so there was no need to go further in the evaluation; the concept has much too large a beginning-cruise weight to meet the low-boom requirement of 0.30 psf.

Case No. 2

A second SBJ was proposed with these mission range and sonic-boom performance characteristics:

- Cruise Mach number of 1.6,
- Mission range of 3100 nmi,
- 10 passengers and a crew of 2,
- Ground overpressure of 0.30 psf at start of cruise,
- Gross takeoff weight of 80,000 lb,
- Empty weight of 36,000 lb,
- Overall length of 140 ft,
- Beginning-cruise altitude of 50,000 ft,
- "Flat-top" F-function and pressure signature.

The inputs used to calculate the beginning-cruise weight at altitude were:

$M = 1.6$	"Flat-Top" Signature	Standard Day Atmosphere
$h = 50{,}000$ ft	$W_{BC} = 0.9 * W_{GTO} = 72{,}000$ lb	GRF = 1.9
$y_f = 4$ ft	$l_e = 140$ ft	$\Delta p = 0.30$ psf

The F-function shown in figure 1 was again the basis for a determination of the beginning-cruise weight and corresponding altitude that met the specified overpressure. This time, calculation results showed that at $h = 50{,}000$ ft, a concept with $W_{BC} = 71{,}548$ lb would generate a nose shock of $\Delta p = 0.30$ psf on the ground if the configuration's geometry were properly low-boom tailored. The W_{GTO} claimed in the proposal was 80,000 lb, so the ratio of W_{BC}/W_{GTO} was 0.894, which was within the range of reasonable W_{BC}/W_{GTO} ratios. In this example, the proposal's estimated sonic-boom performance was qualitatively verified.

Next, mission weights and range were evaluated with the mission-weight prediction code of reference 6 (see Appendix B) with the following inputs:

- Cruise Mach number of 1.6,
- Mission range of 3100 nmi,
- Crew of 2 with 10 passengers,
- Cruise-averaged Lift/Drag ratio of 7.0,
- Cruise-averaged SFC of 1.2 $lb_{fuel}/lb_{thrust}/hr$,
- W_{BC}/W_{GTO} of 0.90,
- Fuel weight (for descent and landing) of 900 lb,
- $W_{F,RES}/W_{GTO}$ of 0.06,
- W_{GTO}/W_E of 2.222 (initial value),
- Range (for takeoff, climb, and accelerate to cruise) of 100 nmi,
- Range (descend and land) of 150 nmi,

- No extra payload,
- Wing area of 1600 ft^2.

The values of W_{GTO} and W_{BC} predicted for these inputs were 79,481 lb and 71,533 lb, respectively. This calculated W_{GTO} was very close to the proposal value, and the derived W_{BC} was also close to the value obtained from the low-boom calculation.

The estimated W_E = 33,636 lb seemed a bit low, but was close to value obtained from the initial W_{GTO}/W_E ratio. Advanced-technology high-strength low-weight metal alloys or composites, and high thrust-to-weight ratio engines would definitely be needed to achieve this low concept empty weight. With a projected area of 1600 ft^2, the begin-cruise wing loading would be about 44.7 psf which is a bit on the low side. The corresponding beginning-cruise C_L = 0.1024 was well within the range of beginning-cruise C_L of previously low-boom supersonic-cruise concepts. A wing area of 1600 square feet is fairly reasonable for an SBJ concept whose effective length is 140 ft, but a wing loading of 49.7 psf at take-off is much too low for an SBJ designed for both low boom and for high aerodynamic efficiency. Since the beginning ground overpressure goal is very low at 0.30 psf, these low take-off and beginning-cruise wing loadings could well be a consequence of this specification, and should not be judged too harshly. At this point in the analyses, it would be concluded that the concept might warrant further study since the comparison of proposal performance and preliminary calculation was in reasonably good agreement.

Case No. 3

A third SBJ concept was proposed with these mission range and sonic-boom performance characteristics:

- Cruise Mach number of 2.0,
- Mission range of 4000 nmi,
- 10 passengers and a crew of 2,
- Ground overpressure of 0.50 psf at start of cruise,
- Gross takeoff weight of 100,000 lb,
- Empty weight of 43,000 lb,
- Overall length of 110 ft,
- Beginning-cruise altitude of 53,000 ft.
- “Ramp” F-function with “ramp” factor of 0.35

The inputs used this time were:

$M = 2.0$	“Ramp” Signature		Standard Day Atmosphere
$h = 53{,}000$ ft	$W_{BC} = 0.9 * W_{GTO} = 90{,}000$ lb		GRF = 1.9
$y_f = 6$ ft	$\xi = 16$ ft	$l_e = 110$ ft	$\Delta p = 0.50$ psf

The F-function shown in figure 2 with a “ramp” factor of 0.35 was used to determine a beginning-cruise weight and corresponding altitude that met the specified overpressure. This time, calculation results showed that at Mach 2 and $h = 53{,}000$ ft, a concept whose geometry was tailored for low sonic boom with a $W_{BC} = 91{,}023$ lb, would generate a ground pressure signature with a nose shock of $\Delta p = 0.50$ psf. The W_{GTO} estimated in the proposal was 100,000 lb, and for this calculated weight, the ratio W_{BC}/W_{GTO} was 0.91, which was comparable but more optimistic than the lower value of 0.90 estimated in the proposal. So, the proposal estimates of sonic-boom performance were qualitatively verified.

Mission weights and range were evaluated with the following inputs:

- Cruise Mach number of 2.0,
- Mission range of 4000 nmi,
- Crew of 2 and 10 passengers,
- Cruise-averaged Lift/Drag ratio of 7.0,
- Cruise-averaged SFC of 1.25 lb_{fuel}/lb_{thrust}/hr,
- W_{BC}/W_{GTO} of 0.90,
- Fuel weight of 950 lb for descent and landing,
- $W_{F,RES}/W_{GTO}$ of 0.06,
- W_{GTO}/W_E of 2.33 (initial value)
- Range of 150 nmi to takeoff, climb, and accelerate to cruise,
- Range of 200 nmi to descend and land,

- No additional payload,
- Wing area of 1500 ft^2.

The W_{GTO} and W_{BC} predicted for these inputs were 101,136 lb and 91,022 lb, respectively. This calculated W_{GTO} was close to the claimed value, and the calculated W_{BC} was reasonably close to the value obtained from the low-boom calculation.

Previously, in Case No. 2, only the original assumed ratio of $W_{BC}/W_{GTO} = 0.90$ was used to obtain a set of weights that would satisfy mission and sonic-boom constraints. Again, in this case, the same ratio, $W_{BC}/W_{GTO} = 0.90$, is used. However, if the more optimistic value of the ratio $W_{BC}/W_{GTO} = 0.91$ is tried, then W_{GTO} and W_{BC} are predicted to be 100,025 lb and 91,022 lb, respectively. Both predictions of W_{BC} are close to what they must be to meet the desired sonic-boom requirement. The two calculated W_{GTO} results are also almost the same although the second predicted value of W_{GTO} is 1,100 lb lighter. Should the wing planform on this proposed concept be shown to have good low-speed characteristics, the lighter W_{GTO} would be an additional factor in its favor.

The estimated empty weight was 41,851 lb when W_{BC}/W_{GTO} was 0.90, and 41,918 lb when W_{BC}/W_{GTO} was 0.91. Again, virtually no practical difference. If advanced-technology high-strength low-weight metal alloys or composites were available, and an engine with a high thrust-to-weight ratio could be found or developed, a vehicle with either optimistic empty weight might be possible. Since planform shape, camber distribution, and twist schedule are not part of the required input, there is no way to justify the selection of one predicted W_{GTO} over the other. At this point in the evaluation, both gross take-off weights are possible, and the small difference in the calculated results does not cast suspicion on the merits of the concept's design.

With a projected area of about 1500 ft^2, which is fairly reasonable for a concept whose effective length is about 110 ft, the proposed business jet sized concept had a beginning-cruise wing loading of about 60.7 psf, and a C_L of about 0.1027. This beginning-cruise C_L value could provide an average lift/drag ratio during cruise of about 7.0 or better, if care was exercised during the low-boom tailoring to keep the wave drag and skin friction drag as low as possible. Since so many key parameters claimed in the proposal and calculated in the analysis were in close agreement, this proposal might warrant a full and complete sonic-boom and mission performance evaluation.

Concluding Remarks

A quick and reasonably accurate empirical method for the quick evaluation of the mission and low-boom merits of a proposed supersonic-cruise concept has been outlined in this report. Since the concept designer could be in the process of evaluating initial configuration ideas, this method would also be useful for calculating the initial sonic-boom characteristics and mission performance characteristics of a potential low-boom concept before it would be given extensive mission range and sonic-boom analysis time as a follow-on to the preliminary design stage.

Three proposed concepts were given a preliminary mission range and sonic-boom evaluation to demonstrate the usefulness of the method. Concept (1) would be rejected outright because the low-boom constraint could not possibly be met. Concept (2) and/or Concept (3) might be accepted or rejected for further study, but that decision was outside the scope of this paper. In the evaluations of these last two proposals, the calculated results were given emphasis that would not usually be extended in a complete proposal evaluation. This was done for convenience in demonstrating the applicability of the method. Results calculated during the application of the method would be balanced by comparisons with similar previously designed concepts.

It should also be remembered that conservative values for W_{BC}/W_{GTO} and cruise-averaged SFC were used in the three evaluations although they were most evident in the last two. The inherently conservative approach could lead to very low empty weight estimates and overly-high values of W_{GTO}/W_E ratio. Since W_{BC} is set by low-boom requirements, and mission fuel weight is strongly dependent on supersonic-cruise SFC, this conservatism could force the empty weight down to optimistically low levels to meet the range requirement. Using conservative values for the weight ratios and moderately optimistically values for the supersonic-cruise SFC should be used to obtain the widest possible view of the potential concept's merits. Thus, the method has built-in flexibility which would verify the merits of a potentially good proposals, while making it possible to determine why technically implausible concepts should be eliminated from further consideration.

The amount of input data, the number of analysis codes, and the amount of time required by the evaluation method is small compared to the matrix of data required by the "stable" of analysis codes for a thorough performance analysis. The time used by the preliminary performance estimation method is much less than that needed to analyze, calculate, check, and cross-check in a thorough analysis. However, the method for the evaluation of concept-design merit included enough conceptual aircraft characteristics and description parameters to make possible a reasonably accurate preliminary judgement about its potential mission and sonic-boom performance. Although the method appears to be simple and straightforward, a note of caution must be given. This is not a method to be used by someone with little or no experience with conceptual low-boom aircraft design, minimum-boom theory and application, or sonic-boom theory and analysis.

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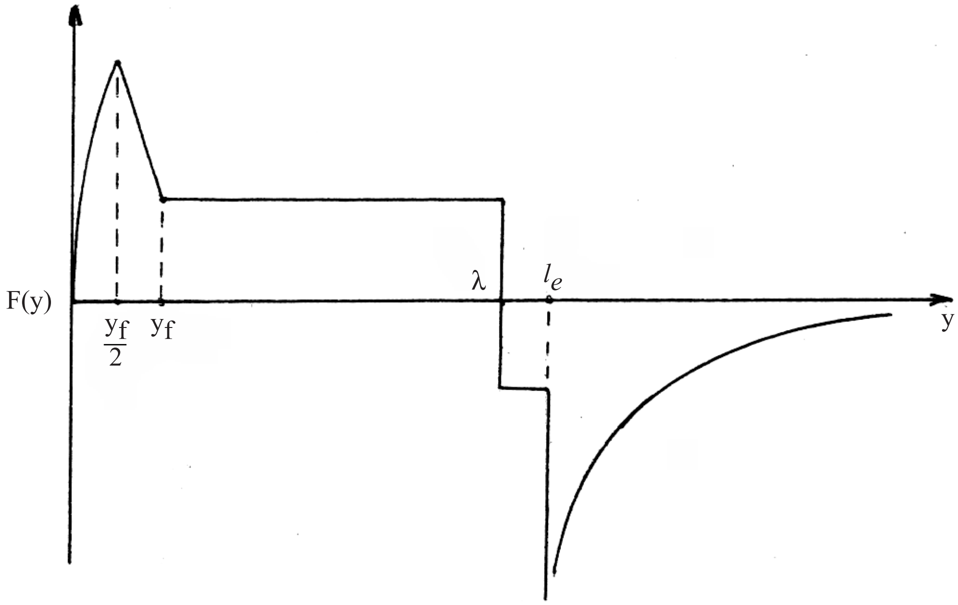

Figure 1. “Flat-top” type of Whitham F-function.

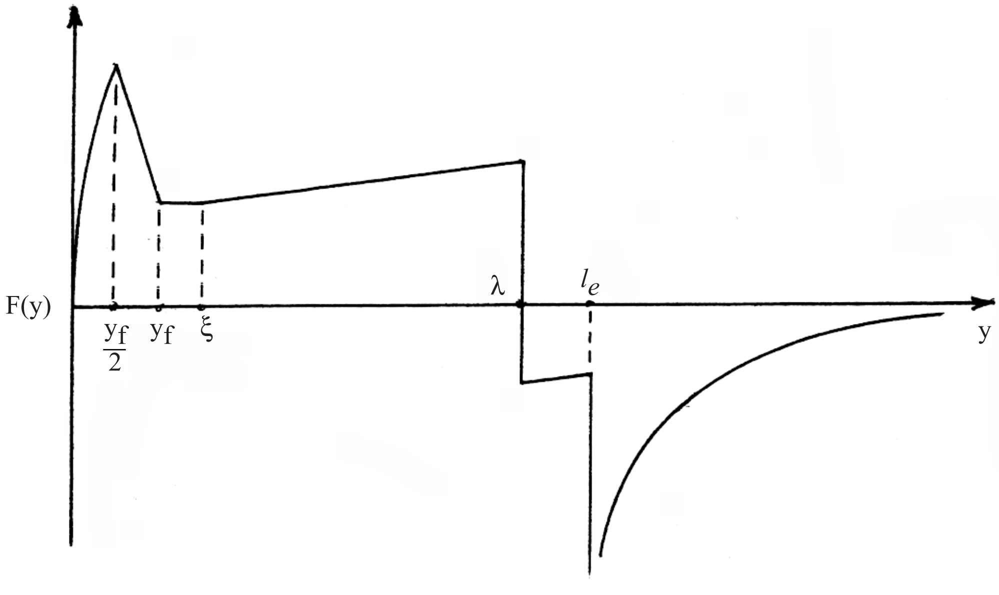

Figure 2. “Ramp” type of hybrid Whitham F-function.

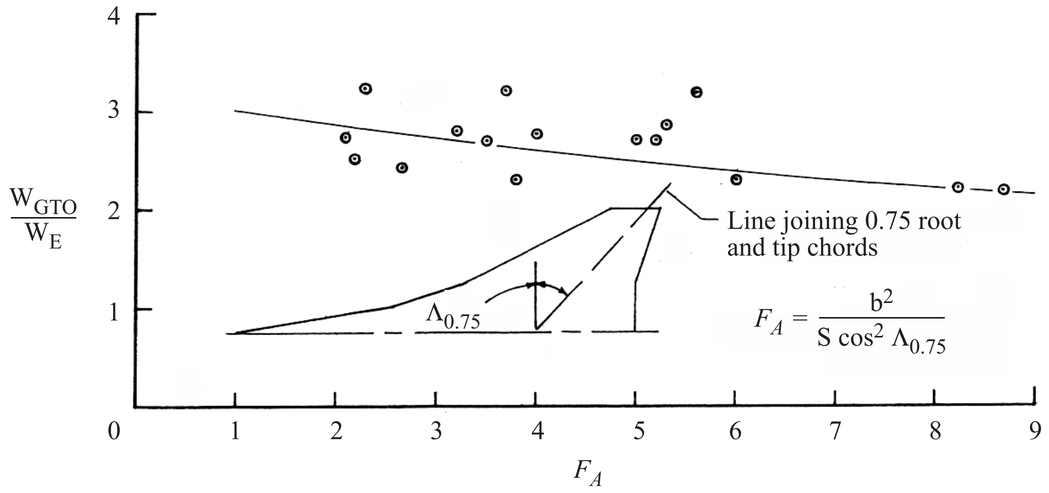

Figure 3. Correlation between (W_{GTO}/W_E) and a structural aspect ratio factor, F_A, reference 6.

Appendix A

Listing of the modified G. Haglund/R. Mack hybrid F-function version of the Seebass and George sonic-boom minimization code. It provides estimates of nose shock and tail shock strengths generated by an aircraft and its beginning-cruise conditions described by the input parameters.

```
      PROGRAM HYBRIDCN
C
      Implicit Double Precision (a-h, o-z)
C
      DIMENSION H(31),POPSL(31)
      Character Text(1)*80
C
C      COMPUTES A HYBRID F-FUNCTION, EQUIVALENT AREAS, AND A
C      PRESSURE SIGNATURE ON THE GROUND THAT HAS PROPAGATED
C      THROUGH A STANDARD HOT-DAY, OR COLD-DAY ATMOSPHERE.
C      THE NOSE SHAPE IS A CONE.
C       THERMALLY PERFECT GAS LAW USED TO EXPRESS DENSITY IN
C       TERMS OF TEMPERATURE AND PRESSURE
C
C       Last Modification: 7 - 31 - 98
C
C       INPUT PARAMETERS:
C
C       YF      = NOSE SHAPING LENGTH, FT.
C       DYF     = CHANGE IN YF AND XI (IF NEEDED TO FORCE SOLUTION) FT.,
C                 DEFAULT IS 0.5
C       XI      = DISTANCE ALONG ALONG X-AXIS WHERE "RAMP" BEGINS, FT.
C       HM      = CRUISE MACH NUMBER
C       HCR     = CRUISE ALTITUDE, FT.
C       RK      = GROUND REFLECTION FACTOR, DEFAULT IS 1.90
C       XLE     = AIRCRAFT EFFECTIVE LENGTH, FT.
C       WCR     = CRUISE LIFT PLUS EQUIVALENT WEIGHT FROM AREAS OF WAKE,
C                   DISPLACEMENT THICKNESS, DIFFERENCE BETWEEN EXHAUST
C                   AND INTAKE AREAS OF NACELLES, ETC., LB.
C       PERCEN  = FRACTION FOUND BY DIVIDING "RAMP" SLOPE BY THE
C                        ADVANCE LINE SLOPE;
C                        FOR FLAT-TOP, PERCEN = 0.0; DEFAULT IS 0.50
C       RATIO   = FRACTION OF (TAIL SHOCK/NOSE SHOCK), DEFAULT IS 1.0
C       DELTAP  = INITIAL ESTIMATE OF NOSE SHOCK, PSF, DEFAULT IS 1.0
C       KATMOS  = DESIGNATES TYPE OF ATMOSPHERE,
C                 0, COLD DAY
C                 1, STANDARD DAY (DEFAULT VALUE)
C                 2, HOT DAY
C       XDEL    = X-STATION INTERVALS WHERE F(XE) AND AE(XE) ARE PRINTED,
C                 XLE / XDEL MUST BE AN INTEGER
C
       NAMELIST/INPUT / YF,XI,HM,HCR,RK,XLE,WCR,PERCEN,RATIO,DELTAP,
      1DYF,KATMOS,AXDEL
C
       DATA(H(J),J=1,31)/0.0,5000.0,10000.0,15000.0,20000.0,25000.0,
```

```
     A30000.0,35000.0,40000.0,45000.0,50000.0,55000.0,60000.0,65000.0,
     B70000.0,75000.0,80000.0,85000.0,90000.0,95000.0,100000.0,105000.0,
     C110000.0,115000.0,120000.0,125000.0,130000.0,135000.0,140000.0,
     D145000.0,150000.0/
C
      DATA(POPSL(J),J=1,31)/1.0,.832087,.687830,.564587,.459912,.371577,
     A.297544,.235962,.185769,.146227,.115116,.090634,.071366,.056202,
     B.044290,.034964,.027649,.021902,.017379,.013813,.010997,.0087692,
     C.0070112,.0056289,.0045371,.0036711,.0029815,.00243013,.00198760,
     D.00163111,.00134291/
C
      PI=2.0*ASIN(1.0)
      RK=1.9
      PERCEN=.50
      DELTAP=1.0
      RATIO=1.0
      KATMOS=1
      XDEL=1.0
      DYF=0.5
C
      READ(5,1) text(1)
     1 FORMAT(A80)
      WRITE(6,1) text(1)
C
      READ(5,INPUT)
C
      xtest=xle/xdel
      ixd=int(xtest)
      resid=xtest-float(ixd)
      if(abs(resid)-0.000000001) 3,3,2
     2 xdel=xle/float(ixd)
     3 continue
C
C      CALCULATE ATMOSPHERIC ADVANCE FACTOR USING EQUATIONS
C      FROM NASA TN D-7842 AND THE PERFECT GAS LAW
C
      if(hcr .gt. h(31)) go to 485
      NH=31
C
C      INTERVAL OF INTEGRATION IS DZ
C      INITIAL STARTING DISTANCE BELOW HSTART IS DZH
C
      SUMZ=0.0
      SUMZZ=0.0
      DZH=2.0
      HSTART=HCR
      DZ=2.0
      DELZ=0.0
C
      CALL TEMP(HSTART,TH,ZA,KATMOS)
C
```

```
      VH=HM*ZA
      BETA=SQRT(HM*HM-1.0)
      TERM1=1.0/BETA
      ZMOB=HM/BETA
      THOTZ=1.0
      Z=HSTART-DZH
C
      CALL TEMP(Z,TZ,ZA,KATMOS)
C
      ZM=VH/ZA
      BETA=SQRT(ZM*ZM-1.0)
      THOTZI=TH/TZ
      ZMOBI=ZM/BETA
      TERM2=1.0/BETA
      SUMZ=SUMZ+0.5*(TERM1+TERM2)*DZ
      TERM3=HM*SUMZ/ZMOBI
      AHOZAI=1.0/TERM3
C
      CALL XYINT(HSTART,PHOP,H,POPSL,DPDZ,NH)
C
      PHOPZ=1.0
C
      CALL XYINT(Z,PZOP,H,POPSL,DPDZ,NH)
C
      PHOPZI=PHOP/PZOP
      SUMZZ=SUMZZ+SQRT(DZ)*(SQRT(PHOPZ)+SQRT(PHOPZI))*(THOTZ**0.75
     1+THOTZI**0.75)*(ZMOB+ZMOBI)*SQRT(ZM/HM)/4.0
      BETAI=BETA
   40 Z=Z-DZ
      IF(Z) 80,60,60
C
   60 CALL TEMP(Z,TZ,ZA,KATMOS)
C
      ZM=VH/ZA
      BETA=SQRT(ZM*ZM-1.0)
      ZMOB=ZM/BETA
      THOTZ=TH/TZ
C
      CALL XYINT(Z,PZOP,H,POPSL,DPDZ,NH)
C
      PHOPZ=PHOP/PZOP
      SUMZ=SUMZ+.5*(1.0/BETA+1.0/BETAI)*DZ
      TERM3=HM*SUMZ/ZMOB
      AHOZA=1.0/TERM3
             SUMZZ=SUMZZ+(SQRT(PHOPZ)+SQRT(PHOPZI))*(THOTZ**.75+THOTZI**.75)*
     1(SQRT(AHOZA)+SQRT(AHOZAI))*(ZMOB+ZMOBI)*DZ/16.0
c        SUMZZ=SUMZZ+((SQRT(PHOPZ*AHOZA)*(THOTZ**.75)*ZMOB)+(SQRT(PHOPZI*
c     1AHOZAI)*(THOTZI**.75)*ZMOBI))*DZ/2.0
      IF(DZ .LT. DELZ) GO TO 100
      ZMOBI=ZMOB
      THOTZI=THOTZ
```

```
      PHOPZI=PHOPZ
      AHOZAI=AHOZA
      BETAI=BETA
      GO TO 40
   80 DELZ=DZ
      DZ=DZ+Z
      Z=0.0
      GO TO 60
  100 BETA=SQRT(HM*HM-1.0)
      TERM1=1.2*HM*HM*HM/SQRT(2.0*BETA)
      ADVANCE=TERM1*SUMZZ
      WRITE(6,700) ADVANCE
  700 FORMAT(/,3x,28HCALCULATED ADVANCE FACTOR = ,F12.6,/)
C
      IF(KATMOS .EQ. 0) DT=-20.0
      IF(KATMOS .EQ. 0) WRITE(6,702)
  702 FORMAT(3X,31HAPPROXIMATE COLD-DAY ATMOSPHERE,/)
      IF(KATMOS .EQ. 1) DT=0.0
      IF(KATMOS .EQ. 1) WRITE(6,704)
  704 FORMAT(3X,35HAPPROXIMATE STANDARD-DAY ATMOSPHERE,/)
      IF(KATMOS .EQ. 2) DT=20.0
      IF(KATMOS .EQ. 2) WRITE(6,706)
  706 FORMAT(3X,30HAPPROXIMATE HOT-DAY ATMOSPHERE,/)
C
      AHOAG=DZH*AHOZA
      DPGODPH=SQRT(AHOAG/PHOP)*((TH/(518.67+DT))**.25)
      DPHOPF=1.4*HM*HM/SQRT(2.0*BETA*DZH)
      DPGOF=DPHOPF*PHOP*2116.22*DPGODPH
      DPOF=DPGOF*RK
C     WRITE(6,707) AHOAG,DPGODPH,DPHOPF,DPGOF,PHOP,TH,DZH
  707 FORMAT(///,5X,7(F12.7),///)
C
        write(6,708) dpof
  708 format(5x,9hDP*RK/F =,f11.7,///)
C
      ADV=ADVANCE
C
C     CALCULATE F-FUNCTION AND PRESSURE SIGNATURE FROM
C     F-FUNCTION PARAMETERS: H,C,YF,XI,XLAM,PERCEN,D,XLE,HM,
      AND WCR,
C     AND PRESSURE SIGNATURE PARAMETERS: DELTAP,RK,RATIO,HCR
C
      Q=.7*PHOP*2116.22*HM*HM
      AEMAX=SQRT(HM*HM-1.0)*WCR/(2.0*Q)
C
      WRITE(6,709) HCR,HM,Q,AEMAX,WCR,VH,RATIO
  709 FORMAT(5X,17HCRUISE ALTITUDE =,4x,F9.3,
     A/,5X,17HCRUISE MACH NO. =,4x,f9.3,
     B/,5X,18HDYNAMIC PRESSURE =,2x,F10.3,
     C/,5X,18HMAX. EQUIV. AREA =,3x,f9.3,
     D/,5X,15HCRUISE WEIGHT =,4x,F11.3,
```

```
     E/,5X,17HCRUISE VELOCITY =,2x,F11.3,
     F/,5x,23hTAIL SHOCK/NOSE SHOCK =,f7.3,//)
      WRITE(6,710)
  710 FORMAT(3x,33hHYBRID-2 F-FUNCTION AND SIGNATURE,/)
C
      NP=0
      DELTAPO=DELTAP
  105 YFO=YF
      XIO=XI
      YFI=YF
      XII=XI
      NDELP=0
      NNNR=0
  110 NNR=0
      NR=0
  120 C=DELTAP/DPOF
      FH=3.0*C*(2.0*C*ADV/YF-1.0)/7.0
C
C     C MUST BE > 5.0*YF/(3.0*ADV)
C
      IF(FH .LE. C) WRITE(6,712) FH,C
  712 FORMAT(2X,3HH =,F8.4,16H < OR = THAN C =,F8.4,/,5x,11hJOB ABORTED)
      IF(FH .LE. C) GO TO 600
C
      B=PERCEN/ADV
C
      XLAM=.85*XLE
      if(xi .gt. yf) xlam=xle-xi
C
      E=-C/5.0
C
C     ITERATE TO OBTAIN XLAM CORRESPONDING TO A VALUE OF XI USING
C     NEWTON-RAPHSON METHOD
C
      NXLAM=0
  140 NL=0
  160 NE=0
  180 D=C*(1.0+RATIO)+B*(XLE-XI)-E
      YR=XLE+RATIO*C*ADV
      D1=FH*XLE*(.5*pi+asin((YF-XLE)/XLE))/sqrt(.5*YF)
      D2=2.0*FH*sqrt(XLE-.5*YF)-16.0*(FH-C)*((XLE-.5*YF)**1.5)/(3.0*YF)
      D3=(16.0/3.0)*(FH-C)*((XLE-YF)**1.5)/YF
      D4=(8.0/3.0)*B*((XLE-XI)**1.5)
      IF(XLE-XLAM) 182,182,184
  182 if(xlam .lt. xi) go to 440
      pdp=deltap
C     WRITE(6,720) nxlam,pdp,XLAM
  720 FORMAT(2X,6hNXLAM=,I4,5x,7HDELTAP=,F8.4,5X,5HXLAM=,F12.7,/)
      if(nxlam .gt. 2) go to 450
      deltap=deltap+0.05
      GO TO 110
```

```
  184 D5=4.0*(-D)*SQRT(XLE-XLAM)
      DAPR=-(D1+D2+D3+D4+D5)/(2.0*PI)
C
      CALL FOFX(YR,YF,FH,C,B,XI,XLAM,XLE,D,DAPR,PI,FYR)
C
      DIF=ABS((E-FYR)/FYR)
      IF(DIF .LT. 0.0000001) GO TO 200
      NE=NE+1
      IF(NE .GT. 50) GO TO 600
      E=FYR
      GO TO 180
C
  200 CALL CALC(YF,FH,C,B,XI,XLAM,XLE,D,AEXLE,0,1,XDEL,PI)
C
      dellam=2.0
      R=ABS((AEXLE-AEMAX)/AEMAX)
      daeoae=(aexle-aemax)/aemax
C      write(6,722) nxlam,daeoae,xlam
  722 format(/,5x,2hN=,i3,5x,7hdAE/AE=,f11.7,5x,5hxlam=,f11.6)
C      write(6,723) yf,xi
  723 format(5x,3hyf=,f9.6,5x,3hxi=,f9.6)
      IF(R .LT. .0000001) GO TO 280
      IF(AEXLE-AEMAX) 220,280,220
  220 IF(NL) 240,240,260
  240 AE1=AEXLE
      XLA1=XLAM
      NL=NL+1
      XLAM=XLAM-dellam
      GO TO 160
  260 AE2=AEXLE
      XLA2=XLAM
      DADL=(AE2-AE1)/(XLA2-XLA1)
      XLAM=XLA1-(AE1-AEMAX)/DADL
      IF(XLAM .LT. XI) GO TO 440
      NXLAM=NXLAM+1
      IF(NXLAM .GT. 100) GO TO 460
      GO TO 140
  280 CONTINUE
C
C      CALCULATE INTEGRAL OF F(Y) BETWEEN XLE AND YR FOR TAIL SHOCK
C      DETERMINATION BY AREA BALANCING
C
      SUMAX=0.0
      FOFLE=C+B*(XLE-XI)-D
      YRR=XLE+(RATIO*C-E)*ADV
      AREA1=.5*(FOFLE+FYR)*(YR-XLE)
      XINT=YR-XLE
      NINT=200
      DX=XINT/FLOAT(NINT)
      X=XLE+DX
C
```

```
      CALL FOFX(X,YF,FH,C,B,XI,XLAM,XLE,D,DAPR,PI,FX)
C
      FX1=FX-DAPR/SQRT(DX)
      SUMAX=SUMAX+.5*(FOFLE+FX1)*DX+2.0*DAPR*SQRT(DX)
      F1=FX
      DO 300 NNINT=2,NINT
      X=X+DX
C
      CALL FOFX(X,YF,FH,C,B,XI,XLAM,XLE,D,DAPR,PI,FX)
C
      SUMAX=SUMAX+.5*DX*(F1+FX)
      F1=FX
  300 CONTINUE
      R=SUMAX-AREA1
      RR=ABS(R/SUMAX)
      IF(ABS(RR) .LE. 0.00001) GO TO 360
      IF(NR) 320,320,340
  320 R1=R
      P1=DELTAP
      DELTAP=DELTAP+0.10
      NR=NR+1
      GO TO 120
  340 R2=R
      P2=DELTAP
      DPDR=(P2-P1)/(R2-R1)
      DELTAP=P2-R2*DPDR
C
      IF(DELTAP) 345,345,350
  345 WRITE(6,725)
  725 FORMAT(15x,13hDelta P < 0.0,/)
      GO TO 600
C
  350 NR=0
C     NNR=NNR+1
      rrr=(deltap-p1)/p1
C     write(6,355) nnr,rrr,p1,deltap
  355 format(/,2x,4hNNR=,i4,2x,4hrrr=,f10.7,2(2x,f9.6))
      GO TO 120
C
  360 CONTINUE
C
      if(NP .GT. 0) write(6,727)
  727 format(/,2x,45hPERCEN was increased to search for a solution,//)
C
      flam1=C+B*(XLAM-XI)
      flam2=flam1-D
      fxle=flam2+B*(XLE-XLAM)
      WRITE(6,740) YF,FH,C,B,D,XI,XLAM,XLE,AEMAX,flam1,flam2,fxle
      WRITE(6,730) DELTAP,PERCEN
  730 FORMAT(9X,8HDELTAP =,F7.4,/,9X,8HPERCEN =,F7.4,/)
C
```

```
  740 FORMAT(7X,4HYF =,F16.6,/,7X,3HH =,F17.6,/,7X,3HC =,F17.6,/,7X,3HB
     A=,F17.6,/,7X,3HD =,F17.6,/,7X,4HXI =,F16.6,/,7X,6HXLAM =,f14.6,/,7
     BX,5HXLE =,F15.6,/,7X,7HAEMAX =,F13.6,/,7x,9HF1(lam) =,f11.6,/,7x,9
     CHF2(lam) =,f11.6,/,7x,8HF(xle) =,f12.6,/)
C
      WRITE(6,745)
  745 FORMAT(/,9X,1HX,10X,1HF,13X,2HAE)
C
      CALL CALC(YF,FH,C,B,XI,XLAM,XLE,D,AEXLE,1,0,XDEL,PI)
C
      XXX=YR-XLE
      NXX=INT(XXX/XDEL)+1
      IF(NXX .LT. 5) NXX=5
      X=XLE+1.0
C
      CALL FOFX(X,YF,FH,C,B,XI,XLAM,XLE,D,DAPR,PI,F1)
C
      X=X+1.0
C
      CALL FOFX(X,YF,FH,C,B,XI,XLAM,XLE,D,DAPR,PI,F2)
C
      DFDX=F2-F1
      IF(DFDX .LT. 0.0) WRITE(6,750) DFDX
  750 FORMAT(3X,12HNOTE: DF/DX=,F12.8,21H AND IS LESS THAN 0.0,/)
      X=XLE
C
      NXX=INT(2.0*XLE/XDEL)+1
C
      DO 380 NNX=1,NXX
      X=X+XDEL
C
      CALL FOFX(X,YF,FH,C,B,XI,XLAM,XLE,D,DAPR,PI,FX)
C
      if(X .LE. 1.5*XLE) WRITE(6,760) X,FX,AEMAX
  760 FORMAT(2X,F10.4,2X,F10.7,3X,F10.5)
  380 CONTINUE
C
C     CALCULATE PRESSURE SIGNATURE ON THE GROUND
C
      WRITE(6,775)
      WRITE(6,770)
  770 FORMAT(2X,10HX-BETA*HCR,7X,2HP1,10X,2HP2,9X,4HT-T0,/)
  775 FORMAT(///,5X,32HPRESSURE SIGNATURE ON THE GROUND,/)
      P1=0.0
      X=YF-ADV*C
      T=X/VH
      P2=C*DPOF
C
      nvel=int(0.002*vh+1.0)
      xdel1=float(nvel)
C
```

```
      pnose=p2
      trise=3.0/pnose
C
      WRITE(6,780) X,P1,P2,T
  780 FORMAT(2X,F9.4,3X,F9.4,3X,F9.4,3X,F9.4)
      IF(XI .EQ. YF) GO TO 390
      X=XI-ADV*C
      T=X/VH
      P2=C*DPOF
      WRITE(6,790) X,P2,T
  790 FORMAT(2X,F9.4,15X,F9.4,3X,F9.4)
  390 X=XLAM-ADV*(C+B*(XLAM-XI))
      T=X/VH
      P2=(C+B*(XLAM-XI))*DPOF
C
      dppeak=p2-pnose
C
      WRITE(6,790) X,P2,T
      X=XLAM-ADV*(C+B*(XLAM-XI)-D)
      T=X/VH
      P2=(C+B*(XLAM-XI)-D)*DPOF
      WRITE(6,790) X,P2,T
      X=YRR
      T=X/VH
      P2=(C+B*(XLE-XI)-D)*DPOF
      P1=E*DPOF
      ptail=p1-p2
      WRITE(6,780) X,P2,P1,T
      NS=0
      X=YR
  400 X=X+XDEL1
      CALL FOFX(X,YF,FH,C,B,XI,XLAM,XLE,D,DAPR,PI,FX)
      XS=X-ADV*FX
      T=XS/VH
      P2=FX*DPOF
      WRITE(6,790) XS,P2,T
      NS=NS+1
      IF(NS .LE. 15) GO TO 400
      GO TO 500

  420 CONTINUE
      WRITE(6,800)
  800 FORMAT(5X,36HXLAM > XLE, AND XI < YF, JOB ABORTED,/)
      GO TO 600
  440 CONTINUE
      WRITE(6,810)
  810 FORMAT(15X,9HXLAM < XI)
      go to 600
  450 continue
c     WRITE(6,820)
  820 format(3x,49hPERCEN increased by .001 to search for a solution,/)
```

```
C
C     RESTART WITH CHANGED PERCEN VALUE
C
      deltap=deltapo
      percen=percen+0.001
      if(percen .gt. 1.0) go to 460
      np=1
      go to 105
  460 WRITE(6,830)
  830 FORMAT(/,5X,32HValue for XLAM will not converge,/)
      go to 600
C
  500 CONTINUE
C
C     Approximate outdoor noise calculation based on a RISE TIME of
C           3.0/(DeltaP), millisec.
C
      pldb=106.0
      if(B) 505,505,510
  505 pn=pnose
      pldb=pldb+23.1*dlog10(pn)-5.8*sqrt(trise)
      go to 515
  510 pn=pnose
      pp=pnose+dppeak
      pldb=pldb+17.0*dlog10(pn)+4.5*dlog10(pp)-6.0*sqrt(trise)
  515 write(6,520) pnose
  520 format(//,10x,12hNose Shock =,f7.4,4h psf)
      write(6,525) ptail
  525 format(/,10x,12hTail Shock =,f7.4,4h psf)
      write(6,530) pldb
  530 format(/,5x,35hApproximate Outdoor Noise Level Is ,f4.1,5h Pldb,/)
      go to 600
C
  485 write(6,490) hcr
  490 format(//,2x,11hh(cruise) =, f11.2,23h exceeds altitude range,//)
C
  600 END
C
      SUBROUTINE XYINT(X,A,XE,AE,AEP,NN)
C
      implicit double precision(a-h,o-z)
C
C     INTERPOLATION SCHEME TO GET VALUE OF "A" AT STATION "X"
C     TABLES XE AND AE MUST CONTAIN AT LEAST 4 VALUES
C
      DIMENSION XE(NN),AE(NN)
C
      N=1
    1 X1=XE(N)
      X2=XE(N+1)
      X3=XE(N+2)
```

```
      X4=XE(N+3)
      IF(X .GT. X2) GO TO 3
    2 A1=AE(N)
      A2=AE(N+1)
      A3=AE(N+2)
      A4=AE(N+3)
      XX1=(X3-X1)*(A2-A1)-(X2-X1)*(A3-A1)
      YY1=XX1/((X2-X1)*(X3-X1)*(X2-X3))
      XX2=(X4-X1)*(A3-A1)-(X3-X1)*(A4-A1)
      YY2=XX2/((X3-X1)*(X4-X1)*(X3-X4))
      CC=(YY1-YY2)/(X2-X4)
      BB=YY2-CC*(X3+X4-2.0*X1)
      AA=(A2-A1-BB*((X2-X1)**2)-CC*((X2-X1)**3))/(X2-X1)
      A=A1+AA*(X-X1)+BB*((X-X1)**2)+CC*((X-X1)**3)
      AEP=AA+2.0*BB*(X-X1)+3.0*CC*((X-X1)**2)
      GO TO 4
    3 IF(N+3 .GE. NN) GO TO 2
      N=N+1
      GO TO 1
    4 RETURN
      END
C
      SUBROUTINE CALC(Y,H,C,B,XI,XLAM,XL,D,AEFIN,K,KL,DX,PI)
C
C       CALCULATES F(Y) AND AE(Y) FOR 0.0 < Y < XL
C
      implicit double precision(a-h,o-z)
C
C       pi=2.0*asin(1.0)
      Y2=.5*Y
      lx=0
      X=-DX
      IF(KL .EQ. 1) X=XL-DX
    1 X=X+DX
      F=H*sqrt(X/Y2)
      AA=H*X*X/sqrt(2.0*Y)
      A=pi*AA
      IF(X-Y2) 7,7,2
    2 F=2.0*H-C-2.0*(H-C)*X/Y
      A=AA*(.5*pi+asin((Y-X)/X))+H*Y2*sqrt(X-Y2)
      A=A+(5.0/3.0)*H*((X-Y2)**1.5)
      A=A-(32.0/(15.0*Y))*(H-C)*((X-Y2)**2.5)
      IF(X-Y) 7,7,3
    3 F=C
      A=A+(32.0/15.0)*(H-C)*((X-Y)**2.5)/Y
      IF(X-XI) 7,7,4
    4 F=C+B*(X-XI)
      A=A+(16.0/15.0)*B*((X-XI)**2.5)
      IF(X-XLAM) 7,7,5
    5 if(x - xl+.00001) 6,10,10
    6 F=C-D+B*(X-XI)
```

```
      A=A-(8.0/3.0)*D*((X-XLAM)**1.5)
    7 IF(K .EQ. 1 .AND. A .LT. 0.010) WRITE(6,8) X,F,A
    8 FORMAT(2X,F10.4,2X,F10.7,3X,F12.7)
      IF(K .EQ. 1 .AND. A .GT. 0.010) WRITE(6,9) X,F,A
    9 FORMAT(2X,F10.4,2X,F10.7,3X,F10.5)
      if(lx .eq. 1) go to 11
      GO TO 1
   10 x=xl
      lx=1
      go to 6
   11 aefin=a
      if(k .eq. 1) write(6,12) x,a
   12 format(/,2x,f10.4,2x,10h neg. inf. ,3x,f10.5,/)
      RETURN
      END
C
      SUBROUTINE FOFX(X,Y,H,C,B,XI,XLAM,XL,D,DA,PI,FX)
C
C     CALCULATES F(X) FOR X > XL WITH CONSTANT AE(MAX) AFT OF XL
C
      implicit double precision(a-h,o-z)
C
C     Terms that are functions of y/2
C
      Y2=0.5*Y
      PI2=0.5*PI
      tpi=2.0*pi
      FX=tpi*H*(sqrt(X)-sqrt(X-XL))/sqrt(Y2)
C
      AA=-pi*H*(sqrt(X-Y2)-sqrt(X-XL))/sqrt(Y2)
      BB=-2.0*sqrt(x-xl)*asin((y-xl)/xl)+pi*sqrt(x-y2)
      BB=H*BB/sqrt(y2)
      CC1=asin((xl*(x+y2)-x*y)/(xl*(x-y2)))+pi2
      CC2=asin((2.0*xl-(x+y2))/(x-y2))+pi2
      CC=-2.0*H*(sqrt(x/Y2)*CC1-CC2)
      DD1=sqrt(-x*y2+xl*(x+y2)-xl*xl)
      DD=(8.0/y)*(H-C)*(-DD1+.5*(X+Y2)*CC2)-4.0*(H-C)*CC2
      FX=FX+AA+BB+CC-DD
C
C     if(x .eq. xl) write(6,10) aa,bb,cc1,cc2,cc,DD1,dd
C  10 format(5x,7(f11.5))
C
C     Terms that are functions of y
C
      AA=-SQRT(-X*Y+XL*(X+Y)-XL*XL)
      BB=.5*(X-Y)*(ASIN((2.0*XL-(X+Y))/(X-Y))+PI2)
      FX=FX+(8.0/Y)*(H-C)*(AA+BB)
C
c     fc=fx/tpi
c     if(x .eq. xl) write(6,11) h,c,fc
c  11 format(10x,2hh=,f9.5,5x,2hc=,f9.5,5x,3hfc=,f9.5)
```

```
c     if(x .eq. xl) go to 3
C
C      Terms that are functions of xi
C
      AA=-SQRT(-X*XI+XL*(X+XI)-XL*XL)
      BB=0.5*(X-XI)*(ASIN((XL-.5*(X+XI))/(.5*(X-XI)))+PI2)
      FX=FX+4.0*B*(AA+BB)
C
C      Term that is a function of Lambda
C
      AA=ASIN((XL-.5*(X+XLAM))/(.5*(X-XLAM)))+PI2
      FX=FX+2.0*(-D)*AA
C
C      Term that is a function of XL
C
      FX=FX/tpi+DA/SQRT(X-XL)
    3 RETURN
      END
C
      SUBROUTINE TEMP(Z,T,ZA,K)
C
      implicit double precision(a-h,o-z)
C
C      INTERPOLATES TO FIND TEMP. "T" AT ALTITUDE "Z"
C
      IF(K .EQ. 0) DT=-20.0
      IF(K .EQ. 1) DT=0.0
      IF(K .EQ. 2) DT=20.0
      T1=518.67+DT
      T2=389.97+DT
      H2=36152.0
      H3=65824.0
      T4=411.289+DT
      H4=105518.0
      T5=479.073+DT
      H5=150000.0
      R=1716.5623
C
      IF(Z-H2) 1,1,2
    1 T=T1+(T2-T1)*Z/H2
      GO TO 7
    2 IF(Z-H3) 3,3,4
    3 T=T2
      GO TO 7
    4 IF(Z-H4) 5,5,6
    5 T=T2+(T4-T2)*(Z-H3)/(H4-H3)
      GO TO 7
    6 T=T4+(T5-T4)*(Z-H4)/(H5-H4)
    7 ZA=SQRT(1.4*R*T)
      RETURN
      END
```

Appendix B

Listing of the program described in reference 6 to estimate the beginning-cruise weight of a low-boom aircraft. Output also lists estimated gross takeoff weight, end-of-cruise weight, and fuel weight required during takeoff, climb and acceleration, cruise, deceleration and descent, and the reserve fuel required to reach an alternate airport at end of cruise.

```
      Program WeightEst
C
C     Program to compute an estimate of mission weights from imputs
C     of Range, No. of Passengers, Mach number, SFC, L/D, and
C     Technology Factor.
C
C     Input:
C
C     xm     = Mach number
C     range  = total range, nautical miles,
C     alod   = average cruise lift/drag ratio,
C     sfc    = average specific fuel consumption, lbf/lbth/hr, default=1.0
C     npass  = number of passengers, default=0
C     tf     = technical factor, tf = Wgto/We, default=1.0
C     fcl    = ratio of Wbegcr/Wgto, default=.92
C     wfdes  = fuel used to descend and land
C     wcargo = cargo weight, default=0.0 lb
C     fres   = ratio of W(reserve fuel)/W(gross take-off), default=0.06
C     rto    = range to take-off, climb, and accelerate, nmi,
C     rdes   = range to deccelerate, descend, and land, nmi,
C     accel  = takeoff acceleration, decimal fraction of g's, default=0.10
C     warea  = wing reference area, square ft
C     hc     = beginning cruise altitude, ft
C     hec    = end-of-cruise altitude, ft
C              hec is defaulted to hf in code, estimate hec to start
C              solution and iterate as many times as necessary
C     cld    = design lift coefficient, default = 0.10
C     ne     = number of engines
C
      Implicit Double Precision(a-h,o-z)
C
      Dimension H(17),DENS(17),SS(17),PH(17),ALT(17)
C
      Character Text(1)*80
C
      NAMELIST/INPUT/xm,range,alod,sfc,npass,tf,fcl,wfdes,fres,rto,rdes,
     1wcargo,accel,warea,hc,hec,cld,ne
C
      DATA(H(J),J=1,17)/40000.0,42500.0,45000.0,47500.0,50000.0,52500.0,
     155000.0,57500.0,60000.0,62500.0,65000.0,67500.0,70000.0,72500.0,
     275000.0,77500.0,80000.0/
C
      DATA(DENS(J),J=1,17)/.000587277,.000521032,.000462273,.000410152,
```

```
     1.000363918,.000322905,.000286523,.000254247,.000225613,.000200209,
     2.000177672,.000157321,.000139202,.000123226,.000109132,
     3.0000966931,.0000857103/
C
      DATA(SS(J),J=1,17)/968.076,968.076,968.076,968.076,968.076,
     1968.076,968.076,968.076,968.076,968.076,968.076,969.209,970.897,
     2972.581,974.263,975.940,977.615/
C
      DATA(PH(J),J=1,17)/58.5115,65.7832,73.9905,83.2579,93.7270,
     1105.559,118.935,134.022,151.027,170.195,191.801,216.156,243.610,
     2274.559,309.449,348.783,393.128/
C
      DATA(ALT(J),J=1,17)/80000.0,77500.0,75000.0,72500.0,70000.0,
     167500.0,65000.0,62500.0,60000.0,57500.0,55000.0,52500.0,50000.0,
     247500.0,45000.0,42500.0,40000.0/
C
      pi=2.0*asin(1.0)
      rcon=1716.5616
      ee=2.718281828
      a=968.076
      wcargo=0.0
      fcl=0.92
      fres=0.060
      g=32.174
      accel=0.10
      cld=0.10
      ne=1
      hec=0.0
C
      READ(5,1) text(1)
    1 format(A80)
      write(6,2) text(1)
    2 format(A80,/)
C
      READ(5,INPUT)
C
      Write(6,3) xm,range,alod,sfc,npass,tf,wfdes,fcl
    3 format(5x,10hMach No. =,f12.2,/,5x,7hRange =,f15.2,/,5x,10hL/D(avg
     1) =,f12.3,/,5x,10hSFC(avg) =,f12.5,/,5x,14hNo. of pass. =,i8,/,5x,
     214hTech. factor =,f8.5,/,5x,7hWdesc =,f15.1,/,5x,10hWcr/Wgto =,f12
     3.5,/)
C
      if(hec .eq. 0.0) hec=hc
      beta=sqrt(xm*xm-1.0)
      vdot=accel*g
      vdotdes=0.75*vdot
C
C     Estimate possible rto and rdes from vdot and vdotdes; compare with
C     input values
C
      eta=(xm*xm*a*a-335.0*335.0)/(2.0*vdotdes)
```

```
      gla=3.0*pi/180.0
      fltpth=sqrt(eta*eta-(hec-5000.0)*(hec-5000.0))
      rdesx=fltpth/6076.11549+5000.0/(6076.11549*tan(gla))
      rdesx=float(int(rdesx+1.0))
      if(rdesx .gt. rdes) rdes=rdesx
C
      eta=(xm*xm*a*a-335.0*335.0)/(2.0*vdot)
      rtox=sqrt(eta*eta-(hc-35.0)*(hc-35.0))/6076.11549
      rtox=float(int(rtox+1.0))
      if(rtox .gt. rto) rto=rtox
C
      rcruz=range-rto-rdes
      bf=(3600.0/6076.11549)*xm*a*alod/sfc
      z=-rcruz/bf
C
      tflim=1.0/(fcl*(ee**z)-fres)
C
      write(6,4) bf,tflim
    4 format(5x,24hAverage Breguet Factor =,f9.3,5h nmi.,//,5x,11hTF(lim
     1it) =,f9.6,)
      if(tf .le. tflim) go to 70
C
      write(6,5) rto,rcruz,rdes
    5 format(/,3x,27hMission Segment Ranges, nmi,/,5x,14hT.O. & Climb =
     1,f7.1,/,5x,8hCruise =,f13.1,/,5x,9hDescend =,f12.1,/)
C
      wpay=210.0*float(npass)+wcargo
      if(npass .lt. 20) wpay=225.0*float(npass)+wcargo
      wcrew=450.0+5.0*float(npass)
      if(npass .lt. 20) wcrew=450.0
      w0=(wcrew+wpay+wfdes)/(fcl*(ee**z)-fres-1.0/tf)
      i=1
    7 w1=tf*(fcl*w0*(ee**z)-wfdes-wpay-wcrew-fres*w0)
      dw1=w1-w0
      if(abs(dw1) .lt. 0.0000001) go to 10
      w2=w0*w0/w1
      i=i+1
      if(i .gt. 200) go to 30
      w0=w2
      go to 7
   10 continue
C
      wgto=.5*(w0+w1)
      wfres=fres*wgto
      we=wgto/tf
      wzfw=we+wcrew+wpay
      wclim=(1.0-fcl)*wgto
      wfuel=wgto-wzfw
      wbcr=fcl*wgto
      wecr=wbcr*(ee**z)
      wfcr=wbcr-wecr
```

```
      wfres=fres*wgto
      write(6,20) we,wcrew,wpay,wzfw,wclim,wfcr,wfdes,wfres,wfuel,wgto
   20 format(/,5x,20hAircraft Weights, lb,//,5x,4hWe =,f18.1,/,5x,7hWcre
     1w =,f15.1,/,5x,6hWpay =,f16.1,/,5x,6hWzfw =,f16.1,//,5x,7hWf,to =,
     2f15.1,/,5x,11hWf,cruise =,f11.1,/,5x,8hWf,des =,f14.1,/,5x,8hWf,re
     3s =,f14.1,/,5x,10hWf,TOTAL =,f12.1,//,5x,6hWgto =,f16.1)
      wland=wecr-wfdes
      write(6,25) wgto,wbcr,wecr,wland,we
   25 format(//,5x,19hMission Weights, lb,//,5x,19hW(gross take-off) =,f
     112.1,/,5x,17hW(begin cruise) =,f14.1,/,5x,15hW(end cruise) =,f16.1
     2,/,5x,9hW(land) =,f22.1,/,5x,10hW(empty) =,f21.1)
      go to 50
C
   30 write(6,40) i,w0,w1
   40 format(//,5x,24hNo solution found after ,i3,11h iterations,/,5x,4h
     1w0 =,f12.5,5x,4hw1 =,f12.5)
      go to 90
   50 continue
C
      call xyint(hc,rho,h,dens,rhop,17)
      call xyint(hc,vs,h,ss,vsp,17)
      q=0.5*rho*vs*vs*xm*xm
      aequiv=.5*beta*wbcr/q
C
      cl=wbcr/(q*warea)
      qf=wecr/(cl*warea)
      rhof=2.0*qf/(vs*vs*xm*xm)
      phf=qf/(0.7*xm*xm)
      call xyint(phf,hf,ph,alt,hfp,17)
      if(hf .gt. 80000.0) go to 63
      write(6,60) aequiv,warea,cl,wecr,hf
   60 format(/,5x,11hAeq(lift) =,f9.4,4h ft2,/,5x,11hWing area =,f9.2,4h
     1 ft2,/,5x,4hCL =,f9.6,/,5x,19hEnd-cruise weight =,f9.1,3h lb,/,5x,
     221hEnd-cruise altitude =,f9.2,3h ft,///)
C
      snew=wbcr/(q*cld)
      qnew=wbcr/(cld*warea)
      pnew=qnew/(0.7*xm*xm)
      call xyint(pnew,hnew,ph,alt,hfp,17)
      write(6,61) cld,snew,hc,hnew,warea
   61 format(5x,14hFor CL(des.) =,f9.5,1h:,/,5x,6hArea =,f10.4,4h ft2,7h
     1 at h =, f9.2,3h ft,/,5x,3hh =,f9.2,3h ft,11h for Area =,f10.4,4h
     2ft2,///)
      go to 90
C
   63 write(6,65)
   65 format(5x,34hEnd-of-cruise altitude > 80000 ft,,17herror in altitu
     1de,///)
      go to 90
   70 write(6,75)
   75 format(//,2x,38hTF is less than TF(limit); job aborted)
```

```
   90 end
C
      SUBROUTINE XYINT(X,A,XE,AE,AEP,NN)
C
      Implicit Double Precision(a-h,o-z)
C
C       Quadratic curve used to get value of "A" at station "X"
C       Tables XE and AE must have at least 4 values, and XE values
C       must be monotonically increasing.
C
      Dimension XE(NN),AE(NN)
C
      n=1
    1 x1=xe(n)
      x2=xe(n+1)
      x3=xe(n+2)
      x4=xe(n+3)
      if(x .gt. x3) go to 3
    2 a1=ae(n)
      a2=ae(n+1)
      a3=ae(n+2)
      a4=ae(n+3)
      xx1=(x3-x1)*(a2-a1)-(x2-x1)*(a3-a1)
      yy1=xx1/((x2-x1)*(x3-x1)*(x2-x3))
      xx2=(x4-x1)*(a3-a1)-(x3-x1)*(a4-a1)
      yy2=xx2/((x3-x1)*(x4-x1)*(x3-x4))
      cc=(yy1-yy2)/(x2-x4)
      bb=yy2-cc*(x3+x4-2.0*x1)
      aa=(a2-a1-bb*((x2-x1)**2)-cc*((x2-x1)**3))/(x2-x1)
      a=a1+aa*(x-x1)+bb*((x-x1)**2)+cc*((x-x1)**3)
      aep=aa+2.0*bb*(x-x1)+3.0*cc*((x-x1)**2)
      go to 4
    3 if(n+3 .ge. nn) go to 2
      n=n+1
      go to 1
    4 return
      end
C
```

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14. ABSTRACT

The characteristics of a proposed low-boom aircraft concept cannot be adequately assessed unless it is given an extensive, time-consuming, mission-performance, and sonic-boom analyses. So, it would be useful to have a method for performing a quick first-order sonic-boom and mission-range analysis. The evaluation method outlined in this report has the attributes of being both fast and reasonably accurate. It can also be used as a design tool to estimate the sonic-boom ground overpressures, mission range, and beginning-cruise weight of a new low-boom concept during the first stages of preliminary design.

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