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TECHNOLOGY OPTIONS FOR AN ENHANCED AIR CARGO SYSTEM

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SUMMARY

A view of the potential enhancements to the air cargo system through technology application is provided herein. The major deficiencies of the current civil and military cargo systems are reviewed, and the role of NASA in addressing areas of primary concern is outlined. The evolution of conventional cargo aircraft design is traced and projected through the 1990's. Some advanced airfreighter concepts incorporating innovative design features (e.g. span-distributed loading, air cushion landing gear) are described to show the potential benefits offered through departures from conventional transport configurations. The NASA Aircraft Energy Efficiency program is discussed, and the prospects for improving fuel efficiency through advances in a wide range of technologies are indicated. Other technology programs are shown to offer benefits to the air cargo system through solutions to some growing aircraft operating problems. Finally, the promise of advanced technology airfreighters is viewed against the background provided by extensive air cargo systems studies to provide an outlook for the future. It is concluded that the benefits of technology may be offset somewhat by adverse economic, environmental, and institutional factors. It is postulated, however, that the stimulus provided by advanced vehicle and subsystems technology may accelerate improvements to other facets of the air cargo infrastructure.

INTRODUCTION

Although the growth rate of the airfreight industry has exceeded that of surface transport for the past twenty years, the volume of cargo shipped by air currently constitutes only a very small portion of the total cargo transported both in the U.S. and worldwide. In spite of its growth rate, the airfreight market continues to be characterized by small, high value, low density, or perishable shipments for which the rate structure is complex due to regulatory constraints, and the rates are high in comparison with surface transport. Additional problems arise from inefficient ground operations and a fleet of aircraft which, for the most part, are not optimized for cargo carriage. The present airfreight fleet is comprised of passenger transports carrying cargo as supplementary payload as well as civil transport derivatives operating as all-cargo carriers.

There is no doubt as to the impending need for new aircraft designed specifically for cargo transport. However, failures of other stimuli (such as reduced rates) to promote the expected increased penetration of air carriers into shipper markets make manufacturers and operators reluctant to make large capital investments in air cargo system improvements. The problems involved in improving the landside operations and alleviating institutional constraints appear to be surmountable through concerted effort and at reasonable cost.

The development and introduction of advanced dedicated aircraft into the system, however, involves a more complex set of concerns. Because of the enormous cost involved in development and production startup of any new aircraft concept, a number of prerequisites must be satisfied in order to induce the airframe industry to commit to new aircraft programs (ref. 1). The new concept must offer some enhanced operational characteristic (e.g. improved fuel efficiency). It must also offer advantages in direct operating costs (DOC) or in indirect operating costs (IOC) by virtue of its compatibility with existing or projected ground interface systems. Finally, there must be a forseeable demand for the improved service which the new aircraft can make possible so that a sufficiently large production quantity is assured to provide a reasonable unit price to the buyer together with a profitable return to the manufacturer.

In addition to the preceding concerns of the civil sector, there are also military concerns regarding strategic airlift capability. The military establishment faces the task of maintaining and enhancing the nation's strategic posture in the face of defense budget constraints which make launching new aircraft development and acquisition programs extremely difficult. Currently, the national military airlift needs are partially fulfilled by the same generation of aircraft as found in the civil fleet; indeed the Civil Reserve Air Fleet (CRAF) provides about 35 percent of the nation's emergency airlift capability. For this reason together with those reasons given in the previous discussion, increased attention is being given to the potential benefits of joint civil/military development of future cargo aircraft. This approach promises the advantages of shared development costs in addition to a high level of civil/military design commonality where minimum cost and time would be required to convert civil aircraft to military use in the event of an emergency.

The Role of NASA

NASA's role in aeronautics has been defined as being the provider of the technical foundations required for advances in aircraft and related operations. Through broad-based disciplinary research and systems studies, NASA attempts to identify the potential benefits of advanced technology and to demonstrate and promote the transfer of that technology to those areas of the nation's aeronautical community where it best applies. In the area of air cargo, NASA is attempting to provide answers to crucial quesitons and offer aid in resolving pertinent issues upon which decisions involving the future air cargo system will depend. As part of this effort, NASA is involved in a number of studies in concert with the U.S. Air Force and the major airframe manufacturers. These studies have the basic objectives of:

1. determining the optimum size and most effective time for introducing future airfreighter concepts.

2. evaluating military logistics requirements to determine the feasibility of joint civil/military aircraft development, and

3. evaluting various advanced design concepts and related systems technology.

In pursuit of the first objective, NASA has sponsored the Cargo Logistics Airlift Systems Studies (CLASS) to evaluate the timing for and the potential market response to advanced technology aircraft. The results of these studies are reported in references 2 and 3. An independent and complementary air cargo systems study conducted by a NASA-sponsored univeristy team is reported in reference 4. In pursuit of the second objective, NASA is supporting the Air Force in ongoing studies which address the issues of commonality and available design options pertinent to the provision of mission-effective and cost-effective transports to serve both military and civil cargo needs. Prospects for the fruition of this effort are discussed in reference 5. Pursuit of the third objective is a continuing NASA activity. Studies of future aircraft concepts and supporting systems are conducted not only in-house but also through contracts with industry and academic institutions. These studies are intended to identify technology voids, to stimulate activity in promising areas of new research, and to encourage and support innovative approaches to solving recognized problems. To date, a body of promising advanced transport technology has been identified and is being vigorously pursued. Also, a number of novel air vehicle concepts have been proposed to provide advantages over current designs by way of unique configurations, advanced technology application, or combinaitons of both.

This paper describes the potential attributes of some advanced vehicle concepts, highlights the ongoing disciplinary technology efforts, and comments on the outlook for the future of air cargo as projected from results of recent systems studies.

THE EVOLUTION OF AIRFREIGHTERS

The evolution of modern airfreighter design is illustrated in figure 1. Starting with the Douglas C-47 in 1935, the growth of both military and civil cargo aircraft over a 34 year period is shown. The Douglas C-54 first flew in 1942. The Lockheed C-130, a current military workhorse, had its first flight in 1954. The Douglas DC-8 (Series 10), introduced in 1958, and the Lockheed C-141, introduced in 1963, had essentially twice the gross weight of the C-130. In turn, the C-5 (1968) and the Boeing 747 (1969) had essentially double the gross weight of their predecessors. During the time span depicted, the aircraft gross weights increased by a factor of about 30; however, the direct operating costs (as of 1973) were reduced from about 34 cents per Mg-km (20 cents per ton mile) to about 9.0 cents per Mg-km (5.4 cents per ton mile). This significant cost reduction is attributed in part to performance gains due to advanced technology with the remainder being attributed to the economics of increased vehicle size. The two concepts on the extreme right of figure 1 represent advanced designs and typically indicate further growth in vehicle size.

NEW AIRCRAFT CONCEPTS .

Advanced Conventional Freighters

A number of studies have been devoted to defining the characteristics of future dedicated airfreighters of conventional design. The three major transport manufacturers in the United States are actively evaluting potential concepts, three of which are shown in figure 2. These designs could be available for production by 1990. The Boeing concept on the upper right is designed to carry thirty 8x8x20-foot containers in four parallel lanes which can be simultaneously loaded through a large nose cargo door. The Douglas Concept on the upper left is designed to have intercontinental range at a gross weight of about 442 Mg (930,000 pounds). The Lockheed concept at the bottom is designed to have a high degree of civil/military commonality.

As mentioned earlier, the issue of civil/military commonality has become a major planning consideration for near-term airfreighter development. As early as 1974, the U.S. Air Force introduced the C-XX airplane concept as a way to achieve economic and strategic benefits through the development of a common civil/military transport design. The economic benefit would accrue through civil/military sharing of development costs and lower acquisition costs in both sectors. The strategic benefit would accrue from the relative ease and speed of converting civil aircraft to emergency military use. The key differences between current civil and military freighters are shown in figure 3. The design approach based on the commonality concept is illustrated in figure 4. The C-XX Design Options Studies being conducted by the major airframe manufacturers for the USAF are defining airplanes of various sizes, some exceeding 454 Mg (one million pounds) gross weight based on this design philosophy. Whatever the aircraft size may be, many observers believe that only through a joint civil/military venture will the civil freight operators acquire a dedicated airfreighter in this century.

Flatbed Aircraft

A very novel approach to providing an aircraft to fulfill both civil and military requirements including the accommodation of outsized cargo is under study by the Lockheed-Georgia Company. The airplane concept is called "Flatbed". As shown in figure 5, the airplane consists of a cockpit section connected to the tail section by a long, flat-topped structural backbone. The backbone is designed to carry outsized military cargo or containerized civil or military cargo with the payload exposed to the airstream. In an alternate operating mode, it could carry preloaded pressurized modules containing either bulk cargo or passengers. Current NASA-sponsored studies are examining the feasibility of the Flatbed concept. Aerodynamic, propulsion, and structural aspects of the concept will be analyzed, and the aircraft economics will be estimated in both civil terms (direct operating costs) and military terms (lift cycle costs). The performance and economics will then be compared with those of a conventional configuration designed to the same mission rules. The results of the Flatbed study are expected to be available in mid-1980.

Distributed Load Freighters

In the earlier discussion of cargo aircraft historical trends, it was shown that each succeeding generation capitalized on the economies of continually greater physical size. With that in mind, it can also be shown that as gross weight increases, the available volume in the wing increases more rapidly than the volume required for fuel and payload (fig. 6); and consequently, there is a gross weight above which (from a volume standpoint) the fuselage is not required (see ref. 6). This fact opens up the potential for large freighter configurations which can carry all of the fuel and payload within the wing. One of the more significant advantages of this arrangement is that the load distributed across the wing span is largely balanced by the local lift. Therefore, significant reductions in bending moments can be achieved in comparison with the moments experienced when the load is concentrated in the fuselage (fig. 7). This reduction in bending moments permits the use of a lighter structure and, as also shown in figure 7, results in lower empty weight fraction.

Large distributed-load freighters which carry all of the payload within the wing are generally envisioned as being technically feasible in the 1990's. A somewhat smaller airplane which could take advantage of the structural benefits of semi-distributed loading and be available in the 1985-1990 period is shown in figure 8. The relative bending moment comparison in figure 9 indicates that this double-fuselage configuration may achieve about half the improvement in empty weight fraction as that achieved by the swept DLF design. Langley is currently supporting feasibility studies of multibody freighter configurations. The studies will assess the technical challenges and economic potential of two-body and three-body configurations representing all-new designs as well as derivatives of current widebody airplanes.

A number of the larger distributed-load freighter (DLF) configurations have already been analyzed by NASA and by major aircraft manufacturers (refs. 7 to 11). The large swept-wing DLF shown in figure 10 has a span of about 152 m (500 feet) and a gross weight of about 1360 Mg (3 million pounds). The swept wing, in addition to allowing increased speed, also provides sufficient overall length to eliminate the need for a separate tail. A Boeing 747 is shown for size comparison. One of the major operational problems for an airplane of this size is that the landing gear tread width would be about 122 m (400 feet) and require special runways. It has been suggested, however, that if very large airplanes of this type were used only between large hub airports in a hub-spoke network system, the cost of widening a few runways would be relatively small.

Studies to date indicate promise for the DLF concept in terms of increased productivity and lower direct operating costs. A comparison of the relative DOC for a current widebody aircraft, an advanced technology conventional configuration, an unswept DLF, and a large swept-wing DLF is shown in figure 11. All three advanced configurations show lower DOC's than current aircraft. The unswept DLF provides only a slight improvement, at the size shown, over the advanced conventional aircraft since its straight wing restricts its cruise speed. The large swept-wing DLF, however, benefits from both increased size and speed capability and shows a significant reduction in operating cost. An artist's concept of a large DLF of this type being loaded through the wing tip is shown in figure 12.

Wing-in-Ground Effect (WIG) Transports

Another innovative and promising concept under study is the wing-in-ground-effect aircraft, an example of which is shown in figure 13. WIG vehicles take advantage of the increased lift/drag ratio due to ground effect; and since the lift/drag ratio varies inversely as the ratio of wing height-to-wing chord, they require large chord wings in order to achieve efficiency at safe heights above the surface. Furthermore, since the concept is dependent upon surface proximity, most WIG designs are intended for overwater transports. The most promising configurations use power augmented ram propulsion where lift enhancement is achieved by directing exhaust from forward-mounted engines into the cavity formed by the wing undersurface, endplates, and trailing-edge flaps. The Lockheed-Georgia Company has conducted mission studies (based on 1990 technology) for WIG vehicles in a water-based logistics system operating over a 4000 nautical mile range (ref. 12). Both span-loaded and fuselage-loaded designs were analyzed for payloads of 200 Mg (441,000 pounds) and 300 Mg (661,500 pounds) at gross weights of about 617 Mg (1.36 million pounds) and 862 Mg (1.9 million pounds), respectively. The results indicate that WIG designs can compare favorably with advanced conventional designs by measures of merit such as payload fraction and fuel efficiency, with the primary deficiency being low cruise speed (Mach number = 0.4). For military applications, however, this deficiency is judged to be appreciably offset by the potential strategic advantage arising from very low cruise altitude (i.e. reduced radar detectability). Further study in the areas of configurations, propulsion, aerodynamics, stability and control, and hydrodynamics are indicated as being necessary to provide increased confidence in the WIG concept.

Turboprop Transports

The speed and altitude advantages afforded by turbojet propulsion led to the decline of propeller-driven transport aircraft. Today's higher fuel prices and emphasis on conservation, however, have led to reexamination of propellers as one approach to fuel conservation and lower operating costs. Highly-loaded, advanced turboprop designs which utilize a larger number of blades than conventional propellers are proposed for efficient high-speed operation. Propulsive efficiencies for conventional turboprops, advanced turboprops and high-bypass turbofans are compared in reference 13. The advanced turboprop is shown to provide improvements over the turbofan of about 20 percent at Mach 0.8 and about 30 to 35 percent at Mach 0.7 (see fig. 14). The analyses of advanced turboprop application to passenger transports in reference 13 indicate significant potential savings in fuel and operating costs. In addition these studies identified both noise and increased drag due to slipstream effects as critical technology areas requiring further examination.

NASA is currently sponsoring a study by the Lockheed-Georgia Company to explore the effects of utilizing advanced turboprop propulsion systems in the design of cargo aircraft with emphasis upon noise reduction in the terminal area. This study will identify the sensitivity of performance, fuel consumption, productivity, and economics to various levels of noise reduction for the turboprop designs and compare the results with those for reference turbofan designs. An artist's concept of an advanced turboprop installation on a large cargo airplane is shown in figure 15.

Air Cushion Landing Gear Transports

As mentioned previously, the advent of very large aircraft creates the potential problem of inadequate runways in terms of both size and load-bearing capacity. The technology for air cushion landing gear currently receiving attention may make future considerations of runway size and strength less critical. The principal benefits of air cushion landing gear (ACLG) are reduction in concentrated ground loads and the capability to operate from water and unprepared land surfaces as well as from conventional runways. A large multimission configuration employing air cushion landing gear is shonw in figure 16. Studies to date indicate that the application in ACLG technology to very large cargo aircraft appears attractive (ref. 14). Not only would ACLG permit the use of waterways as landing sites and allow the establishment of cargo facilities away from major airports, but also the capability for use of unprepared land sites is especially attractive for military applications.

Langley is currently sponsoring systems studies directed toward preliminary conceptual designs of large ACLG amphibious cargo aircraft. The studies will include performance and economic comparisons with wheeled-gear configurations.

ADVANCED TRANSPORT TECHNOLOGY

Although a number of institutional and economic impediments to market growth and demand for advanced dedicated freighters must be removed before commitments to new aircraft development are made, the pursuit of advanced technology which will benefit transport aircraft continues at a vigorous pact. It may well be that the air cargo system will ultimately be enhanced through synergistic effects where improvements to other facets of the total air freight system will be stimulated in anticipation of more efficient and compatible air vehicles and systems. If that be so, then the contribution of advanced technology to the improvement of the future air cargo system will be significant indeed. In view of this, NASA and the major air transport manufacturers are actively involved in a number of disciplinary and systems technology studies. A brief overview of the Langley Research Center effort is given in the following discussion:

The ACEE Program

Four years ago, upon request of the U.S. Congress, NASA launched a program to develop the technology for more energy-efficient aircraft (see ref. 15). The technical plan for this effort was developed in concert with airlines, engine manufacturers, airframers, universities, and various government agencies. The Aircraft Energy Efficient (ACEE) program is now underway with both NASA and industry actively pursuing a broad range of technology advances in aerodynamics, propulsion, structures, and controls. The studies currently under the program are expected to provide many technology benefits of which transport designs in the post-1985 time period can take full advantage. The NASA Lewis Research Center is managing this ACEE propulsion system technology studies while the Langley Research Center is managing the remainder. A summary of the technology objectives being pursued at Langley is given in figure 17. Supercritical airfoil technology is directed toward improving fuel efficiency by increasing wing thickness ratio and permitting lower wing sweep and higher aspect ratio. Winglets are aerodynamically-tailored wing-tip devices which provide for reductions in drag. In the area of propulsion integration, efforts are focused upon minimizing interference drag due to mating of engines and airframe. Studies of advanced composite materials are directed toward increased performance and fuel efficiency by virtue of the reduced weight and increased stiffness and strength afforded by these materials. Laminar flow control systems have the potential for providing significant fuel savings by maintaining smooth flow over greater portions of the airframe surfaces thereby reducing skin-friction drag. Technology advances in maneuver and gust load control and design techniques for reduced static stability take advantage of electronic sensors and on-board computers to limit gust and maneuver loads. Their aim is to permit reductions in the size and weight of structural components and aerodynamic control surfaces.

Estimates of the projected gains in fuel efficiency provided by the various technology advances are shown in figure 18 for the 1980 through post-1995 time period. As evidenced by its comparatively late expected introductory date, laminar flow control will be the most difficult technology to implement operationally. Once accomplished, however, LFC will provide the greatest increment in fuel savings of all the new technologies.

Additional Contributing Technology

Although their focus is not specifically on the needs of air cargo, there are a number of NASA Langley technology programs and studies underway from which future air freight operations will benefit. These efforts are aimed toward improving schedule reliability, safety, and fuel conservation and reducing airport congestion, noise and pollution.

TCV. - The Terminal Configured Vehicle (TCV) program has the goal of developing flight management technology that will benefit terminal area operations (See ref. 16). Primary objectives are (1) improvement of terminal area capacity and efficiency, (2) improvement of approach and landing capability in adverse weather, and (3) reduction of noise. The program involves the integration of advanced airborne avionics systems and the development of advanced flight profiles and procedures. The most recent flight experiments have shown that concepts developed under the TCV program can provide significant fuel savings by enhancing the air traffic controller's ability to regulate traffic flow at busy airports.

Vortex Wake Alleviation. - A complementary program aimed toward permitting full use of advanced automatic landing systems is attempting to solve the problems caused by the powerful vortices which trail behind large aircraft and restrict airport arrival and departure rates (see ref. 17). The analytical and experimental research conducted to date by NASA has identified some promising approaches to solving the vortex wake problem. However, since those techniques which appear most effective involve aircraft performance penalties, considerably more effort will be required before a final solution is reached.

Crosswind landing gear. - Crosswinds can restrict or completely halt landing operations, particularly at single runway airports. One solution to the problem involves the use of landing gear systems which permit the aircraft to make crabbed touchdowns (ref. 18). A NASA program comprised of analytical studies, model experiments, and flight tests of four different crosswind landing-gear concepts has shown promising results. Actual landings have been made with experimental self-aligning gear systems in crosswinds far more severe than could be tolerated with conventional gear, and test pilots indicate that there is sufficient improvement in comfort and safety to justify the development of operational systems.

Alternate fuels - Increasing concerns over shortage of conventional petroleum products have led to studies of potential alternate fuels for aircraft (see ref. 19). Only synthetic Jet-A, cryogenic liquid methane (LCH_4) and cryogenic liquid hydrogen (LH_2) appear to be viable as aviation fuels. To date, the most extensive NASA-sponsored studies have involved the use of liquid hydrogen. A conceptual hydrogen-fueled airplane design is shown in figure 19. Because of the large volume required for fuel tankage and the reduced fuel weight, the fuselage is longer and wider and the wing is smaller than for a conventionally-fueled aircraft designed for the same mission. The direct operating costs of the LH_2 airplane are higher, however, due to the high cost of manufacturing liquid hydrogen. Results to date indicate that production, supply systems, and mission fuel costs for liquid methane may be somewhat less than those for LH_2. From a near-term total system viewpoint, synthetic Jet-A fuel has been determined to be the fuel most economical to supply and most compatible with existing aircraft and ground systems. Further studies will determine the total system impacts of all three fuels in order to provide a solid basis for making informed choices from among them in the future.

OUTLOOK

Although the very large cargo aircraft concepts show promise of significant benefits in performance and economics in comparison with current widebody freighters, their future development as well as that of any of the various other advanced concepts will depend upon a number of factors. Perhaps chief among these factors is the character of the future air cargo market. While predictions of market growth rate vary among analysts from about eleven to sixteen percent, it is fully agreed that without a high growth rate, there will be no requirement for a new, dedicated airfreighter development in this century. In order to stimulate and sustain a sufficiently high growth rate in the near term, a number of institutional issues such as deregulation, revision of tariff structures, and overall national economic ills must be resolved in a manner favorable to that end. Also, the air mode must capture a greater share of the total freight transport market by expanding the variety of commodities transported beyond the traditional high value, unplanned, and perishable shipments which make up the current bulk of goods carried in the system.

There are factors other than market forces, however, which also strongly influence the viability of advanced cargo aircraft. Problems involving ground access to airports and congestion at terminals and gates must be relieved. Current limitations on aircraft size and weight must be eased before freighters larger than today's widebody jets can be used. Some observers believe that the current trend toward diffusion of transfer hubs must be arrested and reversed if very large aircraft are to be utilized efficiently. Still further, significant advancements in terminal automation and standardization of containers between air and surface transport modes must be attained in order to improve the efficiency of the total system. Only when such concerns are satisfied will the total operating costs decrease to a level where significant rate reductions become available to shippers. Even then, according to estimates based on CLASS results, further rate reductions directly traceable to lower DOC's of new aircraft will be relatively small (see ref. 20). The early impact will be small because the new aircraft will comprise only a small part of the freighter fleet and represent fairly modest advances in technology and payload growth. The analysis of reference 20 indicates that the market demand can be met with advanced freighters of less than 181 Mg (400,000 pounds) payload capacity as late as 1994. Later, if the need for larger, advanced concepts occurs, the number of large aircraft required will be small (even in an an expanded market). Aircraft unit costs will be high, and reductions in operating costs achievable through advanced technology will be offset to some extent by the impact of initial acquisition costs. Also, the larger aircraft are likely to incur airport interface problems due to their size; and since noise scales with size, they may suffer from operational restrictions in the absence of major breakthroughs in noise reduction technology in the near future.

CONCLUDING REMARKS

The foregoing discussion provides a brief view of past and ongoing efforts which are aimed toward or can contribute to an enhanced future air cargo system. The major difficulties being faced involve a number of interdependent concerns. First, there is the problem of defining the future growth of air cargo in the total transportation system and determining the extent to which that growth can be stimulated by removing known impediments. Another concern involves the prediction of demand and timing for introduction of new aircraft to fulfill the needs of future markets, the character of which will depend upon the success attained in stimulating growth. Further complexity results from the fact that the aircraft manufacturers require assurances that a certain minimum demand for their product will exist long before they will commit to its development.

For normal operations, future military needs for new aircraft (with respect to both characteristics and numbers) are known with greater certainty. Since emergency military needs are partially fulfilled through use of civil aircraft, however, the total military future airlift capability will depend upon circumstances existing in the civil sector. Even if that were not so, the enormous development and acquisition costs of airplanes for normal operations would alone be sufficient reason to encourage interest in joint civil/military development programs.

In view of these circumstances, the airframe and airfreight industries, the military services, and NASA are engaged in continuing efforts to address the recognized problems of the airfreight transport system. These efforts include analyses of markets, assessments of potential future aircraft demand, and attempts to resolve issues relating to the viability of joint civil/military aircraft development. NASA is also sponsoring and participating in the development of wide-ranging technology advancements applicable to future transport aircraft and encouraging the pursuit of innovative approaches to air vehicle systems and concepts. At present, considerable uncertainty remains with regard to the future impacts of economic, environmental, and institutional constraints. The extent to which those impacts will either enhance or dilute the benefits of advanced technology is an area of concern which will continue to receive the attention of all who share an interest in the air cargo system.

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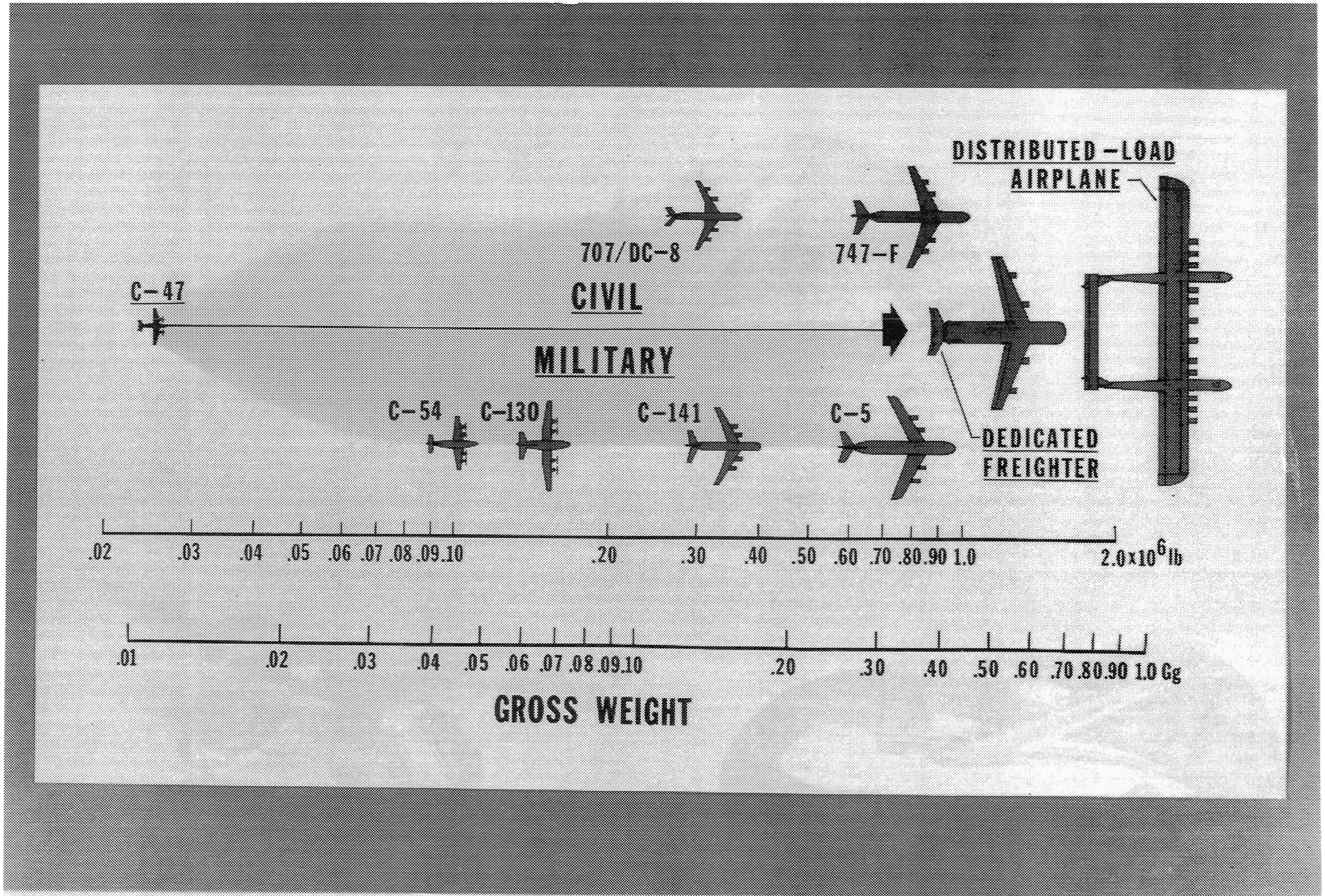


Figure 1. - Airfreighter evolution

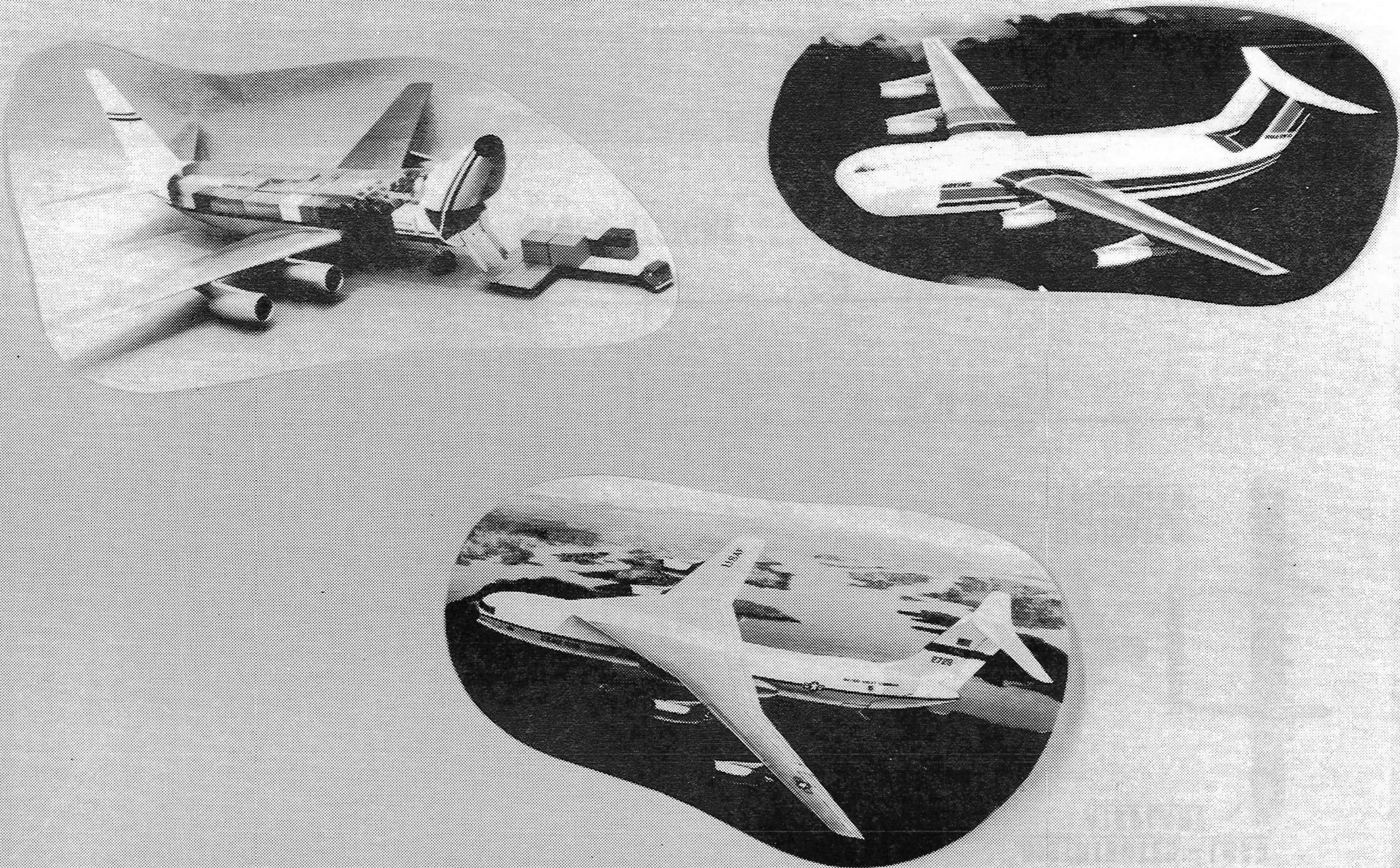
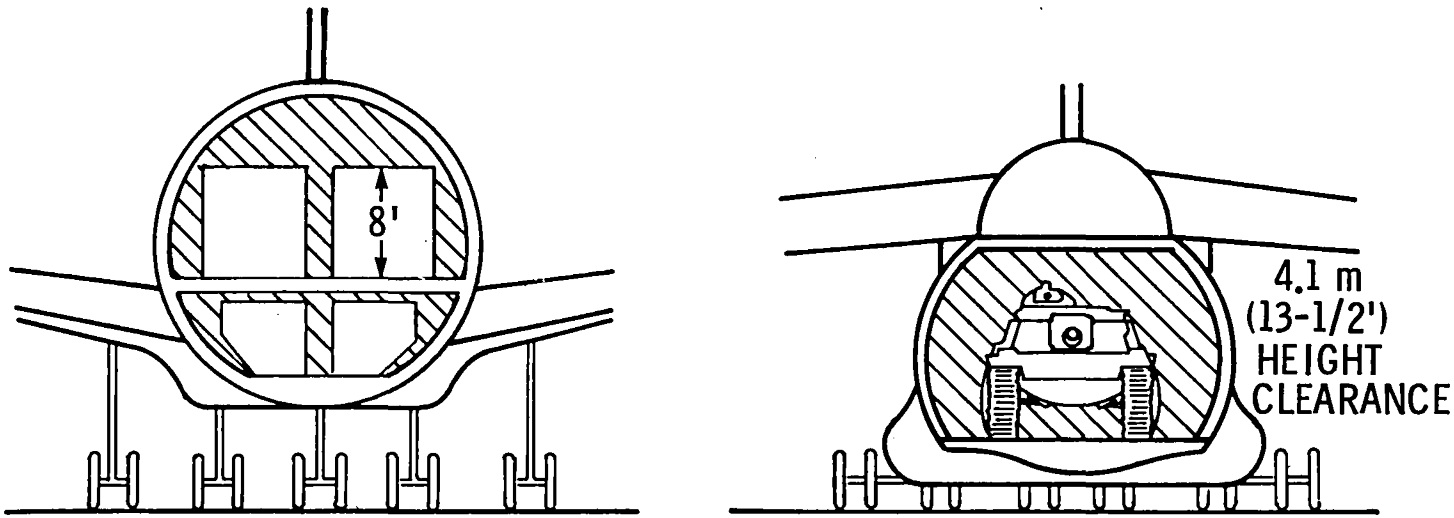


Figure 2. - Industry concepts for 1985 technology freighters

CIVIL–MILITARY DESIGN COMMONALITY

KEY DIFFERENCES IN CURRENT DESIGNS

CIVIL | MILITARY



Civil

- LOW WING, HIGH FLOOR (PASSENGER COMMONALITY)
- 8 × 8 AND LD CONTAINERS
- MODERATE FLOOR LOADING
- FIELD LENGTH = 3.7 km (12 000 ft)

Military

- HIGH WING, LOW FLOOR (TRUCK BED LOADING)
- OUTSIZE CARGO
- HEAVY FLOOR SUPPORT
- SHORT FIELD CAPABILITY

Figure 3. - Civil-military design conflicts

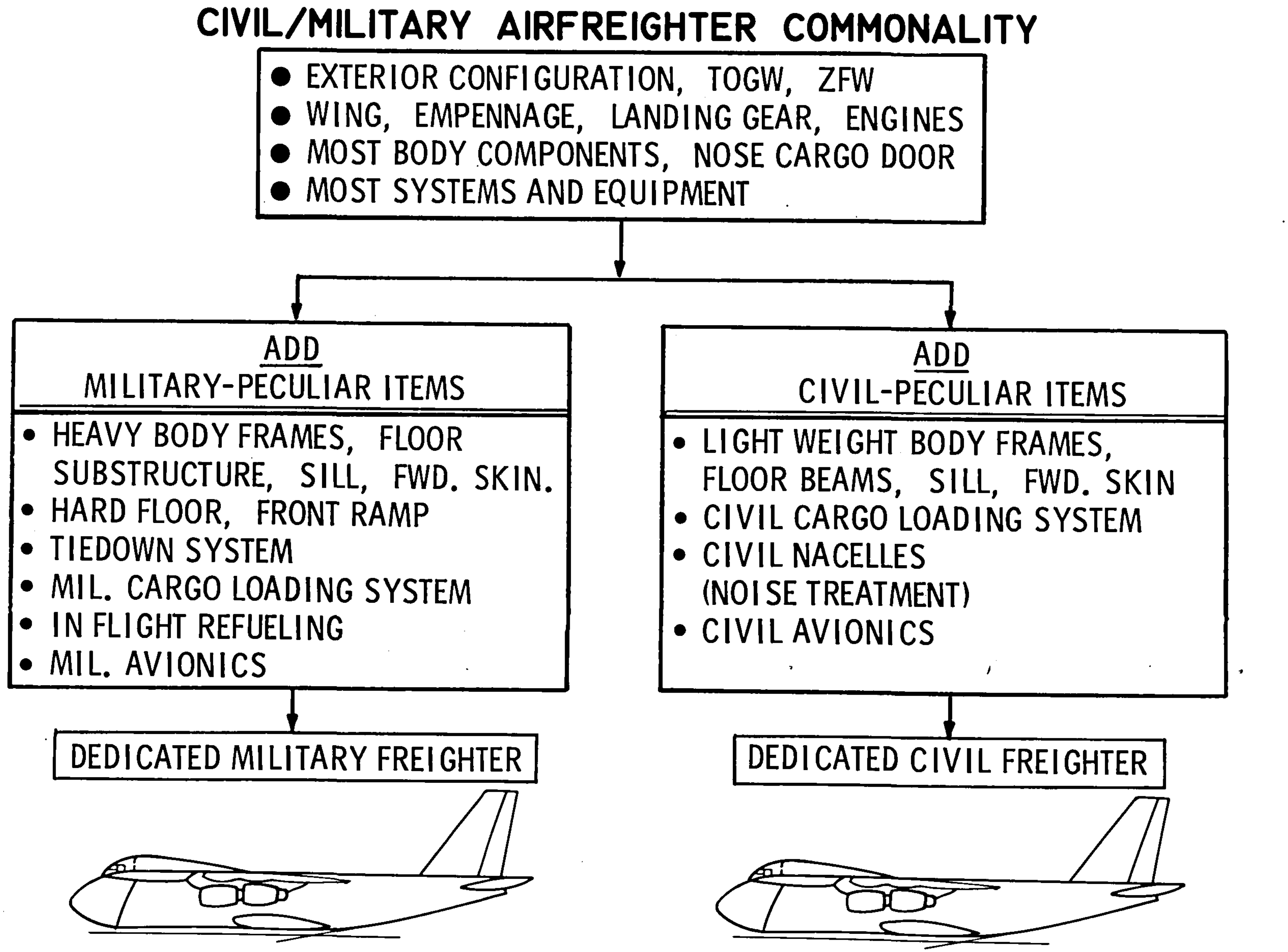


Figure 4. - Civil/military design commonality

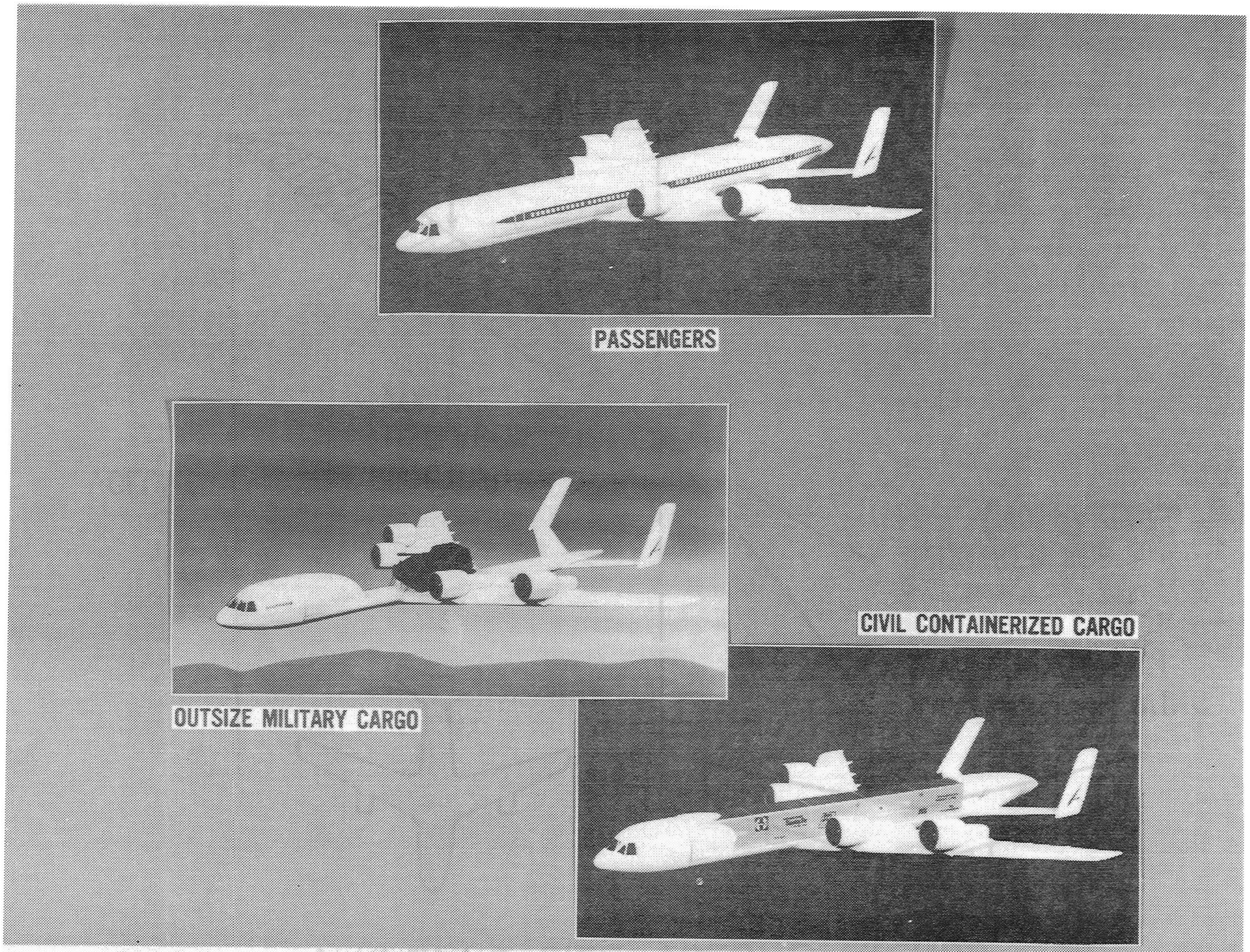


Figure 5. - Flatbed aircraft concept

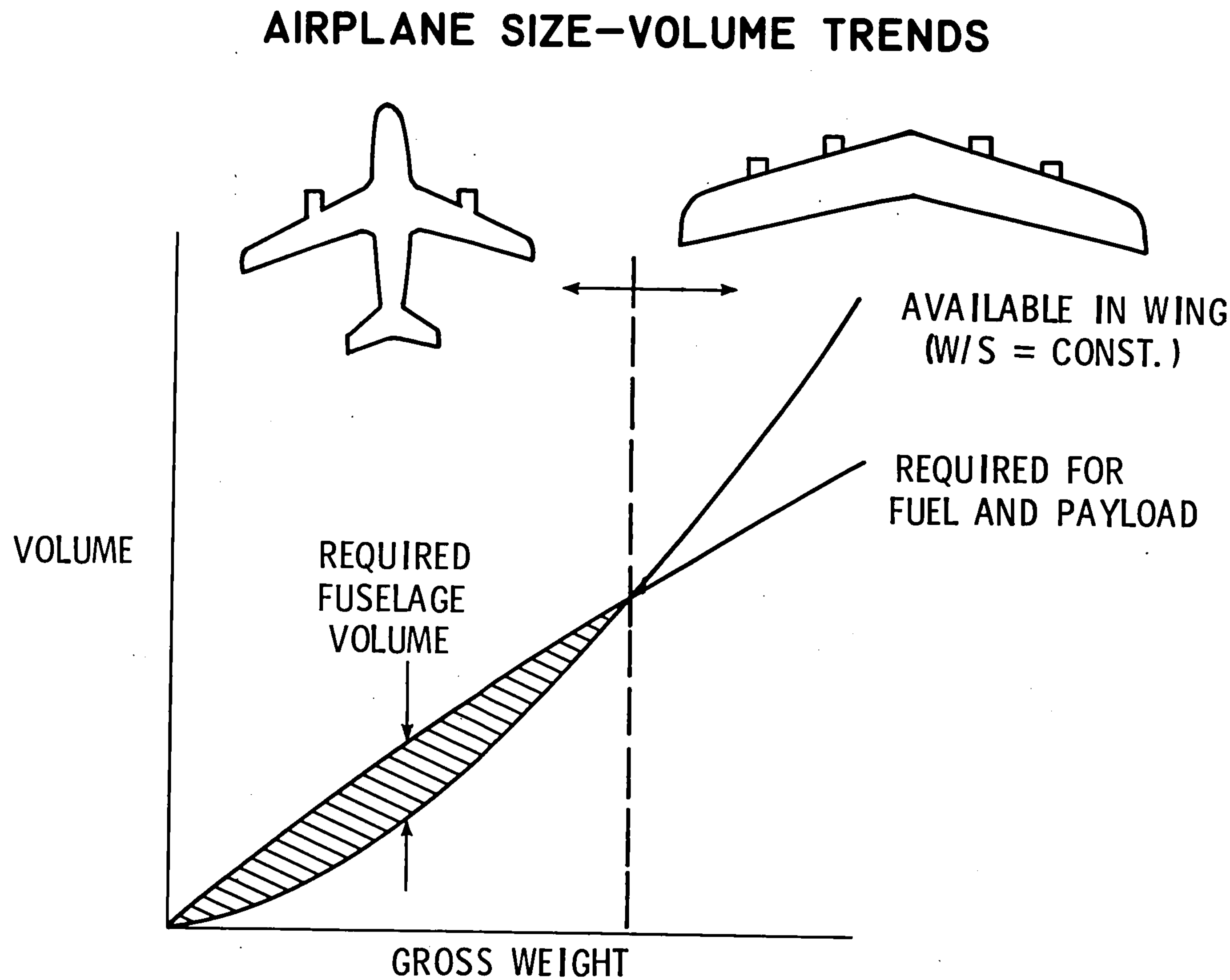


Figure 6. - Airplane size-volume trends

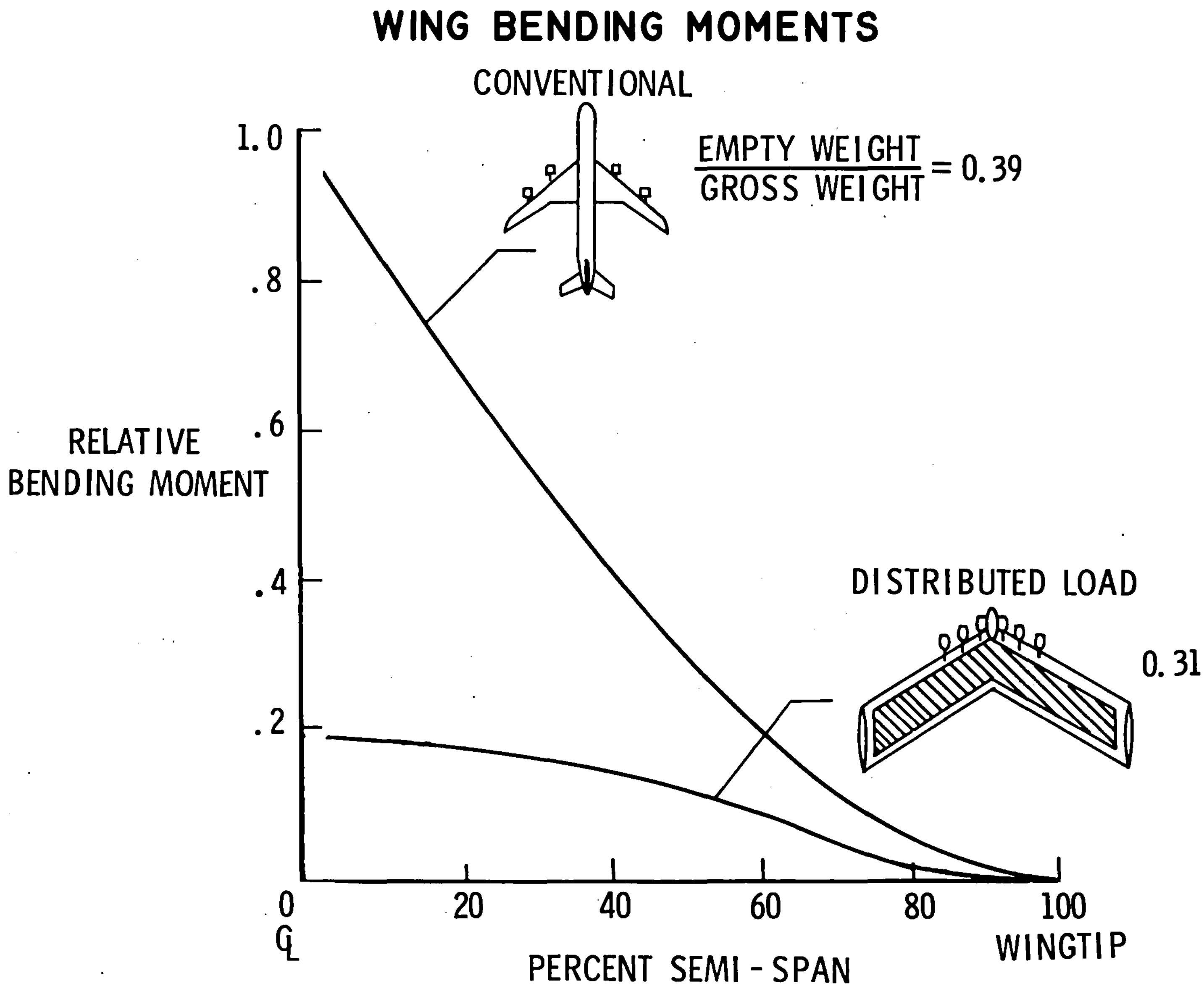


Figure 7. - Wing bending moments

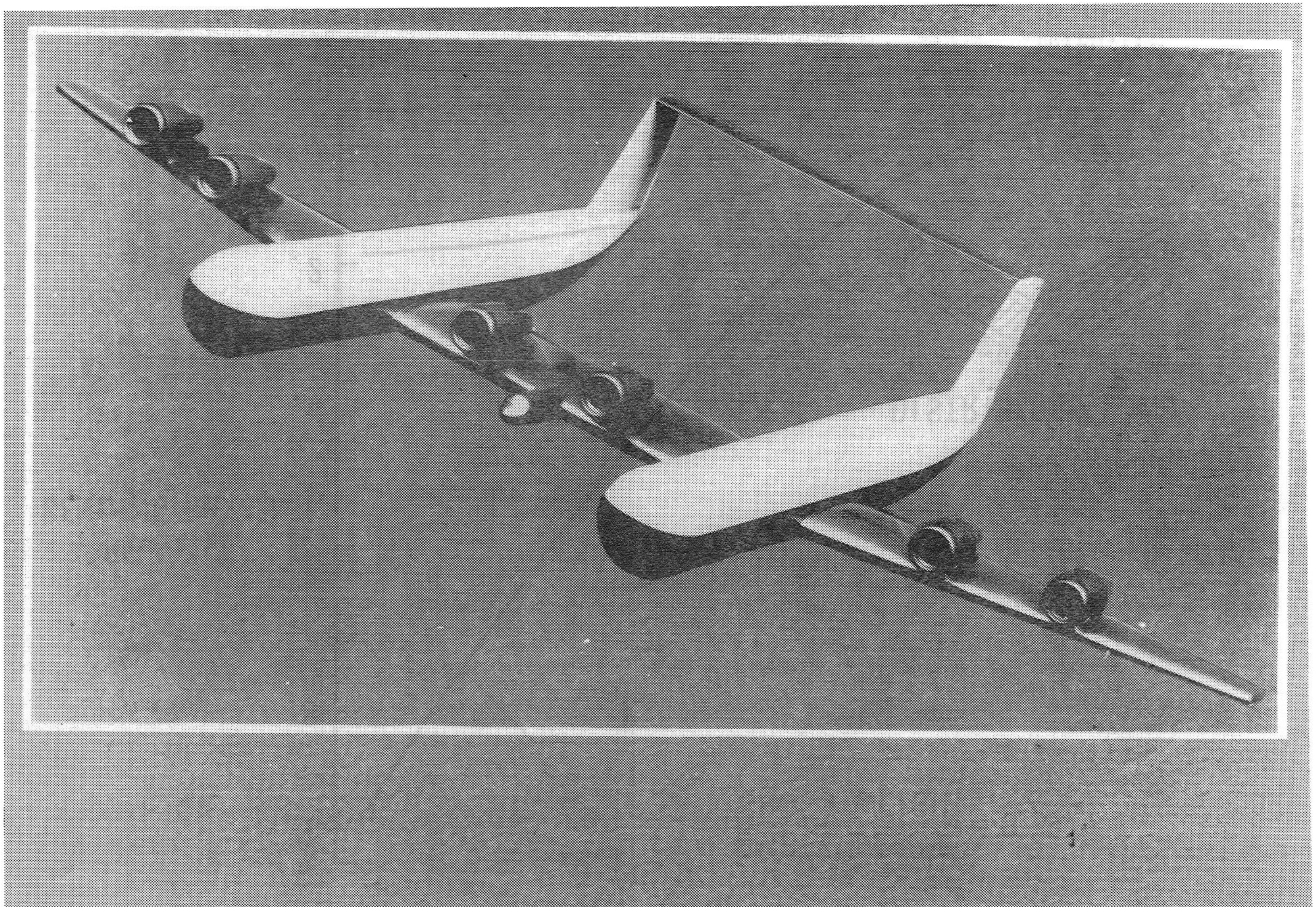


Figure 8. - Twin body cargo airplane concept

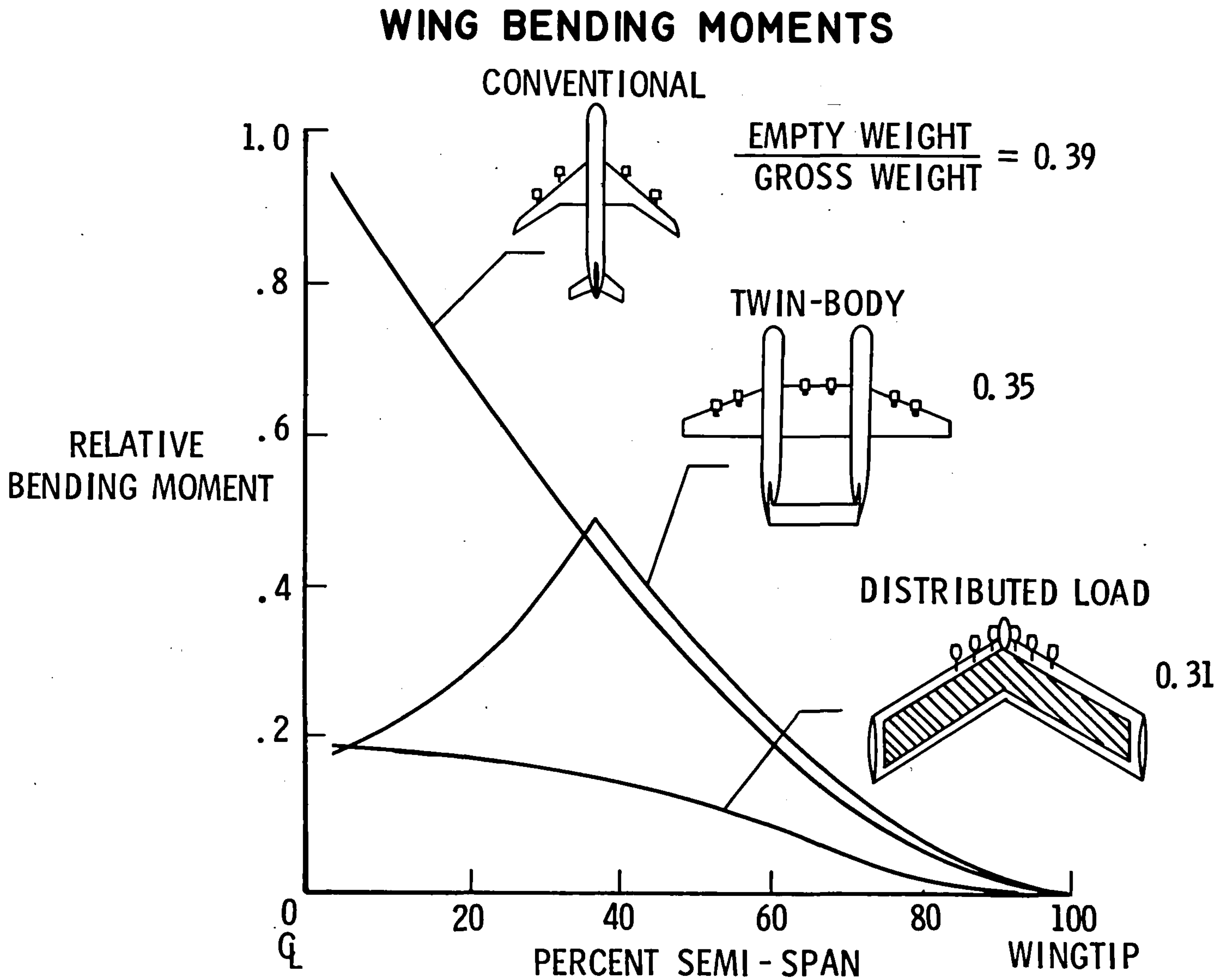


Figure 9. - Wing bending moments

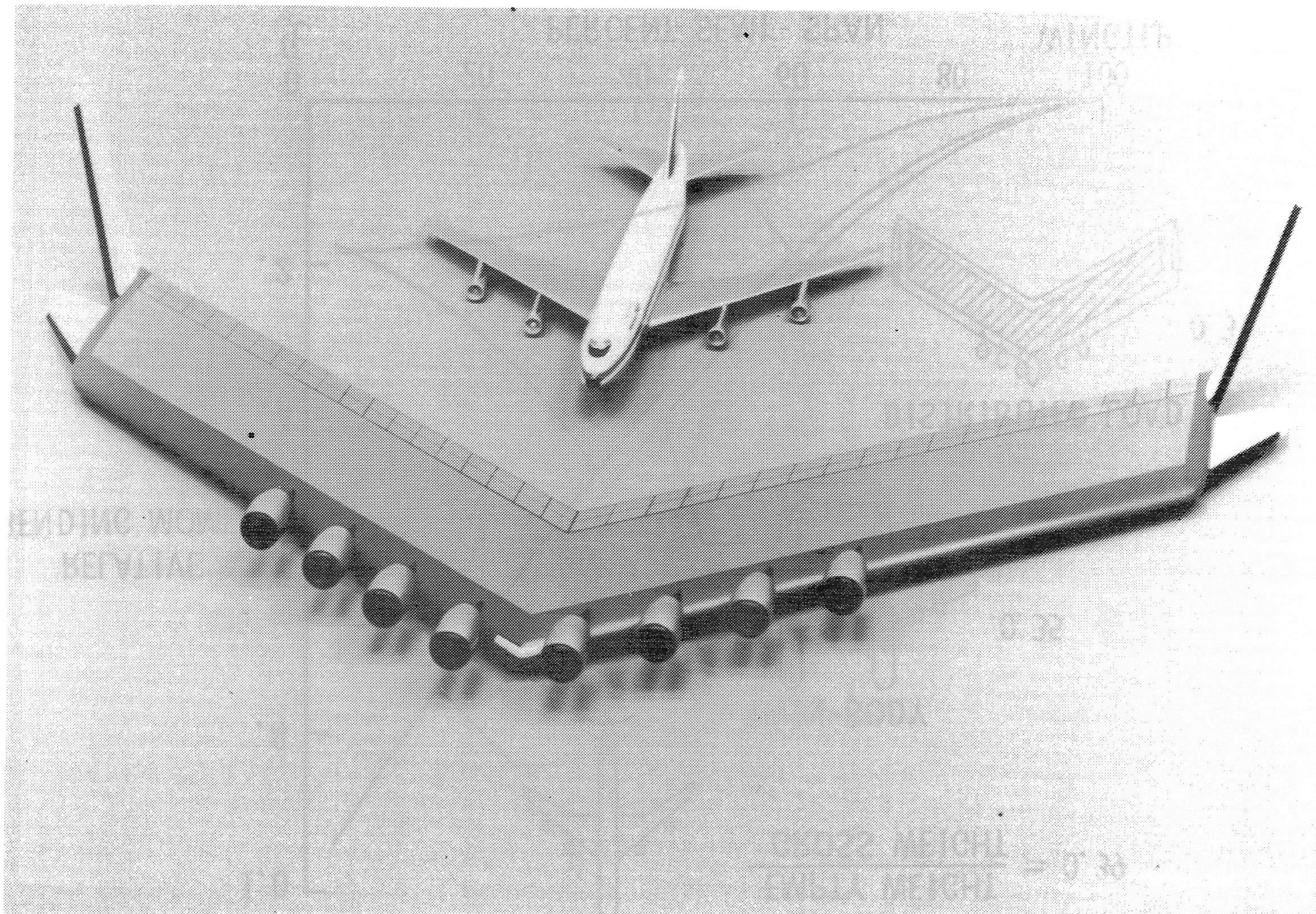


Figure 10. - Swept-wing distributed-load freighter concept

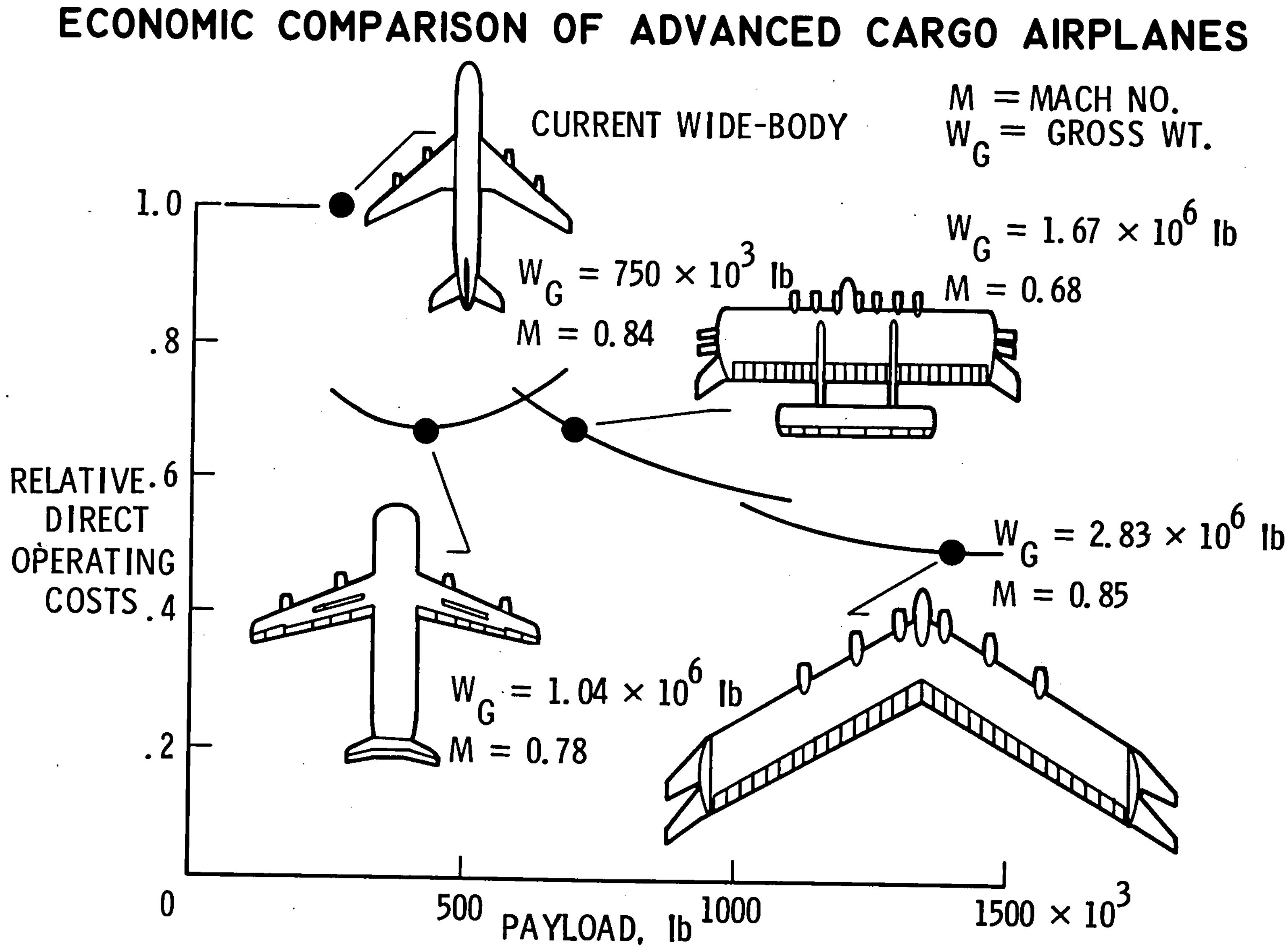


Figure 11. - Economic comparison of advanced airfreighters

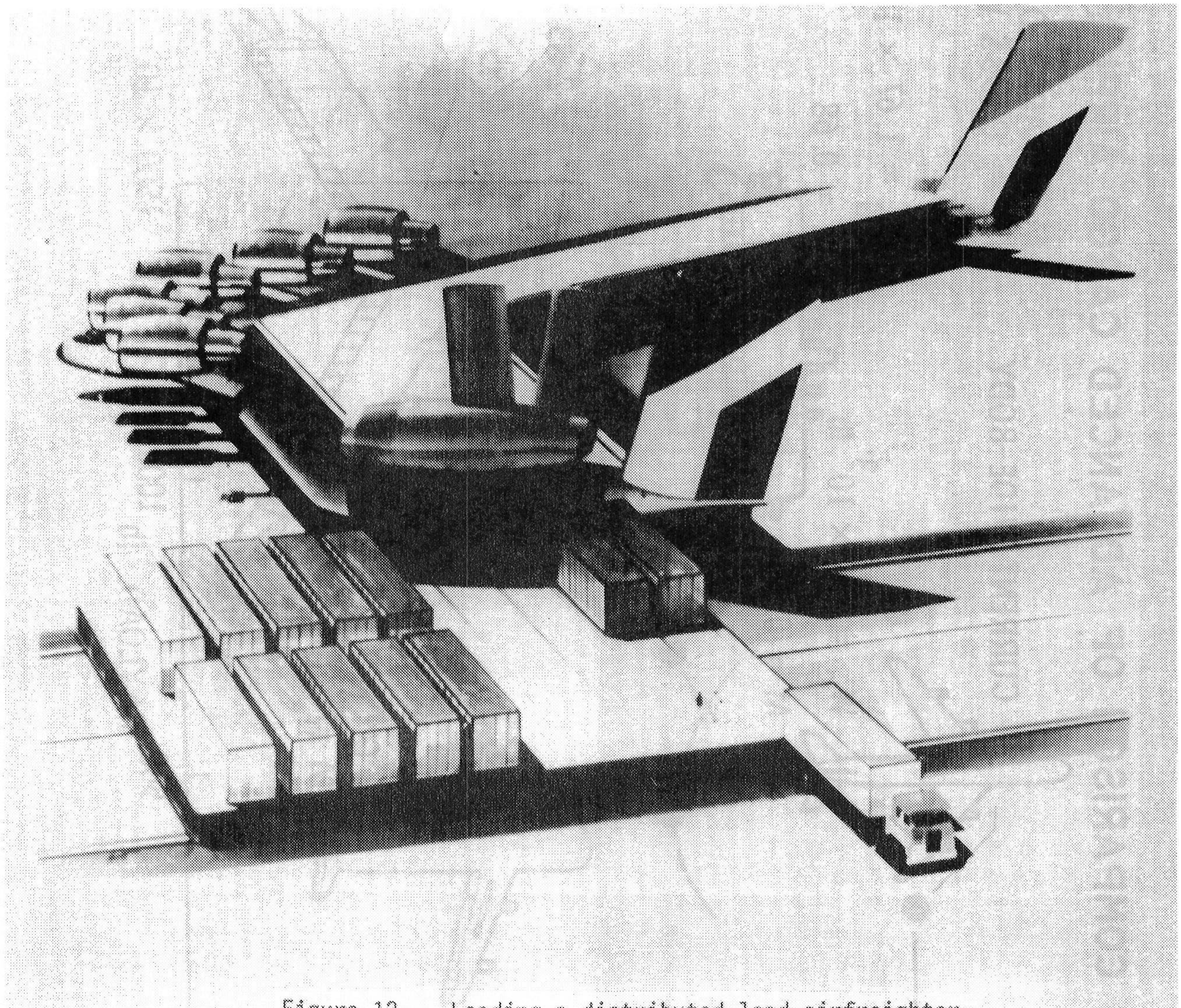


Figure 12. - Loading a distributed-load airfreighter

WING-IN-GROUND EFFECT TRANSPORT

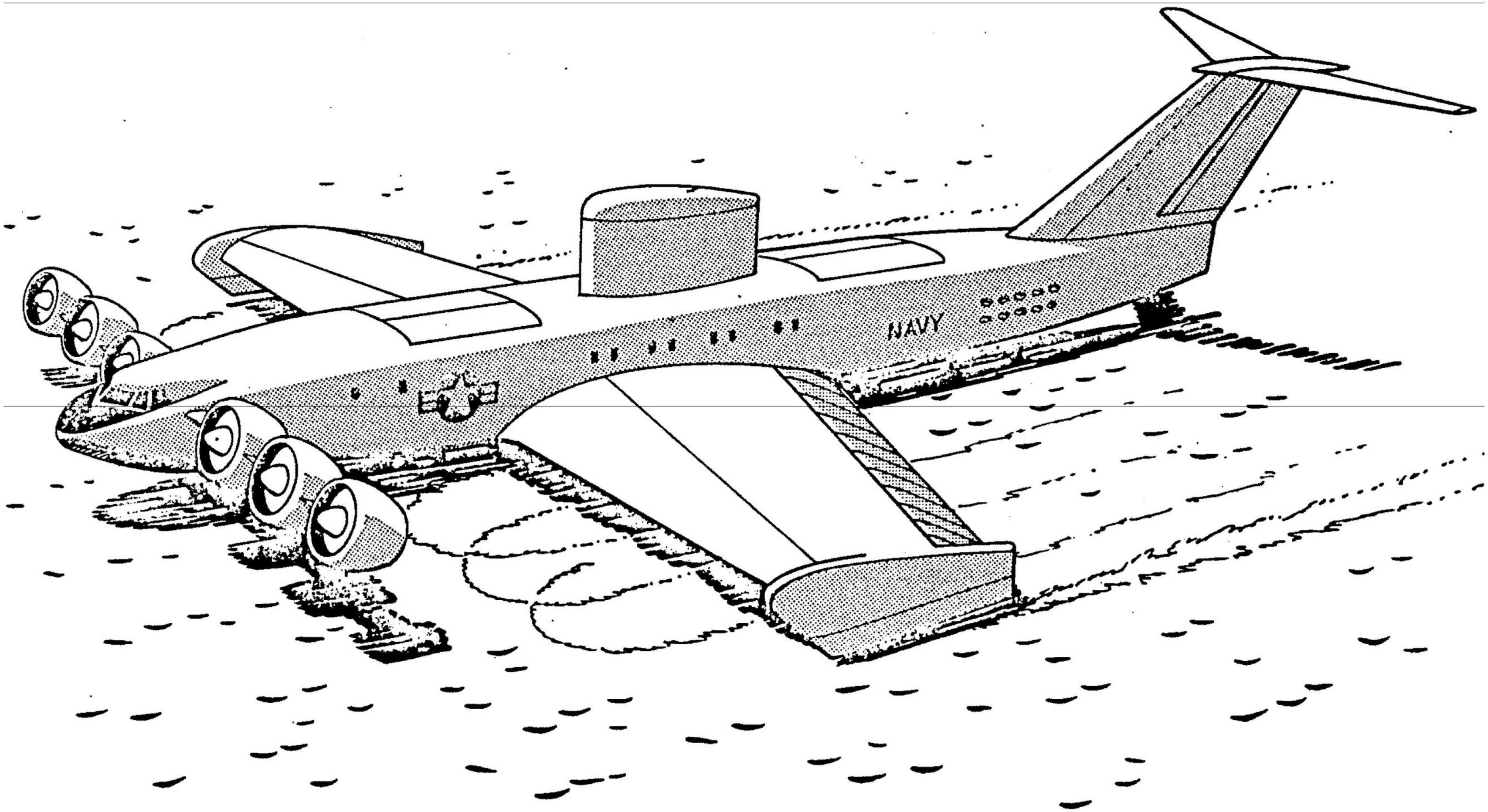


Figure 13. - Wing-in-ground effect freighter concept

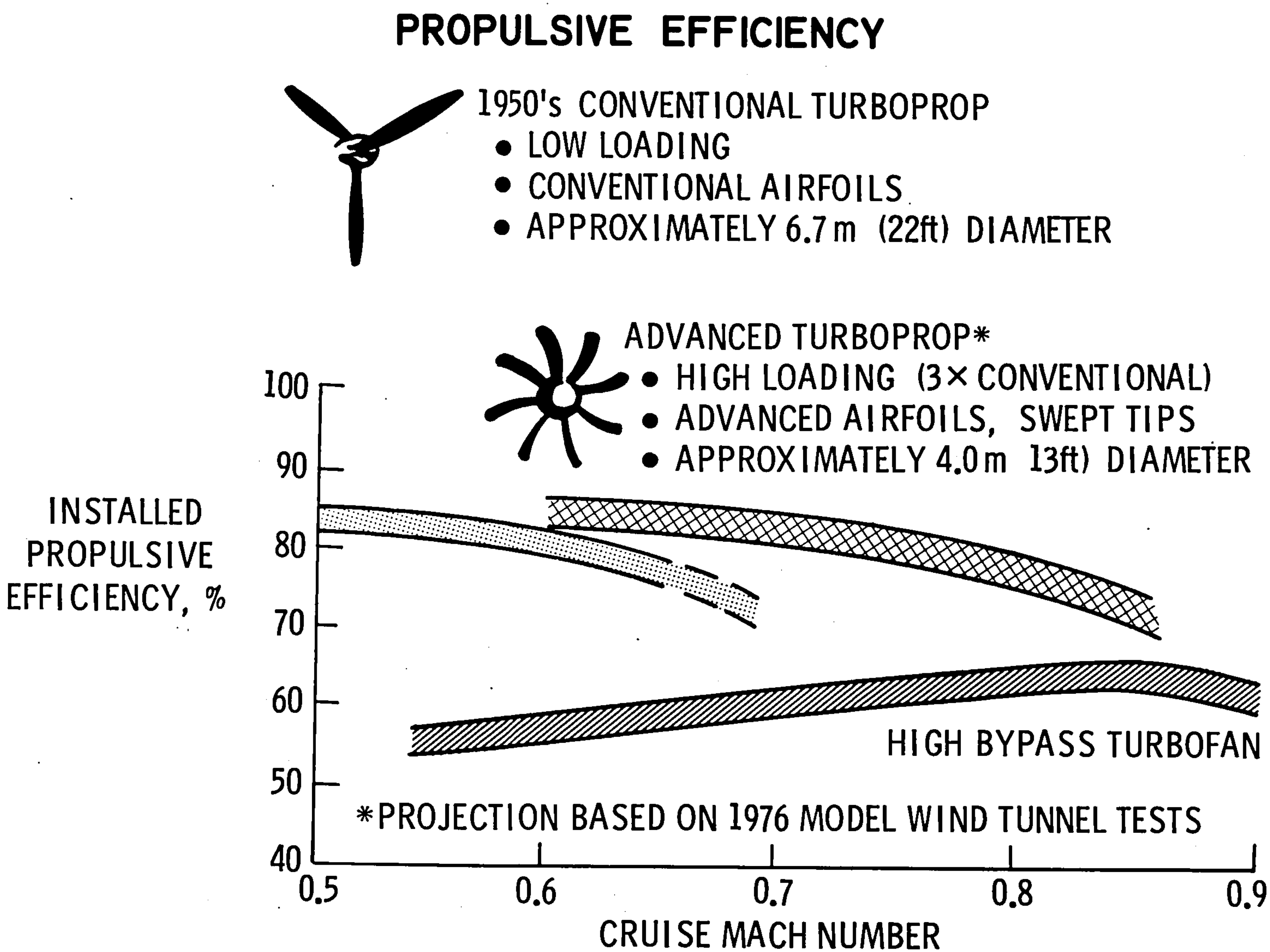


Figure 14. - Propulsive efficiency

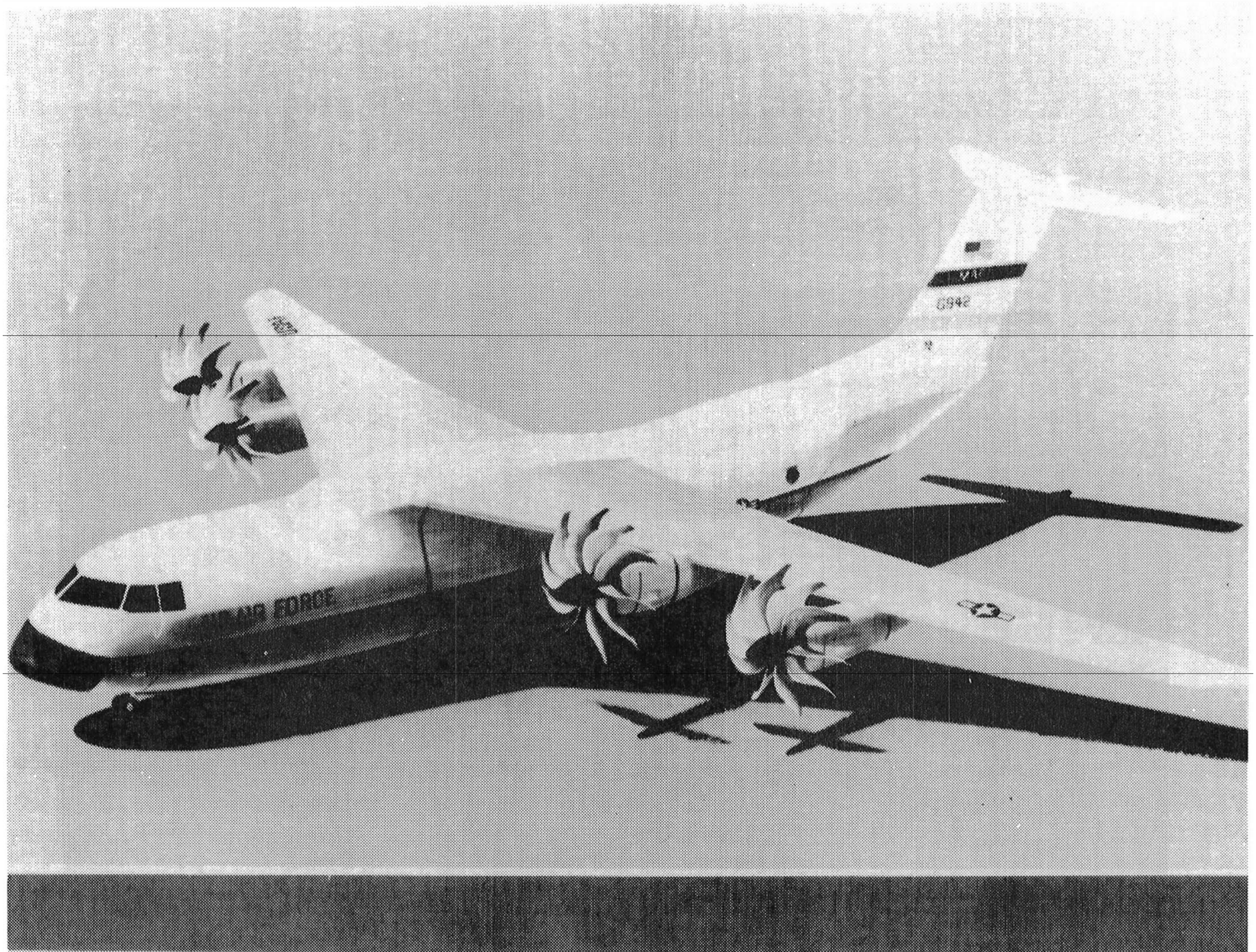


Figure 15. - Advanced turboprop transport concept

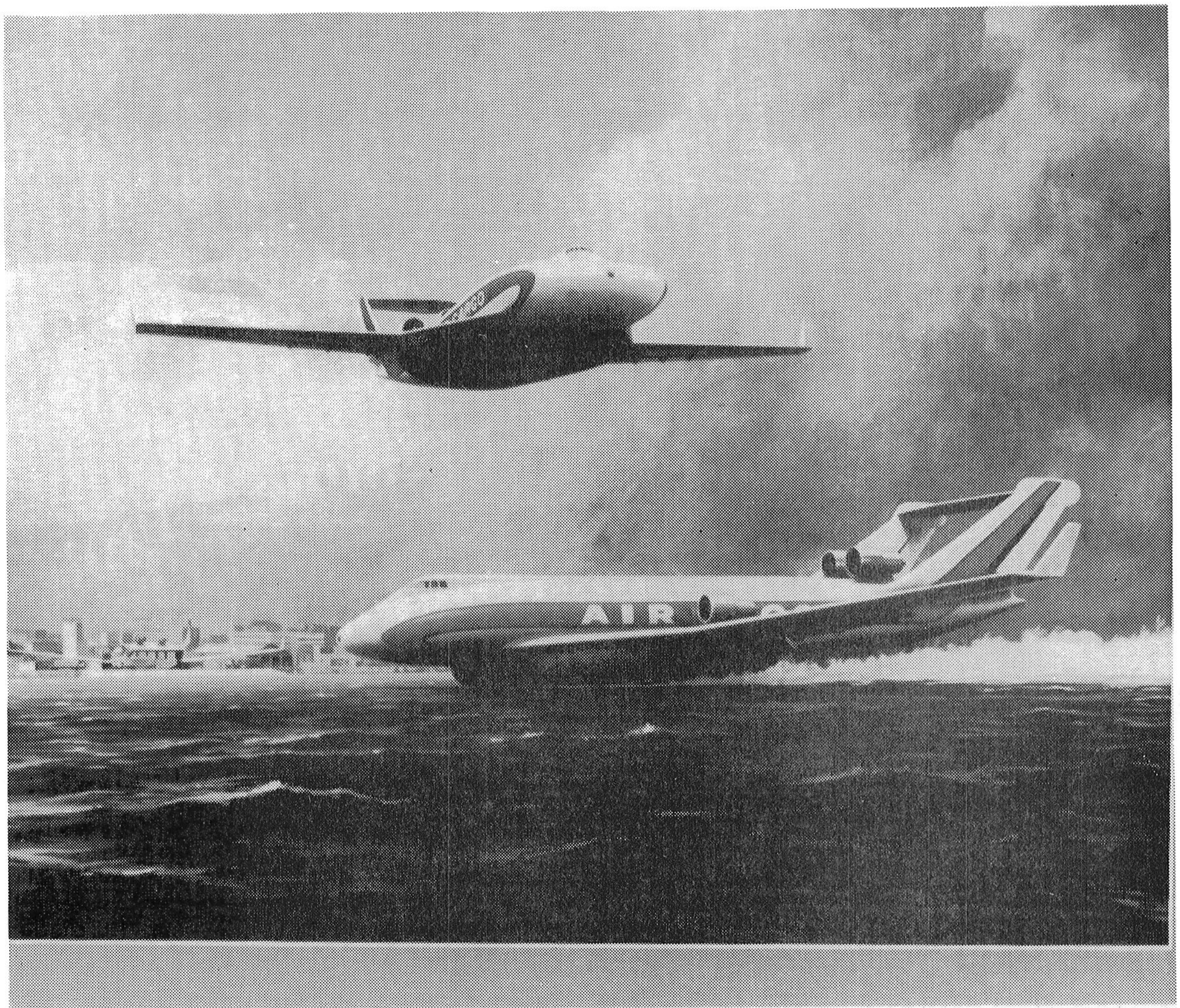


Figure 16. - Air-cushion landing gear transport concept

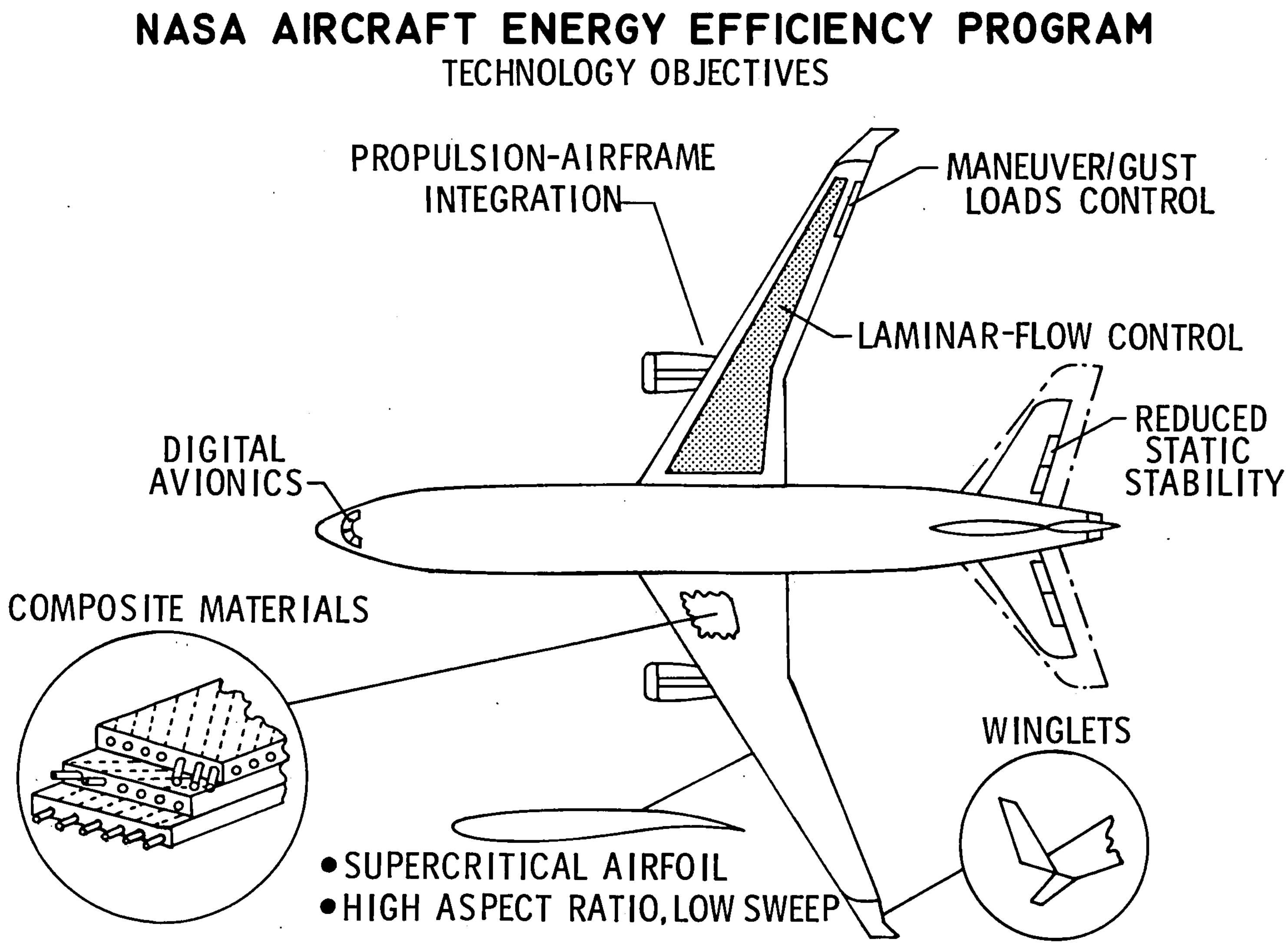


Figure 17. - Aircraft Energy Efficiency (ACEE) program

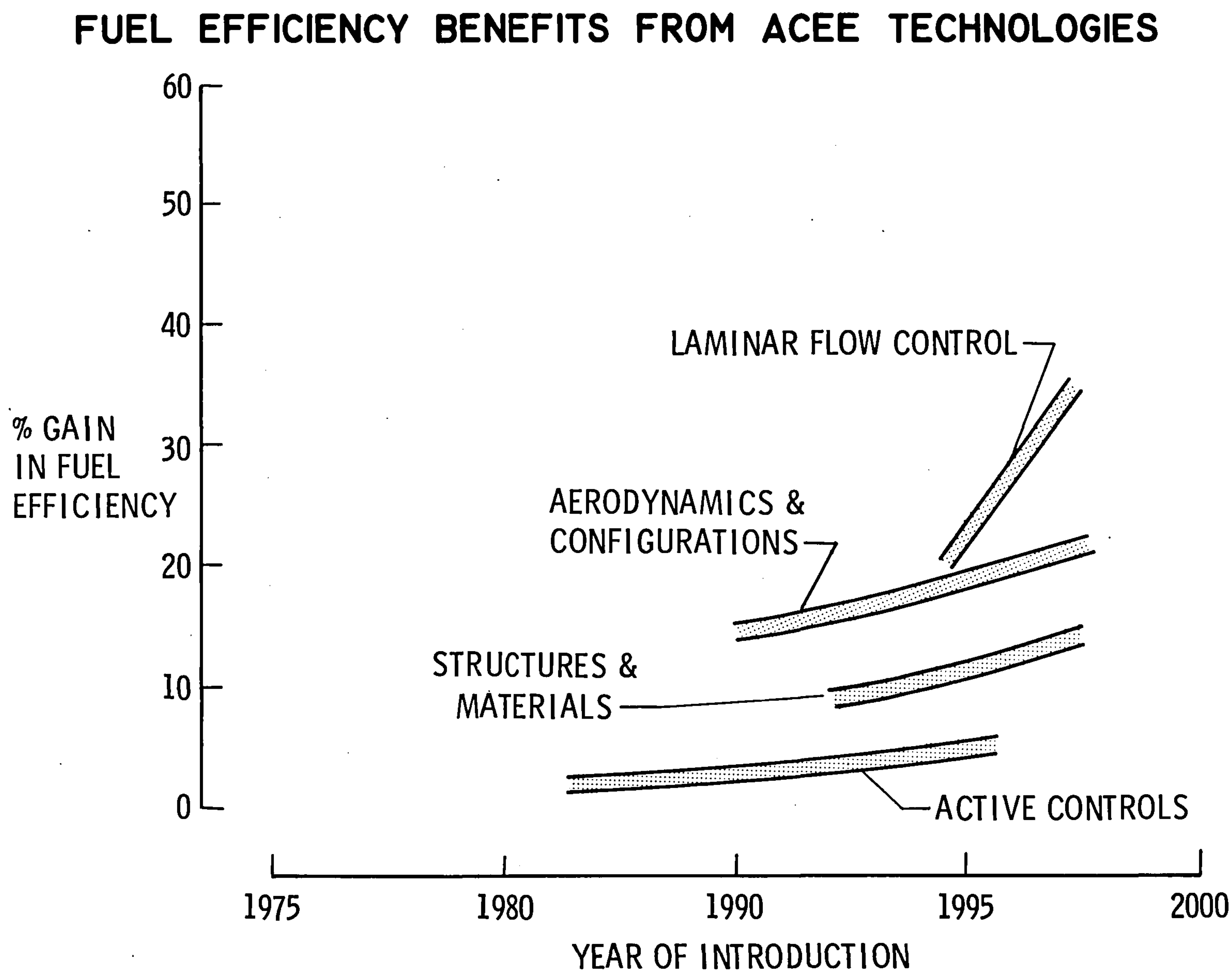


Figure 18. - Fuel efficiency benefits from ACEE technologies

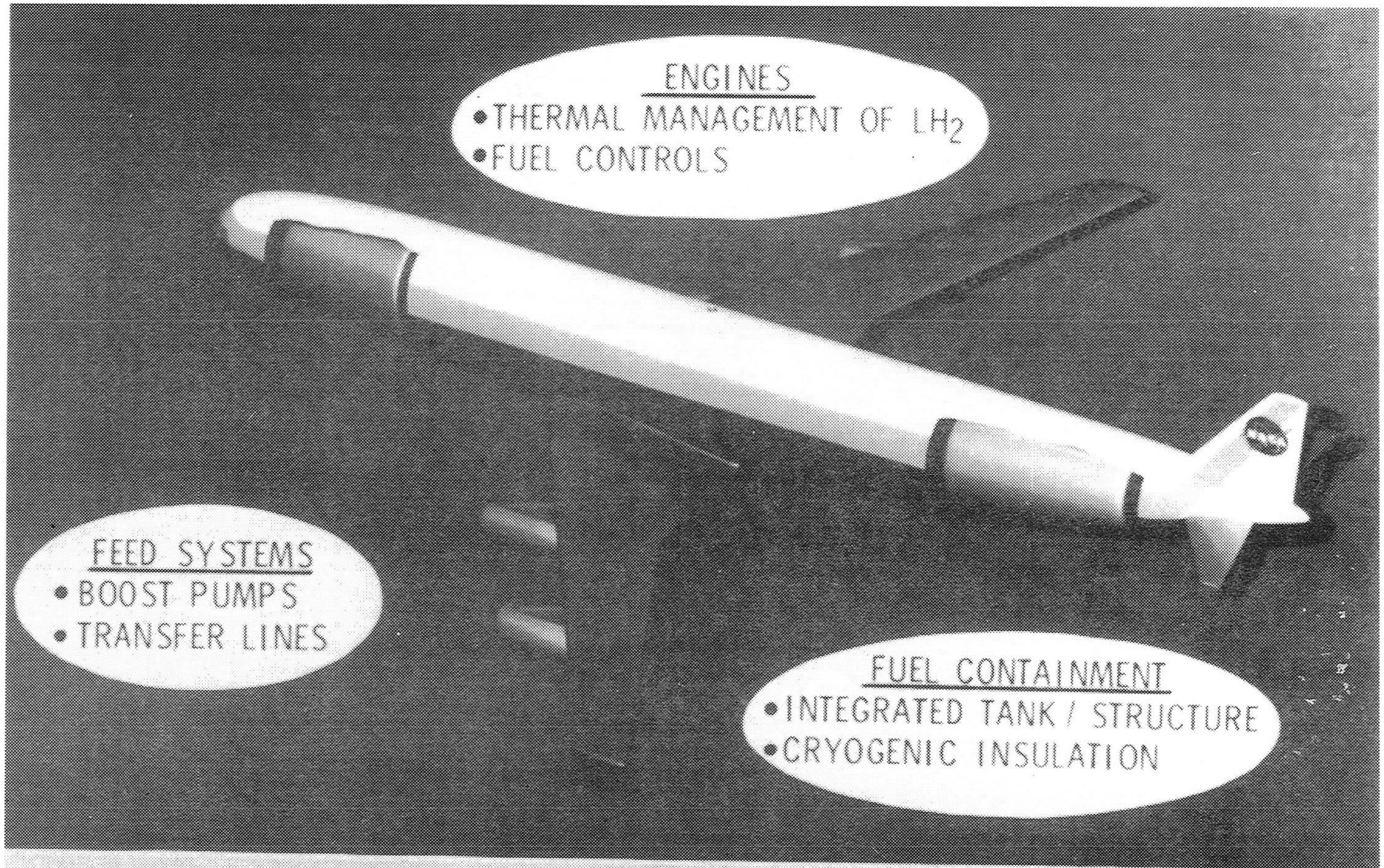


Figure 19. - Liquid hydrogen-fueled aircraft concept.

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15. Supplementary Notes

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16. Abstract

A view of potential enhancements to the air cargo system through technology application is provided. NASA's role in addressing deficiencies of the current civil and military air cargo systems is outlined. The evolution of conventional airfreighter design is traced and projected through the 1990's. Also, several advanced airfreighter concepts incorporating unconventional design features are described to show their potential benefits. A number of ongoing NASA technology programs are discussed to indicate the wide range of advanced technologies offering potential benefits to the air cargo system. The promise of advanced airfreighters is then viewed in light of the future air cargo infrastructure predicted by extensive systems studies. The derived outlook concludes that the aircraft technology benefits may be offset somewhat by adverse economic, environmental, and institutional constraints.

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