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OUTLOOK FOR ADVANCED CONCEPTS IN TRANSPORT AIRCRAFT

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SUMMARY

Examination has been made of air transportation demand trends, air transportation system goals, and air transportation system trends well into Century 21. The outlook is for continued growth in both air passenger travel and airfreight movements. The present system, with some improvements, is expected to continue to the turn of the century and to utilize technologically upgraded, derivative versions of today's aircraft, plus possibly some new aircraft for supersonic long haul, short haul and high density commuter service. Severe constraints of the system, expected by early in Century 21, should lead to innovations at the airport, away from the airport, and in the air; and innovations are illustrated by descriptions of three candidate systems involving advanced aircraft concepts. Advanced technologies and vehicles expected to impact the airport are illustrated by descriptions of laminar flow control aircraft, very large airfreighters and cryogenically fueled transports.

INTRODUCTION

This outlook for advanced concepts in civil transport aircraft examines in some detail the long term trends expected to impact air transportation and introduce new demands, and then describes a number of innovative new aircraft (fig. 1) which might logically be developed to meet these demands. The long term trends will, of course, be significantly influenced by what transpires in broad areas such as the changing life styles of the earth's peoples, the interactions between nations and groups of nations, and/or the resources available and affordable for transportation. The basic air transportation system may well change in character, and several advanced vehicle concepts illustrate advanced systems and operations which may be brought forth. As new concepts will necessarily involve the airports as well as the vehicles, impact on the airports of several of the advanced concepts are pointed out. The paper only briefly addresses the outlook for aircraft at the turn of the next century as several very capable authorities have recently described the situation expected then in air transportation (refs. 1-3).

While the exact timing, or even the occurrence of long-term events, trends and new demands are not predictable, the outlook presented herein hopefully offers foresight well into the first half of the twenty-first century.

IMPACTING TRENDS

Transportation Demand Trends

Continued or even accelerated growth in total transportation has been identified in several recent studies. For example, the Transportation Policy

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Study Commission (ref. 4), identified continued growth in overall domestic passenger transportation demand as stimulated by: growth in travel-prone white collar and service occupations; increased affluence and leisure; increased population in high-travel age groups; more families with fewer dependents; and increased tourism. In just twenty-five years, an increase of 80 to 90 percent is expected in domestic personal travel (passenger-kilometers). A fifty year projection indicates an increase of at least 400 percent even if a super communications system is in being and well used. A significant shift from auto to air is also forecast for intercity travel, particularly for the smaller cities, with very little auto travel over distances greater than a few hundred kilometers. Air travel is expected to increase at a faster rate internationally than domestically, with the greatest increase occurring for the developing or third-world countries.

Redistribution in the origin-destination of air travel will accompany geographic shifts of the population and jobs. A shift is already underway in the United States, as evidenced by the impending reapportionment of seats in the House of Representatives. The Census Bureau estimates that 14 seats will be lost by 8 of the northern tier of states to 10 southern and western states generally characterized by more temperate winter weather. People making this "sunbelt" shift desire to spend less of their disposable income on comfort conditioning and face fewer restrictions to mobility in the winter months. The redistribution will result in above-average size change of certain cities and in the birth of some new cities in favorable locations. Such trends can also be expected in other countries (e.g., Brazil) where a choice of geographic and climatic conditions are available in relatively undeveloped regions (ref. 5).

Growth in total freight movements is expected to increase at an even greater rate than passenger travel. In 25 years, the national domestic freight tonne kilometers are forecast to increase by at least 160 percent and possibly as much as 225 percent (ref. 4). In recent years, airfreight has captured only about 0.1 percent of the total freight movement throughout the world, with the air market generally focussed on emergency shipments, highly time-sensitive freight, and valuable cargo. In the transatlantic cargo trade, for example, air cargo accounts for only a fraction of one percent of the total tonnage but its value amounts to about 25 percent of the total value of cargo transported by all modes. The tiny tonnage fraction of freight presently carried by air provides a poor base for extrapolating growth with any degree of confidence. For several reasons, the air share of the market can be expected to increase significantly. For an ever increasing number of goods and commodities, the speed advantage of air transport can effect cost reductions in warehousing and inventory to more than offset the higher cost of air transportation (ref. 6). Routine, planned air shipment of many such items is envisioned to grow, which in turn will lead to more cosmopolitan consumer tastes and stimulate new demands internationally. Growth in air cargo markets will depend to some degree on the resolution of international institutional issues, such as the regulatory morass and the complex rate structures (ref. 6) which now exist. Of equal or greater importance to the stimulation of the air freight industry, however, will be the degree of operating cost reductions achievable with advanced airfreighters and systems.

Air Transportation System Goals

While the overall objective of air transportation is to move the passengers, or the freight, from the point of origin to the point of destination, there are a number of concerns in getting there with the payload. For many years, three major goals were dominant: get there safely; get there faster; and get there cheaper. Safety is considered to be of paramount importance, not only in winning and maintaining traveler confidence, but also as an expected public right assured by government regulations and inspections. "Get there faster" has been a selling point of air transportation since its inception. Market pressures continue for quicker travel, not only for people on business who desire to travel from home, transact business and return in the same day, but also for vacationers, who have limited leisure time but who want to broaden their choice of available places and attractions. "Get there cheaper" has been emphasized in recent years both through use of more efficient vehicles and mass marketing to achieve higher load factors (e.g., group charters, cut-rate fares).

Fourth and fifth goals have recently emerged: get there using less fuel, and get there in an environmentally acceptable manner. The sky rocketing increase in the price of fuel requires use of less energy if travel fares are to be kept within bounds. Manufacturers and airlines have already improved vehicle efficiency and flight management techniques to save fuel. The total amount of fuel used by U.S. airlines has remained almost constant since 1969 while a 50 percent increase has been achieved in productivity (passenger kilometers per liter). Nevertheless, the fuel fraction of total operating costs for U.S. trunk air carriers increased from a value of 11 percent in 1973 to 26 percent in 1980 (ref. 2) with even higher values anticipated before the end of this century. Environmental acceptability of air transportation centers on powerplant exhaust emissions and on noise. Emission standards generally address improved burning of the petroleum-base fuels to minimize noxious products of combustion. Recent speculation has questioned the burning of any carbonaceous fuel, particularly at high altitude, which could increase the carbon dioxide level in the atmosphere and possibly alter the worldwide climate.

Noise has been of great concern since the advent of turbojet transports in the late 1950's. Strenuous public objections, particularly around airports, have led to the use of much quieter (and more energy conservative) high bypass ratio fanjets. Compared to 20 years ago, today's engines deliver 4 times the power and yet are 20 decibels quieter. The U.S. goal is for an eventual reduction of all intrusive noise into communities from the present day-night sound level rating of about 75 decibels to a level of 55 decibels, which case studies indicate to be generally acceptable, with no overt community reactions likely (ref. 7). This goal is far lower than now technically possible in populated communities around airports, and despite major advances anticipated for aircraft and their operations, may not be achievable around existing major airports in the next century. Indications are, however, that pressures for conservation and land-use optimization, as generally outlined for California (ref. 8), may bring national land-use planning into being in the twenty-first century. Such a major step could greatly aid in meeting the noise goal around

all-new airports by preventing encroachment of residential areas. Meanwhile, aircraft noise requirements can be expected to become more strict to match noise reductions achievable with advances in transport aircraft and their operations. Also, curfews at busy airports can be expected to increase worldwide. The sonic boom noise from supersonic operations of aircraft is another major concern where the problem has yet to be solved in a satisfactory manner. Until such time, supersonic operations of transport aircraft will likely be restricted to nonpopulated areas of the world.

Air Transportation Systems Trends

Of increasing demand is the need for relief from congestion, both in the airways and at the terminals. The number of airports already operating at full capacity is growing, and the resultant delays adversely impact the whole system. Airports in general have earned the reputation of being poor neighbors, particularly environmentally, to adjacent communities despite their bringing in new business to the locale. The reputation is expected to last well beyond the turn of the century, and continuing problems are anticipated in siting new airports near major cities. In some instances, new airports may take advantage of adjacent large areas of relatively undeveloped land (e.g., Montreal) or of water (e.g., Los Angeles proposal (ref. 9)). Geographic and/or economic considerations will greatly restrict the number of these types of installations. The present hub-spoke route network is expected to become more diffuse with an increase in number of both secondary hubs and direct links between city pairs. While some of these changes are already evident, partly because of deregulation, the trend is anticipated to continue or even accelerate to minimize delays due to airport congestion and to decrease travel time and costs as new city-pair markets develop. This somewhat more complex network system, together with overall increases in traffic, will require an improved 4-D air traffic control system by the end of this century to space aircraft closer together both along the airways and during terminal area operations.

Getting there faster during the cruise portion of the flight loses significance when time delays are encountered during the rest of the trip. Door-to-door trip time is becoming increasingly important and points to a demand for more convenient, fast, and energy-efficient intermodal transportation systems. The situation is particularly bad in the United States where, with few exceptions (e.g., Cleveland), little effort has been made to provide downtown rapid rail links directly from the airport terminal. Demonstration of an expedited bus-air-bus system between downtown Montreal and downtown Ottawa was extremely well accepted and used by the business travelers (ref. 10). The carrying of freight on passenger aircraft is anticipated to become increasingly important. Freight is one way of filling an aircraft to its fullest capacity and thereby improving its overall economics, particularly for the thinner routes. There will be need to carry airfreight not only in belly holds but also on the main deck with the passengers when the passenger load factor is low. Accordingly, vehicle/terminal configurations and handling techniques must be developed for loading and unloading both the freight and passengers in the same time frame to minimize turnaround time and thereby maintain high aircraft productivity.

ADVANCED AIRCRAFT CONCEPTS

Turn-of-the-Century Situation

The hub spoke air transportation system is expected to still be in effect in the year 2000 and not be too differently structured from the present. While limited progress is anticipated in addressing the groundside problems of handling passengers, improvements are expected in the air traffic control system. Traffic delays are expected to be serious, however, and many airports will be limited by congestion. The financial health of the air carriers presumably will be sufficiently favorable to generate investments for major aircraft purchases. The high start-up costs of all-new aircraft will significantly limit their number, with those introduced designed as family concepts in order that each basic design can address a wide variety of carrier demands. Derivative versions of existing transports will be very attractive, financially, for upgrading aircraft capability with improved components.

Long Haul Transports - Advanced technology elements for application to aircraft designed in the late 1980's and 1990's are encompassed in the Aircraft Energy Efficiency (ACEE) program by NASA. The ACEE technology areas for long haul transports are pictorially illustrated in figure 2. The goal for the ACEE program is to provide a 50 percent reduction in fuel at the same passenger load. The long-haul airplanes, generally derivatives, will resemble today's aircraft but with wings of higher aspect ratio and engines of somewhat higher bypass ratio (ref. 11).

A new family of supersonic transports should also be in being. Providing only modest fare surcharges are involved, a demand exists for supersonic service as demonstrated in recent months by the Concorde. The service is credited with driving all daylight eastbound subsonic flights from North America to Britain off the market. Since the Concorde was designed, impressive gains have been made in technology (fig. 3) (ref. 12). The family concept for such aircraft would involve lateral, rather than longitudinal, stretch of the fuselage to provide 4-, 5-, or 6-abreast seating. The fuel burned per passenger kilometer would be competitive with today's wide-body subsonic jets. While fuel-burn for supersonic flight will always be greater than for subsonic flight utilizing the same level of technology, the higher productivity is an offsetting factor. Estimated fare surcharges are indicated to be modestly low for the North Atlantic market.

Short-Haul Transports - For short haul operations, the larger transports will resemble the long haul vehicles, described above. An innovation in propulsion systems, however, may be the use of the advanced turboprops (fig. 4) (ref. 13). The NASA ACEE propulsion program is actively addressing technology development of such turboprops and the results are very encouraging. In contrast to propellers used prior to the jet age, high propulsion efficiency can be maintained to Mach 0.8, with a fifteen percent saving in block fuel over contemporary turbofan engines. At slightly lower cruise Mach numbers, even greater benefits are indicated. Before such advanced propellers can be used, technology must be developed in a number of potential problem areas including airframe-propulsion integration, blade structures and dynamics, and

speed reducers sized for large gas turbine engines. Applications can first be expected in small to medium size (approx. 100 passenger) transports, but as technology develops and matures, can likely spread to larger and longer haul aircraft such as airfreighters.

The smaller feeder transports in short haul operations will also be expected to incorporate advanced technology features, such as turboprops or high-bypass-ratio turbofan engines, not only to improve overall economics and fuel efficiency (ref. 13), but also to provide compatibility with the operations of larger airports, with which they must interface (fig. 5). An example for operational compatibility requirements would be for precise, cross-wind landings at those hub airports configured with only parallel runways. This requirement could be met by incorporating aerodynamic side force generators and castering landing gear into the feeder transports (ref. 14). The use of cross-wind landing gear could also be required for larger transports as well, with a precedent already established in the C-5 military airlift aircraft.

Commuter Transports - Exploration can be expected of alternate short haul commuter systems aimed toward expediting travel by directly linking both city center to city center and outlying areas to the city center. The relatively large passenger-carrying aircraft for such systems must necessarily operate in congested regions with limited size landing areas. One type of aircraft anticipated to be available for such systems is the powered-lift transport (ref. 15) (fig. 6) typified by the USAF YC-14 and YC-15 prototype military aircraft. The capability of such aircraft in making climbing turns within the airspace over airports could lead to innovative operational procedures to minimize community noise. Because a high value of aircraft thrust-to-weight ratio is required to achieve the very high lift involved, present type engines tend to be inefficient at the low power settings of cruise flight. Improvement in cruise efficiency could be achieved by development of variable-cycle engines tailored for such operations. The Japanese are presently building a reduced scale prototype of a 150-passenger powered-lift transport designed to operate from 900-meter airstrips. The helicopter (fig. 7) is a second type of aircraft suitable for high capacity commuter systems, such as between downtown London and Paris. Carrying as many as 200 passengers would be practical through innovations such as the ABC concept where the advancing blades are positioned to maximize L/D, and the retreating blades are feathered to become aerodynamically invisible (ref. 14).

Innovations for Alternate Systems

The various types of aircraft identified above as likely being in service at the turn of the twenty first century will undoubtedly continue to be used for several, if not many decades thereafter. New technology will continue to be generated for advanced versions of the vehicles to better meet the five major transportation system goals described earlier. Additional developments will undoubtedly occur, however, which will introduce new requirements and possibly even new goals. One such development considered likely shortly after the turn of the century will be a severe constraining of the air transportation system as it is then configured, because of saturation of both the airport ground capacity and the air traffic control system. The demands for use

of the air, including military and general aviation as well as civil air transportation, will force the evolution of a less constrained system(s). In the process, more expeditious use of airports and the air-space can be expected which will give rise to innovations in the movement of passengers and cargo. These innovations will probably require new aircraft configurations and operations, the specific nature of which cannot be identified with any certainty at the present time. Three advanced concepts are presently under study by NASA, however, which will be described to illustrate innovations possible at the airport, away from the airport, and in the air.

Innovation at the Airport - Air transportation systems innovation at the airport can be exemplified by the Lockheed-Georgia Company's novel concept of the "flatbed" aircraft and its operations (ref. 16) (fig. 8). The objective is to provide a flatbed airplane with the operational flexibility of a semi-trailer road vehicle. Payloads would be carried in individual units moved on and off the basic frame. For passenger transportation, the travelers would board the fuselage module at some convenient location, such as the terminal, which would then be towed to the runway area and attached to the airframe. The aircraft also offers a variety of methods for handling freight. Inter-modal cargo containers could be carried in the open or covered with a lightweight aerodynamically clean cocoon module which could be quickly moved on and off the basic airframe. The modules could be pressurized and environmentally conditioned where required, such as for passenger transportation. The flatbed aircraft would be versatile for special situations such as emergency military airlift where outsize equipment could be secured to the flatbed and carried in the open. The mission versatility and quick-change features of the concept should be economically attractive both in development and acquisitions costs and in productivity.

Innovation Away from Airport - Air transportation systems innovation away from the airport implies the ability to operate without runways such as seaplanes operating off water. Versatility greater than with a seaplane or amphibian could be achieved, however, by using Air Cushion Landing Gear (ACLG) aircraft (fig. 9). Small prototype ACLG aircraft, which effectively take off and land on a cushion of air, have demonstrated operations from any relatively level open area including runways and landing strips, swampy, sodded and cultivated land, and even water, ice or snow. Feasibility studies indicate that ACLG could be incorporated into vehicles of all sizes, ranging from small general aviation aircraft to very large airfreighters (ref. 17). The wide choice of landing surfaces offer operating base flexibility with minimal site improvements. Examples of handy locations for cargo system operations would be the use of land area adjacent to the user's production site or of a shallow body of water, plus a service ramp and a freight terminal warehouse, next to a major highway.

Innovations in the Air - Like innovations at and away from the airport, transportation systems innovations in the air have been dreamed about, proposed and studied for decades. An early example is the World Transport described by Captain Eddie Rickenbacker more than 50 years ago (ref. 18) (fig. 10) where giant dirigibles, one mile long, would cruise but never land and would take on supplies from smaller airships. Passengers would be transported to and from the mother ship by aircraft and smaller airships. A

Century 21 version of the World Transport is the aerial relay passenger transportation system concept (ref. 19) (fig. 11). A very large airliner cruises at high altitude on a fixed repeating route. From primary or secondary airports, smaller feeder aircraft transport passengers and supplies from their point of origin to a rendezvous at altitude with the cruise liner. Inflight transfer between the two aircraft is carried out of passengers beginning, and passengers completing, the cruise portion of their trips. Each feeder aircraft then returns to the ground with its departing passengers but at another airport further along the route. The route shown on the map (fig. 11) might be a good first choice as the swath of land area served presently generates the greatest east-west travel (over 60,000 passengers each way per day). Additional routes could be introduced to provide a network grid to serve the entire nation. As illustrated at the bottom of the figure, a number of flying modules link together in flight to form the liner. After the linking, passengers can move freely between modules. Where two or more liners on different routes meet at a "node" in the sky, a module from each liner could split off and regroup with the other liner(s) to effect interline passenger transfer, normally carried out at hub airports.

Innovations Impacting Airports

A host of innovations in aircraft can be expected in the twenty-first century besides those specifically devised for alternate transportation systems. Many of these developments will undoubtedly provide positive benefits with little or no adverse impact on the transportation systems or their components. Other innovations will impact, in varying degree, the airport configuration and/or operations. Three of these will be discussed in the order of increasing severity of the impacts on the airport.

Laminar Flow Control Aircraft - The first innovation is the application of laminar flow control (LFC) to the exterior surfaces of transport aircraft. A brief description is given in the upper portion of figure 12 regarding laminar and turbulent flows and the substantial benefits of laminar flow control in reducing skin friction drag and direct operating costs. The practical engineering aspects of achieving and maintaining LFC on transport aircraft is quite complex and involves substantial and sustained research and development effort, some of which is presently underway (ref. 20). While all of the aircraft surfaces exposed to the airstream could benefit from LFC, practical considerations will likely result in first use, around the year 2000, on only the upper surface of the wing. As technology subsequently develops, LFC will be applied to other areas such as the fuselage or exterior bracing struts for wings of very high aspect ratio. LFC surface contour shape, smoothness and porosity are very critical factors in manufacturing, operating, and maintaining the aircraft. Great care must be exercised, therefore, in minimizing aircraft operations under conditions where the LFC surface could be abraded or contaminated, with the wing leading edge being particularly critical. The sketch at the bottom of figure 12 illustrates a promising concept presently under study for protecting and cleaning an aircraft wing with LFC incorporated on only its upper surface. In terminal area operations, where insects and dust are most prevalent, slotted Kreuger-type flaps would be deployed to inhibit direct impingement of the contaminants on the forward portion of the LFC

area. Spray nozzles on the flap would also be used to clean the LFC surface. Impact of LFC on the airport will be noticeable but relatively modest. Crucial LFC porous areas on the aircraft will have to be cleaned in situ between each flight, not only on the surface but also through the porous skin. Extra precautions in airport ground maintenance and surface movement of other aircraft also will be required to avoid LFC surface contamination and damage when an LFC transport is on the ground.

Very Large Airfreighters - The second innovation to be discussed as impacting the airport would be the introduction of much larger airfreighters. A future requirements and market evaluation study of air cargo indicates derivatives of current wide-body aircraft, with payload capacity of about 150 tonnes, will be economically attractive for the next two decades, while new dedicated airfreighters will offer little or no economic incentive (fig. 13) (ref. 21). Early in Century 21, continued market growth should merit a new and more efficient airfreighter, possibly of as much as 250-tonne payload capacity. Depending on its size, some research, development, and technology cost sharing by the government may be necessary to achieve economic viability. NASA has been carrying out a series of studies of various technology options for air cargo aircraft (ref. 22) and the multibody arrangement illustrated in figure 13 has structural benefits (e.g., reduced wing bending moment) for airfreighters of large size. Multibody configurations would pose problems in airport compatibility because of the tread width of the landing gear. A 250-tonne payload airfreighter of this type would require runways at least 55 meters wide and taxiways at least 45 meters wide.

Even larger airfreighters may be required later in Century 21, which would lead to radically different aircraft configurations. As gross weight increases, the available volume in the wing increases more rapidly than the volume required for aircraft fuel and payload; and consequently, there is a gross weight above which (from a volume standpoint) the fuselage is not required. This fact makes possible the use of span-distributed-load airfreighters having relatively low structural weight, low number of unique parts and high payload fraction. Feasibility and performance studies indicate such airfreighters would be viable for payloads of 500-tonnes or more. Such a configuration is illustrated in figure 14 together with a Boeing-747 to indicate the relatively much greater wing span. The configuration shown here would have a design wing span of about 150 meters and a gross weight of about 1350 tonnes. The tread width of 120 meters (approx. 400 feet) would require extra wide runways and significantly impact the airport. Such aircraft would be ideal candidates for use of air cushion landing gear. An artist's concept of a large spanloader aircraft being loaded with cargo containers through the wing tip is also shown in figure 14. Special cargo loading docks configured for such operations, would have to be provided. An incidental requirement would be the servicing of the very large engines located above and ahead of the wing leading edge.

Cryofuel Transport Aircraft - The last innovation to be discussed is the use of cryofuels in transport aircraft, which can be expected to occur during the twenty-first century. To better understand the need for, and timing of the introduction of cryofuels, some discussion is required on the general subject of alternatives to petroleum-derived aviation fuels. Only three

alternate fuels have been identified as viable for aircraft (ref. 23): (a) synthetic Jet-A (Synjet) derived from coal or oil shale; (b) liquid methane (LCH_4) derived from coal, oil-shale, natural gas or biomass; and (c) liquid hydrogen (LH_2) derived from coal, oil shale or electrolysis of water. Initially, Synjet will be the first to be used since it is the cheapest to manufacture from coal or oil shale and requires no change in either the aircraft or the airport. Of the two cryogenic fuels, LCH_4 may well be the next alternate fuel introduced some decades after Synjet, in what might be called a transitional phase. It could be produced very easily either from natural gas, if gas remains plentiful, or from biomass, if biomass is developed as a feedstock to provide domestic and industrial methane in quantity. Examination made some years ago indicated LCH_4 to be operationally practical, relatively safe, and economically attractive for automotive use (ref. 24). Fleet operations of LCH_4 automobiles and commercial trucks can be expected within the United States before the year 2000. In the final phase, LH_2 is expected to become the preferred fuel. While it now costs more than LCH_4 to manufacture from coal or oil shale, it can be made from the most universally available sources--water and electricity. LH_2 has been characterized as the best available electricity-to-vehicle energy transport medium; and it also has the most environmentally acceptable emissions, since water vapor is the only chemical product of combustion.

Specially configured aircraft are required for use of cryofuels, primarily because of onboard fuel storage requirements. As shown at the top of figure 15, both of the cryofuels are very cold and have larger volumes than the presently used Jet-A fuel for a given energy content. Aircraft fuel tanks must not only be cryoinsulated but also have a significantly greater internal volume. Transport aircraft configuration studies indicate that for both cryofuels, the best location for fuel storage will be fore and aft in the fuselage. A large diameter, double-deck fuselage is indicated as preferred, and aircraft sized for large payloads over long-haul routes would be the most viable.

Major facilities at each airport will be required to handle cryofuels (fig. 15). The fuel, in gaseous form will be delivered to the airport by pipeline where it will be liquefied and stored. It will then be pumped to the aircraft fueling area and back to the liquifier in a closed circuit. At the aircraft, a special hydrant truck will pump the cryofuel into the aircraft, and extract ullage gas vapors from the aircraft system for return to the liquifier. The complete system at the airport would be expensive, with the system cost (in 1980 dollars) to fuel all aircraft presently departing the Chicago O'Hare Airport estimated to be 600 million and 1100 million dollars for LCH_4 and LH_2 , respectively. There are also unresolved safety aspects of cryofuels which could impact the airport. These aspects include: cryofuel system malfunctions and leaks onboard the aircraft during operation; the likelihood, characteristics, and behavior of fires or detonations following the crash of a cryofueled aircraft; and most importantly to the airport, the likelihood and severity of a fire or detonation following a large-scale cryofuel spill, such as from a ruptured cryofuel supply line or storage tank. Exploratory research is presently underway by NASA to assess the severity of these safety problems.

CONCLUDING REMARKS

The outlook for air transportation systems indicates continued growth well into the twenty-first century in the market demand for transportation of both travelers and freight. More emphasis is expected to be given to systems which conserve energy and to the achievement of environmental acceptability. The present air transportation system, with some improvements, is expected to continue until the turn of the century. At that time, the aircraft in use will closely resemble those of today, but will have significant technology advancements incorporated into derivative versions. Economic constraints will inhibit the development of all-new transports with a few exceptions, such as an advanced supersonic transport. The air transportation system is expected to become severely constrained early in the twenty-first century. This situation should lead to the evolution of air transportation system of less constraint, in which the airports and airspace are more expeditiously used and innovations are made in the door-to-door movement of both travelers and freight.

The outlook for advanced transport aircraft concepts in Century 21 indicates new vehicles may be developed for transportation system innovations at the airport (e.g., flatbed transports), away from the airport (e.g., air-cushion-landing-gear transports), and in the air (e.g., aerial relay transports). Some of the new technologies and vehicle configurations anticipated for use are expected to impact the airports by varying degree. The incorporation of laminar flow control into aircraft will impact the maintenance of both the airport and the LFC aircraft between flights. The introduction of outsize airfreighters will significantly impact the airport runways, taxiways, and cargo loading facilities. The use of liquid methane and/or liquid hydrogen will require the addition of very expensive, complex cryofuel liquefaction, handling and storage systems at the airports.

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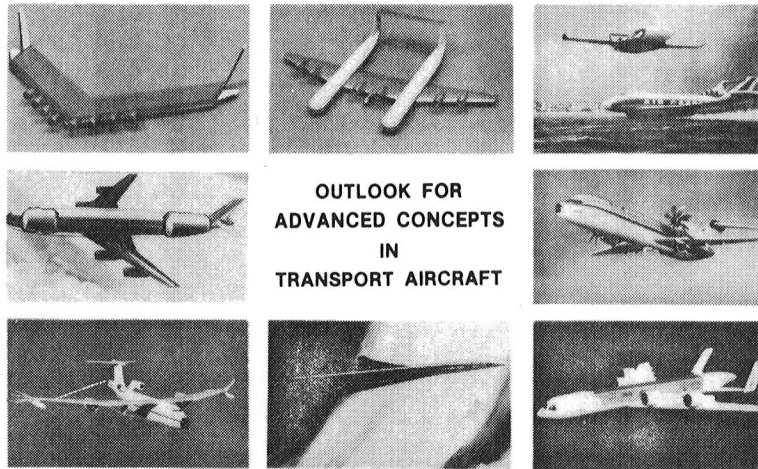


Fig. 1 - Types of advanced-concept transports addressed in the study.

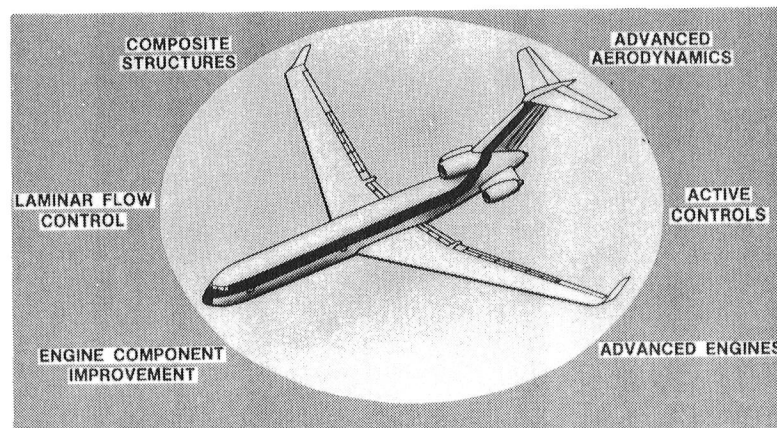


Fig. 2 - Transport aircraft technology areas addressed in the NASA Aircraft Energy Efficiency program.

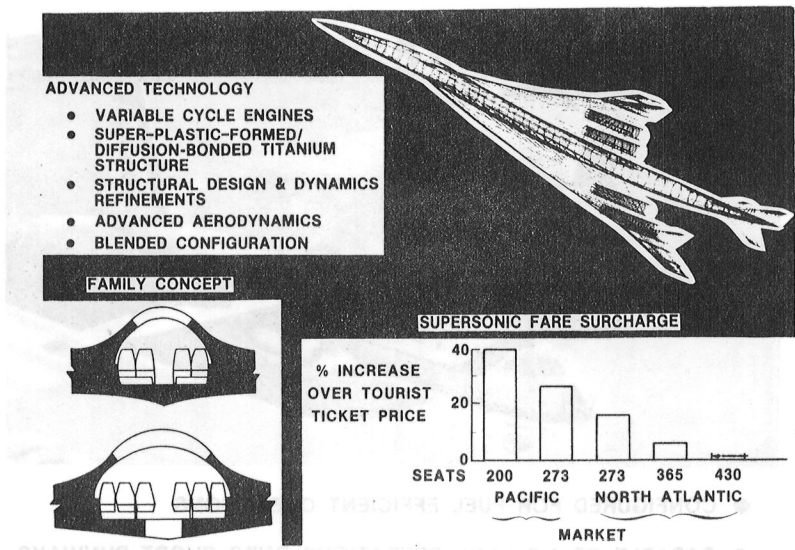


Fig. 3 - Advanced supersonic transport aircraft technology areas, configuration concept, and estimated fare surcharges.

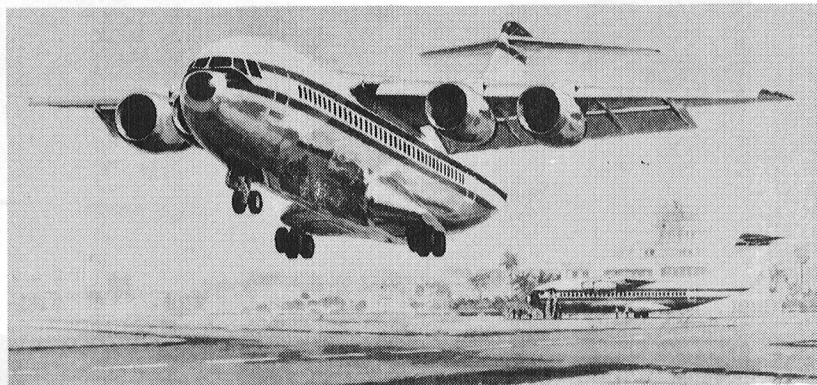


Fig. 4 - Conceptual installation of advanced turboprop propulsion system on a short-haul transport aircraft.



- CONFIGURED FOR FUEL EFFICIENT OPERATIONS
- CAPABLE OF 4-D RTOL OPERATIONS ONTO SHORT RUNWAYS
- OPERABLE IN CROSS WINDS AT HUB AIRPORTS
 - AERODYNAMIC SIDE FORCE GENERATORS
 - CASTERING CROSS WIND LANDING GEAR

Fig. 5 - Conceptual configuration of an advanced small feeder aircraft.



- PROVIDE VERY HIGH LIFT FOR TAKEOFF/LANDING**
- STOL OR RTOL RUNWAY USE POSSIBLE
 - CLIMBING TURNS POSSIBLE WITHIN AIRPORT CONFINES
- REQUIRE HIGH THRUST/WEIGHT RATIO FOR HIGH LIFT**
- INEFFICIENT DURING CRUISE FOR PRESENT ENGINES
 - VARIABLE CYCLE ENGINES COULD PROVIDE EFFICIENCY

Fig. 6 - Conceptual large powered-lift commuter transport aircraft.



Fig. 7 - Conceptual large helicopter commuter transport aircraft.

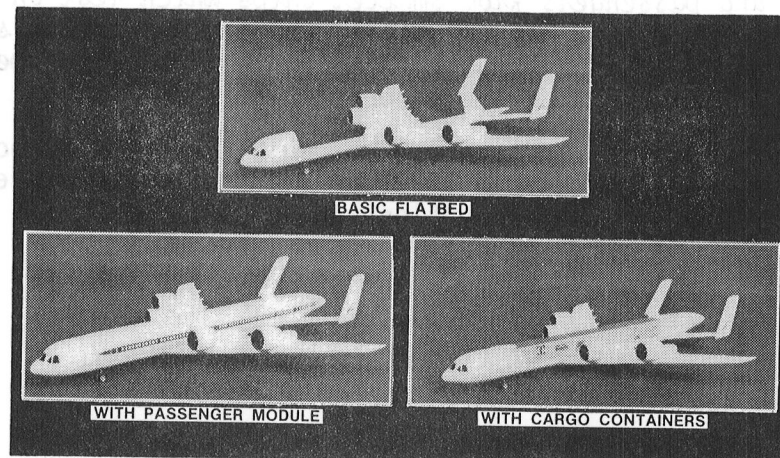


Fig. 8 - Lockheed-Georgia conceptual flatbed transport aircraft for transportation system innovations at the airport.

- OPERATE FROM ANY OPEN AREA**
- RUNWAYS OR LANDING STRIPS
 - SODDED OR BARE LAND
 - WATER, ICE OR SNOW
- OPERATING BASE FLEXIBILITY**
- SITE IMPROVEMENTS MINIMAL
 - HANDY LOCATIONS POSSIBLE
 - AT USER'S PLANT
 - NEXT TO HIGHWAY

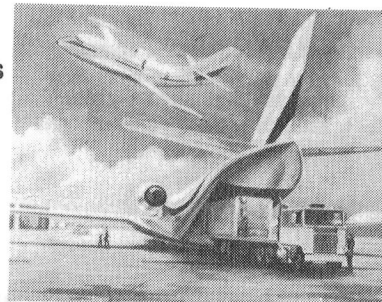
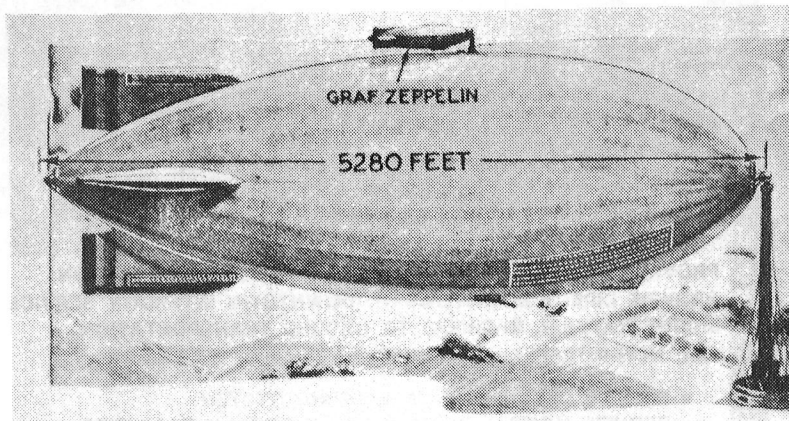


Fig. 9 - Conceptual air-cushion-landing-gear airfreighter for transportation system innovations away from the airport.



"Immense as it is with its length of 750 feet, the Graf Zeppelin is a mere pygmy moored atop one of the mile-long dirigibles of the future. These huge ships will never land, but will take on supplies and passengers from smaller ships which rest on its back, and by planes carried inside the bag and shot out from launching platforms. A city full of people can live inside the cabins in the fins."

Fig. 10 - World Transport dirigible concept proposed by Rickenbacker in 1929 for transportation system innovation in the air.

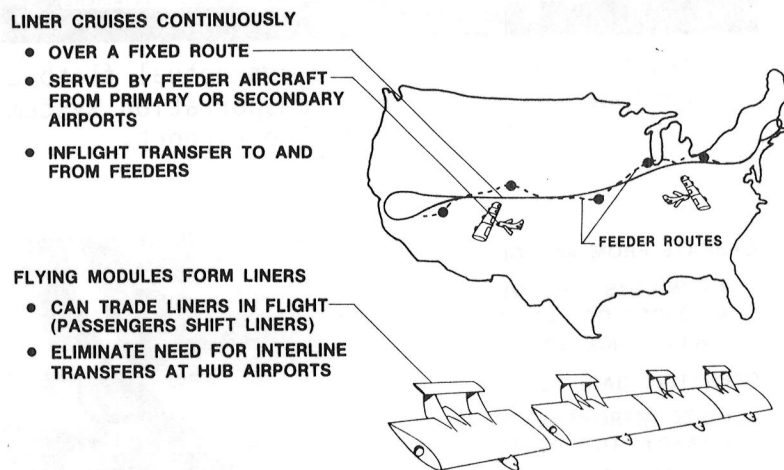


Fig. 11 - Conceptual aerial relay transportation system for transportation system innovation in the air.

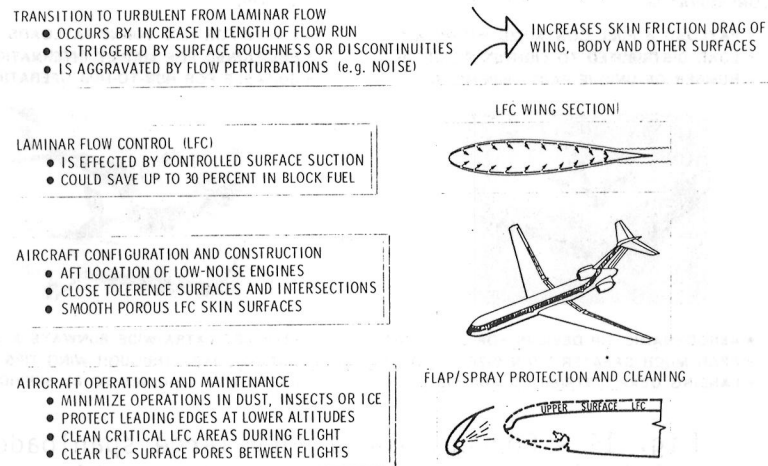


Fig. 12 - Laminar flow control principles, application, and operational concerns.

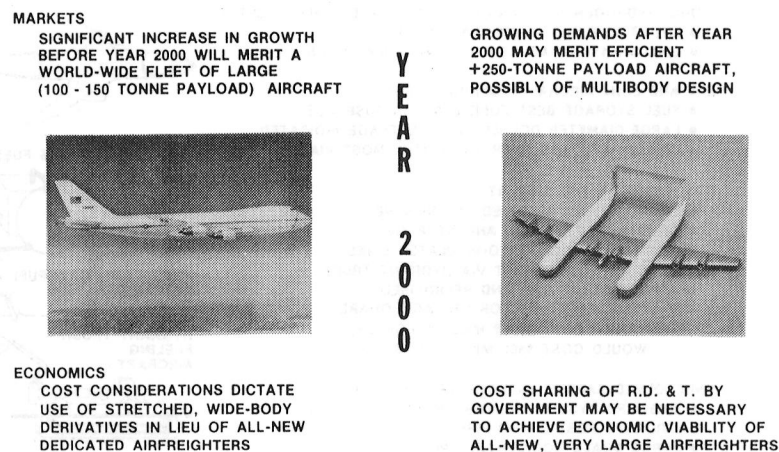
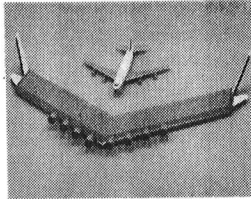


Fig. 13 - Projected scenario for future airfreighter needs and economics.

CONFIGURATION

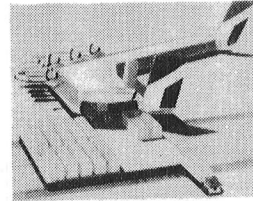
- PAYLOAD & FUEL CONTAINED WITHIN WING
- LOAD DISTRIBUTED TO LIGHTEN STRUCTURE
- NUMBER OF UNIQUE PARTS MINIMIZED



- AERODYNAMIC TIP DEVICES FOR EFFICIENCY
- SPAN MUCH GREATER THAN B-747 (SHOWN)
- LANDING GEAR DISTRIBUTED ACROSS SPAN

OPERATIONS

- VIABLE FOR +500 TONNE PAYLOADS
- ENVISIONED FOR MAINLY INTERNATIONAL USE
- SUITABLE FOR HUB-TO-HUB OPERATIONS ONLY



- REQUIRES EXTRA-WIDE RUNWAYS & TAXIWAYS
- CARGO LOADS THROUGH WING TIPS
- ABOVE-WING ENGINES TO BE SERVICED

Fig. 14 - Concept for a very large spanloader airfreighter configuration and operations.

LIQUID HYDROGEN (LH₂) AND LIQUID METHANE (LCH₄) vs JET A

- LH₂ AT 20° R HAS 4X VOLUME & 0.36 MASS
- LCH₄ AT 111°R HAS 1.6 X VOLUME & 0.86 MASS

LH₂ AND LCH₄ AIRCRAFT CONFIGURATIONS

- FUEL STORAGE BEST FORE & AFT IN FUSELAGE
- LARGE-DIAMETER DOUBLE-DECK FUSELAGE INDICATED
- LARGE PAYLOADS OVER LONG HAUL MOST VIABLE

CRYOFUELS AT THE AIRPORT

- GASEOUS FUEL RECEIVED VIA PIPELINE
- ON-SITE LIQUIFACTION AND STORAGE
- PUMPED THROUGH CRYO-INSULATED LINES
- SERVICED TO AIRCRAFT VIA HYDRANT TRUCK
- VAPORS COLLECTED AND RELIQUIFIED
- SYSTEMS IDENTIFIED FOR CHICAGO OHARE
WOULD COST \$1100 MILLION FOR LH₂
WOULD COST \$600 MILLION FOR LCH₄

UNRESOLVED SAFETY ASPECTS OF CRYOFUELS

- ONBOARD SYSTEM MALFUNCTIONS AND LEAKS
- AIRCRAFT POST-CRASH FIRES
- LARGE SCALE ACCIDENTAL SPILLS

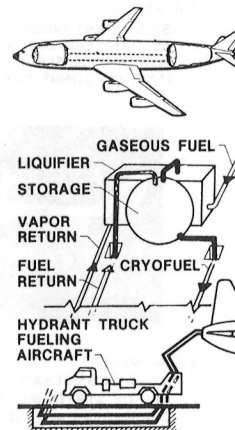


Fig. 15 - Conceptual aircraft configurations, airport system, and operations for use of liquid methane (LCH₄) and liquid hydrogen (LH₂).

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16. Abstract Examination has been made in some detail of air transportation demand trends, air transportation system goals, and air transportation system trends well into Century 21. The outlook is for continued growth in both air passenger travel and airfreight movements. The present system, with some improvements, is expected to continue to the turn of the century and to utilize technologically upgraded, derivative versions of today's aircraft, plus possibly some new aircraft for supersonic long haul, short haul and high density commuter service. Severe constraints of the system, expected by early in Century 21, should lead to innovations at the airport, away from the airport, and in the air; and innovations are illustrated by descriptions of three candidate systems involving advanced aircraft concepts. Advanced technologies and vehicles expected to impact the airport are illustrated by descriptions of laminar flow control aircraft, very large airfreighters and cryogenically fueled transports.					
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