Advanced Technology Transport Configuration

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The development of integrated airplane configurations becomes more important as the design Mach number approaches 1.0. The compromises that must be made, as well as the practical constraints that must be imposed upon the theoretical optimum, require careful assessment. Development of new or advanced technology is necessary to provide the performance base that will allow an environmentally acceptable configuration to be developed and still maintain satisfactory economics for a viable commercial transport. The study indicated that noise levels of approximately FAR 36 minus 10 EPNdB could be reached without an economic penalty provided advances are made in the functional areas of structures, aerodynamics, propulsion and flight controls to maintain the airplane performance at a level sufficiently high to pay for the reduction in noise.

Introduction

THE airlines, over the past 20 years, have been able to improve service to the passenger at a relatively constant fare level because the productivity of the airplanes has improved through technology advances yielding both improved performance, increased size and speed. Realistic appraisal of the benefits that advanced technology can offer to future commercial transports requires that the appraisal be carried out on airplane configurations that are practical from the technical, economic, and producibility standpoints. Such was the case during conduct of NASA Contract NAS1-10703 "Study of the Application of Advanced Technologies to Long-Range Transports," which was successfully pursued by Boeing during 1971, Refs. 1 and 2. The major effort on that contract was devoted to the analysis of advanced technology, including the application of supercritical technology over the high subsonic, Mach 0.90–0.98, speed range. The approach followed, to take best advantage of advanced supercritical aerodynamics, propulsion, noise reduction, and structural and systems technology during the configuration development portion of the contract study, is the subject of this paper. The results provided high confidence that conclusions regarding advanced technology application were made on the basis of a sound potential product definition. These conclusions were further supported by the results of considerable Boeing research, in the high subsonic regime, that had been conducted during the previous 3-year period.

Configuration Cycle

Each new airplane has unique characteristics, depending on the nature of the desired end product. These characteristics are a function of payload-range, application of new technical principles or technology, design speed, and other special characteristics desired by a customer. A well-defined but complex process (Fig. 1) is followed during development of the configuration for any new airplane. The preliminary definition usually comes from an aerodynamic concept with the basic airplane requirements defined (step 1, Fig. 1). Following are some of the desired requirements applicable to the NASA contract studies.

Passenger accommodations—Six-abreast, double-aisle passenger cabin with passenger services equivalent to those of the wide-body airplanes.

Airport compatibility—The airplane should be capable of operating from fields equipped to handle the wide-body airplanes (as to field length, runway flotation, ground support equipment, etc.).

Design speed—The studies considered the Mach 0.90 to 1.0 cruise speed range using supercritical technology. Above approximately Mach 0.92, this also required the use of area ruling. Research wind tunnel data supplied by the NASA supported this aspect of the definition.

Payload-range—The study included configurations capable of 40,000-, 80,000-, and 120,000-lb. payloads operating over 3000- and 5500-naut miles range.

Balance philosophy—A center-of-gravity range that provides good ground handling and minimum trim drag during cruise, and reduced stability with stability augmentation if required.

Noise—The study considered configurations designed to 0, 10, and 20 EPNdB below current FAR 36 requirements.

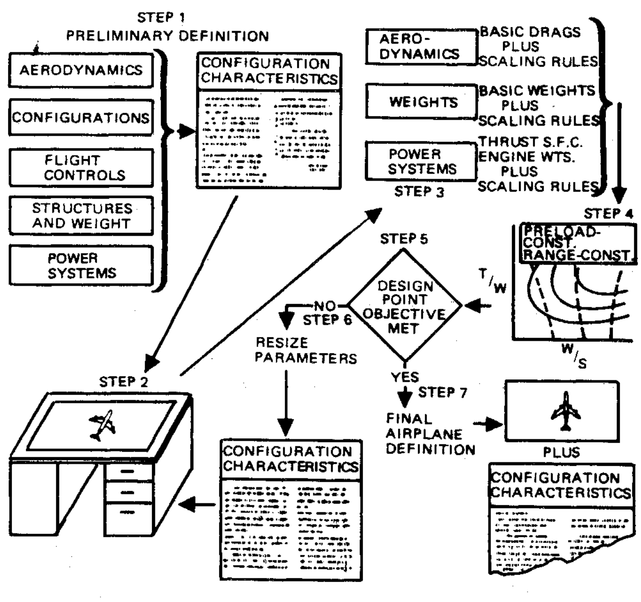

Fig. 1 Configuration cycle.

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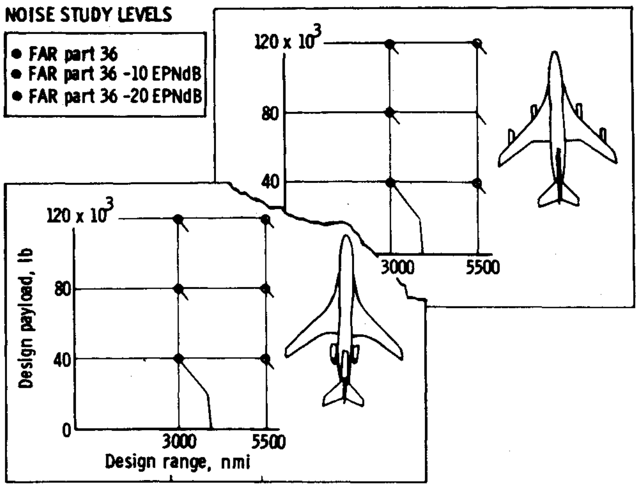


Fig. 2 Payload/range configuration matrix.

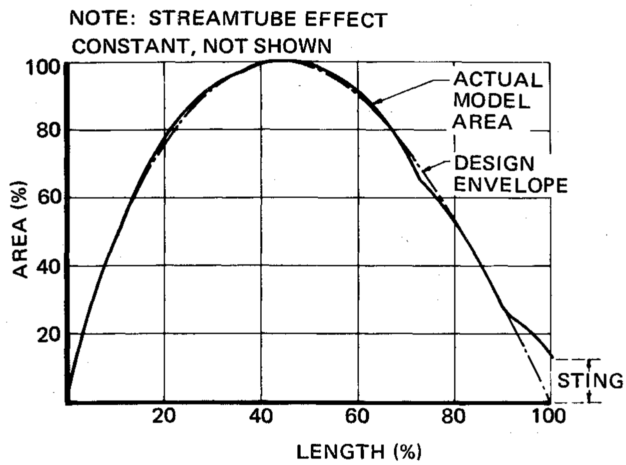


Fig. 4 Area plot development.

Structures design—Application of bonding and composite structure for minimum structural weight.[3]

Power systems—Integration of engines that produce minimum noise and incorporate advanced engine technology. Results of parallel NASA contract studies by General Electric and Pratt & Whitney assisted in this definition.

Reference to Fig. 1 indicates that the preliminary definition (step 1) is turned into a tentative configuration of a full-scale airplane (step 2), which is then analyzed by determining the basic performance characteristics (step 3). After determining the basic performance characteristics, it is necessary to be able to vary each of the basic performance parameters, i.e., the aerodynamics, weights, and propulsion factors about the baseline to be able to optimize the gross weight of the airplane to perform a constant payload range mission. This means that parametric variations or scaling rules must be developed in each of these areas. These are done by allowing the drags, basic weights, thrust, SFC and engine weight to change with gross weight. The performance program can then cycle the airplane until the proper gross weight is determined to do the mission. These factors, plus the basic weights, drags, and engine size used in the preliminary definition are used to develop "airplane size" diagrams (step 4). These plots show the influence of thrust loading and wing loading on airplane gross weight, low-speed performance, initial cruise altitude, and economics. Examining these diagrams and checking the characteristics of the airplane against the design point objectives (step 5), the cycle is repeated if there is a discrepancy, or the final airplane definition is initiated (step 7).

Parallel configurations can be developed simultaneously or in series, as was accomplished in the NASA contract studies. Two configuration arrangements were considered, differing only in the quantity and arrangement of the engines. Six payload-range combinations were included, resulting in 12 basic configurations as shown by the matrix in Fig. 2. Three noise levels (FAR part 36, and FAR 36-10 and -20 EPNdB) were investigated for each of the 12 configurations. The remainder of this paper will concentrate on the configuration development of the 3000-naut mile, 40,000-lb. payload, three-tail-mounted-engine airplane which was identified as the NASA configuration.

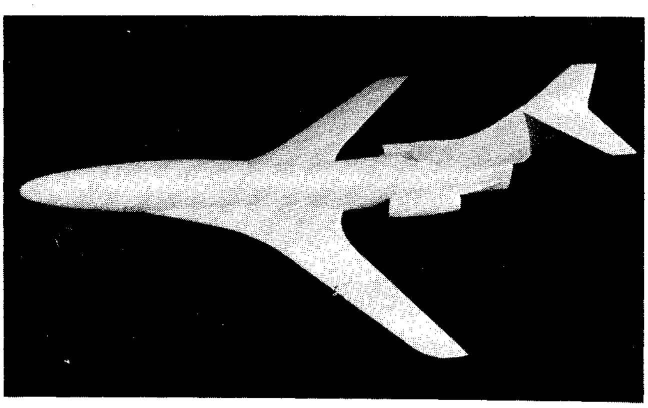


Fig. 3 Wind tunnel model.

Aerodynamic Definition

The NASA wind tunnel model (Fig. 3), was used to develop all of the basic aerodynamic data used in the study. NASA conducted the tests and provided the basic model definition and wind tunnel data. The model represents a three-engine-aft configuration, with an area-ruled body and circular cross section at any longitudinal section. This was modified slightly, in the lower portion under the wing at the wing trailing edge, for landing gear placement. The model was sting-mounted, which prevented a flowthrough center nacelle installation; however, the two side nacelles represent the area progression of a potential propulsion system.

The initial task in developing the airplane configuration was to use the area distribution from the wind tunnel model and convert it into a nondimensional plot, as shown in Fig. 4. Computation of the actual model and design envelope into percentage parameters provided an easy way to transfer the basic cross-sectional area that represents the wind tunnel model, to any size airplane. The airplane was initially sized by scaling the wind tunnel model geometrically to represent the desired wing area, defined by the wing loading, that satisfied the required payload-range performance.

A check was made of the airplane with respect to body volume for passengers and cargo and for wing fuel volume. This provided a full scale airplane that was still representative of the wind tunnel model. The size was determined to provide the necessary body volume for the payload, and the airplane was checked to determine whether other areas must be modified because of balance, landing gear installations, etc.

Figure 5 shows the major areas of modification that were made to the scaled-up wind tunnel model to transpose it into a commercial transport that would carry a 40,000-lb. payload. Each of these areas will be discussed, with details shown on the variations and how they were incorporated into the basic airplane while maintaining the smooth area distribution defined in Fig. 4.

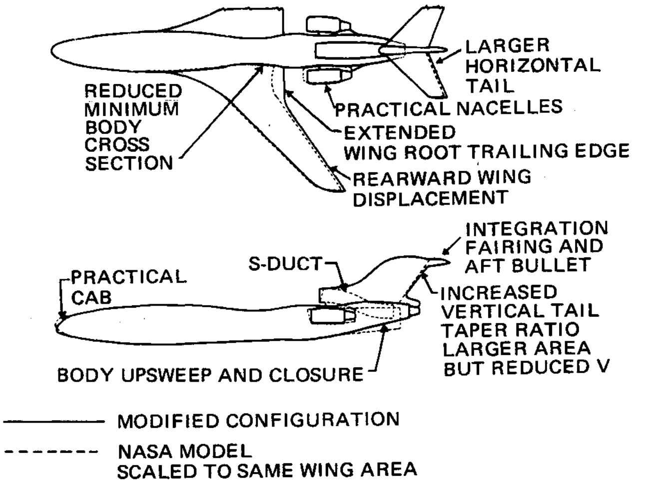


Fig. 5 NASA high-performance configuration comparison.

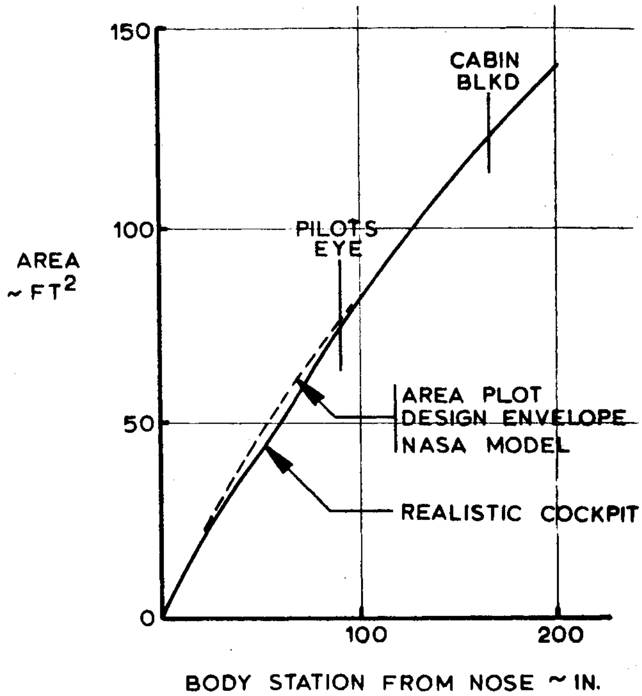


Fig. 6 Cockpit area distribution.

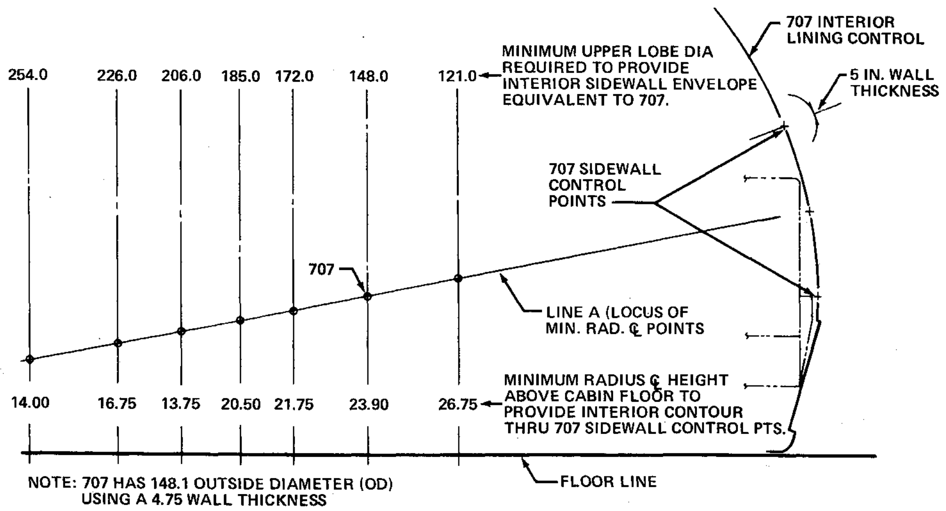
Configuration Definition

Starting at the front of the airplane, a slight modification from the NASA model was necessary to provide visibility for the crew and contours to permit the installation of windshield glass. In this case, unidirectionally curved panes were assumed to minimize the areas but required modification to provide a reasonable design weight. A slight droop or camber was included in the forebody to minimize the amount of windshield glass that must be provided to give the crew adequate vision. These modifications made a minor change to the area distribution at the front of the airplane, as shown in Fig. 6. Testing of similar models with variations in the forward part of the body has indicated negligible change to the over-all drag.

Development of the body cross-sectional shape is of prime importance in a passenger airplane. Most wind tunnel models are developed with circular body cross sections, as was the case in the NASA model. Figure 7 shows the method used to determine the basic side wall clearance and upper lobe diameters required for various seating arrangements. The upper lobe shapes were developed from experience using the 707 side wall clearances at the arm rest and passenger head as the critical control points. In developing the passenger cabin of all study airplanes, a double-aisle, six-abreast seating was a design objective.

The development of each cross-sectional element of the body was controlled by the upper lobe passenger seating and the maximum area permitted by the body area distribution. The critical control points along the length of the body were selected, with subsequent development to the cross sections. The control points were selected to include the cockpit, front of the passenger cabin, the minimum body cross section at the landing gear, and the aft portion of the passenger cabin. The landing gear was the first section developed, since it is close to the point of maximum total airplane area. In the case of the full-scale airplane developed from the expanded wind tunnel model, the body area was determined by subtracting the wing from the total airplane area. The body cross-section area was then used to control the upper and lower body lobes. Starting with the body section at the landing gear, the lower lobe area was defined as that necessary to contain the landing gear. The remainder determined the size of the upper lobe of the cross section, using Fig. 7, which met the design objective and was used to define the minimum body cross section at the center of the aiplane. The process was completed for each of the other control points. This established the plan view of the body, since the lines must meet the rate of change of curvature to prevent separation and provide the proper area progressions. Scale-up of the wind tunnel model through the above process resulted in a two-aisle, five-across seating arrangement for a limited portion of this configuration.

Fig. 7 Upper lobe sizing tool.



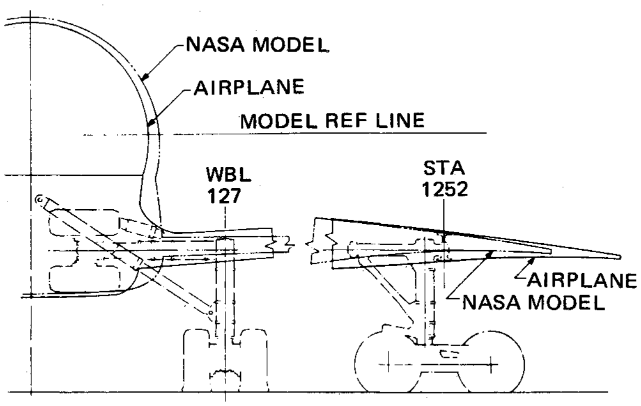


Fig. 8. Landing gear installation.

Integration of the main landing gear required extensive modification of the inboard wing, wing body intersection, and lower body lobe area for stowage. Location of the main landing gear with respect to the c.g. was determined by the static margin aft of the aft limit that must be maintained for satisfactory ground operation, at the same time maintaining at least 3% of the gross weight on the nose gear for nose wheel steering. The length of the main gear was established by the rotation angle required for takeoff and landing. Stowage of the gear in the body located the spanwise position on the wing. The distance of the main gear from the centerline was then checked to ensure that the lateral stability was adequate for required turning velocities.

Once the gear location was established, the wing was checked for adequate thickness at the critical rear support point of the gear trunnion. In this case, it was necessary to almost double the available wing thickness as represented by the scaled-up NASA model. A rearward extension of the inboard wing trailing edge was used to provide more thickness in the wing, as shown in Fig. 8. Airfoils inboard of 40% semispan were affected by this wing planform modification and were changed by scaling to the new chord while maintaining the same chordwise thickness and camber distribution. The required additional thickness was added geometrically about the camber line without further extension of the inboard wing trailing edge. The area plot of the basic and modified wings are shown in Fig. 9. It is seen that the area added by this wing thickening for the landing gear appeared at the maximum wing cross-sectional area, requiring an increase to the total area plot or a revamping of the body cross section. As shown in Fig. 8, the additional wing cross-sectional area was compensated for by reducing the upper lobe contour to provide only sufficient body cross section for a minimum double-aisle, five-abreast passenger cabin. The lower body was also deepened slightly to house the landing gear, and some of the side fairing was cut back to help compensate for the additional wing cross section.

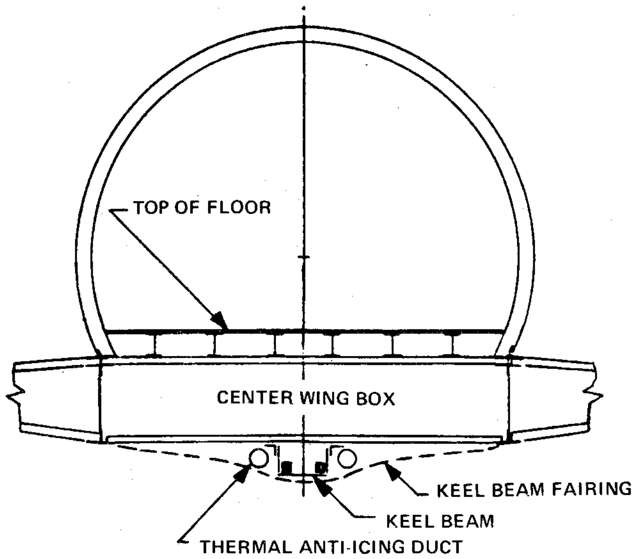


Fig. 10 Keel beam installation.

As noted above, the critical section for the body for the minimum cross-sectional area occurred at the landing gear. This is also where the primary structural wing box passes through the body. The lower surface of the body and the lower surface of the wing tend to coincide, providing a minimum cross-sectional area. A discontinuity in the body lower lobe structure occurs where the main landing gear wheels are stowed, just aft of the wing center section. To restore the body bending material, a keel beam connecting the fore and aft fuselage was provided below the wing (Fig. 10). The body keel line was modified to provide additional depth for the keel beam at a minimum curvature to prevent excessive loads being transmitted into the supporting structure. Sufficient area was also provided for air conditioning air ducts, fuel lines, control systems, hydraulic lines, etc., to pass forward and aft of the wing center section. Figure 10 shows a method that may be used with minimum impact on the total area distribution. The major keel members were brought together to pass between the landing gear wheels in the wheel well. The box thus formed was then carried on forward of the center section wing, providing area for the systems to pass beside it.

Aft body closure was a primary problem in transposing sting-mounted wind tunnel models to full-scale airplanes. This is especially true with aft-body-mounted engines. In this case, the two side engines were not a problem and were translated directly from the wind tunnel model to the full-scale airplane. However, the center engine, with

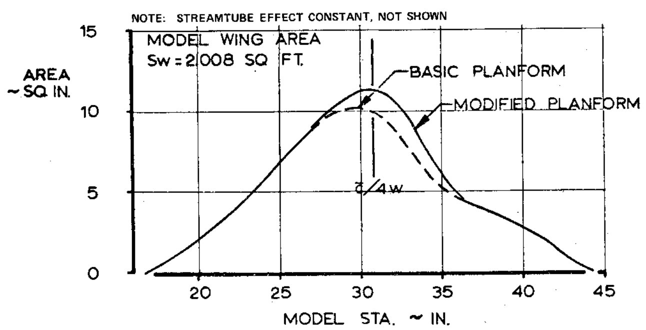


Fig. 9 Model wing area distribution.

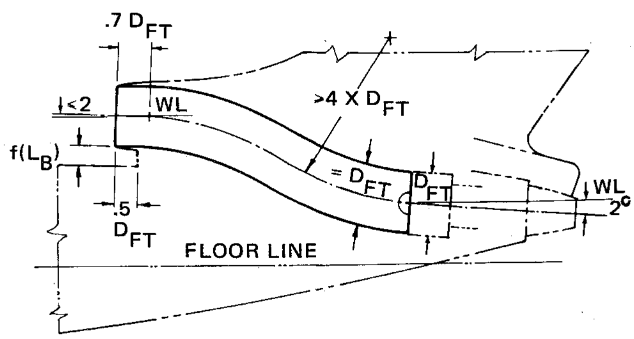


Fig. 11 S duct geometry.

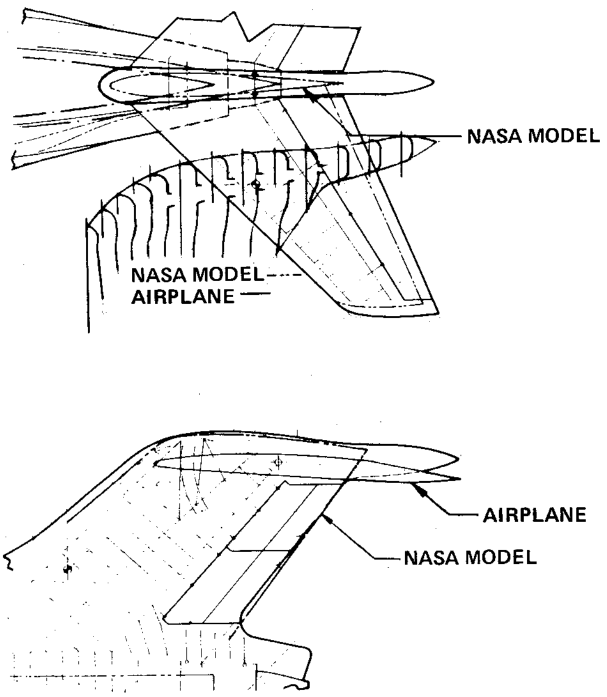


Fig. 12 Vertical-horizontal integration fairing.

either an "S" duct or a straight duct design, required careful integration and compensation to convert from the untapered sting-mounted aft body, to the tapered full-scale airplane. Figure 11 shows the controlling requirements that were used in developing the "S" duct and the center engine. The vertical position of the engine and its tail pipe is fixed by the rotation angle the airplane must have for takeoff and landing. The length of the duct was then established by the curvature that could be permitted in the duct without flow distortion, and the vertical displacement between the centerline of the inlet and the engine. Care was taken to provide adequate clearance between the lip of the inlet and the top of the body for the boundary layer on the body during all flight conditions and angles of attack. Testing of these types of installations, including the closure that must be made behind the inlet in tapering out the width of the inlet aft along the vertical tail, must be accomplished with models that have plate mounts under either the body or the wing tips. The propulsion system integration into the over-all configuration is important and must be considered in developing the over-all airplane. This is covered in detail in Ref. 4.

The integration of an all-moving horizontal stabilizer and a vertical tail required careful assessment of the empennage intersection. The stabilizer sizing and balance philosophy used is discussed later, but the airplane required a volume coefficient or tail area that was slightly larger than that for the NASA model. The vertical tail area, however, was satisfactory. The design aspects that required modification were: The horizontal stabilizer pivot was located at 25% of the MAC of the horizontal stabilizer to minimize stabilizer actuation loads. The vertical tail was relocated so that the stabilizer pivot could be supported at the vertical tail rear spar. The pivot support points were moved 25 in. apart, requiring a fairing width of 33 in. as compared to the 17 in. on the wind tunnel model to provide an effective reaction to the moments generated on the horizontal stabilizer. The vertical tail surfaces in the area of the all-moving stabilizer were relofted to provide flat wiping surfaces to accommodate sealing of the stabilizer through a travel of $-10°$ to $+6°$. Leakage in these critical areas cannot be tolerated; therefore, a smooth wiping surface to minimize seal complexity was required. An envelope was provided that permitted a multiple actuator system near the stabilizer front spar with the actuators arranged side by side. In this case, a triple system was used to provide redundancy for system failure.

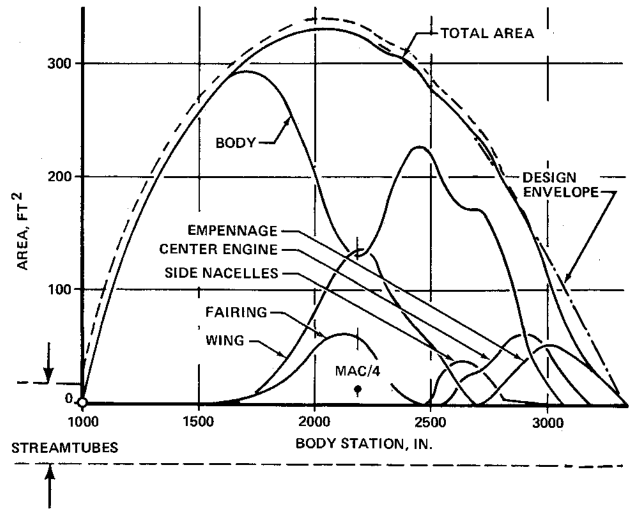


Fig. 13 Airplane area distribution.

A vertical-horizontal integration fairing was designed for the geometry constraints listed above to fill in and smooth the total empennage area distribution, as shown in Fig. 12. In addition, an aft bullet fairing was designed to reduce the closure of the local horizontal plus fairing area distribution. In the plan view, contouring of the fairing was designed to follow the desired streamlines over the

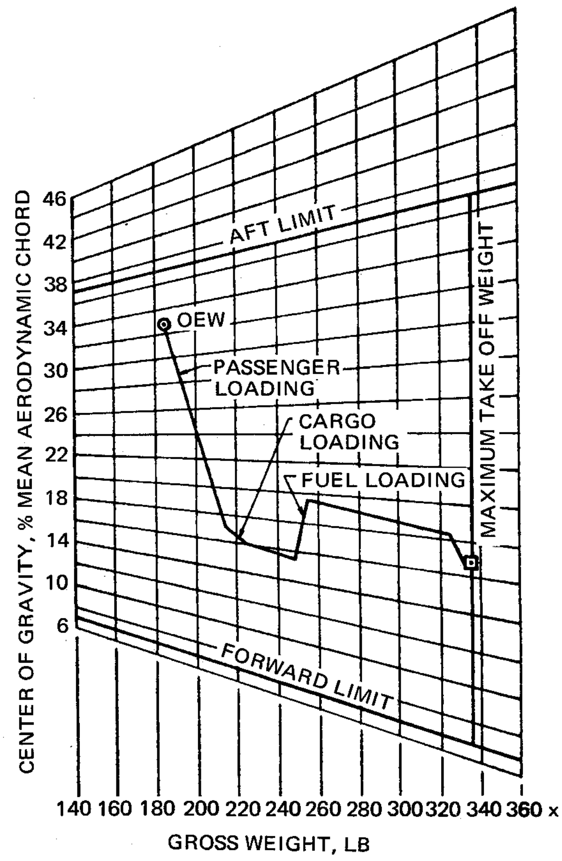


Fig. 14 Airplane balance—Phase I, NASA and alternate configurations, minimum tail volume coefficient ($\bar{V}$).

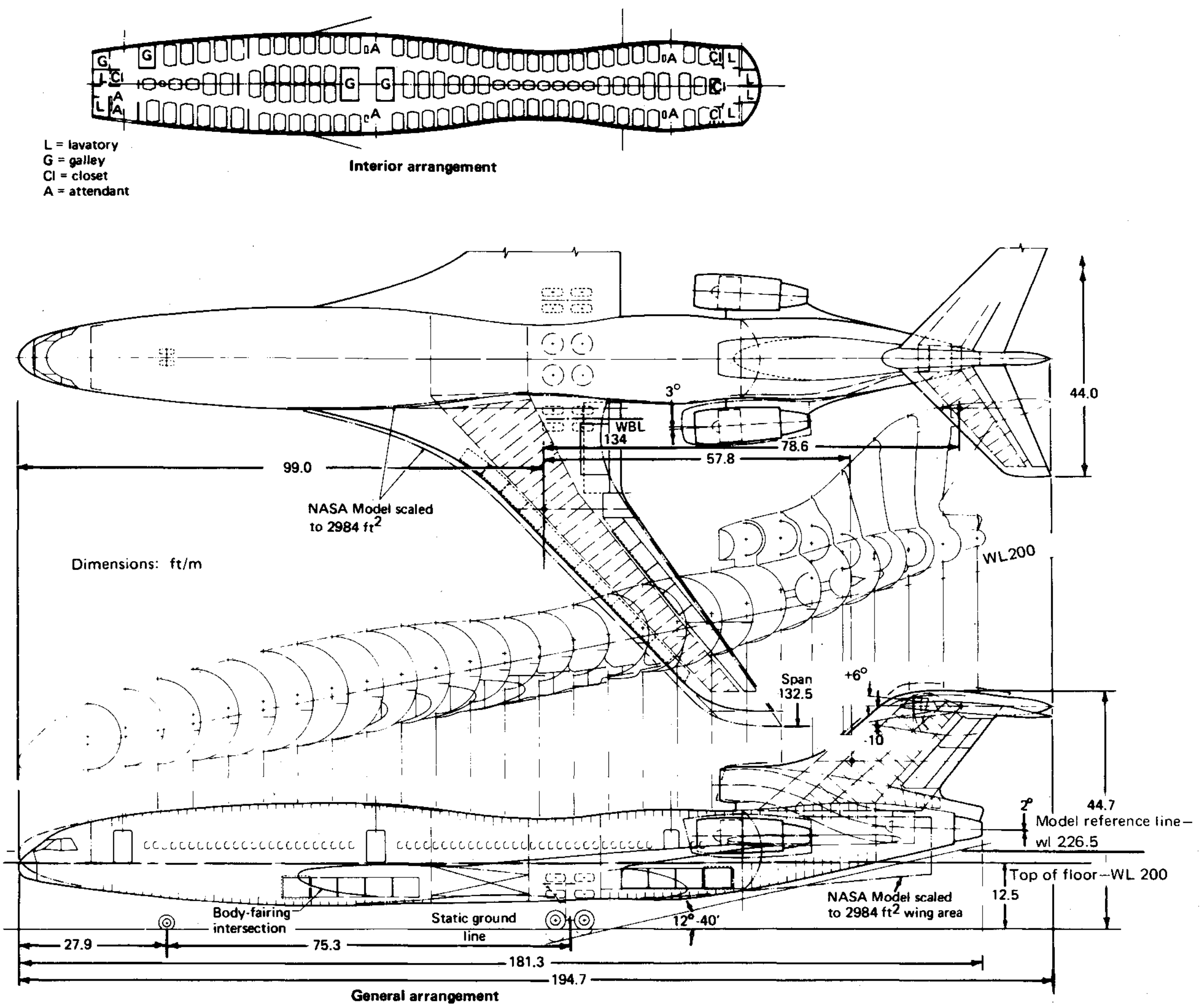


Fig. 15 Airplane configuration.

lower lifting surface of the horizontal stabilizer root section. To avoid an abrupt closure of this fairing forward of the horizontal stabilizer leading edge intersection, a forward extension of the fin leading edge was necessary which reduced aspect ratio and increased fin area and taper ratio.

Full-Scale Airplane

Incorporation of the modifications to the full-scale wind tunnel model required changes to cross-sectional area breakdown of the area plot. The component area distribution for the total full-scale airplane is shown in Fig. 13. The streamtube for the three engines is shown below and to the left of the area plot. The exhaust area is carried below the abscissa, and the inlet area minus the exhaust area is carried above the airplane area plot (shown by the dotted line), disappearing when the inlet location is reached along the length of the airplane. The remaining part of the nacelle, the area of the engine and nacelle minus the streamtube, is shown in the area plot above the abscissa. Figure 4 shows the design envelope that was developed in comparison to the total equivalent area of the airplane. In Fig. 13, the wing area distribution that was modified by the landing gear requirements is subtracted from the total area, together with the empennage, fairings, side nacelles, and center engine areas, leaving the cross-sectional area of the body. The body was developed into the upper and lower lobe to provide the required volumes and seating space for the configuration, as described previously.

The balance diagram for a three-engine-aft-type airplane is shown in Fig. 14. The aft c.g. limit is located at the most forward maneuver point. The forward c.g. limit is located by the ability to trim the landing approach flaps-down wing lift and pitching moments using a nominal horizontal tail lift coefficient. Airplanes with aft-mounted engines exhibit a very steep passenger loading curve; therefore, the loaded airplane tends to balance at a relatively forward c.g.

Figure 15 shows two views of the resulting configuration in solid line and the scaled-up NASA wind tunnel model in the phantom line. The difference in the wing planform, the engine, and the slight difference in the tail body shape are evident. This reflects the same variations shown in Fig. 5. The interior arrangement included in this figure shows a small region of five-abreast double aisles through the minimum body cross section. This results from the wind tunnel model being too narrow for six-abreast seating when scaled up to the proper wing area, as well as the additional reduction of body volume due to the yehudi wing area for the landing gear. The interior arrangement was for 199 passengers—29 first class and 170 tourist. The seating arrangement provides nominal 38-in. pitch in the first class and 34-in. pitch in the tourist section. Galley and lavatory accommodations per passenger are similar to those provided in current wide-body airplanes. Forward

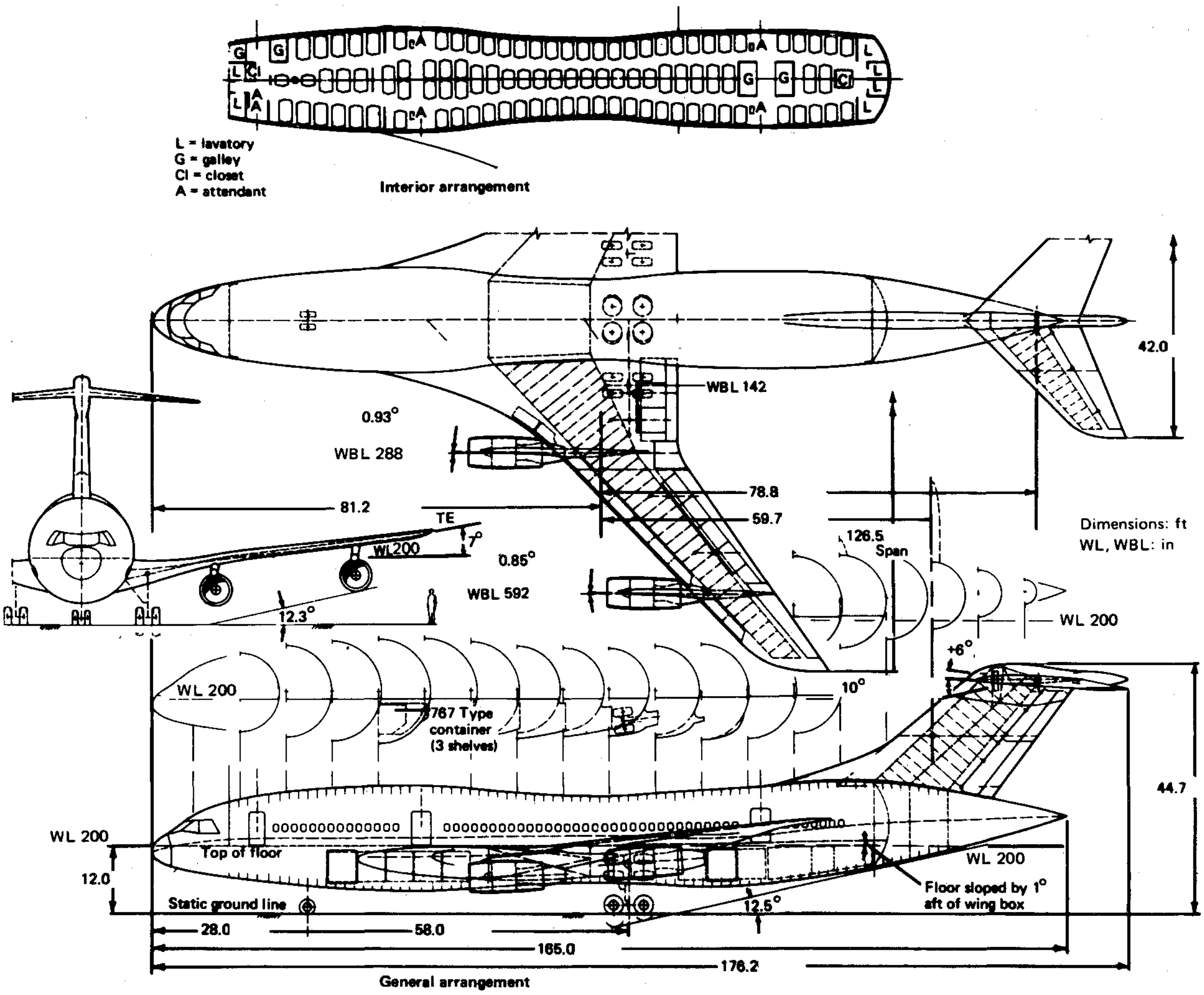


Fig. 16 Alternate airplane configuration.

and aft lower deck containerized cargo compartments are provided for loading flexibility.

Alternate Configuration

In parallel with the development of an airplane such as that described above, one or more variations are usually carried along to determine whether the baseline configuration arrangement can be improved or whether any problems encountered can be solved in an easier way. Figure 16 shows one alternate arrangement that was developed in parallel with the NASA configuration. The primary difference is in the engine location, which provides a check on engine placement effects. When compared to the NASA three-tail-mounted-engine configuration, the wing is much farther forward on the body and there is a slight reduction in the amount of body contouring. The wing-mounted engines impose some aerodynamic problems, in placing the engines spanwise to provide the proper impact on the flutter of the wing, and in designing the wing to fly without a penalty in the flowfield developed by the nacelle. Indications are that practical solutions to such problems are available.

The basic arrangements of the two airplanes were otherwise maintained as close as possible, including a T-tail arrangement. The passenger cabin arrangements are very similar, except that in this case the double-aisle, six-abreast arrangement entails a slight increase in the total area of the airplane. The effect on the balance can be seen in Fig. 17, where the curve for the four-engine airplane is added to that of the three-engine airplane. The passenger loading curve is much flatter and provides a means of keeping a fairly constant c.g. during all phases of the flight. This eases airplane loading problems and makes it easier to design the airplane to fly close to the aft limit for minimum trim drag.

Configuration Evaluation

Figure 18 shows the economic evaluation results for the range, payload, and configuration arrangement matrix defined by Fig. 2. The relative direct operating cost (DOC) is plotted for each of these airplanes, using a DOC of unity for the 200-passenger, 3000-naut mile, three-engine-aft (NASA configuration) airplane as the anchor point. The 3000-naut mile range, four-engine airplane shows a 5% lower DOC than the three-engine airplane with 200 passengers, increasing to 10% with 600 passengers. The 5500-naut mile DOC curve shows a minimum level for the three-engine airplane at about 300 passengers, and increases rapidly for higher payloads. The rapid increase in direct operating costs results from the rapid growth in gross weight as the payload increases at constant range. The three-engine aft configuration has a basic balance problem as the engine size and gross weight increase. The increased engine weight must be balanced by moving the wing aft on the body. This has a practical limit since the vertical and horizontal tail increase as the tail arm or distance between wing and empennage gets shorter. When this limit is reached, ballast must be added to the forward

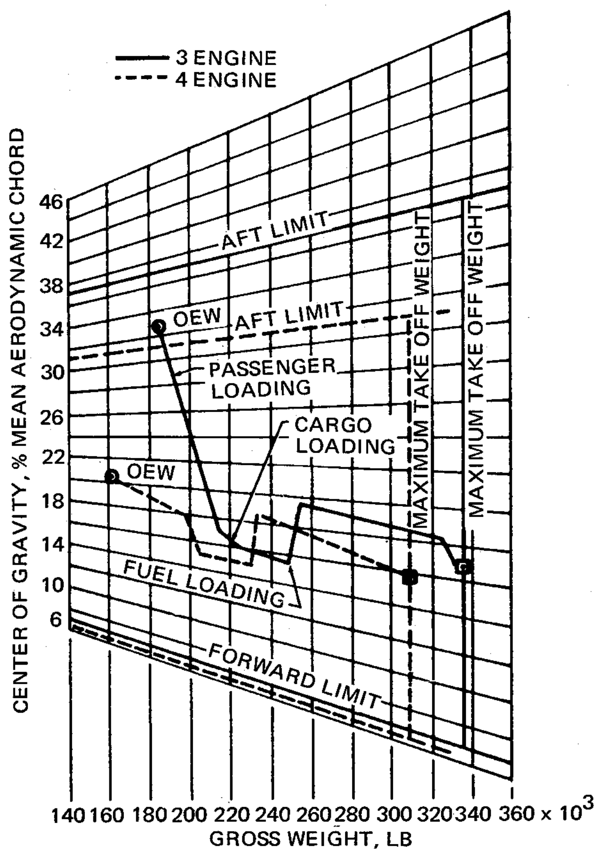


Fig. 17 Airplane balance.

part of the airplane or an engine location change considered. The divergent effect of wing area, engine size, and balance on gross weight made it impractical to include

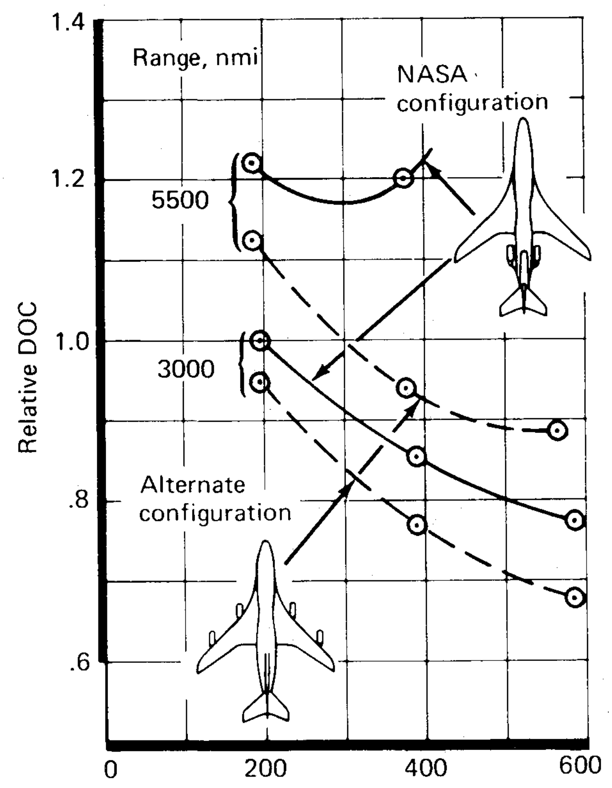


Fig. 18 Impact of configuration arrangement.

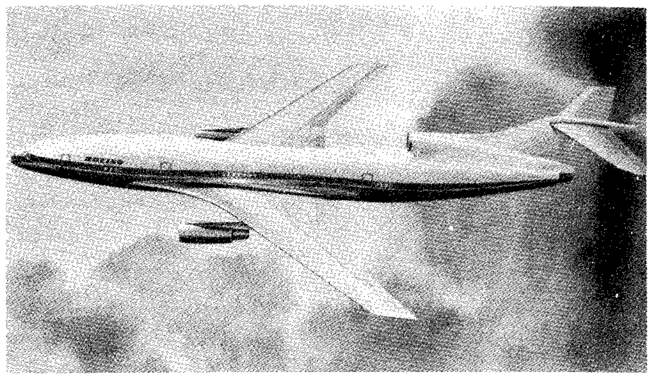


Fig. 19 Final configuration.

airplanes larger than 400 passengers at intercontinental range. As higher payloads are considered for the four-engine version, the curve begins to flatten out while maintaining an improvement in DOC with increased payload. This indicated that the three-engine airplane could be improved by moving the engines forward. A third basic configuration arrangement, with two engines on the wing and one engine in the tail, shown in Fig. 19, was defined to incorporate the better features of the previous configurations.

A different balance philosophy was used in the two-forward, one-aft-mounted-engine airplane, to reduce the trim drag during cruise. Figure 20 shows the impact on lift/drag at cruise for various c.g. locations. This indicates that the c.g. should be at about 40% to prevent the large amount of trim drag during cruise shown for the normally statically stable balanced airplane. The aft balance was accomplished as shown in Fig. 21, which indicates that an airplane with a minimum tail size is no longer optimum. The aft c.g. was moved aft to 40% along the critical maneuver variation line to provide the proper location. This results in a lighter airplane, even with the increased tail area required, because the cycled airplane requires a smaller wing and engine size. The same loadability c.g. range was maintained, which established the forward control limit. The limit is not where landing approach trim intersects the loadability curve, but rather where adequate loadability is provided. As the airplane is balanced farther aft, however, the amount of trim used during landing and takeoff is also reduced so that the airplane tends to fly with much less trim drag on approach, which impacts noise and drag in that flight regime.

Results of the aft balance philosophy are shown in Fig. 22 compared with the balance diagram applicable to the previous airplane, shown in Fig. 14. The previous method of balance is shown as a dashed line, the aft balance as a solid line. The slopes of the passenger and fuel usage

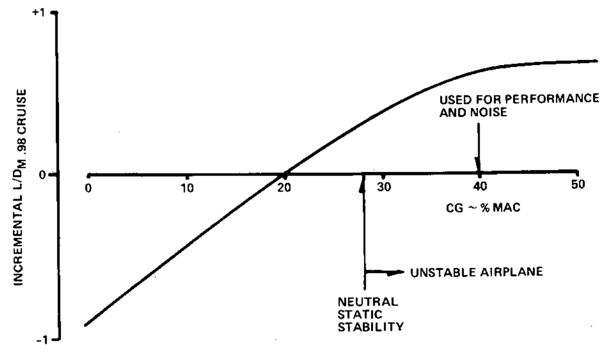


Fig. 20 Effect of center of gravity on cruise efficiency.

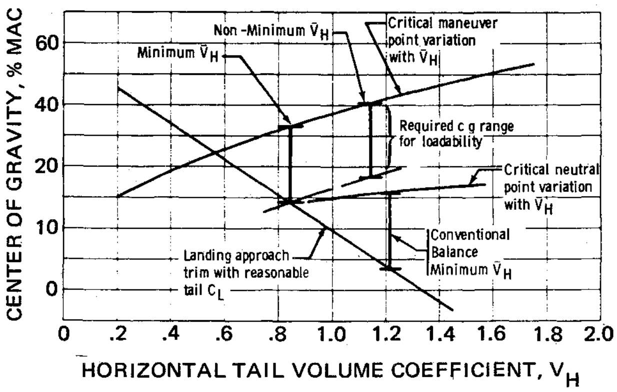


Fig. 21 Horizontal tail sizing philosophy.

curves are greatly reduced, and the airplane can be flown close to the aft limit with a large decrease in trim drag because of aft c.g. shift. The results of the aft c.g. balance philosophy and placing of the two engines or the wing are shown in Fig. 23. In other respects, this airplane was configured to the same basic philosophy as was used on the previous configurations, including a T-tail, but with one center aft engine, and two wing-mounted engines. The basic drag and engine performance of the airplane is considered to be similar to the previous configuration. However, the major improvement over the aft engine airplane is the reduction

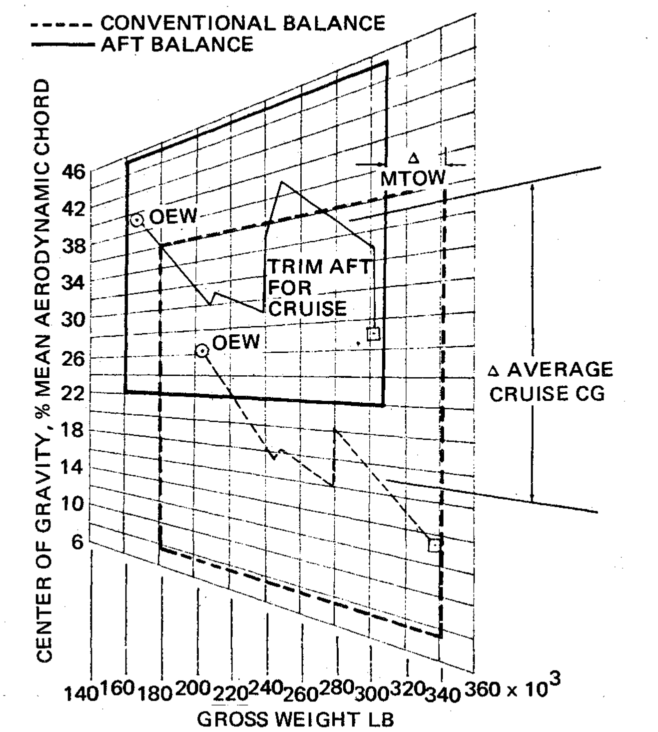


Fig. 22 Airplane balance—gross weight and center of gravity, effect of aft balance.

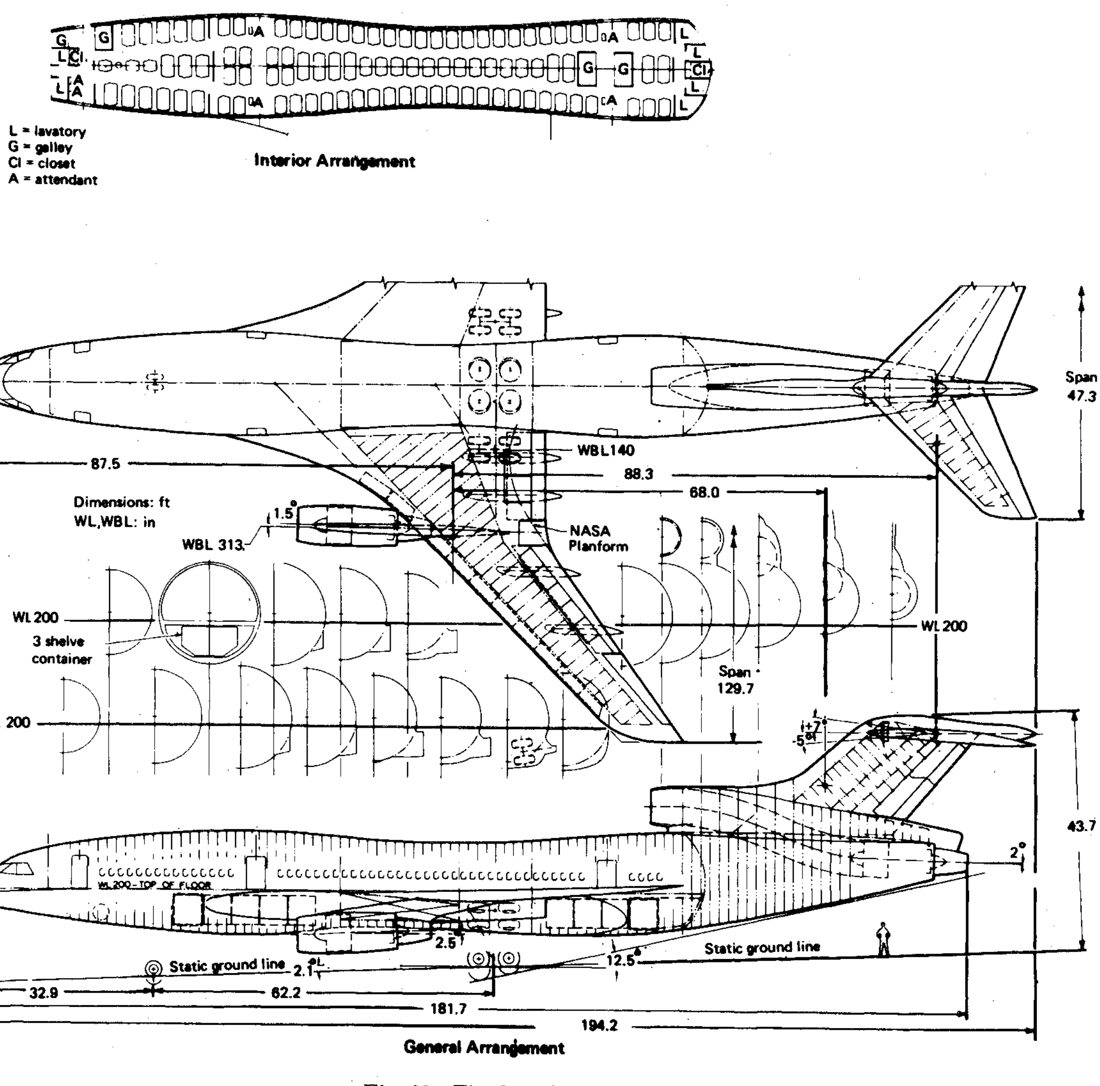


Fig. 23 Final configuration.

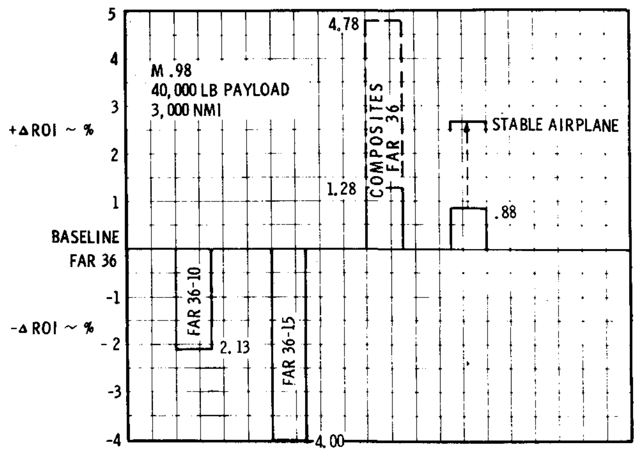


Fig. 24 Impact of technology on return on investment.

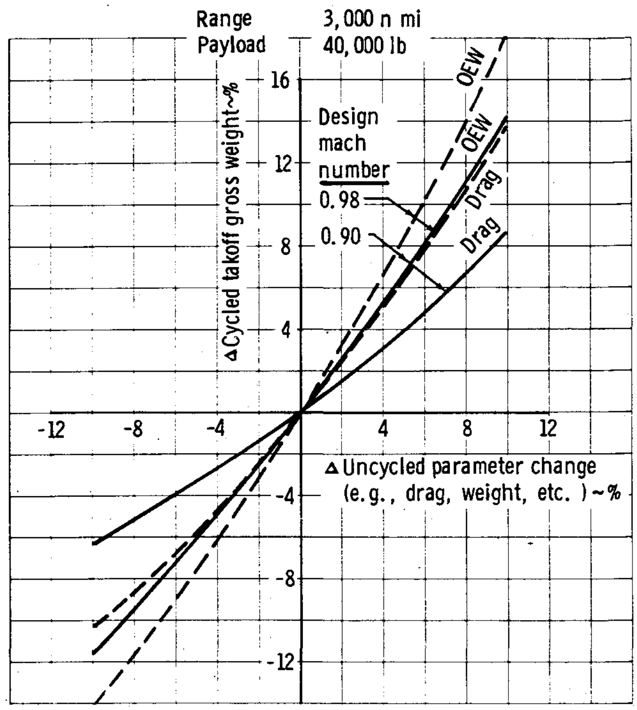


Fig. 26 Design sensitivity.

in trim drag and OEW due to the improved balance. The combination of these factors moved the wing considerably forward, providing a much better balanced airplane. The resulting interior arrangement is shown with a double-aisle, six-abreast seating arrangement for the minimum cabin and an interior that will handle 199 passengers. In this case, the split in passengers in 31 first class and 168 tourist. This change was due to the reshaping of the passenger cabin which makes the break between first class and tourist slightly different than that of the interiors shown in Fig. 15.

Technology Impact

The configuration development work described above supplemented the major effort on the study, which was directed to a) the appraisal of benefits that could accrue by application of advanced technology, b) evaluation of the state of readiness of attractive technology items, and c) preparation of recommendations for future action. The configuration development activity reflected the results of the major technology evaluation effort, as results of those studies became available. As expected, significant weight and cost penalties were imposed to reduce noise to 10 and 20 EPNdB below current FAR part 36 standards; however, advanced structures, flight control, and propulsion system technologies offered potential benefits that could largely overcome penalties due to noise. Application of advanced composites yielded potential structural weight reductions of over 20%, Ref. 3. Full application of the control configured vehicle (CCV) philosophy to the three-engine-aft Mach 0.98 configuration, designed to be independent of stability augmentation, yielded an 11.5% reduction in takeoff gross weight. Although not as dramatic additional contributions were indicated by application of active controls for flutter suppression and load alleviation.

An airplane designed to meet FAR 36 noise standards will realize significant improvements in return on investment (ROI) from the application of advanced technologies. In Fig. 24, composite structure for a Mach 0.98, 40,000-lb payload, 3,000-naut mile range transport will improve ROI by 1.28% (from 18% to 19.28%). If the production costs of composite structure were the same as those of conventional structure, the ROI increment would increase to 4.78%. Active controls produce an ROI increment of 0.88% applied to the stability-augmentation-systems-dependent example airplane. An ROI increase of 2.58% for active controls when they are applied to a stable airplane is shown for reference only. Penalties are incurred by designing to reduced noise levels. Without the benefits of advanced technologies, the ROI would be reduced by 2.13% at a noise level 10 EPNdB below FAR 36. At FAR 36 − 15 EPNdB, the ROI penalty increases to 4%. The inclusion of noise reduction, composite structures, and active controls in an airplane combine to pro-

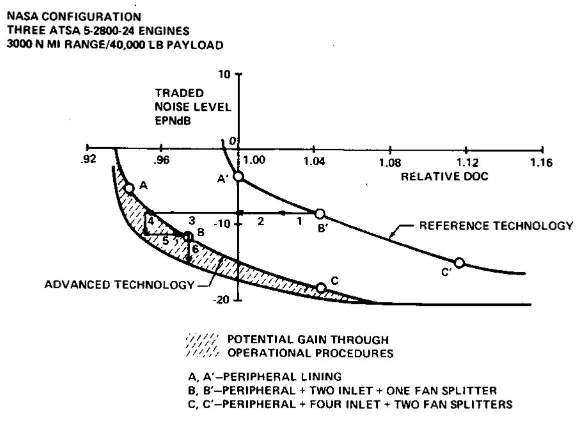


Fig. 25 Effect of technology on noise—DOC trade.

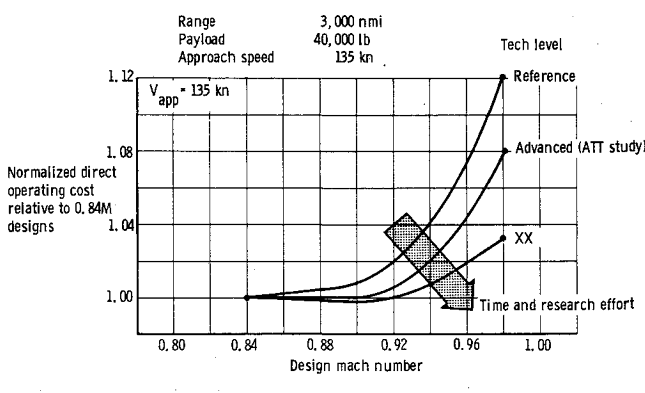


Fig. 27 Influence of technology advancements.

vide noise reduction without a large penalty in ROI. Due to the variation in airplane and engine size with varying amounts of technological change, the increments are not additive. In the case shown in Fig. 24, combining the technologies and noise reduction result in an FAR 36 − 10 EPNdB level with an improvement in ROI of 0.6% and an FAR 36 − 15 EPNdB level with reduction in ROI of 0.50%.

Although it was not possible to reflect all advanced technology study results on an integrated configuration basis, data were developed that provided insight into the impact that could be expected. Noise reduction is of primary importance. The impact of technology on the noise reduction penalties for the airplanes just described is shown in Fig. 25. A plot of relative DOC vs EPNdB traded noise level is shown. The reference technology represents an airplane that has current wide-body jet structures and engine technology, supercritical wing, and the balance at the most forward maneuver point.

Points A, B, and C in Fig. 25 reflect increasing amounts of engine treatment and the respective penalty in terms of direct operating cost. The shift in the line from the reference technology to advanced technology comes about by a series of improvements in all areas of the airplane. For instance, in going from point B′ to B and using the arrows and the numbers in the diagram to represent the various improvements, item 1 is obtained from improved aerodynamic smoothness throughout the surface of the airplane, item 2 from an improvement in the thrust-to-weight ratio of the engines over today's technology, item 3 from an improvement in airframe structural weight due to bonding and composite technology, item 4 from improved acoustic treatment, both in the material and the application to the propulsion system, item 5 from a slight penalty in DOC due to increased cost of manufacture of the advanced structure, and item 6 from noise reduction through improved approach procedures and instrumentation which allows for steeper glide paths, curved approached, etc. It can be seen that advancements in each technical area can contribute. The potential exists for achieving low noise levels while maintaining or improving the economics of long-range transports, even at the high subsonic speeds considered by the study. This will be possible only if the necessary research and technology are pursued on a timely basis.

Conclusions

Development of airplane configurations is an important, but not a major part of advanced technology investigations as covered by the studies conducted under the NASA contract. Basically, configurations are technology sensitive but the development of the technology can be independent of the airplane. It's required, however, that the technologies be tested on a basic airplane to prevent them from becoming academic rather than applicable to a marketable product. Their development provides confidence that the results are based on a realistic appraisal of potential application and a frame of reference to establish impact measurements. Integration of the various components into the airplane configurations is very critical when high subsonic speeds and application of advanced technology in all technical areas are considered. Figure 26 gives an indication of the impact on operational empty weight and drag as the Mach number changes from 0.9 to 0.98. The steepness of the curves indicates the increased penalty even with cycling of the airplane to take maximum advantage of the change in wing area and engine size.

Figure 27 shows the total impact in terms of relative DOC, compared to Mach 0.84 airplane, of the various levels of technology. The study used the increment from the reference technology to the advanced ATT study technology. As the Mach number increases, the gains become larger. It is reasonable to assume that additional research will bring this down to a lower level, possibly that shown by the level XX, with specific technology advances yet undefined.

If the airplane is to be compatible with the community and at the same time provide improved operating costs, it is imperative, even for the speed range of Mach 0.84 to 0.9, that study and research be continued to improve our capability to produce lighter, more efficient airplanes, Ref. 5. The configuration process described above provides the tool to optimize the airplane, but the configuration arrangement and development is dependent on the level and application of new technology.

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