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TECHNOLOGY REQUIREMENTS AND READINESS FOR VERY LARGE AIRCRAFT

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Abstract

Aircraft categories addressed included conventional aircraft with turbofan, turboprop, or alternate fuel propulsion; multibody and spanloader aircraft; and vehicles not generally requiring runways, such as air-cushion-landing-gear aircraft, wing-in-ground effect aircraft, airships, and helicopters. More than fifty technology requirements were identified as unique or particularly critical to very large aircraft. The state of technology readiness was judged to be poor to fair for slightly more than one-half of the requirements. Readiness was less advanced for requirements pertaining to aircraft systems and operations than for those in the classic disciplinary areas of aerodynamics, propulsion, acoustics, and structures.

Introduction

The technology requirements for designing, manufacturing and operating any vehicle depend in large part on the configuration of that vehicle. [1] Under the general heading of Very Large Aircraft (VLA), configurations are many and varied, so, therefore, are the technology requirements. The brief study reported herein was limited to technology requirements of particular interest to very large aircraft. While many were of common interest, a few technology requirements critical to specific VLA types were also covered. Not included were the small technology refinements unique to a specific vehicle configuration since this level of technology is considered to normally be developed on an ad hoc basis.

The paper addresses in turn: common VLA concerns and how they influence configurations and technology; the methodology followed in selecting requirements and assessing readiness; the resultant technology requirements and readiness; and finally some overall observations regarding technology areas judged to be particularly critical.

Common Concerns and Aircraft Configurations

Common concerns of very large aircraft exist in the areas of economics, transportation system interfaces and operational problems (see Fig. 1). The concerns of a specific aircraft may give rise to several configuration requirements that are not always compatible with one another and conflicts sometime arise. Attempts to resolve these conflicts often generate novel configurations, some of which require technology which may not yet be developed. The remainder of this section discusses some of these concerns and their impact on certain technology requirements which subsequently were evaluated.

Economics

The number of aircraft produced from a given design is very important to first cost. For a conventional transport aircraft to be successful, a production run in the hundreds is considered necessary to avoid pricing the aircraft out of reach. On the other hand, a production run measured in tens rather than in hundreds will be more likely for most VLA types. Such low productions will result from the limited demands for the unique capabilities of these aircraft and/or their high productivities. Significant effort must be directed toward both maximizing the number produced and reducing the first cost for a given production run. [2]

Multiuse capability holds great attraction for increasing the demand for an aircraft. Examples of multiuse include the transportation of cargo as well as passengers, and transportation of military equipment as well as civil cargo. Design of aircraft for multiple use can lead to conflicts in the qualities to be emphasized. For example, the transportation of passengers requires safety and speed to be the prime factors, while the transportation of cargo requires a greater emphasis be given to cost and intermodal responsibilities. Likewise in the transportation of cargo, civil use emphasizes cost while military use emphasizes capability to perform missions. Also, cargo density, packaging and handling requirements can differ substantially.

Resolution of conflicts can narrow choices of aircraft configurations. An example would be the location of the wing on an aircraft configured to be compatible for both passenger transportation and military airlift use. A low wing location is generally preferred for passenger safety and aircraft flight performance, while a fuselage deck at truck-bed height is preferred for military airlift to expedite handling cargo at forward locations. A configuration satisfying both of these constraints would have the wing mounted low on a fuselage which in turn would sit very close to the ground (see Fig. 2). Of necessity, the landing gear would have to be relatively compact and the powerplant would have to be located other than below the wing. Thus, new technology needs could be envisioned for the landing gear and powerplant systems as well as for minimizing any adverse ground effects.

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For a given anticipated production run, reducing first costs includes the use of: off-the-shelf components, a minimal number of unique parts, and easy-to-fabricate structural shapes. Vehicle manufacturers currently use all of these strategies. What could be different for very large vehicles would be a greater use of strategies which adversely impact other areas. An example would be an aircraft wing which is deliberately untapered to reduce the number of unique parts. Since lack of taper would adversely affect aerodynamic efficiency, a requirement would then exist for technology to design auxiliary aerodynamic devices (e.g., winglets) to upgrade aerodynamic efficiency (see Fig. 2).

Minimization of operating costs is also very important for all transport vehicles regardless of size. A principal design objective is to provide high ratios of payload to empty weight and of lift to drag.

Other Concerns

Concerns of the interface of the aircraft with the transportation system also impact the configuration. Good compatibility is needed between the aircraft and existing terminal facilities. Changes in terminal geometry and equipment to accommodate very large aircraft would require not only the expenditure of considerable sums of money but also the solution of space accommodation problems. Additional space is not always available and a dilemma could result from trying to realize the full benefits of increasing vehicle size. New features could be incorporated into the aircraft configuration to help the situation. For example, achieving a decrease in wing span to meet ramp and gate spacing restrictions could be accomplished through use of either a variable geometry feature (e.g., hinged wing) or a new aerodynamic configuration (e.g., winglets). Of particular concern to very large aircraft is their compatibility with the geometry and strength of existing runways and taxiways. Runway waviness and bearing strength at some major airports already pose problems for current widebody aircraft.

Another concern centers on environmental problems as affecting both the passengers and the community. While very large vehicles generally have more interior room to minimize crowding, they also have a greater amount of installed power which can introduce noise problems within the passenger compartment. These problems could be aggravated by certain nonconventional locations (e.g., above the wing) of the powerplants proposed in some VLA designs. In community acceptance, the power plant emissions and external noise problems may be aggravated, or at least be different, for very large vehicles. Increased vehicle size also makes more practical the use of certain alternate fuels (e.g. hydrogen, nuclear) which will pose problems different from conventionally fueled aircraft.

A final concern is the area of hazards which very large aircraft may pose to the passengers and the community. Questions are raised regarding the crashworthiness and passenger survivability of certain VLA concepts, particularly those where the fuel is housed near the passengers, such as in the fuselage.

Methodology for Assessing Technology

The term, Very Large Aircraft, is quite broad in scope, and so are the many and varied items of technology required for success in their design, fabrication and operation. To bring within reasonable bounds an assessment of technology for such a broad subject area, an arbitrary approach was followed both in the selection of specific technology requirements and in carrying out an appraisal of their readiness. The approach methodology is described herein.

Selection of Technology Requirements

The technology requirements selected were those judged to be unique to very large aircraft, critical to specific kinds of aircraft and/or common to several aircraft types. Particularly stressed were uniqueness and criticality rather than broadness of technology application.

Aircraft systems and operations were addressed in addition to the classic disciplines (e.g., aerodynamics, propulsion, structures) required in vehicle design. A balance in technology items between disciplines was arbitrarily made by selecting two to four items in each of sixteen subareas equally divided among the following four major disciplinary areas: aerodyunamics; propulsion and acoustics; structures; and aircraft systems and operations. The sixteen subareas are listed in Table 1.

Table 1 Technology areas addressed

AREA	SUBAREA
AERODYNAMICS	2-D PHENOMENA 3-D CONFIGURATIONS COMPONENT INTERFERENCES WIND AND WAVE INPUTS
PROPULSION AND ACOUSTICS	TURBOFAN ENGINES PROPELLERS AND ROTORS ALTERNATE FUELS ACOUSTICS AND NOISE REDUCTION
STRUCTURES	MATERIALS AND MANUFACTURING STRUCTURAL CONFIGURATIONS STRUCTURAL DYNAMICS LANDING SYSTEMS
AIRCRAFT SYSTEMS AND OPERATIONS	ACTIVE CONTROL SYSTEMS FLIGHT DYNAMICS INTERACTING VEHICLES HAZARDS

Assessment of Technology Readiness

The knowledge and expertise required to adequately assess the broad range of technologies represented in the current study does not reside in any one organization. While a very considerable amount of information is in the public domain, some is not readily available because of proprietary or security restrictions. The approach followed in the present study was to consult with and obtain information from a number of senior specialists who could be identified as knowledgeable in specific disciplinary areas. The majority of these specialists were from NASA, principally the Langley Research Center. In individual areas, opinions of the evaluators have generally been in agreement both as to the identification of appropriate technology requirements and the assessment of their readiness.

Assessment of technology readiness is a judgemental process and cannot be indisputably quantified. The approach followed in the present study was to subjectively rate by adjective, which could range from "poor" to "excellent", each item of technology for which a requirement has been identified. In many instances, the rating is qualified (e.g., limit on range of application). The relative comparability of ratings between technology items may not be fully consistent because of two factors: a difference in level of conservatism between evaluators, and a difference in state of technology development and application between factors. Where the state of development is somewhat mature, problems may have arisen during real world experience which originally had not been anticipated but which now adversely affect the assessment. When the technology is less mature and developmental problems have not yet been identified, the tendency of an evaluator is to be optimistic and rate the technology readiness to be somewhat better than probably it really should be.

Technology Requirements and Readiness

The identified technology requirements and the companion assessments of technology readiness will be presented in the order listed in Table 1. It should be recognized that some technology items listed under one area may in fact involve several technology areas.

Aerodynamics

All Very Large Aircraft have one design goal in common: achievement of high operating efficiency. For the types of vehicles presently being addressed, efficiency depends on the vehicle aerodynamic characteristics. Since the criticality of these characteristics increases with speed, judgement must be exercised for the various types of vehicles regarding the importance given to aerodynamics. In the present review, the general area has arbitrarily been divided into four subareas: two-dimensional shapes; three-dimensional configurations; interferences between vehicle components; and wind and wave inputs which perturb aircraft. Thirteen technology requirements have been identified in these subareas. These requirements and associated appraisals of technology readiness are discussed in the following paragraphs.

Two-Dimensional Phenomena (Table 2). A requirement exists for thick (15 to 30 percent) lifting foils which have good lift-drag ratios. Thick shapes make possible not only high structural efficiency but also more usable volume within the foils. Such volume is very important for those VLA concepts where fuel and payload are to be accommodated primarily within the lifting surface rather than within a nonlifting body (see Fig. 2) Technology radiness is rated "very good" for thicknesses to 20 percent. Methodology, backed by considerable data and experience is available to address the lower Mach number design situations. Presently lacking is the technology

Table 2 Technology requirements and readiness for two-dimensional aerodynamic phenomena

REQUIREMENTS	READINESS
THICK FOILS HAVING GOOD LIFT/DRAG RATIOS	VERY GOOD - TO 20 PERCENT THICKNESS AT SUBCRITICAL MACH NUMBERS; TECHNOLOGY LACKING FOR GREATER THICKNESSES AND HIGHER MACH NUMBERS
BLUFF NONLIFTING BODIES HAVING LOW DRAG	VERY GOOD - FOR ISOLATED BODIES
EFFECTS OF VERY HIGH REYNOLDS NUMBER	FAIR - FOR LIFTING FOILS GOOD - FOR NONLIFTING BODIES

to provide adequate designs for greater thicknesses and for higher Mach numbers (see Fig. 3). A somewhat similar requirement exists for bluff nonlifting bodies having low drag. Again the technology readiness is rated "very good" for isolated bodies. An additional requirement common to both foils and bodies concerns the effects of very high Reynolds numbers. The technology readiness is rated only "fair" for lifting air foils. Uncertainties exist particularly in the aft chord region.

Table 3 Technology requirements and readiness for three-dimensional aerodynamic configurations

REQUIREMENTS	READINESS
OPTIMIZED VLA CONFIGURATIONS	GOOD - FOR CONFIGURATIONS HAVING ATTACHED FLOWS AT SUBCRITICAL M. LARGER DATA BASE NEEDED TO ADDRESS NOVEL CONFIGURATIONS
IMPROVED LIFT/DRAG RATIOS OF COMPROMISED CONFIGURATIONS	FAIR - NOT ADEQUATE FOR HANDLING WIDE-TIPPED LIFTING SURFACES
EFFECTS OF VERY CLOSE PROXIMITY TO GROUND	GOOD - FOR MOST CONFIGURATIONS FAIR - FOR SEPARATED FLOW OR VORTEX LIFT
FLOW CONTROL FOR SURFACES AND BODIES	VERY GOOD - FOR FLOW SEPARATION CONTROL POOR - FOR LAMINAR FLOW CONTROL

Three-Dimensional Configurations (Table 3). For any VLA where performance is important, a need exists for technology to optimze the aerodynamic configuration. This need is admittedly broad in scope because of the many different VLA types. The technology readiness is considered to be "good" for configurations having attached flows at subcritical Mach numbers. Technology development has not yet been extended to address situations where lifting surfaces are thick or where Mach number values are very high. A much larger data base is needed to address novel experimental configurations. A second need, discussed earlier, involves improvement of the lift-drag ratios for compromised configurations such as lifting surfaces of low aspect ratio; here, technology readiness is rated as only "fair". It certainly is not adequate for handling wide-tipped wings. A third need concerns understanding and modeling of the aerodynamic ground effects when the VLA lifting surfaces are in close proximity to the ground. The technology readiness of this item is rated "good" for most configurations but "fair" for configurations having separated flow or with vortex lift (e.g., as with a highly swept leading edge). Configurations incorporating thick lifting surfaces could also pose problems. A fourth need is flow control for VLA lifting surfaces and bodies. The technology readiness for flow control required to avoid flow separation is fairly well understood with technology readiness rated as "very good". The rating decreases to "poor" where laminar flow is to be maintained. Problems are much more severe in maintaining laminar flow [3] for all configurations (see Fig 4) and for high Reynolds number. [4]

Table 4 Technology requirements and readiness for aerodynamic component interferences

REQUIREMENTS	READINESS
LIFTING SURFACES INTERSECTING AUXILIARY SURFACES, STRUTS, PROTUBERANCES	GOOD - LACK OF SUITABLE EXPERIMENTAL INFORMATION; THICK SURFACES REQUIRE LOCAL TAILORING
MULTIPLE LIFTING SURFACES	VERY GOOD - FOR ALL BUT EXTREME CONFIGURATIONS
THICK LIFTING SURFACES INTERSECTING BODIES	FAIR - PROBLEMS IN HANDLING BOUNDARY LAYER AND REYNOLDS NUMBER EFFECTS
PROPULSION SYSTEMS IN UNCONVENTIONAL LOCATIONS	FAIR - PROBLEMS WITH HIGHER BPR ENGINES, TURBOPROPS WITH SUPERCRITICAL WINGS, AND INLETS TO BURIED ENGINES

Component Interference Minimization (Table 4). Four technology needs were identified in the subarea of aerodynamic interferences between vehicle components. The first need addresses the technology to treat the problems of intersections of primary lifting surfaces by auxiliary lifting surfaces, struts, and/or protuberances. Technology readiness is rated "good". Rather sophisticated analytical models have been developed, but there is a lack of suitable experimental information to adequately validate the models. Use of thick lifting surfaces, which lower the critical Mach number, aggravates the problem and requires local tailoring of the contours of intersecting elements to minimize the interference. A related and second technology need concerns the handling of interactions between multiple, but nonintersecting lifting surfaces (e.g. biplane wings, wing-tail combinations). Technology readiness is rated as "very good". Although techniques are judged to be fully adequate to address a great variety of configurations, extreme configurations (e.g., high sweep angles, extreme stagger) still require technology development. A third need concerns bodies intersecting thick lifting surfces, where the readiness is rated "fair" (see Fig. 5). Problems exist in handling boundary layer and Reynolds number effects. The fourth area is that of achieving aerodynamically efficient integration of propulsion systems in unconventional locations (e.g., above the wing for airplanes). Technology readiness is rated "fair"; troublesome areas exist for high-bypass-ratio turbofans, for turbopropellers mated to wings incorporating supercritical sections, and for the inlet region of powerplants buried within the wing and operating at high angles of attack.

Table 5 Technology requirements and readiness for wind and wave dynamic inputs

REQUIREMENTS	READINESS
GUST/ TURBULENCE SPATIAL VARIATIONS	FAIR - THEORY AVAILABLE BUT EXPERIMENTAL DATA LACKING
EFFECTS OF GEOGRAPHIC AREA AND SEASON ON WIND AND WAVE INPUTS	FAIR - FOR GUSTS AND TURBULENCE, PHENOMENA UNDERSTOOD BUT DATA LACKING; FOR WAVES, DATA ADEQUATE BUT PROBLEM IN HOW TO USE FOR WIGS

Wind and Wave Inputs (Table 5). The dynamic loads and motion of aircraft are influenced to a very significant degree by the dynamic inputs of the external environment. Two technology requirements involving the dynamic inputs are addressed in this subarea (requirements concerned with dynamic responses to such inputs will be addressed subsequently). The first requirement concerns the spatial variations of gusts and turbulence occurring throughout the volume occupied by the aircraft at given points in time. Technology readiness can be rated no better than "fair". While theory is available, experimental data are lacking. Obtaining such data simultaneously throughout volumes as large as the biggest VLA (such as Lighter Than Air (LTA) vehicles) may be difficult to accomplish. The maximum dynamic loading inputs possible for some VLA (e.g. LTA, WIGS,) could well be too large for a practical vehicle. In such instances, vehicles would be designed for lesser loadings and restricted in operations. Accordingly, a second technology requirement concerns the effects of geographic area and season on dynamic input characteristics. Technology readiness is rated "fair". For gusts and turbulence, the phenomena are generally understood, but existing data are not adequate as they consist mainly of indirect measurements of vehicle response to the inputs. For wave spectra of water, a great quantity of data are available, but the problem centers around the question of how to use the data in the design of Wing in Ground Effect (WIG) aircraft.

Propulsion and Acoustics

Propulsion systems for very large aircraft, as for conventional size aircraft, must satisfy three major requirements: be compatible with the geometric and operational requirements of the aircraft; be fuel efficient and economical in operation; and be environmentally acceptable. Acoustics has been listed in the title with propulsion since it embraces a technology area broader than the acoustics associated with just the propulsion system. [5] In the present review, the general area has been divided into four subareas: turbofan engines; propellers and rotors; alternate fuel propulsion; and acoustics and noise reduction. Thirteen technology requirements have been identified in these subareas. These requirements and associated appraisals of technology readiness are discussed in the following paragraphs.

Table 6 Technology requirements and readiness for turbofan engine

REQUIREMENTS	READINESS
VERY LARGE, EFFICIENT HIGH BPR TURBOFAN ENGINES	GOOD - SCALE EFFECTS POSE PROBLEMS
VERY-HIGH-BPR ENGINES FOR HIGH QUANTITY, LOW PR NEEDS	VERY GOOD - FOR EXISTING CORES, AND CONVENTIONAL OPERATIONS; FAIR - FOR UNCONVENTIONAL OPERATIONS
VARIABLE-CYCLE ENGINES FOR EFFICIENT SUBSONIC/SUPERSONIC USE	FAIR - PREFERRED COMBINATION OF CYCLES NOT YET SELECTED
EFFICIENT OPERATIONS OF TURBOFANS IN UNCONVENTIONAL LOCATIONS	GOOD - IN LOCATIONS WHERE EXTERNAL AERODYNAMICS HAVE GOOD FLOWS

Turbofan Engines (Table 6). Historically, substantial increase in size for most vehicle types has been achieved first by utilizing existing propulsion units of appropriate number with some tailoring as required. Then larger, more specially tailored propulsive units have been developed where demand has warranted. To ease VLA developmental costs, such an approach will undoubtedly be followed except for those unique situations (e.g. nuclear-powered aircraft) where the vehicle and its geometry may be critically dependent on an all-new propulsion unit. Anticipating that VLA demand will be sufficiently large, a requirement has been identified for the technology to design very large, efficient engines of high bypass ratio (8-12). Technology readiness is rated "good". Scale effects pose some problems in areas such as near-sonic tip speed of the fan. A second technology need is in the area of very high bypass ratio (20-40) engines for high quantity, low-pressure-ratio flow needs (e.g. ram air for WIG vehicles). [6] Technology readiness is rated "very good" for engines utilizing existing cores. The rating downgrades to "fair", however for unconventional operations of the propulsion unit. Examples include inlet upwash problems for mechanically-tilted engines and substantial losses in thrust from the trapped efflux for WIG machines. A third technology requirement is in the area of variable cycle engines suitable for efficient operations at either of two conditions, such as for either supersonic cruise or subsonic cruise. Technology readiness is rated "fair". A preferred combination of cycles has not yet been selected. A fourth requirement is for technology to provide efficient operations of propulsion systems when located in unconventional regions such as above the wing on aircraft (or for powered-lift configurations employing upper surface blowing. [7] Technology readiness is rated "good" for those locations where the external aerodynamic flow is unseparated and has a thin boundary layer.

Table 7 Technology requirements and readiness for propeller and rotors

REQUIREMENTS	READINESS
PROPELLERS/ROTORS HAVING HIGH EFFICIENCY, LOW NOISE AND LOW MAINTENANCE	POOR - AT MACH 0.8 SPEED GOOD - AT MACH 0.6 SPEED FAIR - FOR LARGE HELICOPTERS
DRIVE TRAINS WHICH ARE RELIABLE AND LONG LIVED	POOR - PROBLEMS STILL PERSIST FOR CONVENTIONAL SIZE VEHICLES

Propellers and Rotors (Table 7). During the last two decades, large high performance aircraft have relied on turbojet and turbofan propulsion rather than turbopropellers. Propeller driven aircraft which match the size and operating speeds of present wide-body aircraft should therefore qualify as advanced very large aircraft (see Fig. 6). For both propeller and rotor aircraft, helical tip speeds are much higher than vehicle forward speed. The associated sonic flow problems of the blades introduce design constraints, which for VLA applications, may result in propellers or rotors of unusual design operating at relatively low rotational speeds. A requirement has been identified for technology to configure propellers and rotors for VLA having high efficiency, low noise, and low maintenance. While considerable effort is underway by NASA in developing advanced propfan propulsion [8], technology readiness is rated "poor" for propeller-driven aircraft operating at Mach number of about 0.8 (the cruise speed of today's transport aircraft), "good" to "very good" at Mach number of about 0.6, where some problems still exist (e.g., integration with supercritical wings), and "fair" for helicopters of large size. A second technology requirement relates to drive trains, for VLA engines which are quiet, reliable, and long lived. Technology readiness is rated "poor." While progress has been made in recent years in drive trains for present size vehicles, significant problems still persist.

Alternate Fuel Propulsion (Table 8). There is a rather narrow choice of alternate fuels for gas turbine powered aircraft because of the particularly adverse qualities of most of the candidate fuels. The most attractive finalists are synthetic kerosene, cryogenic methane, and cryogenic hydrogen (see Fig. 7). [9] Little difference exists between synthetic and petroleum-derived kerosene, although the synthetic kerosene may be degraded in quality to simplify the manufacturing process to lower fuel cost. No VLA-unique problems are envisioned and technology readiness is rated "very good". Cryogenic methane and hydrogen do pose volume problems. Not only is the fuel volume greater than for kerosene to provide a given amount of energy, but additional volume is required for insulating the cryogenic lines and tanks. Studies indicate, however, that aircraft performance could equal or better that for conventional fuels when the cryofuel is housed within the fuselage (see Fig.

Table 8 Technology requirements and readiness for alternate fuels

REQUIREMENTS	READINESS
SYNJET FROM COAL OR OIL SHALE ACCEPTABLE FOR VLA USE	VERY GOOD - GENERALLY COMPATIBLE. ACCOMODATION OF BROAD SPEC FUEL AN ISSUE
CRYOFUEL ENGINES AND FUEL SYSTEMS ACCEPTABLE FOR VLA USE	GOOD - VERY GOOD UNDERSTANDING; FULL SCALE EXPERIENCE NEEDED, PARTICULARLY FOR PUMPS AND INSULATION
NUCLEAR ENERGY ENGINES AND SYSTEMS FOR VLA USE	GOOD - FULL SCALE EXPERIENCE NEEDED

8) and where the payload and stage length have large values. Hence, the cryofuels are candidates for VLA applications. A requirement exists for the technology to provide cryofuel engines and fuel systems which are acceptable for VLA use. Technology readiness is rated "good". While there is a very good understanding in this area, full scale experience is needed, particularly for the pumps and insulation. A similar requirement exists for engine and fuel system technology for VLA nuclear propulsion which has been identified as viable for certain vehicle requirements.[10] Technology readiness is rated "good" with full scale experience again being the principal need.

Table 9 Technology requirements and readiness for acoustics and noise reduction

REQUIREMENTS	READINESS
NOISE PREDICTION FROM VARIOUS CONTRIBUTING VLA SOURCES	FAIR - AIRFRAME NOISE NOT WELL UNDERSTOOD, LACK FULL-SCALE EXPERIMENTS
VLA CONFIGURATION CONTROL FOR DIRECTIONAL NOISE REDUCTION	FAIR - GOOD PREDICTIVE METHODS LACKING FOR IN-FLIGHT SITUATIONS
UNDERSTANDING NOISE TRANSMISSION AND METHODS FOR ATTENUATION	GOOD - GOOD UNDERSTANDING BUT DESIGN TECHNIQUES LACKING TO ACHIEVE ACCEPTABLE LEVELS
UNDERSTANDING PASSENGER AND COMMUNITY REACTIONS TO VLA NOISE	POOR - LITTLE EXPERIENCE WITH LOW FREQUENCY NOISE; LAB STUDIES ARE DIFFICULT TO PERFORM

<u>Acoustics and Noise Reduction (Table 9).</u> Increase in aircraft size not only increases the noise level of the aircraft but also changes the character of the noise, both of which can cause problems. One change in character is a downward shift in noise frequency which deceases noise attenuation. A technology requirement exists for the prediction of noise from the several contributing VLA noise sources. Technology readiness is rated "fair". Airframe noise, which will likely be an important noise source for VLA configurations, is not well understood and experimental studies at large scale have been constrained by lack of an appropriate test facility. One factor that has not been exploited for noise control is the shielding provided by the vehicle structure (e.g., aircraft wings). Accordingly, a second technology requirement concerns the means for decreasing, in certain directions, source noise by vehicle configuration control. Technology readiness is rated "fair". While understanding exists of such phenomen as refraction, reflection and diffraction, good prediction methods are still lacking for inflight situations. Compared with conventional size vehicles, VLA noise will no doubt be more intense at the lower frequencies and probably will be a bigger problem in cabin areas. Also, low frequency noise will be propogated through the atmosphere with a low rate of attenuation. Accordingly, a technology requirement concerns understanding the transmission of VLA noise and methods for its attenuation. Technology readiness is rated "good". Noise transmission technology is well understood. The basics of noise attenuation are pretty well understood but the design techniques to achieve acceptable noise levels are not necessarily available. A fourth technology requirement is an understanding of passenger and community reactions to VLA noise. Technology readiness is rated "poor". There is little experience with low frequency noise exposures and appropriate laboratory tests are very difficult to perform. Community reaction to the noise of aircraft which have much larger propulsion systems than today's aircraft is considered to be a little understood phenomena.

<u>Structures</u>

This general area broadly includes the entire aircraft structure which must provide the internal and external shapes efficiently and still withstand the loadings and other environments unique to the various VLA categories. Specifically included are all of the various structural subsystems, the materials and their fabrication which enter into these subsystems, and the dynamic behavior of the structure which must be addressed and accounted for in the design and operation of the aircraft. In the present review, the general area has arbitrarily been divided into four subareas: materials and manufacture; structural configurations; structural dynamics; and landing systems. Fifteen VLA technology requirements have been identified in these subareas. These requirements and associated technology readiness are discussed in the following paragraphs.

<u>Materials and Manufacture (Table 10).</u> A number of specialized material and material manufacturing requirements exist for the various VLA categories and are represented by the four technology requirements which will be discussed. Many of the VLA configurations can take advantage of advanced composites to provide viable structural elements suitable for manufacture in relatively small quantities.[11] A requirement exists for the technology to design, efficiently manufacture and inspect advanced composite structural elements. Technology readiness is rated "good: with design technology considered well in hand. Techniques are lacking for adequate field inspection. Titanium is an excellent material for VLA structures where there are problems of corrosion or elevated temperatures. As for advanced composites, a need exists for the technology to design and efficiently manufacture stiffened titanium structural elements. Technology readiness is judged "fair". Recent advances have been made in fabricating complex

Table 10 Technology requirements and readiness for materials and manufacturing

REQUIREMENTS	READINESS
ADVANCED COMPOSITES DESIGN, MANUFACTURE AND INSPECTION	GOOD - TECHNIQUES LACKING FOR ADEQUATE FIELD INSPECTION
STIFFENED TITANIUM PANEL DESIGN AND EFFICIENT MANUFACTURE	FAIR - ONLY MODEST SIZE PANELS TO DATE; FIELD EXPERIENCE LACKING
HIGH PERFORMANCE FABRICS AND FILMS FOR NONRIGID AIRSHIPS	FAIR - SUBSCALE TESTS OF PROMISING MATERIAL SHOWS STRENGTH DETERIORATION
MATERIALS AND LAYUP FOR LONG-LIFE ACLG TRUNKS FOR VLA	FAIR - UNDERSTAND PROBLEMS; NO SUCCESSFUL FULL-SIZE TRUNK FABRICATED

stiffened panels by a super-plastic-forming and diffusion-bonding technique (see Fig. 9).[12] Panels of only modest size have been fabricated to date and field experience with full scale panels is lacking. Nonrigid airships, because of their very large surface area, require flexible surface materials of very light weight.[13] Some of the newer materials show promise for considerable reductions in weight. A technology requirement exists for high performance fabrics and films for nonrigid airships. Technology readiness is rated as "fair". Based on small scale tests, deterioration of material strength with loading time is not a fully understood problem. As described later, some VLA configurations may utilize air cushion of air landing gear (ACLG) which consist of flexible, retractable, doughnut-shaped inflated trunks, perforated on the bottom to allow an outflow of air and provide a cushion on which to takeoff and land. There is a technology requirement for materials and material layup technique for long-life ACLG trunks. Technology readiness is rated "fair". While there is a good understanding of the problems involved, no fully successful full-size trunk has been fabricated for conventional size aircraft.

Table 11 Technology requirements and readiness for structural configurations

REQUIREMENTS	READINESS
OPTIMAL STRUCTURAL CONFIGURATIONS FOR VARIOUS VLA CONFIGURATIONS	FAIR - ADEQUATE STRUCTURAL PRINCIPALS AND COMPUTER TOOLS; LOADINGS NOT ALWAYS KNOWN; LACK DATA BASE AND EXPERIENCE
LOW COST FOR LIMITED PRODUCTION OF STRUCTURAL SUBSYSTEMS	POOR - RELATIVELY UNEXPLORED AREA
BOUNDARY-LAYER AND LAMINAR-FLOW-CONTROL STRUCTURAL SYSTEMS	VERY GOOD - FOR BLC STRUCTURAL SYSTEMS FAIR - FOR LFC STRUCTURAL SYSTEMS

Structural Configurations (Table 11). VLA concepts very often involve nonstandard structural configurations where prior experience is limited or nonexistent. Accordingly, a requirement exists for the technology to identify optimal configurations for VLA concepts embracing a wide range of structural features (e.g., flexible envelope [13] multibody, [14] span-distributed-load, [14]). Technology readiness is rated only "fair". While structural principles and computer tools (see Fig. 10) are adequate, loading conditions are not always sufficiently known, and there is a lack of an adequate data base and experience. To decrease first costs for vehicles manufactured in very limited quantity, a requirement exists for technology to select a design approach and to design structural subsystem configurations suitable for low cost manufacture with a low production run. Technology readiness is rated "poor"; this is a relatively unexplored area. A third requirement is for the technology to design and fabricate the structural systems suitable for providing either boundary layer or laminar flow control for VLA airframe components. Technology readiness is rated "very good" for boundary-layer-control structures which require much greater precision of both the surface and the surface ventilation geometry, and also require a leading edge surface clearing capability.[3]

Table 12 Technology requirements and readiness for structural dynamics

REQUIREMENTS	READINESS
VLA STRUCTURAL DYNAMICS PHENOMENA	GOOD - GENERAL METHODS AVAILABLE; REQUIRES UNIQUE DEVELOPMENT PER CONFIGURATION
VLA FLUTTER PHENOMENA	GOOD - TO TREAT INVISCID FLOW CONDITIONS; NOT ADEQUATE FOR VISCOUS FLOWS, SHOCKS
DEFORMATION DYNAMICS OF LARGE FLEXIBLE STRUCTURES	GOOD - ANALYTICAL METHODS AVAILABLE; EXPERIMENTAL VALIDATION IS A PROBLEM
DEFORMATION DYNAMICS OF ACLG FLEXIBLE TRUNKS	GOOD - FOR CONVENTIONAL SHAPES OVER LAND; NOT ADEQUATE OVER WATER

Structural Dynamics (Table 12). Very large vehicles may experience a variety of problems in structural dynamics and aeroelasticity because of unusual levels and distributions of mass and stiffness, large variations in payload and fuel load, large spans, thick lifting surfaces, relatively low torsional stiffness, and onboard rotating equipment. Accordingly, a need exists for technology to address VLA structural dynamics phenomena. Technology readiness is rated "good" with general methodology available but with unique developments required for each individual configuration. A related second requirement is for technology to address VLA flutter phenomena. Again, the readiness is rated "good" with methodology available to treat inviscid flow conditions. Where viscous flows and/or shocks occur, technology is not yet in hand to adequately handle the aerodynamic portion of the flutter phenomena. For vehicles having large flexible structures (e.g., nonrigid airships), a technology requirement has been identified relative to deformation dynamics. Technology readiness is rated "good". Analytical methods are available which were developed in part to address large space structures. However, problems exist in techniques and equipment appropriate for experimental validation of the methods. Problems in dynamics can occur for critical subsystems as well as for the entire vehicle. One example is the air cushion landing gear (ACLG) which sometimes exhibits dynamic instability. A technology requirement exists related to the deformation dynamics of the inflated ACLG flexible trunk operating on either land or water. Technology readiness is rated "good" as it is considered adequate for handling noncompartmented trunks of elongated planform shape operating on land. [16] Technology is not yet adequate to address trunks of nonregular planform or trunks of any configuration operating over water at below "hump" speed.

Table 13 Technology requirements and readiness for landing systems

REQUIREMENTS	READINESS
TIRE/ BRAKING SYSTEMS FOR VLA AIRCRAFT	FAIR - TODAY'S SYSTEMS MARGINAL, VLA SYSTEMS WILL BE MORE COMPLEX
CROSS-WIND LANDING SYSTEMS	GOOD - EXPERIENCE ON LARGE AIRCRAFT; SMALL-SCALE ADVANCED SYSTEM FLIGHT TESTED
VLV LANDING SYSTEM FOR CONVENTIONAL RUNWAYS	POOR - TODAY'S SITUATION MARGINAL, ACLG SYSTEM HAS GOOD POTENTIAL
RESPONSE CONTROL OF FLEXIBLE VLA TO RUNWAY WAVINESS	GOOD - PROBLEMS UNDERSTOOD AND SYSTEM DESIGNED; FULL-SCALE EXPERIENCE REQUIRED

Landing Systems (Table 13). Based on experiences with present day transports, very large aircraft which are airborne during cruise operation, and which takeoff and land at significant speed, may have problems with their landing systems. A requirement exists for technology to design and manufacture tires and brakes for VLA landing systems. Technology readiness is rated "fair". Landing systems for present transport aircraft have little extra margin as evidenced by their consistent standing near the top in costs of all items of airframe maintenance. [17] Tire size is limited if landing speed remains constant. Increase in vehicle weight will therefore require a proportionate increase in number of tires and complexity of the landing system. A second technology requirement concerns VLA landing capability in strong cross winds. Technology readiness is rated "good." Systems have been operational for some years whereby the gear is skewed prior to landing. More advanced systems have subsequently been developed and flight tested on small aircraft. ACLG systems, once fully developed, should also provide adequate capability. A third technology requirement concerns VLA accommodation by runways of conventional width, contour, and allowable loading. This requirement results from the anticipated small number of most VLA aircraft and the desirability for freedom in their origin and destination options. The technology readiness is rated "poor". Runways at a number of present major airports are marginal in handling present wide-body aircraft. The use of ACLG, once developed, has great potential for spreading the loadings over the runway and easing the problems. A final technology requirement is in the area of controlling the structural response of flexible VLA to runway waviness. Technology readiness is rated "good". The problems are believed well understood and systems have been designed and ground tested. Full scale tests and experience have not yet been achieved.

Aircraft Systems and Operations

For the most part, technology requirements discussed thus far have been concerned with the classic disciplinary areas which enter into the general design of aircrft. A complementary major area is that concerned with the operations of the aircraft and which necessarily includes the systems peculiar to such operations. This major area will now be discussed. It has been divided into four subareas: active control systems, flight dynamics, interacting vehicles, and hazards. Thirteen technology requirements have been identified in these subareas. These requirements and associated appraisals of technology readiness are discussed in the following paragraphs.

Table 14 Technology requirements and readiness for active control systems

REQUIREMENTS	READINESS
AERODYNAMIC LOAD ALLEVIATION BY ACTIVE CONTROLS	GOOD - INDEPENDENT CONTROL OF LIFT AND PITCH A PROBLEM
AUGMENTED STABILITY BY ACTIVE CONTROLS	VERY GOOD - PROVIDING ADEQUATE CONTROL AUTHORITY IS PROBLEM
DECOUPLING DEGREES OF FREEDOM FOR COMPLEX VEHICLES	FAIR - NEEDED ARE DECOUPLING REQUIREMENTS AND DESIRED DYNAMIC RESPONSE OF DECOUPLED MODES
FLUTTER SUPPRESSION BY ACTIVE CONTROLS	POOR - PROBLEMS WITH RAPIDLY DIVERGING MODES

Active Control Systems (Table 14). A number of time-dependent phenomena occur during aircraft operations which can advantageously be altered or eliminated by automatic application of corrective actions through active control. One example is the last technology requirement discussed under Landing Systems: control of flexible structure aircraft to runway waviness. Other VLA requirements which involve active controls also have been identified. The first technology requirement concerns aerodynamic load alleviation from gust or maneuvers of structually efficient VLA configurations. Technology readiness is rated "good". There remains a problem in providing independent control of lift and pitching moment for some VLA configurations such as span-distributed load aircraft (see Fig. 11). A second technology requirement concerns augmented stability for VLA configurations having either marginal stability or strict stability requirements. Technology readiness is rated "very good". The principal problem is providing aerodynamic control surface authority adequate to produce corrective action of the desired magnitude. A third technology requirement concerns decoupling degrees of freedom for dynamically complex vehicles (e.g., helicopters, VTOL's). Technology readiness is rated "fair". Effort is needed to establish decoupling requirements and the desired dynamic responses of decoupled modes. A fourth technology requirement is in the area of flutter suppression of very large aircraft. Technology readiness is rated "poor". While progress has been made toward suppressing relatively moderate types of flutter, technology is far from adequate to address flutter modes characterized by sudden and rapid divergence.

Table 15 Technology requirements and readiness for flight dynamics

REQUIREMENTS	READINESS
CONTROL OF VLA HAVING HIGH MASS MOMENT OF INERTIA	POOR - NEED MEANS TO PROVIDE ROLL CONTROL AUTHORITY
FIXED-ATTITUDE TAKEOFF AND LANDING	VERY GOOD - CONSIDERABLE EXISTING EXPERIENCE; POWERED-LIFT VLA NEED ATTENTION
4-D TERMINAL AREA COMPATABILITY	VERY GOOD

Flight Dynamics (Table 15). Many types of very large aircraft are characterized by large values of mass and/or moments of inertia. Such characteristics can introduce problems in terminal area operations during both maneuvers and takeoff and landing operations. A technology requirement exists in the area of attitutde control of aircraft having high mass moments of inertia. Technology readiness is rated "poor". Means are needed to provide roll control authority. A second requirement concerns the technology to provide fixed-attitude takeoff and landings when the aircraft/landing gear configuration limits vehicle rotation on the ground. Technology readiness is rated "very good" based on capability of, and experience with present large military aircraft. Technology development is needed where powered-lift is to be utilized. A third technology requirement concerns VLA operational compatibility with 4-D terminal area air traffic control systems utilizing curved flight paths. Technology readiness is rated "very good". The capability of most VLA aircraft should be adequate to perform the required turns and maneuvers.

Table 16 Technology requirements and readiness for interacting vehicles

REQUIREMENTS	READINESS
TRAILING VORTEX MINIMIZATION	FAIR - UNCONVENTIONAL CONFIGURATIONS NOT YET ADDRESSED
TUG-GLIDER OPERATIONS USING VLA	FAIR - NO LARGE SCALE DATA AVAILABLE
TIP-COUPLED OPERATIONS	POOR - PRIOR ATTEMPTS PROVED DIFFICULT
IN-FLIGHT DOCKING TO A VLA	POOR - AT MOST CRUISE SPEEDS GOOD - FOR AIRSHIPS AT LOW SPEEDS

Interacting Vehicles (Table 16). VLA operations are somtimes intimately associated with the operation of other vehicles, which gives rise to a variety of problems which require technology. One such requirement concerns the minimization of trailing vortices from very large aircraft which affect terminal area operations of other aircraft (see Fig. 12).[18] Technology readiness is rated "fair". Trailing vortices are very configuration dependent. While the technology is rated "good" for conventional aircraft, unconventional configurations have not yet been addressed. Flight data for each type of configuration is required. A second technology requirement concerns tug-glider operations using a VLA nuclear tug (see Fig. 13).[19] Technology readiness is rated "fair". No large scale data are available. A third technology requirement concerns tip-coupled vehicle operations. One example would be fighter aircraft coupled to a VLA mother aircraft for ferry missions. A second example would be where two or more very large aircraft couple to each other for in-flight transfer of passengers or crew (see Fig. 14).[20] Technology readiness is rated "poor". Prior attempts at coupling operations involving conventional size aircraft proved very difficult. A fourth technology requirement concerns in-flight docking of a smaller vehicle to a very large vehicle. Technology readiness is rated "poor" for cruise speeds of the order of transport aircraft speeds. Flow interference problems have been found to be quite severe. In-flight docking has been successful, however, where relatively small vehicles are docked to a VLA mother ship operating at low speeds. An example was the docking of small aircraft to rigid, LTA vehicles carried out some four or five decades ago.

Table 17 Technology requirements and readiness for hazards

REQUIREMENTS	READINESS
WEATHER HAZARDS TO VLA	FAIR - ADVANCED DETECTION A PROBLEM
ALTERNATE FUEL HAZARDS TO VLA	POOR - POST-CRASH BEHAVIOR A PROBLEM FOR NUCLEAR AND CRYO-FUEL VLA

Hazards (Table 17). As for conventional size aircraft, VLA operations will necessarily involve hazards. The most likely time for accidents is during bad weather and during takeoffs and landings. Other types of hazards are those peculiar to specific vehicles such as the previously discussed trailing vortex phenomena which can produce a hazardous situation for other aircraft. A technology requirement exists in the area of VLA hazards associated with weather phenomena. Technology readiness is rated "fair". The art of detection and advance warning of dangerous weather phenomena, such as wind shears and clear air turbulence, is rated not better than "fair". Also as noted in the discussion of wind and wave inputs, technology readiness is only "fair" regarding the characteristics of the environmental inputs, once they are encountered.

A second technology requirement concerns the risks and risk probabilities of hazards associated with the use of alternate fuels, which includes both cryo and nuclear fuels. Technology readiness is rated "poor". For both types of fuels, there is no accident experience in VLA use. There are significant unknowns for cryofuels regarding in-flight leaks, post-crash fires, and large ground spills. Post-crash containment of nuclear fuels has always been a concern; while modeling and subscale tests have been carried out, full scale in-depth experiments are needed.

Concluding Remarks

Fifty-four technology requirements for very large vehicles have been identified and rated with regard to technology readiness. None of the requirements were considered to have an excellent state of technology readiness. For the disciplines of aerodynamics, propulsion, acoustics, and structures, the technology readiness was rated poor to fair for slightly less than one-half of the requirements and good or very good for the remainder. For the area of aircraft systems and operations, however, the technology readiness was rated poor or fair for two-thirds of the requirements (see Fig. 15); seventy percent of the "poor" ratings would be included if the subarea of landing systems had been located in this area rather than under the area of structures. Thus, the technology readiness in the classic disciplinary areas appears to be considerably more advanced than for aircraft systems and operations.

The sixteen subareas of technology requirement have been examined to identify any "drivers" which may be particularly significant in the development of successful very large aircraft. Two subareas considered to fall in this category are those of safety for all VLA types, and landing systems for VLA aircraft which utilize airport runways. Two other subareas which may also be very significant, depending on what develops in the nations's energy situation, are those relating to propellers and rotors and to alternate fuels. An adverse development would be a worsening of the nation's petroleum energy availability, while a favorable development would be a breakthrough in nuclear fusion to make available relatively cheap electrical energy and, thus, less expensive hydrogen fuel.

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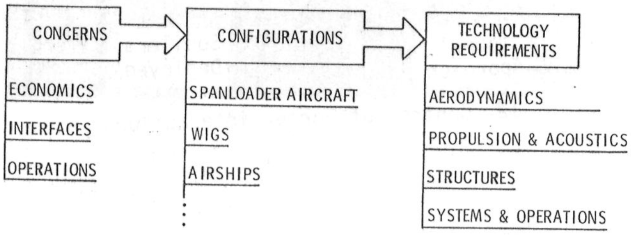

Fig. 1 Identification of technology requirements.

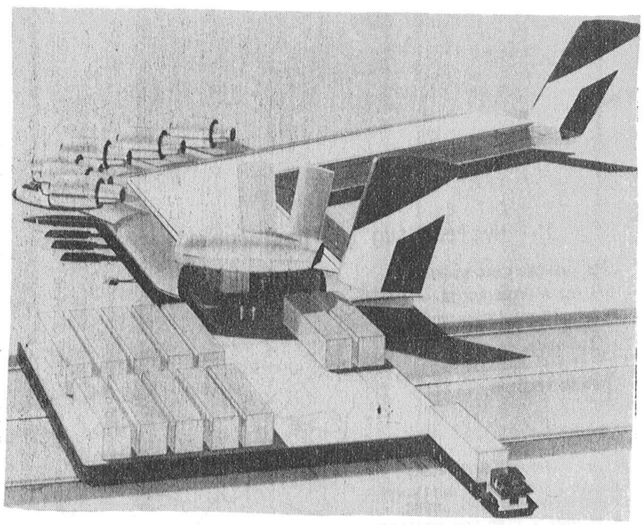

Fig. 2 Loading a distributed load airfreighter.

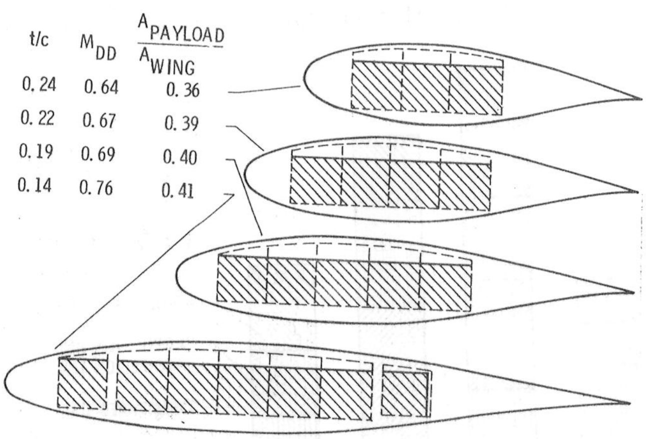

Fig. 3 Wing section trades.

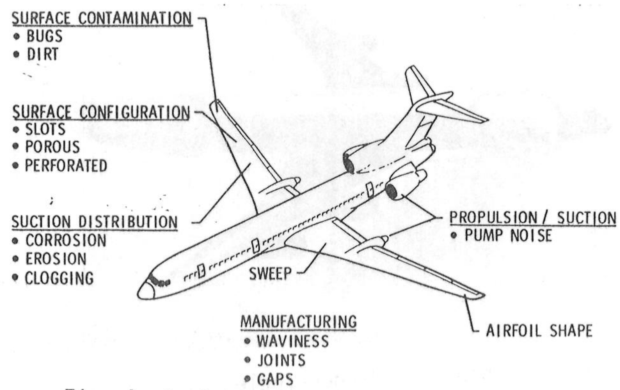

Fig. 4 Factors affecting laminar flow.

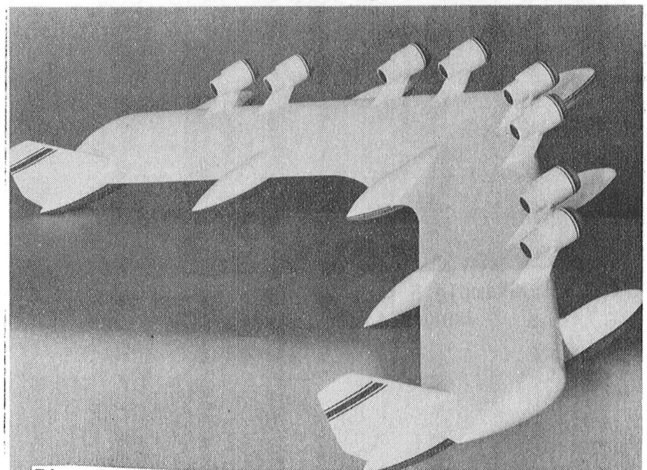

Fig. 5 Early concept of spanloader transport.

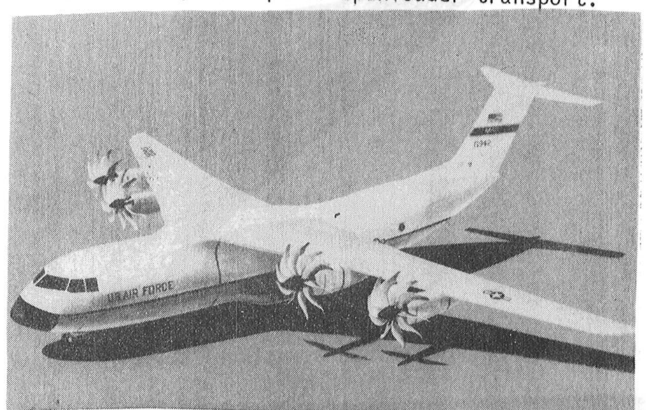

Fig. 6 Advanced propeller airfreighter concept.

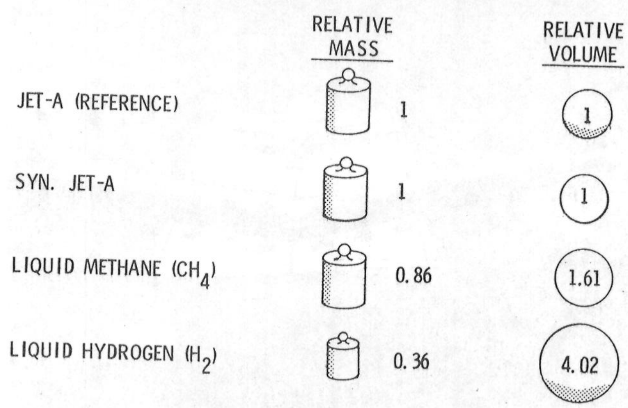

Fig. 7 Candidate liquid fuels judged viable.

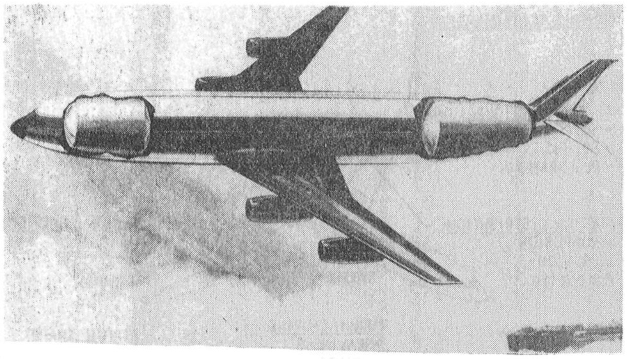

Fig. 8 Subsonic hydrogen-fueled aircraft concept.

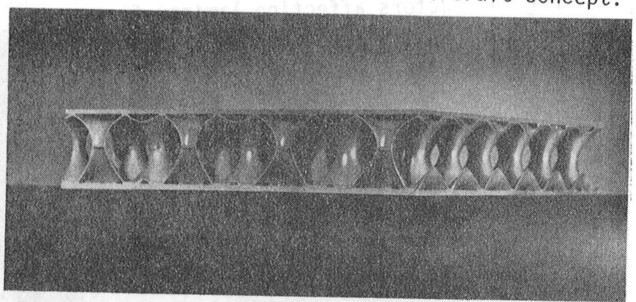

Fig. 9 Example 5 super-plastic-formed diffusion-bonded-titanium structure.

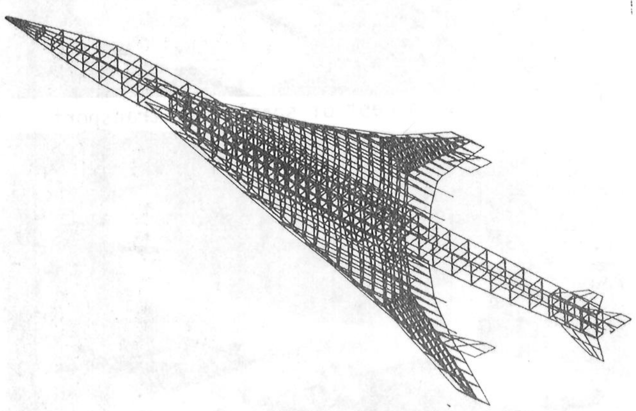

Fig. 10 Computer-aided structural design model.

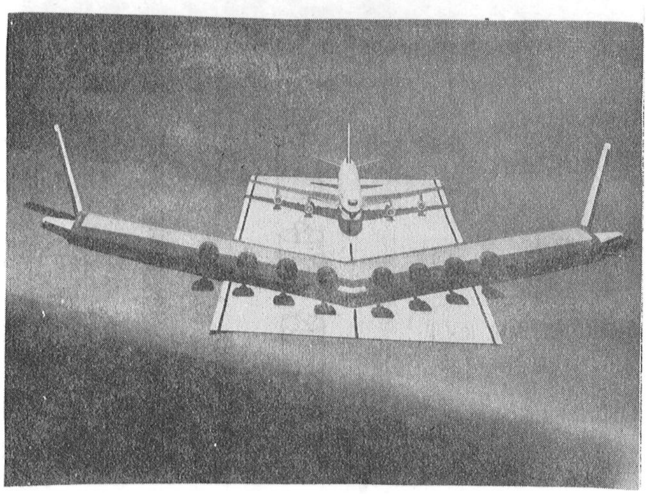

Fig. 11 Swept wing span-distributed-load concept.

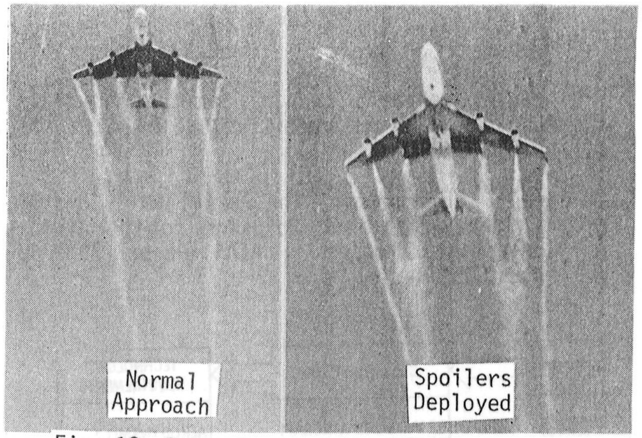

Fig. 12 Control of vortex interactions.

Fig. 13 Nuclear tug towing large airfreighters.

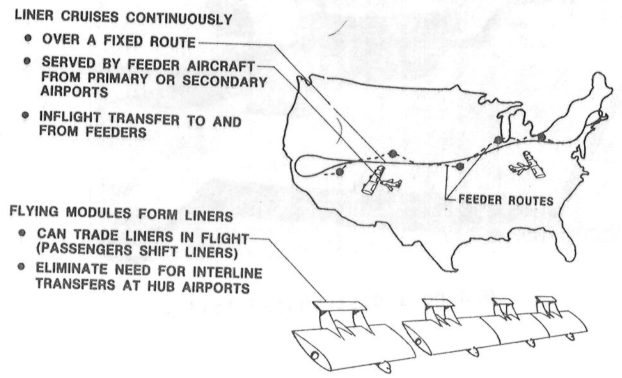

Fig. 14 Aerial relay system concept.

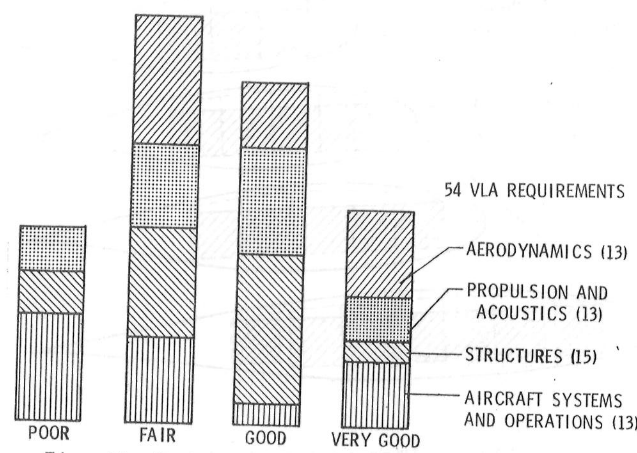

Fig. 15 Technology readiness by disicipline.

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16. Abstract

Common concerns of very large aircraft in the areas of economics, transportation system interfaces and operational problems have been reviewed regarding their influence on vehicle configurations and technology. Fifty-four technology requirements have been identified which are judged to be unique, or particularly critical, to very large aircraft. The requirements were about equally divided among the four general areas of aerodynamics, propulsion and acoustics, stuctures, and vehicle systems and operations. The state of technology readiness was judged to be poor to fair for slightly more than one-half of the requirements. In the classic disciplinary areas, the state of technology readiness appears to be more advanced than for vehicle systems and operations.

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