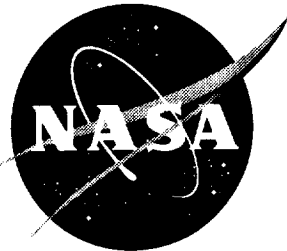# A Rapid Empirical Method for Estimating the Gross Takeoff Weight of a High Speed Civil Transport

Robert J. Mack
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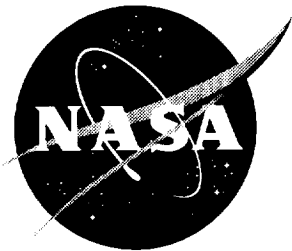- CONTRACTOR REPORT. Scientific and technical findings by NASA-sponsored contractors and grantees.

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A Rapid Empirical Method for Estimating the Gross Takeoff Weight of a High Speed Civil Transport

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SUMMARY

During the cruise segment of the flight mission, aircraft flying at supersonic speeds generate sonic booms that are usually maximum at the beginning of cruise. The pressure signature with the shocks causing these perceived booms can be predicted if the aircraft's geometry, Mach number, altitude, angle of attack, and cruise weight are known. Most methods for estimating aircraft weight, especially beginning-cruise weight, are empirical and based on least-square-fit equations that best represent a body of component weight data. The empirical method discussed in this report used simplified weight equations based on a study of performance and weight data from conceptual and real transport aircraft. Like other weight-estimation methods, weights were determined at several points in the mission. While these additional weights were found to be useful, it is the determination of beginning-cruise weight that is most important for the prediction of the aircraft's sonic-boom characteristics.

INTRODUCTION

Weight estimation is one of the most essential, yet one of the most difficult tasks required during the design of an HSCT concept. It is of particular importance when designing a low-sonic-boom concept because its beginning-cruise weight must be known for both aerodynamic performance and sonic-boom characteristics analyses. The results of these analyses often lead to modifications which impact the configuration weight during the entire mission including that at the beginning of cruise. A simple yet effective method for estimating beginning-cruise weight would be a help during this process even though the weight would be back-of-the-envelope accurate. As the configuration took shape, more exact methods could supply weight estimates so that a design solution which satisfied both sonic-boom and mission requirements would quickly converge.

The method described in this paper for estimating mission weights is based on weights from similar real aircraft and conceptual HSCT designs that fly similar missions. The weights in this

data base provide estimates that are consistent with the accuracy of the initial input data. General design perturbations for reducing the sonic boom can be introduced and the trends in weight change, due to these perturbations, can be estimated so that sonic boom characteristics and mission performance data can be determined simultaneously.

SYMBOLS

a	speed of sound at altitude, ft/sec
b	wing span, ft
B	Brequet range factor, $(M\,a\,/\,c)\,(L\,/\,D)$, nmi, equation (11)
c	mean specific fuel consumption, lb_{fuel}/lb_{thrust}-hr
e	basis of natural logarithms, 2.71828...
F_A	structural aspect ratio factor, defined in figure 2
k_C	ratio of $W_{F,Climb}/W_{GTO}$
k_R	ratio of $W_{F,Res}/W_{GTO}$
ln	natural logarithm
$L\,/\,D$	mean lift to drag ratio during cruise
M	Mach number
n	number of passengers
R	total range, nmi
R_{Climb}	range in climb and acceleration, nmi
R_{CR}	range in cruise, nmi
R_{Desc}	range to descend, nmi
S	wing area, ft^2
W	weight, lb
$W_{CR,e}$	weight at end of high-speed cruise flight, lb

$W_{CR,i}$ weight at beginning of high-speed cruise flight, lb

W_{Crew} weight of pilot, first officer, and flight attendants, lb

W_{Desc} weight of fuel required to descend and land, lb

W_E empty weight, lb

$W_{F,Climb}$ weight of fuel used to takeoff, climb, and accelerate to cruise Mach number, lb

$W_{F,CR}$ weight of fuel used during high-speed cruise, $W_{CR,i} - W_{CR,e}$, lb; equation (10)

$W_{F,Res}$ weight of reserve fuel, lb

W_{GTO} gross takeoff weight, lb

W_{Pass} weight of passengers and baggage, lb

Z exponent of e in the range equation

$\Lambda_{0.75}$ sweep angle of the line between the 75 percent stations of the root and tip chords

DISCUSSION

The weight of a conceptual aircraft depends on its mission. In this paper, a simplified mission consisting of takeoff and climb, cruise, descend and land, figure 1, is used to obtain an estimate of start-of-cruise weight. However, to obtain this weight estimate, it is also necessary to calculate end-of-cruise weight, landing weight, empty weight, and gross takeoff weight.
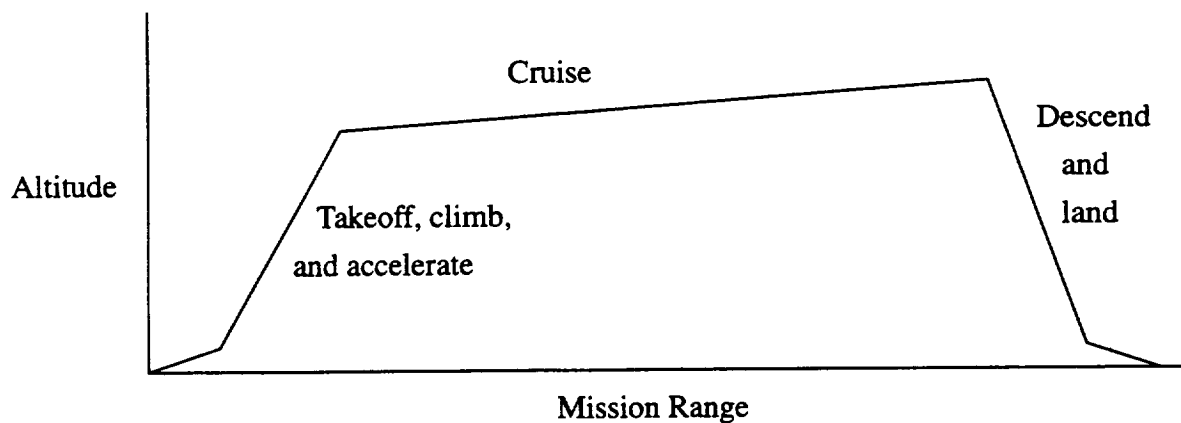

Figure 1. Mission profile.

The cruise segment of the mission is flown at a constant supersonic Mach number, and begins immediately after completion of the climb and acceleration segment of the mission. The segment

of the mission describing a diversion to an alternate airport is not shown, but the required fuel is included in the reserves.

The gross takeoff weight of a conceptual HSCT can be written as

$$W_{GTO} = W_{Pass} + W_{Crew} + W_{F,Climb} + W_{F,Desc} + W_{F,CR} + W_{F,Res} + W_E. \tag{1}$$

Each of these weight items is discussed in the following paragraphs.

Passenger Weight, W_{Pass}. The weight of the total number of passengers and their baggage is usually estimated from an average weight of 210 lb per passenger. However, most of the desired routes will be intercontinental so passengers will probably be given an extra 20 pounds of luggage. Using the higher luggage allowance,

$$W_{Pass} = 230\,n. \tag{2}$$

Crew Weight, W_{Crew}. The weight of the crew, W_{Crew}, is estimated from 450 lb of pilot and first officer weight added to the weight of 150 lb per flight attendant. For an HSCT aircraft, one flight attendant for every 30 passengers is considered average for commercial service. So

$$W_{Crew} = 450 + 5\,n. \tag{3}$$

Fuel Used During Climb, W_{Climb}. Data from references 1 to 5 indicate that from 6 to 12 percent of the gross takeoff weight, W_{GTO}, is used to take off, climb, and accelerate to start of cruise. If high-technology engines are used on the concept, 6 to 8 percent is a reasonable fraction. However, technology based on long, reliable engine life indicates that 10 to 12 percent is appropriate. Low aspect ratio wings are ideal for supersonic cruise, but poor for the subsonic segments of the mission. Using a general approach

$$W_{F,Climb} = k_C\,W_{GTO} \tag{4}$$

where k_C can be in the 0.06 to 0.15 range. During this flight segment, an average of from 300 to 400 nautical miles, nmi, will be travelled. This estimate of climb-and-acceleration range, like the estimate of climb-and-acceleration fuel weight, was obtained from references 1 to 5.

An average climb angle of 2 to 3 degrees was obtained from a study of several flight profiles. Mach number and noise constraints imposed dynamic pressure and throttle limits on the climb and accelerate phase of the mission, constraining the average climb angle further. Using conservative start-of-cruise altitudes, a range increment of

$$R_{Climb} = 300 \text{ to } 400 \text{ nmi} \tag{5}$$

was found to be a reasonable initial estimate for many conceptual low-boom concepts. Thrust-to-weight ratio needed to be in the 0.25 to 0.30 range for this empirical estimate to be reasonable, especially if a balanced field length of 10,000 to 12,000 feet is required. When the solution for W_{GTO} is calculated, the engine size can also be estimated from this range of assumed thrust-to-weight ratios.

Fuel Used During Descent, W_{Desc}. The body of conceptual HSCT mission weight data showed that for configurations carrying from 250 to 300 passengers over a mission range of about 5000 nmi, about 5000 to 7000 pounds of fuel, W_{Desc}, are needed to descend and land, i.e.,

$$W_{F,Desc} = 5000 \text{ to } 7000 \text{ lb.} \tag{6}$$

Like many of the other features of the method, this is an oversimplification, but it was found repeatedly in the fuel scheduling for aircraft of 600,000 to 800,000 lb gross takeoff weight, and seemed to be a reasonable first approximation for the first round of weight estimation. However, the method of reference 2 estimated that less than $0.010 \, W_{GTO}$ of fuel was used during descent, and in reference 6, $0.015 \, W_{CR,e}$ was the estimate of fuel used during descent. As a first estimate, equation (6) was used in the method when applied to low-boom concepts.

The flight angle used during the descent segment is usually higher than during the climb-and-acceleration segment. Since the aircraft climbs slowly during cruise to maintain aerodynamic efficiency, it ends the cruise segment higher than when it started. So the descent angle must be steeper to reduce descent and landing time to a minimum. For this, a descent range of about

$$R_{Des} = 200 \text{ to } 300 \text{ nmi} \tag{7}$$

was used as an initial estimate for a typical low-boom concept. The lower value, 200 nmi, gives an average descent angle of about 3.5 degrees which is comfortably close to a final glide path angle of 3 degrees often used on landing approaches.

Cruise Fuel Weight, W_{CR}. The cruise range was found from

$$R_{CR} = R - R_{Climb} - R_{Desc}$$

or, with the estimates of R_{Climb} and R_{Desc} already mentioned in equations (5) and (7)

$$R_{CR} = R - (500 \text{ to } 700) \text{ nmi} \tag{8}$$

was used to obtain an estimate of fuel consumed during the cruise segment of the mission. This mission cruise range is used to calculate beginning-cruise and end-of-cruise weights, $W_{CR,i}$ and $W_{CR,e}$ respectively, from the Breguet equation

$$R_{CR} = (M \, a \, / \, c)(L \, / \, D) \, ln \, (W_{CR,i} \, / \, W_{CR,e}). \tag{9}$$

where ln denotes the logarithm to base e rather than the logarithm to base 10. The beginning-cruise weight has been specified by equation (4), so equation (9) provides the end-of-cruise weight. Then, the cruise-fuel weight can be estimated from

$$W_{F,CR} = W_{CR,i} - W_{CR,e}. \tag{10}$$

Defining B, the Breguet factor, as

$$B = (M \, a \, / \, c) \, (L \, / \, D) \tag{11}$$

where the variables on the right-hand side are performance parameters already determined. The end-of-cruise weight, $W_{CR,e}$, can be determined from

$$W_{CR,e} = W_{CR,i} \, (e^Z) \tag{12}$$

where the constant, Z, is

$$Z = - R_{CR} \, / \, B. \tag{13}$$

Since the weight, $W_{CR,i}$, is defined as the gross takeoff weight, W_{GTO}, minus the weight of fuel required to takeoff, climb, and accelerate to cruise Mach number, $W_{F,Climb}$, it can be written as

$$W_{CR,i} = W_{GTO} - W_{F,Climb} = (1.0 - k_C)\, W_{GTO}. \qquad (14)$$

Equations (10), (12), and (14) express $W_{F,CR}$ is a function of W_{GTO} because both initial and end-of-cruise weights, $W_{CR,i}$ and $W_{CR,e}$, can be expressed as functions of W_{GTO} and the known range, cruise Mach number, and mean engine-fuel consumption parameters

Reserve Fuel Weight, W_{Res}. A review of mission performance weights showed that the reserve fuel weight was usually a constant fraction of the gross takeoff weight, i.e.

$$W_{F,Res} = k_R\, W_{GTO}. \qquad (15)$$

In the application of this method to a low-boom concept, $k_R = 0.06$ is used to obtain an initial estimate of W_{GTO} so that $W_{CR,i}$ can be calculated. If a more reserve fuel is desired, values of k_R in the range of 0.06 to 0.065 could be used to determine W_{GTO} and $W_{CR,i}$.

Empty Weight, W_E. The final weight increment needed to complete the gross take-off weight equation is the empty weight of the aircraft. Several related factors must be considered when estimating this increment. The first factor is materials technology, i.e. conventional metals versus composites. A second factor is engine technology where combustion temperatures and cruise Mach number dictates the choice of metals, bypass ratios, inlet design, and thrust-to weight ratios. A third factor is noise suppression technology. Noise generated by exhaust gases strongly impacts nozzle weight and takeoff patterns which, in turn, impacts fuel burned and gross takeoff weight. A fourth factor is wing planform shape and the structural aspect ratio. This last factor influences and is influenced by the previous three. In figure 2, a plot of (W_{GTO}/W_E) versus a structural aspect ratio factor, F_A, is presented using data from a number of real and conceptual configurations. The data base for this curve is presented in Appendices A and B.
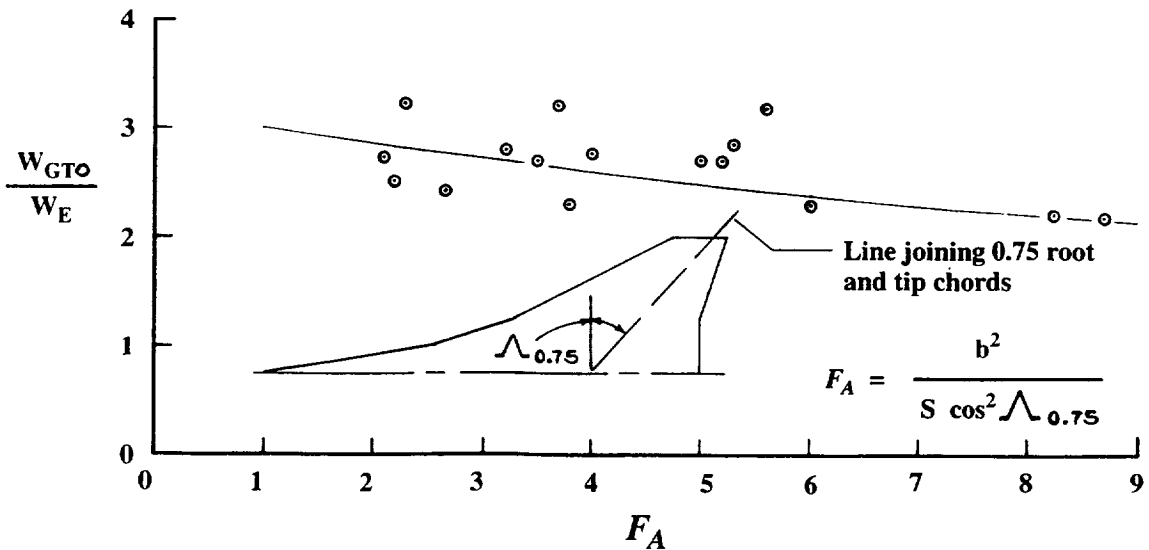

Figure 2. Correlation between (W_{GTO}/W_E) and a structural aspect ratio factor, F_A.

With only a back-of-the-envelope sketch and some preliminary performance calculations available, this ratio of (W_{GTO}/W_E) can be used to obtain a first estimate of W_{GTO}. Only then can a beginning cruise weight be obtained for an initial sonic boom prediction. Note that commercial aircraft like the Boeing 747, the BAC VC-10, the Tu-144, and the Concorde, have (W_{GTO}/W_E) ratios that vary from 2.2 to 2.7. This is a modest range considering that the first two are subsonic-cruise, moderate aspect ratio wing, low fuel consumption rate aircraft, and the last two are supersonic-cruise, low aspect ratio wing, high fuel consumption rate aircraft, with mission ranges that varied from 3500 to about 5200 nautical miles. For one factor to reflect differences in cruise Mach number and mission ranges indicates that several design details have been combined to simplify a complex weight-estimation procedure. Contrast the (W_{GTO}/W_E) ratios and mission ranges of these four aircraft with the (W_{GTO}/W_E) ratios and mission ranges of the Boeing 874 concept, the LB-16 concept, and the baseline Mach 2.4 concept, the highest three points on the chart. The first four aircraft are or were used commercially to carry passengers, while the last three were conceptual aircraft designed with highly-refined future technology.

Obviously, the curve of (W_{GTO}/W_E) vs. F_A in figure 2 is not the only possible interpretation or point-weighing of the data. For this report, the curve drawn was used as the upper limit of a narrow band with heavy emphasis on the data from the Concorde and Tu-144 supersonic-cruise aircraft, and to a lesser extent, on the data from the Boeing 747 and VC-10 subsonic-cruise aircraft. The effect of this weight-ratio data and the projected weight curve on the predicted low-sonic-boom characteristics of conceptual aircraft will be demonstrated in the *Application* section.

With the aid of the somewhat-optimistic weight-ratio curve shown in figure 2, the empty weight

$$W_E = W_{GTO} / (W_{GTO}/W_E) \qquad (16)$$

can be estimated and used to obtain an estimate of the gross take-off weight, W_{GTO}, and the beginning-cruise weight, $W_{CR,i}$. Reference 7 suggested that (W_{GTO}/W_E) could be expressed as an exponential function of W_{GTO} for various types of aircraft. This approach would be useful if the real and conceptual aircraft data in figure 2 were not available. Other weight-ratio data bases of similar concepts and aircraft exist, but for this simplified method and its application to sonic boom prediction, the data which formed the curve fairing in figure 2 are used to obtain an estimate of $W_{CR,i}$.

Combining equations (1) through (16) results in

$$W_{GTO} = (W_{Pass} + W_{Crew} + W_{F,Desc}) / ((1.0 - k_C) e^{-R/B} - k_R - 1.0 / (W_{GTO}/W_E)). \qquad (17)$$

This gross take-off weight estimate is obtained without the need for iteration because several materials technology and the overall weight influences of engine performance have been combined in the variable, (W_{GTO}/W_E). Even with these simplifications, the data curve in figure 2 is not linear although the second-order effects are small.

Since fuel weight is a major item for a long-range HSCT concept, the simplifications incorporated in the (W_{GTO}/W_E) ratio require an accurate estimate of the average specific fuel consumption, c, during cruise. It should be noted that several engine-technology related factors k_C, k_R, and B, not just c, affect the (W_{GTO}/W_E) ratio and the beginning-cruise weight. Misleading results will certainly be obtained if overzealous optimism is given free rein. The applications that follow demonstrate that this method can provide useful first-estimate results of $W_{CR,i}$ when it is

7

employed judiciously. While the estimated beginning-cruise weight will not be exact, it can be used to obtain the necessary wing lift, angle of attack, effective length, and lift equivalent area distribution for calculating the pressure signature at the beginning-cruise point. Ideally, this value of $W_{CR,i}$ will be somewhat on the high side. When better weight estimates are made with more-exact methods, $W_{CR,i}$ and the predicted sonic boom will usually be found to be lower than the initial predictions. This is preferable to the reverse situation since it is easier to reach a converged solution for the aircraft's weight and sonic boom when the weight is being reduced for an aircraft of a given size.

APPLICATION

A hypothetical HSCT concept from reference 9 was used to provide geometry and mission data for the application of equations (1) to (17) and the use of the (W_{GTO}/W_E) vs. F_A curve in figure 2. The concept's design had advanced just beyond the back-of-the-envelope stage, and consisted of a wire-frame three-view drawing, figure 3.
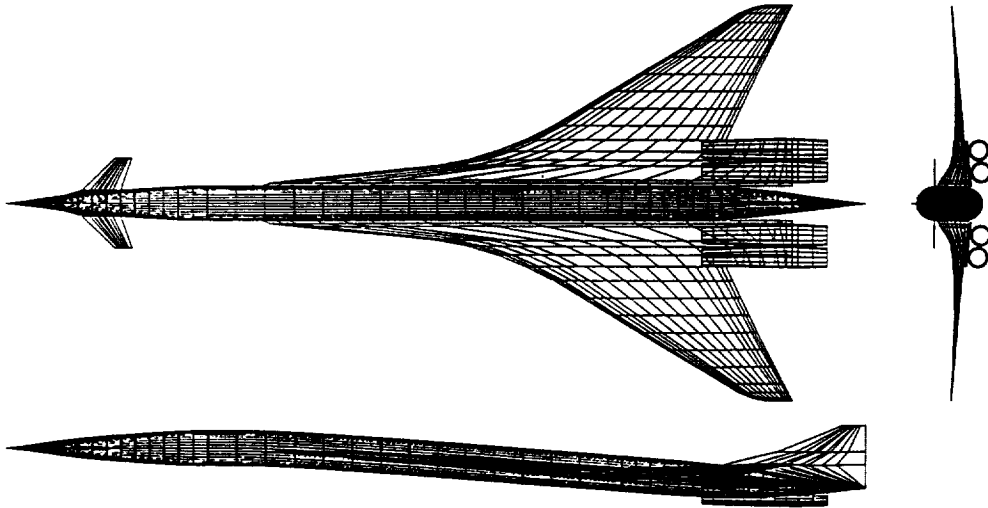

Figure 3. Three-view drawing of the HSCT-11E concept from reference 9.

A fuselage, sized to provide a pilots compartment, seating for 300 passengers seated 5-abreast, and room for aft-fuselage fuel, had an overall length of about 300 feet. The wing planform had a span of about 138 feet and an area of about 10,300 square feet for an aspect ratio of about 1.84. A canard surface near the nose furnished lifting moment for controlling attitude and rotation during takeoff and landing, but did not provide lift during the cruise segment of the mission. The structural aspect ratio factor, F_A, computed from the sweep angle of a line between the 75 percent stations of the root and tip chords, was about 3.5, and provided a (W_{GTO}/W_E) value of 2.65. Due to the concept's wing area which was about 9 percent larger than found on many previous baseline configurations, and the unusual planform shape, the (W_{GTO}/W_E) factor was reduced to 2.5 for this application of the weight-calculation method. Engine specific fuel consumption data was known from generic engine-performance data, but engine size, weight, and thrust would not be known until W_{GTO} had been estimated. Preliminary lift, drag, and pitching moment data had been calculated from geometry, but the (L / D) was still only an estimate since it included crude

estimates of skin friction and roughness drag coefficients. Input data for the initial estimate of the concept's mission weights were as follows:

$$M = 2.4$$
$$R = 5000.0 \text{ nmi}$$
$$L / D = 9.2$$
$$c = 1.35 \text{ lb/lb/hr}$$
$$n = 300$$
$$F_A = 3.5$$
$$(W_{GTO}/W_E) = 2.5 \text{ (adjusted for planform area and shape)}$$
$$k_C = 0.11$$
$$k_R = 0.062$$
$$R_{Climb} = 400 \text{ nmi}$$
$$R_{Desc} = 300 \text{ nmi}$$
$$W_{F,Desc} = 6000.0 \text{ lb}$$

The resulting solution for W_{GTO}, W_E, and $W_{CR,i}$ was:

$$W_{GTO} = 763{,}708.3 \text{ lb}$$
$$W_E = 305{,}483.3 \text{ lb}$$
$$W_{CR,i} = 679{,}700.4 \text{ lb}$$

which is very close to, but not exactly the same as, the weight estimates given in reference 9 which was obtained by a more complicated process.

From this value of $W_{CR,i}$, a cruise Mach number of 2.4, an effective length of 300 ft, a beginning-cruise altitude of 58,000 ft, and a "flat-top" signature shape, the methods described in references 10 and 11, subject to the cautions mentioned in reference 12, were used to calculate a low-boom equivalent-area curve. The equivalent areas represented by this curve includes both volume and lift contributions. Near the nose volume is the dominant contributor, but toward the tail of the concept, the lift slowly becomes the dominant contributor. On an HSCT concept, the maximum areas from lift can be from three to five times larger than the maximum areas from volume. At the tail of the concept, from 90 to 95 percent of the maximum equivalent area at the tail comes from the lift; the other 5 to 10 percent is due to the nacelles, boundary-layer wake, and engine plumes.

These equivalent areas, in turn, were used to predict a base-line low-boom ground-level nose-shock strength, Δp, of:

$$\Delta p \text{(Base-Line)} = 1.05 \text{ psf}$$

which became the shock strength for further comparisons. Tail-shock strengths are affected by the nacelle placement which was only tentative at this time. So, only nose-shock strengths are used to access the low-boom potentials since from 75 to 80 percent of the effective length must be tailored to control the nose shock.

The simplified weight-estimation method permits easy, quick studies to be made of the effects of improvements in aerodynamics, engine performance, and materials technology on sonic-boom characteristics. If the value of any constant in B, the Breguet factor in equation (11), was changed such that B was improved by the ratio (2.6/2.5), an increase of 4 percent, the calculated solution for W_{GTO}, W_E, and $W_{CR,i}$ was:

$$W_{GTO} = 694,697.8 \text{ lb}$$
$$W_E = 277,281.1 \text{ lb}$$
$$W_{CR,i} = 618,879.2 \text{ lb}$$

The matrix of low-boom input variables that provided the first estimate of ground-level shock strength were used, changing only $W_{CR,i}$, to get a similar estimate of sonic boom for this second beginning-cruise weight. The decrease of about 61,400 lb in $W_{CR,i}$ reduced the nose-shock strength from $\Delta p = 1.05$ psf to:

$$\Delta p \text{(Improved Breguet Factor)} = 0.98 \text{ psf.}$$

Now, instead of an improvement in aerodynamics or engine efficiency, a "break-through" in materials technology was assumed. This improvement was introduced as an increase in the (W_{GTO}/W_E) ratio from 2.5 to 2.6, the same amount of improvement used in the previous (L / D) ratio calculation to increase the Breguet factor, B. The solution for W_{GTO}, W_E, and $W_{CR,i}$ for this improvement in materials technology was:

$$W_{GTO} = 662,545.4 \text{ lb}$$
$$W_E = 254,825.2 \text{ lb}$$
$$W_{CR,i} = 589,665.4 \text{ lb}$$

This new value of $W_{CR,i}$, a decrease of about 90,000 lb in $W_{CR,i}$ from that of the initial concept, reduced the nose-shock strength from $\Delta p = 1.05$ psf to:

$$\Delta p \text{(Improved Structural Efficiency)} = 0.95 \text{ psf.}$$

If only one improvement were realizable, the reduction in sonic boom would be an encouragement but not a breakthrough. Should there be a 4 percent improvement in both factors simultaneously, the reduction in weights would be

$$W_{GTO} = 609,977.5 \text{ lb}$$
$$W_E = 234,606.7 \text{ lb}$$
$$W_{CR,i} = 542,880.0 \text{ lb}$$

and nose-shock strengths would drop from $\Delta p = 1.05$ psf to:

$$\Delta p \text{((Combined Improvements)} = 0.89 \text{ psf}$$

all due to the 136,800 lb reduction in $W_{CR,i}$. The inescapable conclusion is that for aircraft beginning-cruise weights in the 600,000 to 700,000 lb range with an overall length of about 300 ft, weight reductions of a 140,000 lb result in overpressure nose-shock strength reductions of only about 0.15 psf. This is not encouraging for aircraft designers who envision supersonic-cruise concepts that generate only 0.5 psf on the ground while carrying 300 passengers at Mach numbers of 2.4. However, 1.0 psf overpressure shock is a considerable reduction from 3.0 psf nose-shock strength generated by a concept configured for maximum aerodynamic and structural efficiency which is cruising at a similar altitude with the same number of passengers and at the same Mach number. Should more compromises be required to meet all mission constraints, the shock strengths can be permitted to drift upward. This is a more feasible strategy than try to force shock strengths downward through modest and limited geometric tailoring of a heavy concept.

However, the single best reduction in beginning-cruise weight is obtained by improvements in materials technology. From a practical viewpoint, only small improvements in materials technology, engine technology, and aerodynamic efficiency can be expected with state-of-the-art technology. So, before the aircraft designer invest much time in extensive sonic-boom analyses, the beginning-cruise weight trends must be known even if is only to first-order accuracy.

These examples demonstrate the extent of the changes in low-boom performance from changes in beginning-cruise weight due to improvements in materials, engine technology, and/or aerodynamic efficiency. They illustrate how such studies can easily and quickly be done with this simplified weight-estimation method. Thus, practical engineering limits to the cruise (L / D) ratio, engine performance, and materials technology could be explored on a particular configuration so that their effects on sonic boom and mission range can be credibly predicted before concept features were frozen in place during the preliminary-design process.

High values (2.75 or higher) of the (W_{GTO}/W_E) ratio were clearly out of place in a preliminary design of a near-term, modest-technology HSCT, but they could employed when it was desired to predict the results and benefits of potential long-term materials and manufacturing methods research breakthroughs. For example, they could be used to show the level of technology required to achieve sonic-boom levels of 0.75 psf and lower, or set the predicted aircraft performance levels required to achieve the optimistic results set forth in reference 8.

This empirical weight-estimation method is not meant to replace more sophisticated methods for calculating conceptual aircraft weights. However, these more sophisticated methods require much more time and effort to supply the necessary input information for calculating sonic-boom characteristics. By "weeding out" inefficient design features, unnecessary complexity, and undersized engines at an early stage, the preliminary design can be advanced to the stage where the extra time and effort needed to use the advanced codes are worthwhile. Then, the increased accuracy in W_{GTO}, W_E, and $W_{CR,i}$ estimates can be used to make refinements in structural design, engine selection, fuel tank location, landing gear, etc. so that a sonic-boom evaluation can be made on a concept capable of meeting mission requirements.

CONCLUDING REMARKS

The application of equations (1) to (17) and the curve of (W_{GTO}/W_E) vs. F_A, a structural aspect parameter, can provide an initial estimate of the beginning-cruise weight, as well as other mission weights of a conceptual HSCT geometrically tailored for low sonic boom. From the estimated beginning-cruise weight, the cruise Mach number, the cruise altitude, and the angle of attack, a low-boom equivalent area curve can be calculated for the concept. With the calculated equivalent area curve, the corresponding ground-level pressure signature can be predicted. By making incremental changes to selected component lengths, shapes, location, and weights, to mission segment range, and to fuel consumption rates during cruise segments of the overall mission, trends in weights and their effects mission performance, and predicted ground-level sonic boom can also be estimated.

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APPENDIX A.

Weights, Planform Parameters, And Ranges For A Sample Of HSCT Concepts And Long-Range Aircraft.

HSCT Concepts

Configuration	M	W_{GTO}, lb	W_E, lb	W_{GTO}/W_E	F_A	W_{GTO}/S	Range, nmi
Baseline Mach 2.4	2.4	614,302	191,474	3.21	3.7	67.5	6500
Baseline Mach 3.0	3.0	709,999	263,658	2.69	3.5	58.3	6500
LB - 16	1.6/2.0	646,356	203,310	3.18	5.6	69.8	6500
HSCT - 10B	1.8/2.4	662,000	245,000	2.69	5.2	63.3	5000
Boeing 874	0.9/2.4	666,857	206,527	3.23	2.3	105.7	5000
Boeing 910	1.7/2.4	823,641	295,076	2.79	3.2	82.7	5000
Boeing 911	1.7/2.4	778,685	273,807	2.84	5.3	77.8	5000
Boeing 935	1.7/2.4	731,600	319,300	2.29	6.0	81.3	5000
HSCT - 8A	1.6	690,000	255,000	2.71	5.0	57.1	5000
AST 100	2.7	718,000	312,299	2.30	3.8	72.0	4000
McD - AST	2.2	750,000	310,313	2.42	2.65	75.0	4400
McD Low Boom	1.8/2.4	830,000	299,200	2.77	4.0	66	5000

Commercial Aircraft

Supersonic-Cruise

	M	W_{GTO}, lb	W_E, lb	W_{GTO}/W_E	F_A	W_{GTO}/S	Range, nmi
Concorde	2.0	385,000	141,000	2.73	2.1	99.8	3800
Tu - 144	2.2	396,830	157,500	2.52	2.2	72.7	3500

Subsonic-Cruise

	M	W_{GTO}, lb	W_E, lb	W_{GTO}/W_E	F_A	W_{GTO}/S	Range, nmi
Boeing 747 - 200B	0.85	823,000	371,700	2.21	8.2	150	5190
BAC VC - 10	0.85	321,995	146,979	2.18	8.7	107.1	5040

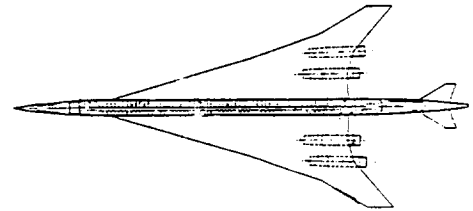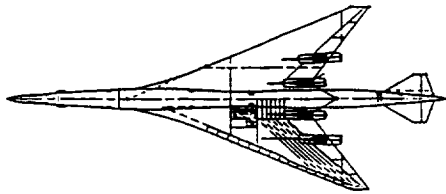Appendix B. Planforms Of The Aircraft And The Concepts Listed In Appendix A.
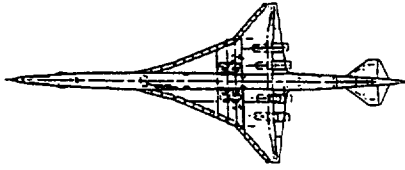
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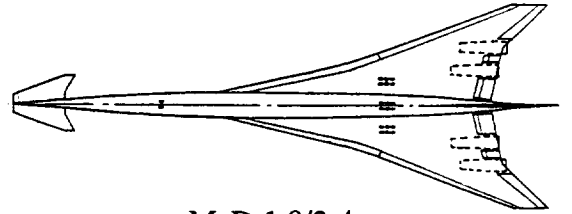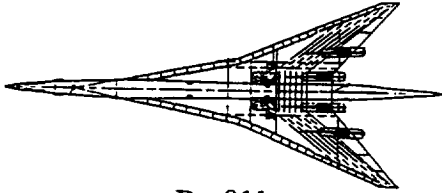
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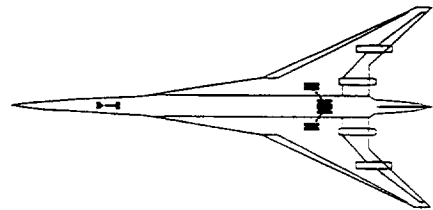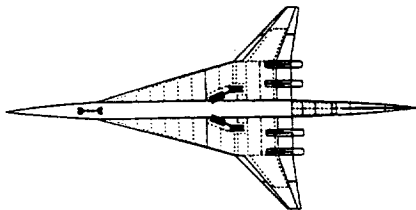Baseline Mach 2.4

Baseline Mach 3.0

B - 747

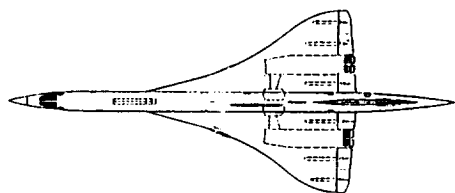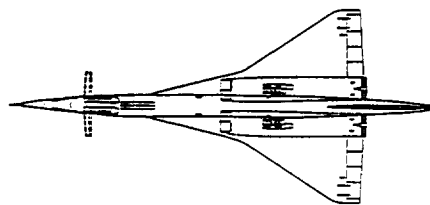McD 1.8/2.4

AST - 100

LB - 16
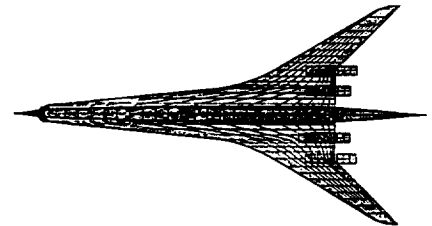
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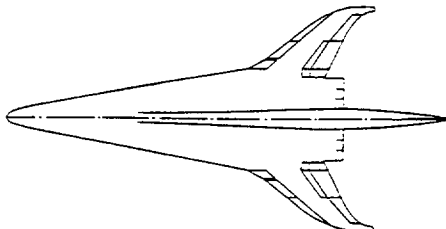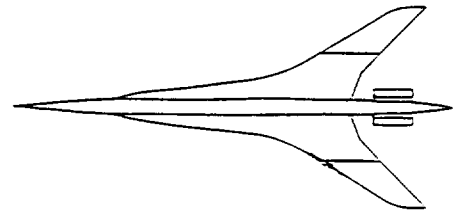
LB - 18 (HSCT - 10B)
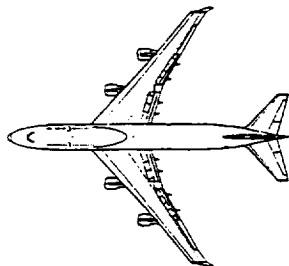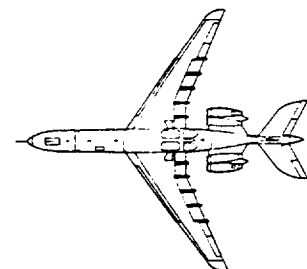
VC - 10
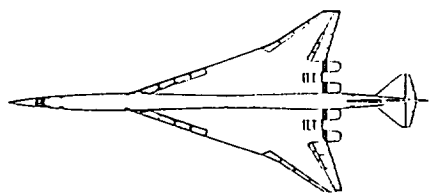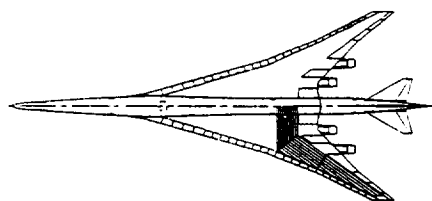
Appendix B. Concluded.

Concorde

Tu - 144

MCDONNELL DOUGLAS AST

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13. ABSTRACT *(Maximum 200 words)*
During the cruise segment of the flight mission, aircraft flying at supersonic speeds generate sonic booms that are usually maximum at the beginning of cruise. The pressure signature with the shocks causing these perceived booms can be predicted if the aircraft's geometry, Mach number, altitude, angle of attack, and cruise weight are known. Most methods for estimating aircraft weight, especially beginning-cruise weight, are empirical and based on least-square-fit equations that best represent a body of component weight data. The empirical method discussed in this report used simplified weight equations based on a study of performance and weight data from conceptual and real transport aircraft. Like other weight-estimation methods, weights were determined at several points in the mission. While these additional weights were found to be useful, it is the determination of beginning-cruise weight that is most important for the prediction of the aircraft's sonic-boom characteristics.

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