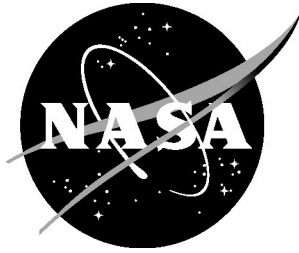


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A Quick Method for Evaluating the Merits of a Proposed Low Sonic Boom Concept

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November 2003

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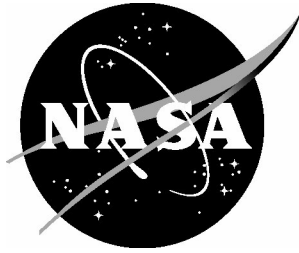
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Summary

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, $\text{lb}_{\text{fuel}}/\text{lb}_{\text{thrust}}/\text{hr}$
W_{BC}	beginning-cruise weight, lb
W_E	empty weight, lb
$W_{\text{F,RES}}$	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
$h = 45,000 \text{ ft}$	$W_{BC} = 0.9 * W_{GTO} = 81,000 \text{ lb}$	$GRF = 1.9$
$y_f = 4 \text{ ft}$	$l_e = 100 \text{ ft}$	$\Delta p = 0.30 \text{ psf}$

Calculated results indicated that for $h = 45,000 \text{ ft}$, the desired beginning-cruise overpressure of $\Delta p = 0.30 \text{ psf}$ could be obtained if $W_{BC} = 46,815 \text{ lb}$ 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 $1.2 \text{ lb}_{\text{fuel}}/\text{lb}_{\text{thrust}}/\text{hr}$,
- 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 ft².

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 ft², 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 $1.25 \text{ lb}_{\text{fuel}}/\text{lb}_{\text{thrust}}/\text{hr}$,
- 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 ft².

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 ft², 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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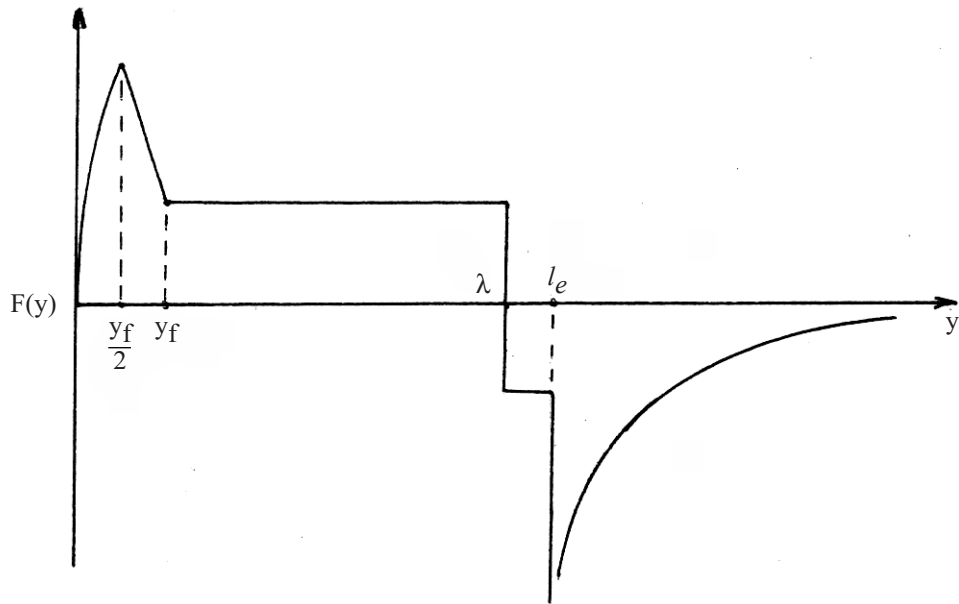


Figure 1. "Flat-top" type of Whitham F-function.

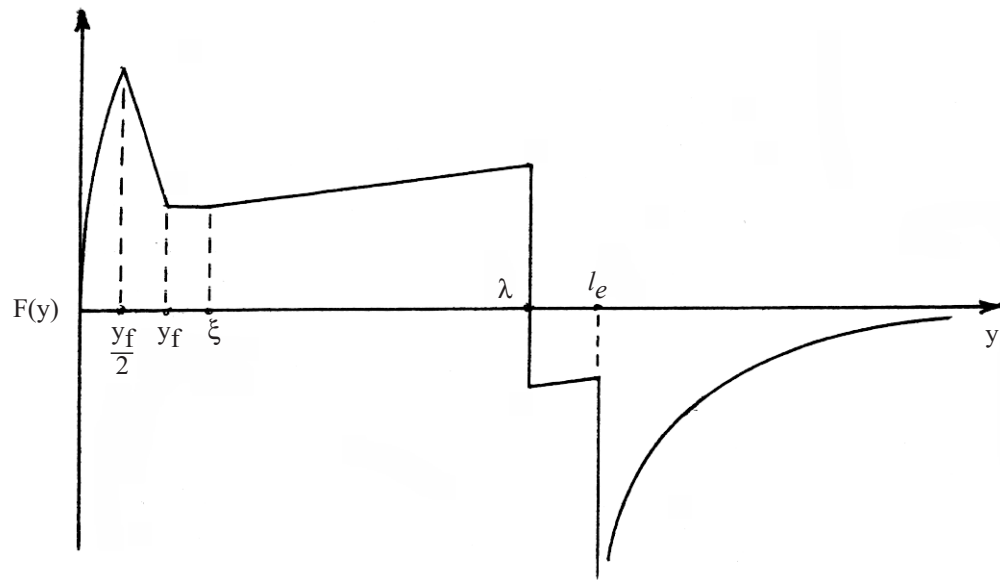


Figure 2. "Ramp" type of hybrid Whitham F-function.

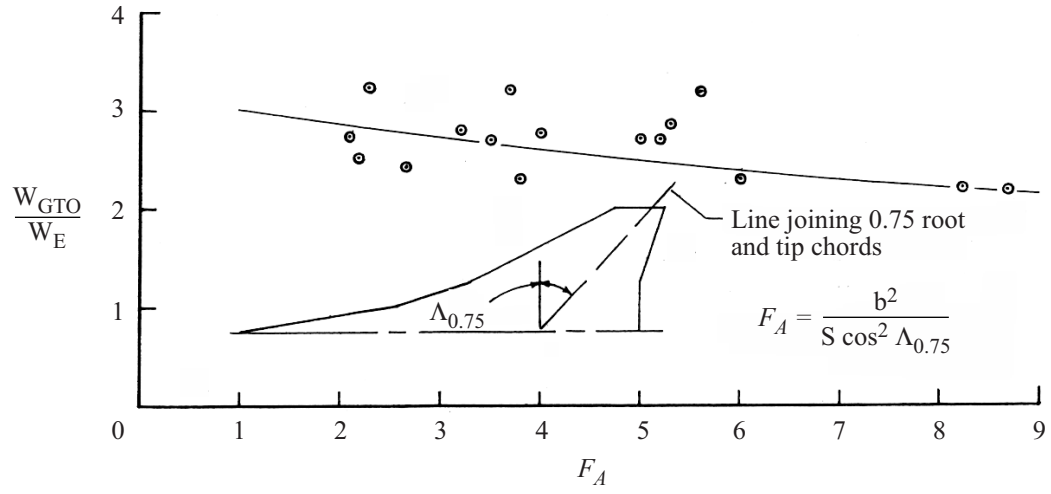


Figure 3. Correlation between (W_{GTO}/W_E) and a structural aspect ratio factor, F_A , reference 6.

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.

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

```

45  A30000.0,35000.0,40000.0,45000.0,50000.0,55000.0,60000.0,65000.0,
46  B70000.0,75000.0,80000.0,85000.0,90000.0,95000.0,100000.0,105000.0,
47  C110000.0,115000.0,120000.0,125000.0,130000.0,135000.0,140000.0,
48  D145000.0,150000.0/
49  C
50  DATA(POPSL(J),J=1,31)/1.0,.832087,.687830,.564587,.459912,.371577,
51  A.297544,.235962,.185769,.146227,.115116,.090634,.071366,.056202,
52  B.044290,.034964,.027649,.021902,.017379,.013813,.010997,.0087692,
53  C.0070112,.0056289,.0045371,.0036711,.0029815,.00243013,.00198760,
54  D.00163111,.00134291/
55  C
56  PI=2.0*ASIN(1.0)
57  RK=1.9
58  PERCEN=.50
59  DELTAP=1.0
60  RATIO=1.0
61  KATMOS=1
62  XDEL=1.0
63  DYF=0.5
64  C
65  READ(5,1) text(1)
66  1 FORMAT(A80)
67  WRITE(6,1) text(1)
68  C
69  READ(5,INPUT)
70  C
71  xtest=xle/xdel
72  ixd=int(xtest)
73  resid=xtest-float(ixd)
74  if(abs(resid)-0.000000001) 3,3,2
75  2 xdel=xle/float(ixd)
76  3 continue
77  C
78  C CALCULATE ATMOSPHERIC ADVANCE FACTOR USING EQUATIONS
79  C FROM NASA TN D-7842 AND THE PERFECT GAS LAW
80  C
81  if(hcr .gt. h(31)) go to 485
82  NH=31
83  C
84  C INTERVAL OF INTEGRATION IS DZ
85  C INITIAL STARTING DISTANCE BELOW HSTART IS DZH
86  C
87  SUMZ=0.0
88  SUMZZ=0.0
89  DZH=2.0
90  HSTART=HCR
91  DZ=2.0
92  DELZ=0.0
93  C
94  CALL TEMP(HSTART,TH,ZA,KATMOS)
95  C

```

```

96   VH=HM*ZA
97   BETA=SQRT(HM*HM-1.0)
98   TERM1=1.0/BETA
99   ZMOB=HM/BETA
100  THOTZ=1.0
101  Z=HSTART-DZH
102 C
103  CALL TEMP(Z,TZ,ZA,KATMOS)
104 C
105  ZM=VH/ZA
106  BETA=SQRT(ZM*ZM-1.0)
107  THOTZI=TH/TZ
108  ZMOBI=ZM/BETA
109  TERM2=1.0/BETA
110  SUMZ=SUMZ+0.5*(TERM1+TERM2)*DZ
111  TERM3=HM*SUMZ/ZMOBI
112  AHOZAI=1.0/TERM3
113 C
114  CALL XYINT(HSTART,PHOP,H,POPSL,DPDZ,NH)
115 C
116  PHOPZ=1.0
117 C
118  CALL XYINT(Z,PZOP,H,POPSL,DPDZ,NH)
119 C
120  PHOPZI=PHOP/PZOP
121  SUMZZ=SUMZZ+SQRT(DZ)*(SQRT(PHOPZ)+SQRT(PHOPZI))*(THOTZ**0.75
122  1+THOTZI**0.75)*(ZMOB+ZMOBI)*SQRT(ZM/HM)/4.0
123  BETAI=BETA
124  40 Z=Z-DZ
125  IF(Z) 80,60,60
126 C
127  60 CALL TEMP(Z,TZ,ZA,KATMOS)
128 C
129  ZM=VH/ZA
130  BETA=SQRT(ZM*ZM-1.0)
131  ZMOB=ZM/BETA
132  THOTZ=TH/TZ
133 C
134  CALL XYINT(Z,PZOP,H,POPSL,DPDZ,NH)
135 C
136  PHOPZ=PHOP/PZOP
137  SUMZ=SUMZ+.5*(1.0/BETA+1.0/BETAI)*DZ
138  TERM3=HM*SUMZ/ZMOB
139  AHOZA=1.0/TERM3
140  SUMZZ=SUMZZ+(SQRT(PHOPZ)+SQRT(PHOPZI))*(THOTZ**.75+THOTZI**.75)*
141  1(SQRT(AHOZA)+SQRT(AHOZAI))*(ZMOB+ZMOBI)*DZ/16.0
142 c  SUMZZ=SUMZZ+((SQRT(PHOPZ*AHOZA)*(THOTZ**.75)*ZMOB)+(SQRT(PHOPZI*
143 c  1AHOZAI)*(THOTZI**.75)*ZMOBI))*DZ/2.0
144  IF(DZ .LT. DELZ) GO TO 100
145  ZMOBI=ZMOB
146  THOTZI=THOTZ

```

```

147 PHOPZI=PHOPZ
148 AHOZAI=AHOZA
149 BETAI=BETA
150 GO TO 40
151 80 DELZ=DZ
152 DZ=DZ+Z
153 Z=0.0
154 GO TO 60
155 100 BETA=SQRT(HM*HM-1.0)
156 TERM1=1.2*HM*HM*HM/SQRT(2.0*BETA)
157 ADVANCE=TERM1*SUMZZ
158 WRITE(6,700) ADVANCE
159 700 FORMAT(/,3x,28HCALCULATED ADVANCE FACTOR = ,F12.6,/)
160 C
161 IF(KATMOS .EQ. 0) DT=-20.0
162 IF(KATMOS .EQ. 0) WRITE(6,702)
163 702 FORMAT(3X,31HAPPROXIMATE COLD-DAY ATMOSPHERE,/)
164 IF(KATMOS .EQ. 1) DT=0.0
165 IF(KATMOS .EQ. 1) WRITE(6,704)
166 704 FORMAT(3X,35HAPPROXIMATE STANDARD-DAY ATMOSPHERE,/)
167 IF(KATMOS .EQ. 2) DT=20.0
168 IF(KATMOS .EQ. 2) WRITE(6,706)
169 706 FORMAT(3X,30HAPPROXIMATE HOT-DAY ATMOSPHERE,/)
170 C
171 AHOAG=DZH*AHOZA
172 DPGODPH=SQRT(AHOAG/PHOP)*((TH/(518.67+DT))**.25)
173 DPHOPF=1.4*HM*HM/SQRT(2.0*BETA*DZH)
174 DPGOF=DPHOPF*PHOP*2116.22*DPGODPH
175 DPOF=DPGOF*RK
176 C WRITE(6,707) AHOAG,DPGODPH,DPHOPF,DPGOF,PHOP,TH,DZH
177 707 FORMAT(///,5X,7(F12.7),/)
178 C
179 write(6,708) dpof
180 708 format(5x,9hDP*RK/F =,f11.7,/)
181 C
182 ADV=ADVANCE
183 C
184 C CALCULATE F-FUNCTION AND PRESSURE SIGNATURE FROM
185 C F-FUNCTION PARAMETERS: H,C,YF,XI,XLAM,PERCEN,D,XLE,HM,
AND WCR,
186 C AND PRESSURE SIGNATURE PARAMETERS: DELTAP,RK,RATIO,HCR
187 C
188 Q=.7*PHOP*2116.22*HM*HM
189 AEMAX=SQRT(HM*HM-1.0)*WCR/(2.0*Q)
190 C
191 WRITE(6,709) HCR,HM,Q,AEMAX,WCR,VH,RATIO
192 709 FORMAT(5X,17HCRUISE ALTITUDE =,4x,F9.3,
193 A/,5X,17HCRUISE MACH NO. =,4x,f9.3,
194 B/,5X,18HDYNAMIC PRESSURE =,2x,F10.3,
195 C/,5X,18HMAX. EQUIV. AREA =,3x,f9.3,
196 D/,5X,15HCRUISE WEIGHT =,4x,F11.3,

```

```

197 E/,5X,17HCRUISE VELOCITY =,2x,F11.3,
198 F/,5x,23hTAIL SHOCK/NOSE SHOCK =,f7.3,/ )
199 WRITE(6,710)
200 710 FORMAT(3x,33hHYBRID-2 F-FUNCTION AND SIGNATURE,/ )
201 C
202 NP=0
203 DELTAPO=DELTA P
204 105 YFO=YF
205 XIO=XI
206 YFI=YF
207 XII=XI
208 NDELP=0
209 NNNR=0
210 110 NNR=0
211 NR=0
212 120 C=DELTA P/DPOF
213 FH=3.0*C*(2.0*C*ADV/YF-1.0)/7.0
214 C
215 C C MUST BE > 5.0*YF/(3.0*ADV)
216 C
217 IF(FH .LE. C) WRITE(6,712) FH,C
218 712 FORMAT(2X,3HH =,F8.4,16H < OR = THAN C =,F8.4,/,5x,11hJOB ABORTED)
219 IF(FH .LE. C) GO TO 600
220 C
221 B=PERCEN/ADV
222 C
223 XLAM=.85*XLE
224 if(xi .gt. yf) xlam=xle-xi
225 C
226 E=-C/5.0
227 C
228 C ITERATE TO OBTAIN XLAM CORRESPONDING TO A VALUE OF XI USING
229 C NEWTON-RAPHSON METHOD
230 C
231 NXLAM=0
232 140 NL=0
233 160 NE=0
234 180 D=C*(1.0+RATIO)+B*(XLE-XI)-E
235 YR=XLE+RATIO*C*ADV
236 D1=FH*XLE*(.5*pi+asin((YF-XLE)/XLE))/sqrt(.5*YF)
237 D2=2.0*FH*sqrt(XLE-.5*YF)-16.0*(FH-C)*((XLE-.5*YF)**1.5)/(3.0*YF)
238 D3=(16.0/3.0)*(FH-C)*((XLE-YF)**1.5)/YF
239 D4=(8.0/3.0)*B*((XLE-XI)**1.5)
240 IF(XLE-XLAM) 182,182,184
241 182 if(xlam .lt. xi) go to 440
242 pdp=deltap
243 C WRITE(6,720) nxlam,pdp,XLAM
244 720 FORMAT(2X,6hNXLAM=,I4,5x,7HDELTA P=,F8.4,5X,5HXLAM=,F12.7,/ )
245 if(nxlam .gt. 2) go to 450
246 deltap=deltap+0.05
247 GO TO 110

```

```

248 184 D5=4.0*(-D)*SQRT(XLE-XLAM)
249   DAPR=-(D1+D2+D3+D4+D5)/(2.0*PI)
250 C
251   CALL FOFX(YR,YF,FH,C,B,XI,XLAM,XLE,D,DAPR,PI,FYR)
252 C
253   DIF=ABS((E-FYR)/FYR)
254   IF(DIF .LT. 0.0000001) GO TO 200
255   NE=NE+1
256   IF(NE .GT. 50) GO TO 600
257   E=FYR
258   GO TO 180
259 C
260 200 CALL CALC(YF,FH,C,B,XI,XLAM,XLE,D,AEXLE,0,1,XDEL,PI)
261 C
262   dellam=2.0
263   R=ABS((AEXLE-AEMAX)/AEMAX)
264   daeoae=(aexle-aemax)/aemax
265 C   write(6,722) nxlam,daeoae,xlam
266 722 format(/,5x,2hN=,i3,5x,7hdAE/AE=,f11.7,5x,5hxlam=,f11.6)
267 C   write(6,723) yf,xi
268 723 format(5x,3hyf=,f9.6,5x,3hxi=,f9.6)
269   IF(R .LT. .0000001) GO TO 280
270   IF(AEXLE-AEMAX) 220,280,220
271 220 IF(NL) 240,240,260
272 240 AE1=AEXLE
273   XLA1=XLAM
274   NL=NL+1
275   XLAM=XLAM-dellam
276   GO TO 160
277 260 AE2=AEXLE
278   XLA2=XLAM
279   DADL=(AE2-AE1)/(XLA2-XLA1)
280   XLAM=XLA1-(AE1-AEMAX)/DADL
281   IF(XLAM .LT. XI) GO TO 440
282   NXLAM=NXLAM+1
283   IF(NXLAM .GT. 100) GO TO 460
284   GO TO 140
285 280 CONTINUE
286 C
287 C   CALCULATE INTEGRAL OF F(Y) BETWEEN XLE AND YR FOR TAIL SHOCK
288 C   DETERMINATION BY AREA BALANCING
289 C
290   SUMAX=0.0
291   FOFLE=C+B*(XLE-XI)-D
292   YRR=XLE+(RATIO*C-E)*ADV
293   AREA1=.5*(FOFLE+FYR)*(YR-XLE)
294   XINT=YR-XLE
295   NINT=200
296   DX=XINT/FLOAT(NINT)
297   X=XLE+DX
298 C

```

```

299 CALL FOFX(X,YF,FH,C,B,XI,XLAM,XLE,D,DAPR,PI,FX)
300 C
301 FX1=FX-DAPR/SQRT(DX)
302 SUMAX=SUMAX+.5*(FOFLE+FX1)*DX+2.0*DAPR*SQRT(DX)
303 F1=FX
304 DO 300 NNINT=2,NINT
305 X=X+DX
306 C
307 CALL FOFX(X,YF,FH,C,B,XI,XLAM,XLE,D,DAPR,PI,FX)
308 C
309 SUMAX=SUMAX+.5*DX*(F1+FX)
310 F1=FX
311 300 CONTINUE
312 R=SUMAX-AREA1
313 RR=ABS(R/SUMAX)
314 IF(ABS(RR) .LE. 0.00001) GO TO 360
315 IF(NR) 320,320,340
316 320 R1=R
317 P1=DELTAP
318 DELTAP=DELTAP+0.10
319 NR=NR+1
320 GO TO 120
321 340 R2=R
322 P2=DELTAP
323 DPDR=(P2-P1)/(R2-R1)
324 DELTAP=P2-R2*DPDR
325 C
326 IF(DELTAP) 345,345,350
327 345 WRITE(6,725)
328 725 FORMAT(15x,13hDelta P < 0.0,/)
329 GO TO 600
330 C
331 350 NR=0
332 C NNR=NNR+1
333 rrr=(deltap-p1)/p1
334 C write(6,355) nnr,rrr,p1,deltap
335 355 format(/,2x,4hNNR=,i4,2x,4hrrr=,f10.7,2(2x,f9.6))
336 GO TO 120
337 C
338 360 CONTINUE
339 C
340 if(NP .GT. 0) write(6,727)
341 727 format(/,2x,45hPERCEN was increased to search for a solution,/)
342 C
343 flam1=C+B*(XLAM-XI)
344 flam2=flam1-D
345 fxle=flam2+B*(XLE-XLAM)
346 WRITE(6,740) YF,FH,C,B,D,XI,XLAM,XLE,AEMAX,flam1,flam2,fxle
347 WRITE(6,730) DELTAP,PERCEN
348 730 FORMAT(9X,8HDELTAP =,F7.4,/,9X,8HPERCEN =,F7.4,/)
349 C

```

```

350 740 FORMAT(7X,4HYF =,F16.6/,7X,3HH =,F17.6/,7X,3HC =,F17.6/,7X,3HB
351 A=,F17.6/,7X,3HD =,F17.6/,7X,4HXI =,F16.6/,7X,6HXLAM =,f14.6/,7
352 BX,5HXLE =,F15.6/,7X,7HAEMAX =,F13.6/,7X,9HF1(lam) =,f11.6/,7X,9
353 CHF2(lam) =,f11.6/,7X,8HF(xle) =,f12.6,/)
354 C
355 WRITE(6,745)
356 745 FORMAT(/,9X,1HX,10X,1HF,13X,2HAE)
357 C
358 CALL CALC(YF,FH,C,B,XI,XLAM,XLE,D,AEXLE,1,0,XDEL,PI)
359 C
360 XXX=YR-XLE
361 NXX=INT(XXX/XDEL)+1
362 IF(NXX .LT. 5) NXX=5
363 X=XLE+1.0
364 C
365 CALL FOFX(X,YF,FH,C,B,XI,XLAM,XLE,D,DAPR,PI,F1)
366 C
367 X=X+1.0
368 C
369 CALL FOFX(X,YF,FH,C,B,XI,XLAM,XLE,D,DAPR,PI,F2)
370 C
371 DFDX=F2-F1
372 IF(DFDX .LT. 0.0) WRITE(6,750) DFDX
373 750 FORMAT(3X,12HNOTE: DF/DX=,F12.8,21H AND IS LESS THAN 0.0,/)
374 X=XLE
375 C
376 NXX=INT(2.0*XLE/XDEL)+1
377 C
378 DO 380 NNX=1,NXX
379 X=X+XDEL
380 C
381 CALL FOFX(X,YF,FH,C,B,XI,XLAM,XLE,D,DAPR,PI,FX)
382 C
383 if(X .LE. 1.5*XLE) WRITE(6,760) X,FX,AEMAX
384 760 FORMAT(2X,F10.4,2X,F10.7,3X,F10.5)
385 380 CONTINUE
386 C
387 C CALCULATE PRESSURE SIGNATURE ON THE GROUND
388 C
389 WRITE(6,775)
390 WRITE(6,770)
391 770 FORMAT(2X,10HX-BETA*HCR,7X,2HP1,10X,2HP2,9X,4HT-T0,/)
392 775 FORMAT(///,5X,32HPRESSURE SIGNATURE ON THE GROUND,/)
393 P1=0.0
394 X=YF-ADV*C
395 T=X/VH
396 P2=C*DPOF
397 C
398 nvel=int(0.002*vh+1.0)
399 xdel1=float(nvel)
400 C

```

```

401  pnose=p2
402  trise=3.0/pnose
403  C
404    WRITE(6,780) X,P1,P2,T
405  780 FORMAT(2X,F9.4,3X,F9.4,3X,F9.4,3X,F9.4)
406    IF(XI .EQ. YF) GO TO 390
407    X=XI-ADV*C
408    T=X/VH
409    P2=C*DPOF
410    WRITE(6,790) X,P2,T
411  790 FORMAT(2X,F9.4,15X,F9.4,3X,F9.4)
412  390 X=XLAM-ADV*(C+B*(XLAM-XI))
413    T=X/VH
414    P2=(C+B*(XLAM-XI))*DPOF
415  C
416    dppeak=p2-pnose
417  C
418    WRITE(6,790) X,P2,T
419    X=XLAM-ADV*(C+B*(XLAM-XI)-D)
420    T=X/VH
421    P2=(C+B*(XLAM-XI)-D)*DPOF
422    WRITE(6,790) X,P2,T
423    X=YRR
424    T=X/VH
425    P2=(C+B*(XLE-XI)-D)*DPOF
426    P1=E*DPOF
427    ptail=p1-p2
428    WRITE(6,780) X,P2,P1,T
429    NS=0
430    X=YR
431  400 X=X+XDEL1
432    CALL FOFX(X,YF,FH,C,B,XI,XLAM,XLE,D,DAPR,PI,FX)
433    XS=X-ADV*FX
434    T=XS/VH
435    P2=FX*DPOF
436    WRITE(6,790) XS,P2,T
437    NS=NS+1
438    IF(NS .LE. 15) GO TO 400
439    GO TO 500
440
441  420 CONTINUE
442    WRITE(6,800)
443  800 FORMAT(5X,36HXLAM > XLE, AND XI < YF, JOB ABORTED,/)
444    GO TO 600
445  440 CONTINUE
446    WRITE(6,810)
447  810 FORMAT(15X,9HXLAM < XI)
448    go to 600
449  450 continue
450  c  WRITE(6,820)
451  820 format(3x,49hPERCEN increased by .001 to search for a solution,/)

```

```

452 C
453 C   RESTART WITH CHANGED PERCEN VALUE
454 C
455     deltap=deltapo
456     percen=percen+0.001
457     if(percen .gt. 1.0) go to 460
458     np=1
459     go to 105
460 460 WRITE(6,830)
461 830 FORMAT(/,5X,32HValue for XLAM will not converge,/)
462     go to 600
463 C
464 500 CONTINUE
465 C
466 C   Approximate outdoor noise calculation based on a RISE TIME of
467 C       3.0/(DeltaP), millisec.
468 C
469     pldb=106.0
470     if(B) 505,505,510
471 505 pn=pnose
472     pldb=pldb+23.1*dlog10(pn)-5.8*sqrt(trise)
473     go to 515
474 510 pn=pnose
475     pp=pnose+dppeak
476     pldb=pldb+17.0*dlog10(pn)+4.5*dlog10(pp)-6.0*sqrt(trise)
477 515 write(6,520) pnose
478 520 format(/,10x,12hNose Shock =,f7.4,4h psf)
479     write(6,525) ptail
480 525 format(/,10x,12hTail Shock =,f7.4,4h psf)
481     write(6,530) pldb
482 530 format(/,5x,35hApproximate Outdoor Noise Level Is ,f4.1,5h Pldb,/)
483     go to 600
484 C
485 485 write(6,490) hcr
486 490 format(/,2x,11hh(cruise) =, f11.2,23h exceeds altitude range,/)
487 C
488 600 END
489 C
490     SUBROUTINE XYINT(X,A,XE,AE,AEP,NN)
491 C
492     implicit double precision(a-h,o-z)
493 C
494 C   INTERPOLATION SCHEME TO GET VALUE OF "A" AT STATION "X"
495 C   TABLES XE AND AE MUST CONTAIN AT LEAST 4 VALUES
496 C
497     DIMENSION XE(NN),AE(NN)
498 C
499     N=1
500     1 X1=XE(N)
501     X2=XE(N+1)
502     X3=XE(N+2)

```

```

503   X4=XE(N+3)
504   IF(X .GT. X2) GO TO 3
505 2 A1=AE(N)
506   A2=AE(N+1)
507   A3=AE(N+2)
508   A4=AE(N+3)
509   XX1=(X3-X1)*(A2-A1)-(X2-X1)*(A3-A1)
510   YY1=XX1/((X2-X1)*(X3-X1)*(X2-X3))
511   XX2=(X4-X1)*(A3-A1)-(X3-X1)*(A4-A1)
512   YY2=XX2/((X3-X1)*(X4-X1)*(X3-X4))
513   CC=(YY1-YY2)/(X2-X4)
514   BB=YY2-CC*(X3+X4-2.0*X1)
515   AA=(A2-A1-BB*((X2-X1)**2)-CC*((X2-X1)**3))/(X2-X1)
516   A=A1+AA*(X-X1)+BB*((X-X1)**2)+CC*((X-X1)**3)
517   AEP=AA+2.0*BB*(X-X1)+3.0*CC*((X-X1)**2)
518   GO TO 4
519 3 IF(N+3 .GE. NN) GO TO 2
520   N=N+1
521   GO TO 1
522 4 RETURN
523   END
524 C
525   SUBROUTINE CALC(Y,H,C,B,XI,XLAM,XL,D,AEFIN,K,KL,DX,PI)
526 C
527 C   CALCULATES F(Y) AND AE(Y) FOR 0.0 < Y < XL
528 C
529   implicit double precision(a-h,o-z)
530 C
531 C   pi=2.0*asin(1.0)
532   Y2=.5*Y
533   lx=0
534   X=-DX
535   IF(KL .EQ. 1) X=XL-DX
536 1 X=X+DX
537   F=H*sqrt(X/Y2)
538   AA=H*X*X/sqrt(2.0*Y)
539   A=pi*AA
540   IF(X-Y2) 7,7,2
541 2 F=2.0*H-C-2.0*(H-C)*X/Y
542   A=AA*(.5*pi+asin((Y-X)/X))+H*Y2*sqrt(X-Y2)
543   A=A+(5.0/3.0)*H*((X-Y2)**1.5)
544   A=A-(32.0/(15.0*Y))*(H-C)*((X-Y2)**2.5)
545   IF(X-Y) 7,7,3
546 3 F=C
547   A=A+(32.0/15.0)*(H-C)*((X-Y)**2.5)/Y
548   IF(X-XI) 7,7,4
549 4 F=C+B*(X-XI)
550   A=A+(16.0/15.0)*B*((X-XI)**2.5)
551   IF(X-XLAM) 7,7,5
552 5 if(x - xl+.00001) 6,10,10
553 6 F=C-D+B*(X-XI)

```

```

554   A=A-(8.0/3.0)*D*((X-XLAM)**1.5)
555   7 IF(K .EQ. 1 .AND. A .LT. 0.010) WRITE(6,8) X,F,A
556   8 FORMAT(2X,F10.4,2X,F10.7,3X,F12.7)
557   IF(K .EQ. 1 .AND. A .GT. 0.010) WRITE(6,9) X,F,A
558   9 FORMAT(2X,F10.4,2X,F10.7,3X,F10.5)
559   if(lx .eq. 1) go to 11
560   GO TO 1
561  10 x=xl
562   lx=1
563   go to 6
564  11 aefin=a
565   if(k .eq. 1) write(6,12) x,a
566  12 format(/,2x,f10.4,2x,10h neg. inf. ,3x,f10.5,/)
567   RETURN
568   END
569 C
570   SUBROUTINE FOFX(X,Y,H,C,B,XI,XLAM,XL,D,DA,PI,FX)
571 C
572 C   CALCULATES F(X) FOR X > XL WITH CONSTANT AE(MAX) AFT OF XL
573 C
574   implicit double precision(a-h,o-z)
575 C
576 C   Terms that are functions of y/2
577 C
578   Y2=0.5*Y
579   PI2=0.5*PI
580   tpi=2.0*pi
581   FX=tpi*H*(sqrt(X)-sqrt(X-XL))/sqrt(Y2)
582 C
583   AA=-pi*H*(sqrt(X-Y2)-sqrt(X-XL))/sqrt(Y2)
584   BB=-2.0*sqrt(x-xl)*asin((y-xl)/xl)+pi*sqrt(x-y2)
585   BB=H*BB/sqrt(y2)
586   CC1=asin((xl*(x+y2)-x*y)/(xl*(x-y2)))+pi2
587   CC2=asin((2.0*xl-(x+y2))/(x-y2))+pi2
588   CC=-2.0*H*(sqrt(x/Y2)*CC1-CC2)
589   DD1=sqrt(-x*y2+xl*(x+y2)-xl*xl)
590   DD=(8.0/y)*(H-C)*(-DD1+.5*(X+Y2)*CC2)-4.0*(H-C)*CC2
591   FX=FX+AA+BB+CC-DD
592 C
593 C   if(x .eq. xl) write(6,10) aa,bb,cc1,cc2,cc,DD1,dd
594 C  10 format(5x,7(f11.5))
595 C
596 C   Terms that are functions of y
597 C
598   AA=-SQRT(-X*Y+XL*(X+Y)-XL*XL)
599   BB=.5*(X-Y)*(ASIN((2.0*XL-(X+Y))/(X-Y))+PI2)
600   FX=FX+(8.0/Y)*(H-C)*(AA+BB)
601 C
602 c   fc=fx/tpi
603 c   if(x .eq. xl) write(6,11) h,c,fc
604 c  11 format(10x,2hh=,f9.5,5x,2hc=,f9.5,5x,3hfc=,f9.5)

```

```

605 c   if(x .eq. xl) go to 3
606 C
607 C   Terms that are functions of xi
608 C
609     AA=-SQRT(-X*XI+XL*(X+XI)-XL*XL)
610     BB=0.5*(X-XI)*(ASIN((XL-.5*(X+XI))/(.5*(X-XI)))+PI2)
611     FX=FX+4.0*B*(AA+BB)
612 C
613 C   Term that is a function of Lambda
614 C
615     AA=ASIN((XL-.5*(X+XLAM))/(.5*(X-XLAM)))+PI2
616     FX=FX+2.0*(-D)*AA
617 C
618 C   Term that is a function of XL
619 C
620     FX=FX/tpi+DA/SQRT(X-XL)
621 3 RETURN
622     END
623 C
624     SUBROUTINE TEMP(Z,T,ZA,K)
625 C
626     implicit double precision(a-h,o-z)
627 C
628 C   INTERPOLATES TO FIND TEMP. "T" AT ALTITUDE "Z"
629 C
630     IF(K .EQ. 0) DT=-20.0
631     IF(K .EQ. 1) DT=0.0
632     IF(K .EQ. 2) DT=20.0
633     T1=518.67+DT
634     T2=389.97+DT
635     H2=36152.0
636     H3=65824.0
637     T4=411.289+DT
638     H4=105518.0
639     T5=479.073+DT
640     H5=150000.0
641     R=1716.5623
642 C
643     IF(Z-H2) 1,1,2
644     1 T=T1+(T2-T1)*Z/H2
645     GO TO 7
646     2 IF(Z-H3) 3,3,4
647     3 T=T2
648     GO TO 7
649     4 IF(Z-H4) 5,5,6
650     5 T=T2+(T4-T2)*(Z-H3)/(H4-H3)
651     GO TO 7
652     6 T=T4+(T5-T4)*(Z-H4)/(H5-H4)
653     7 ZA=SQRT(1.4*R*T)
654     RETURN
655     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.

```

1      Program WeightEst
2 C
3 C      Program to compute an estimate of mission weights from inputs
4 C      of Range, No. of Passengers, Mach number, SFC, L/D, and
5 C      Technology Factor.
6 C
7 C      Input:
8 C
9 C      xm      = Mach number
10 C      range  = total range, nautical miles,
11 C      alod   = average cruise lift/drag ratio,
12 C      sfc    = average specific fuel consumption, lbf/lbth/hr, default=1.0
13 C      npass  = number of passengers, default=0
14 C      tf     = technical factor, tf = Wgto/We, default=1.0
15 C      fcl    = ratio of Wbegcr/Wgto, default=.92
16 C      wfdes  = fuel used to descend and land
17 C      wcargo = cargo weight, default=0.0 lb
18 C      fres   = ratio of W(reserve fuel)/W(gross take-off), default=0.06
19 C      rto    = range to take-off, climb, and accelerate, nmi,
20 C      rdes   = range to decelerate, descend, and land, nmi,
21 C      accel  = takeoff acceleration, decimal fraction of g's, default=0.10
22 C      warea  = wing reference area, square ft
23 C      hc     = beginning cruise altitude, ft
24 C      hec    = end-of-cruise altitude, ft
25 C           hec is defaulted to hf in code, estimate hec to start
26 C           solution and iterate as many times as necessary
27 C      cld    = design lift coefficient, default = 0.10
28 C      ne     = number of engines
29 C
30      Implicit Double Precision(a-h,o-z)
31 C
32      Dimension H(17),DENS(17),SS(17),PH(17),ALT(17)
33 C
34      Character Text(1)*80
35 C
36      NAMELIST/INPUT/xm,range,alod,sfc,npass,tf,fcl,wfdes,fres,rto,rdes,
37      lwcargo,accel,warea,hc,hec,cld,ne
38 C
39      DATA(H(J),J=1,17)/40000.0,42500.0,45000.0,47500.0,50000.0,52500.0,
40      155000.0,57500.0,60000.0,62500.0,65000.0,67500.0,70000.0,72500.0,
41      275000.0,77500.0,80000.0/
42 C
43      DATA(DENS(J),J=1,17)/.000587277,.000521032,.000462273,.000410152,
```

```

44 1.000363918,.000322905,.000286523,.000254247,.000225613,.000200209,
45 2.000177672,.000157321,.000139202,.000123226,.000109132,
46 3.0000966931,.0000857103/
47 C
48 DATA(SS(J),J=1,17)/968.076,968.076,968.076,968.076,968.076,
49 1968.076,968.076,968.076,968.076,968.076,968.076,969.209,970.897,
50 2972.581,974.263,975.940,977.615/
51 C
52 DATA(PH(J),J=1,17)/58.5115,65.7832,73.9905,83.2579,93.7270,
53 1105.559,118.935,134.022,151.027,170.195,191.801,216.156,243.610,
54 2274.559,309.449,348.783,393.128/
55 C
56 DATA(ALT(J),J=1,17)/80000.0,77500.0,75000.0,72500.0,70000.0,
57 167500.0,65000.0,62500.0,60000.0,57500.0,55000.0,52500.0,50000.0,
58 247500.0,45000.0,42500.0,40000.0/
59 C
60 pi=2.0*asin(1.0)
61 rcon=1716.5616
62 ee=2.718281828
63 a=968.076
64 wcargo=0.0
65 fcl=0.92
66 fres=0.060
67 g=32.174
68 accel=0.10
69 cld=0.10
70 ne=1
71 hec=0.0
72 C
73 READ(5,1) text(1)
74 1 format(A80)
75 write(6,2) text(1)
76 2 format(A80,/)
77 C
78 READ(5,INPUT)
79 C
80 Write(6,3) xm,range,alod,sfc,npass,tf,wfdes,fcl
81 3 format(5x,10hMach No. =,f12.2,/,5x,7hRange =,f15.2,/,5x,10hL/D(avg
82 1) =,f12.3,/,5x,10hSFC(avg) =,f12.5,/,5x,14hNo. of pass. =,i8,/,5x,
83 214hTech. factor =,f8.5,/,5x,7hWdesc =,f15.1,/,5x,10hWcr/Wgto =,f12
84 3.5,/)
85 C
86 if(hec .eq. 0.0) hec=hc
87 beta=sqrt(xm*xm-1.0)
88 vdot=accel*g
89 vdotdes=0.75*vdot
90 C
91 C Estimate possible rto and rdes from vdot and vdotdes; compare with
92 C input values
93 C
94 eta=(xm*xm*a*a-335.0*335.0)/(2.0*vdotdes)

```

```

95     gla=3.0*pi/180.0
96     fltpth=sqrt(eta*eta-(hec-5000.0)*(hec-5000.0))
97     rdesx=fltpth/6076.11549+5000.0/(6076.11549*tan(gla))
98     rdesx=float(int(rdesx+1.0))
99     if(rdesx .gt. rdes) rdes=rdesx
100 C
101     eta=(xm*xm*a*a-335.0*335.0)/(2.0*vdot)
102     rtox=sqrt(eta*eta-(hc-35.0)*(hc-35.0))/6076.11549
103     rtox=float(int(rtox+1.0))
104     if(rtox .gt. rto) rto=rtox
105 C
106     rcruz=range-rto-rdes
107     bf=(3600.0/6076.11549)*xm*a*alod/sfc
108     z=-rcruz/bf
109 C
110     tflim=1.0/(fcl*(ee**z)-fres)
111 C
112     write(6,4) bf,tflim
113     4 format(5x,24hAverage Breguet Factor =,f9.3,5h nmi.,/,5x,11hTF(lim
114     1it) =,f9.6,)
115     if(tf .le. tflim) go to 70
116 C
117     write(6,5) rto,rcruz,rdes
118     5 format(/,3x,27hMission Segment Ranges, nmi.,/,5x,14hT.O. & Climb =
119     1,f7.1,/,5x,8hCruise =,f13.1,/,5x,9hDescend =,f12.1,/)
120 C
121     wpay=210.0*float(npass)+wcargo
122     if(npass .lt. 20) wpay=225.0*float(npass)+wcargo
123     wcrew=450.0+5.0*float(npass)
124     if(npass .lt. 20) wcrew=450.0
125     w0=(wcrew+wpay+wfdes)/(fcl*(ee**z)-fres-1.0/tf)
126     i=1
127     7 w1=tf*(fcl*w0*(ee**z)-wfdes-wpay-wcrew-fres*w0)
128     dw1=w1-w0
129     if(abs(dw1) .lt. 0.0000001) go to 10
130     w2=w0*w0/w1
131     i=i+1
132     if(i .gt. 200) go to 30
133     w0=w2
134     go to 7
135     10 continue
136 C
137     wgto=.5*(w0+w1)
138     wfres=fres*wgto
139     we=wgto/tf
140     wzfw=we+wcrew+wpay
141     wclim=(1.0-fcl)*wgto
142     wfuel=wgto-wzfw
143     wbcr=fcl*wgto
144     wecr=wbcr*(ee**z)
145     wfcf=wbcr-wecr

```

```

146   wfres=fres*wgto
147   write(6,20) we,wcrew,wpay,wzfw,wclim,wfcr,wfdes,wfres,wfuel,wgto
148 20 format(/,5x,20hAircraft Weights, lb,/,5x,4hWe =,f18.1/,5x,7hWcre
149   1w =,f15.1/,5x,6hWpay =,f16.1/,5x,6hWzfw =,f16.1/,5x,7hWf,to =,
150   2f15.1/,5x,11hWf,cruise =,f11.1/,5x,8hWf,des =,f14.1/,5x,8hWf,re
151   3s =,f14.1/,5x,10hWf,TOTAL =,f12.1/,5x,6hWgto =,f16.1)
152   wland=wecr-wfdes
153   write(6,25) wgto,wbcr,wecr,wland,we
154 25 format(/,5x,19hMission Weights, lb,/,5x,19hW(gross take-off) =,f
155   112.1/,5x,17hW(begin cruise) =,f14.1/,5x,15hW(end cruise) =,f16.1
156   2/,5x,9hW(land) =,f22.1/,5x,10hW(empty) =,f21.1)
157   go to 50
158 C
159 30 write(6,40) i,w0,w1
160 40 format(/,5x,24hNo solution found after ,i3,11h iterations,/,5x,4h
161   1w0 =,f12.5,5x,4hw1 =,f12.5)
162   go to 90
163 50 continue
164 C
165   call xyint(hc,rho,h,dens,rhop,17)
166   call xyint(hc,vs,h,ss,vsp,17)
167   q=0.5*rho*vs*vs*xm*xm
168   aequiv=.5*beta*wbcr/q
169 C
170   cl=wbcr/(q*warea)
171   qf=wecr/(cl*warea)
172   rhof=2.0*qf/(vs*vs*xm*xm)
173   phf=qf/(0.7*xm*xm)
174   call xyint(phf,hf,ph,alt,hfp,17)
175   if(hf .gt. 80000.0) go to 63
176   write(6,60) aequiv,warea,cl,wecr,hf
177 60 format(/,5x,11hAeq(lift) =,f9.4,4h ft2/,5x,11hWing area =,f9.2,4h
178   1 ft2/,5x,4hCL =,f9.6/,5x,19hEnd-cruise weight =,f9.1,3h lb,/,5x,
179   221hEnd-cruise altitude =,f9.2,3h ft,/)
180 C
181   snew=wbcr/(q*cld)
182   qnew=wbcr/(cld*warea)
183   pnew=qnew/(0.7*xm*xm)
184   call xyint(pnew,hnew,ph,alt,hfp,17)
185   write(6,61) cld,snew,hc,hnew,warea
186 61 format(5x,14hFor CL(des.) =,f9.5,1h:/,5x,6hArea =,f10.4,4h ft2,7h
187   1 at h =, f9.2,3h ft,/,5x,3hh =,f9.2,3h ft,11h for Area =,f10.4,4h
188   2ft2,/)
189   go to 90
190 C
191 63 write(6,65)
192 65 format(5x,34hEnd-of-cruise altitude > 80000 ft,,17herror in altitu
193   1de,/)
194   go to 90
195 70 write(6,75)
196 75 format(/,2x,38hTF is less than TF(limit); job aborted)

```

```

197 90 end
198 C
199 SUBROUTINE XYINT(X,A,XE,AE,AEP,NN)
200 C
201 Implicit Double Precision(a-h,o-z)
202 C
203 C Quadratic curve used to get value of "A" at station "X"
204 C Tables XE and AE must have at least 4 values, and XE values
205 C must be monotonically increasing.
206 C
207 Dimension XE(NN),AE(NN)
208 C
209 n=1
210 1 x1=xe(n)
211 x2=xe(n+1)
212 x3=xe(n+2)
213 x4=xe(n+3)
214 if(x .gt. x3) go to 3
215 2 a1=ae(n)
216 a2=ae(n+1)
217 a3=ae(n+2)
218 a4=ae(n+3)
219 xx1=(x3-x1)*(a2-a1)-(x2-x1)*(a3-a1)
220 yy1=xx1/((x2-x1)*(x3-x1)*(x2-x3))
221 xx2=(x4-x1)*(a3-a1)-(x3-x1)*(a4-a1)
222 yy2=xx2/((x3-x1)*(x4-x1)*(x3-x4))
223 cc=(yy1-yy2)/(x2-x4)
224 bb=yy2-cc*(x3+x4-2.0*x1)
225 aa=(a2-a1-bb*((x2-x1)**2)-cc*((x2-x1)**3))/(x2-x1)
226 a=a1+aa*(x-x1)+bb*((x-x1)**2)+cc*((x-x1)**3)
227 aep=aa+2.0*bb*(x-x1)+3.0*cc*((x-x1)**2)
228 go to 4
229 3 if(n+3 .ge. nn) go to 2
230 n=n+1
231 go to 1
232 4 return
233 end
234 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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