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Aeronautical Vehicles—1970 and Beyond

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Introduction

THE development of modern aircraft has resulted in a revolution in domestic and international transportation. Our concepts of the relative accessibility of various places in the United States and in the world have undergone a drastic change as a result of the time shrinkage associated with modern high-speed air transportation. Methods of communication have accordingly changed as have methods of conducting business operations. Whereas air transportation was at one time the province of the adventurer and the affluent, all classes of people are now traveling by air for both business reasons and pleasure. Americans are today traveling in unprecedented numbers by air, on schedules, and at prices undreamed of 20 to 30 years ago. People are seeing and experiencing cultures in other parts of the country and the world to an extent which would have been incomprehensible in past generations.

Yet, marvelous as our modern aircraft are, our air transportation system can be improved appreciably in many respects. For example, an efficient, dependable, safe, and convenient STOL or V/STOL short-haul system is much needed. Such air travel today is embryonic and just beginning to emerge. General aviation has many problems associated with cost, safety, and utility. Long-haul air transportation as it exists today is, of course, the most advanced form of air travel. There are problems of noise, safety, and efficiency, however, in our long-haul system. In addition, there is much to be done in the areas of supersonic and hypersonic systems to provide fast and safe air travel over very long-range routes such as those between the United States and the Orient.

An air transportation system is made up of many elements such as airports, airways structure, air traffic control, and the air vehicle itself. The present discussion will be limited to the air vehicle under the categories of general aviation, short haul (STOL, helicopter, and V/STOL), and long haul (subsonic, supersonic, and hypersonic). In each instance, the importance of a particular class of aircraft as a means of transportation will be considered, after which the problems, potentialities, and possible directions of future research and development leading to improvement will be examined.

General Aviation

General aviation is a term which is used to encompass all aeronautical activity except that of the air carrier fleet and the military. The size of the general aviation activity in the United States is indicated in Table 1. A comparison of sev-

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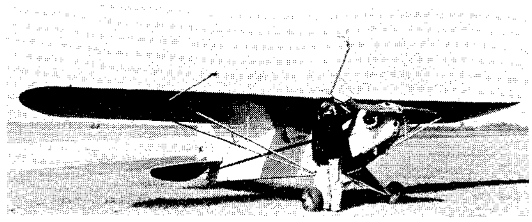

Fig. 1 Piper J-3 Cub.

eral facets of general aviation activity in 1968 and 1969 is made with FAA projections of that activity in 1980.[1,2] The number of aircraft on the register at the end of 1969 is seen to be nearly 131,000, which compares with a projected number of 235,000 by 1980. The corresponding number of pilots holding private licenses is projected to grow from almost 300,000 to about 676,000 by 1980. The number of aircraft produced in 1969 is seen to be about 13,000 at a sale price of approximately $585 million. Thus, when considered in relation to the 2000 to 3000 aircraft operated by the scheduled airlines, general aviation is seen to be by far the largest aeronautical activity in the United States in terms of the number of aircraft operated. The large number of general aviation aircraft in operation today and projected for the future will, of course, have a profound influence on the design and development of future air traffic handling systems. The 25 million hours flown by general aviation in 1969 suggests that this type of activity is an important element of our over-all air transportation capability.

The uses to which general aviation aircraft are put are indicated in Table 2 in terms of the number of aircraft employed in each of several categories, and in terms of the hours flown in each category. The largest number of aircraft, 71,500, are seen to be utilized for personal purposes; whereas the next largest number of aircraft, about 24,000, are employed in business and executive operations. About 16,000 aircraft are employed for instructional purposes; and aerial application, air taxi, and various special uses make up the remainder of the general aviation fleet.

In the minds of many people, the image of a typical general aviation aircraft is that of the venerable Piper J-3 Cub shown in Fig. 1. The Cub, beloved by many, was produced by the thousands before, during, and for a short time, after World War II. Within that time frame, the Cub was indeed a symbol and image of general aviation. Today, however, although recalled with fond memories by many gray-haired pilots and ex-pilots, the J-3 Cub must now be considered an anachronism no longer representative of modern general aviation. Today, the general aviation aircraft may be a fast, comfortable, single-engine airplane, or it may be a light twin-engine aircraft such as that shown in Fig. 2. The aircraft, shown mounted in the NASA Langley full-scale tunnel,

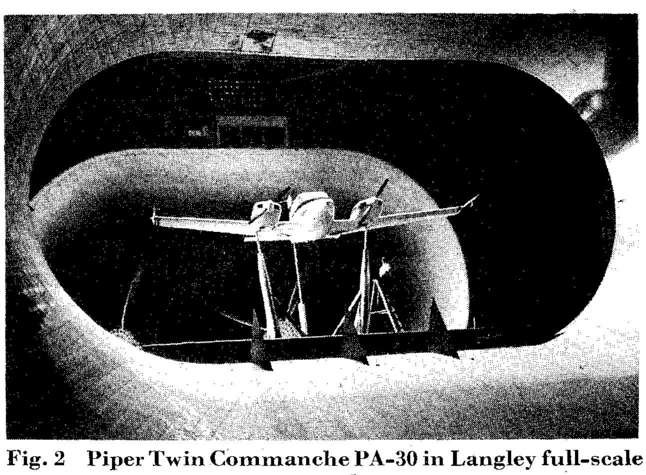

Fig. 2 Piper Twin Commanche PA-30 in Langley full-scale tunnel.

Table 1 Size of general aviation activity

	Calendar year 1968	1969	1980
Number of aircraft	124,237	130,806	235,000
Number of pilots (private)	283,865	299,491	676,000
Aircraft produced	14,253	13,070	31,650
Hours flown $\times 10^{-6}$	24.1	25.4	
Cost of aircraft produced		$584,458,000	

is equipped with retractable landing gear, flaps, and constant-speed propellers, and is capable of cruising speeds near the 200-mile-an-hour mark. Four to six people can travel in this aircraft, which is equipped with radio, navigation, and blind flying equipment. Other small general aviation aircraft are equipped with superchargers which permit them to fly at altitudes in excess of 20,000 ft. Thus, many of the small general aviation aircraft of today are entering the speed regimes which some of our military aircraft were exploring in 1939 and 1940, and many of the problems which were encountered by military aircraft of that era are now being experienced by general aviation aircraft. General aviation aircraft also include such large high-performance machines as the four-engine Lockheed Jet Star shown in Fig. 3. The level of sophistication of this aircraft is analogous to that of the modern high-speed jet transport.

The only problems of general aviation aircraft to be considered herein are those which are peculiarly associated with operations by nonprofessional pilots. First, uncertainties as to weather conditions seriously reduce the confidence with which the nonprofessional pilot can plan and execute a future trip. One way to overcome, or at least to ameliorate this problem, is for the pilot to become instrument rated and to equip the aircraft for instrument operation. Instrument flying is difficult, however, and requires continual training and practice to maintain currency and proficiency. Time is often not available for the nonprofessional pilot to maintain currency and proficiency in instrument flying, to say nothing of the fact that such flying may constitute a large financial burden to the individual. Further, an aircraft is not very forgiving of human error, at least in some phases of flight, and again, the necessity for continued maintenance of currency and proficiency in the particular type of aircraft operated is important even in fair-weather flying. Finally, all aspects of flying, including the cost of the aircraft, the cost of the equipment in the aircraft, and cost of the fuel, the tie-down fees at the airport, and so forth, appear to be extremely high.

In order to elaborate on the consequences of some of the preceding points, some comparative accident statistics compiled by the National Safety Council are shown in Table 3. The passenger fatalities per hundred million passenger miles

Table 2 Usage of general aviation aircraft

Calendar year 1969	Airplanes Number	Airplanes Percent of total	Hours flown (000)	Hours flown Percent of total
Personal	71,531	54.7	5,999	23.7
Business and executive	24,390	18.6	7,064	27.8
Instructional	15,895	12.2	7,023	27.7
Aerial application	5,795	4.4	1.440	5.7
Air taxi	5,642	4.3	2,544	10
Industrial/special & other	7,553	5.8	1,281	5.1
Total	130,806	100.0	25,351	100.0

Table 3 Comparative accident data

Passenger fatalities/100 × 10^6 passenger miles			
	Calendar year		
Mode of transportation	1967	1968	1969
Passenger automobiles and taxies	2.40	2.40	2.30
Buses	0.18	0.24	0.22
Railroad passenger trains	0.09	0.10	0.07
Domestic scheduled air transport planes	0.29	0.30	0.13
General aviation aircraft	18	19	18

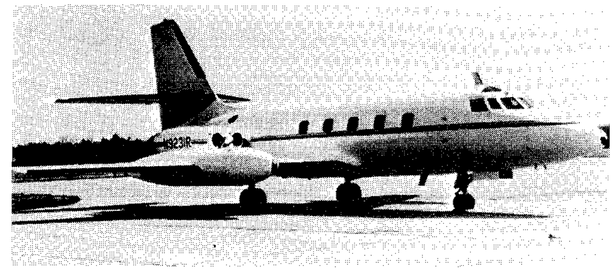

Fig. 3 Lockheed Jet Star.

are compared for automobiles and taxies, buses, passenger trains, domestic scheduled air transport, and general aviation aircraft. Data are shown for the years 1967, 1968, and 1969. Accident statistics can be expressed in various ways to show different things. Hence, a meaningful measure of the relative safety of different modes of transportation is difficult. Nevertheless, the large disparity between the safety record of general aviation aircraft, as compared to other forms of transportation, makes evident the need for work directed toward improvement in the safety of general aviation aircraft.

With regard to price, an interesting comparison is shown in Fig. 4 of the cost of general aviation aircraft and helicopters relative to automobiles. The data, obtained from Ref. 3, are shown in the form of the purchase price per pound of useful load vs speed. The price of general aviation aircraft is seen to vary from about \$10/lb of useful load to about \$30 or more per pound of useful load as the speed varies from 120 to 230 mph. The price range of the helicopter is in the order of \$55/lb of useful load. By way of contrast, the automobile is seen to cost about \$2.50/lb of useful load. The data in Fig. 4 suggest that work needs to be done to reduce the cost of general aviation aircraft.

The preceding discussion indicates that future research and development on general aviation aircraft should emphasize improvements in the safety and utility of the aircraft and reductions in the cost of the aircraft and its operation. In order to provide some guidance as to where research is needed to improve the safety of general aviation aircraft, the data of Table 4 (Ref. 3) are presented. These data relate to the phase of flight in which accidents occur. Although these statistics cover the 1963–1964 time period, indications are that the present-day situation is essentially the same. The data show that 67% of the accidents occur in landing, 16% in takeoff, and 7% in taxiing. Thus, 90% of general aviation accidents are associated in some way with operations on or near the ground in the terminal area.

On the basis of these statistics, and in view of the fact that the accidents in cruise are associated primarily with bad weather situations or inadequate navigation, fruitful directions for aeronautical research and development on general aviation aircraft are thought to be: new flight techniques and design concepts for the critical takeoff and landing maneuvers; new concepts for simple autopilots and SAS; simplified instrument and navigational displays, including CAS-PWI; and novel approaches for reducing costs—electronics, power plant.

Table 4 General aviation accident causes

1963–1964	
Phase of flight	Percent of accidents
Taxi	7
Takeoff	16
Cruise	8
Landing	67
Operation—static or unknown	2

First, new flight techniques and design concepts for the critical takeoff and landing maneuvers are required. The manner in which an aircraft is landed has not significantly changed in the last 50 yr. The introduction of the nose wheel has, of course, made the landing maneuver easier. Yet the nose wheel can hardly be considered new since Glenn Curtiss employed such a landing gear as early as 1910. The landing flare maneuver is a transient situation in which velocity, lift coefficient, drag coefficient, moment coefficient, angle of attack, flight-path angle, and aircraft attitude are all varying. The effect of aircraft design parameters on this critical maneuver and on the ease or difficulty with which the maneuver can be accomplished are not well understood. The flare maneuver needs thorough and detailed investigation to provide an understanding of the critical elements involved and of how the design parameters of the aircraft may be altered in order to minimize the difficulty of making the maneuver. Furthermore, if the details of the maneuver are sufficiently well understood, there seems to be the possibility of developing ingenious methods of synthesizing the controls of the aircraft so as to provide a simplified technique for making the landing maneuver. The second and third items in the list relate to new concepts which would permit the private pilot to travel from place to place simply and easily without becoming lost and, perhaps, to penetrate and successfully traverse moderate weather situations. The final item relates to novel approaches for reducing costs, particularly with regard to the electronic systems in the aircraft and the power plant. These two systems constitute the most expensive elements of the aircraft. For example, work is now underway in the laboratories of NASA to develop the technology for small, cheap, gas turbine power plants, and to simplify the circuitry in radio communication and navigation devices as applied to general aviation aircraft. More work along these lines is required.

In the past, little research and development has been directed specifically toward the problems of the general aviation aircraft. Perhaps the time has now come when the government should take the lead in fostering research and demonstration activities which will permit the development of advanced general aviation aircraft for the nonprofessional pilot.

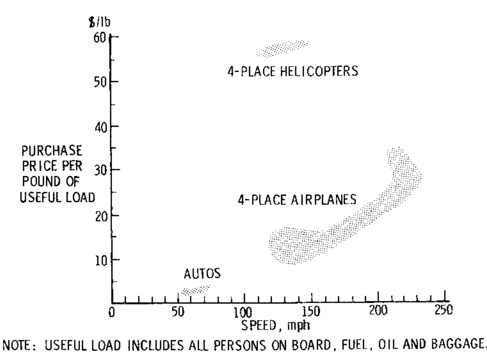

Fig. 4 Price per pound of useful load vs speed.

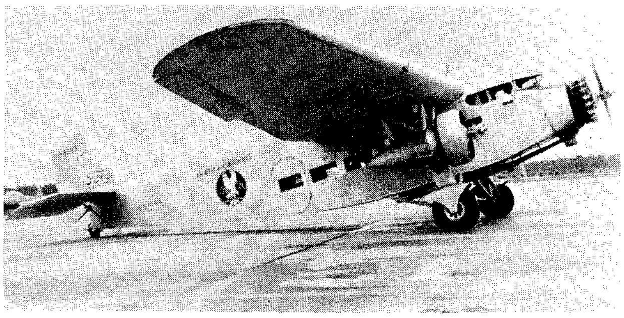

Fig. 5 Ford Trimotor.

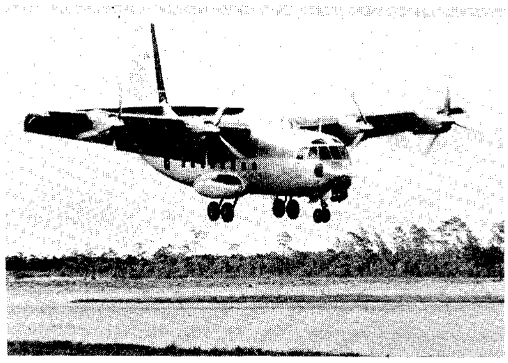

Fig. 7 McDonnell-Douglas Model 188 STOL aircraft.

Short-Haul Systems

No area in our air transportation system is in more urgent need of improvement than that which may be termed the STOL or V/STOL short-haul system. Short-haul transportation can be categorized in terms of the intercity systems or intracity systems. Intercity systems may be characterized by stage lengths which vary from 75–500 miles, whereas intracity systems may be characterized by segments which vary up to 50 or 75 miles.

An intercity system must offer speed, comfort, safety, convenience, and economy to the passenger, profits to the operator, and a level of noise and pollution which is acceptable to the community into which the aircraft must operate. In order to provide convenience and good service to the passenger, the aircraft must be capable of operation from small fields located close to these communities. In addition, the aircraft must be capable of operation from small specially designated strips on large airports without the necessity of competing with long-range aircraft for the available air space. The system must be designed so that excessive holding and diversion at the major airports is rarely encountered, and, of course, all-weather operation is required.

The intracity transport aircraft must satisfy in general the same requirements as the intercity machine; however, speed is much less important in this case than in the intercity system. A requirement may exist, however, for the intracity aircraft to takeoff and land vertically in order to provide transportation from within the city to outlying areas or airports. The development of a successful STOL or V/STOL short-haul system involves a new airways structure, new airports, new concepts for interacting with other forms of transportation, improved instrument landing systems, and new vehicles. Unless all parts of the problem are considered together and are developed in unison, a successful short-haul system will not emerge. The present discussion, however, will concern itself only with the aircraft necessary for a successful STOL or V/STOL short-haul system.

STOL Aircraft

Any discussion of STOL aircraft should be prefaced by a definition since STOL appears to mean different things to different people. One of the best STOL aircraft ever developed was the Ford Trimotor shown in Fig. 5. This aircraft, which was designed in 1926, had excellent short field performance. Unfortunately, the Ford Trimotor was also characterized by very poor cruise performance and a rough and rocky ride which was most unpleasant to the passengers. The Trimotor achieved its good STOL performance through the use of low wing loading and high power-to-weight ratio. Most of the so-called STOL aircraft in operation today are simply conventional aircraft which employ low wing loading, high power-to-weight ratio, and moderately powerful flaps. In some degree, these aircraft suffer from the same deficiencies as the Ford Trimotor.

If true short field take-off and landing performance is to be achieved, together with acceptable cruise performance and good riding qualities for the passenger, the use of power in the generation of lift becomes necessary. The relationships between several of the design and performance parameters of STOL aircraft are shown in Fig. 6 in which the approach speed and landing field length are plotted against aircraft wing loading. Lines of constant approach lift coefficient are plotted on the figure. The shaded areas indicate the relationships between the various design parameters for conventional jet aircraft, current propeller driven STOL aircraft, light planes, and jet flap STOL aircraft.

The approach lift coefficients on Fig. 6 are based on an approach speed which for the conventional aircraft is 1.3 times the power-off stall speed and for the powered lift STOL aircraft is 1.3 times the stall speed with one engine out. The approach speeds are calculated for the given lift coefficients and wing loadings. The field lengths shown are only approximate and are based on a correlation of field length with approach speed for conventional aircraft. Two crosshatched regions labeled "Current Propeller STOL" are indicated on Fig. 6. The region corresponding to wing loadings of about 30 psf and approach speeds of 75 knots is for aircraft such as

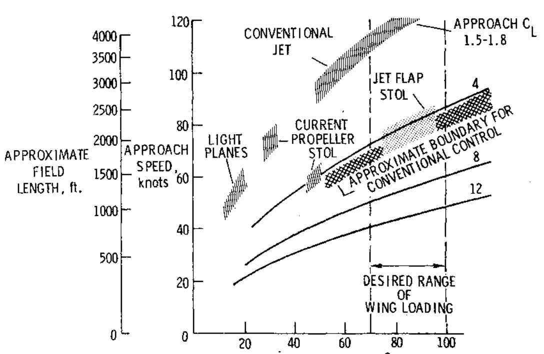

Fig. 6 Aircraft landing field length design consideration.

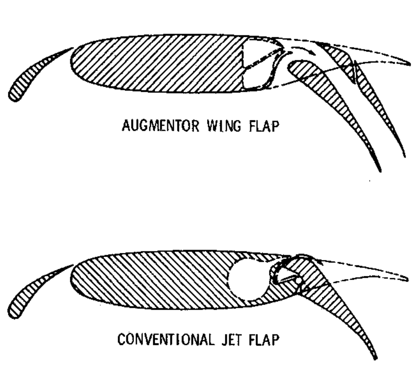

Fig. 8 Internally blown jet flaps.

the DeHavilland Twin Otter. The region shown at a wing loading of about 45 psf and an approach speed of 60 knots represents the performance of the rather sophisticated deflected-slipstream, propeller-driven McDonnell Douglas model 188 STOL aircraft shown in Fig. 7. The technology for the type of aircraft exemplified by the model 188 is well advanced, and aircraft of this class may be in use within a few years. Wing loadings in the range of 70–100 psf appear to be desirable however, if good cruise performance, together with acceptable passenger comfort, is to be achieved. A comfortable ride for the passenger can perhaps also be achieved by the use of some type of gust alleviation device; however, the use of such equipment appears to be some years ahead, and for the present time, must be considered the subject of research and study. Along with wing loadings of 70–100 psf, field lengths of 1500–2000 ft are thought to be desirable in order to provide the type of STOL performance that is required. As can be seen from Fig. 6, this combination of field length and wing loading tends to dictate a jet powered aircraft employing some type of powered lift, such as a jet flap or lift engines. It is perhaps of interest to note that for the range of wing loading selected, the use of field lengths much below 1500 ft would require the use of some type of reaction control system for low-speed operation of the aircraft.

The types of STOL aircraft which are thought to provide the most promise for satisfying the combinations of wing loading and field length which have just been discussed are internally blown flap, externally blown flap, and lift-fan configurations. The ultimate STOL aircraft will probably be jet powered. Both internally and externally blown flaps appear to be promising, as does the use of auxiliary lift fans. Two types of internally blown flap concepts are shown in Fig. 8. The concept shown at the top of the figure was originated by DeHavilland of Canada and is called an augmentor wing flap. In order to obtain flight-test experience with this concept, NASA is having a DeHavilland C-8 Buffalo aircraft modified to incorporate the augmentor wing flap. In the augmentor wing concept, a near-sonic jet issues from the internal duct in the wing into a biplane flap arrangement and acts somewhat as a jet pump. In addition, the flow is held attached to the upper surface of the top flap by means of flow sucked into the region between the upper and lower flap through a slot in the top flap. The system is effective but complicated, and careful consideration must be given to the quantity flow and pressure ratio requirements of the high-lift jet in relation to the characteristics of the main propulsion system. The conventional internally blown jet flap is shown at the bottom of Fig. 8. This type of high-lift device is characterized by the issuance of a high-speed jet through a slot at the leading edge of the flap.

Another type of jet-lift system called the externally blown jet flap is illustrated in Fig. 9. In this type of flap, the flow from the engine passes through the flap system in order to produce high-lift coefficients. The blown flap was first proposed by John P. Campbell of NASA, in the mid-1950's. No serious consideration was given to the external-flow flap at that time because of the impingement on the wing and flap surfaces of the high-temperature flow from the existing straight-through turbojet engines, and because of the relatively small mass flow issuing from these engines. With the advent of the high-bypass-ratio turbofan engine, however, not only is the efflux from the engine relatively cool but, in addition, large quantities of air are available for passage through the flaps. In comparison with the internally blown

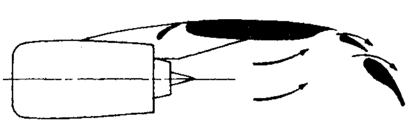

Fig. 9 External-flow jet flap.

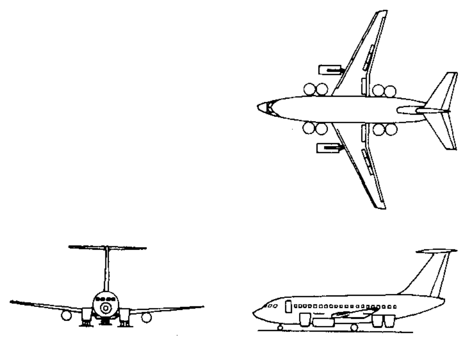

Fig. 10 Direct-lift transport.

jet flap, the externally blown flap appears to be relatively simple. The one-engine-out condition was long considered to be the major problem with the externally blown jet flap. Promising approaches to this problem are now under study. There is no flight experience, however, with an aircraft equipped with an externally blown jet flap. Such experience is badly needed in order to explore the practical and operational problems of the use of an externally blown jet flap on an aircraft.

The use of direct-lift engines to achieve STOL performance is illustrated in Fig. 10. The use of direct-lift engines, which could be folded away in the aircraft in the cruise configuration, appears to be simpler and more flexible than the blown flap arrangements in that the engines which augment the lift are uncoupled from those which provide the forward propulsion capability. The fuel utilization in the slow flight condition may be greater, however, for the direct-lift engine system than that for the blown flap systems shown in Figs. 8 and 9. Again, flight studies of the use of direct-lift fans to provide STOL performance are necessary in order to explore and understand the practical and operational problems involved.

A brief assessment of the present situation with regard to STOL aircraft follows. First, the available STOL aircraft are characterized by low wing loadings. Second, successful STOL aircraft require high wing loadings both for cruise performance and for ride quality. Third, within the next few years, interim propeller driven high wing loading STOL types will probably come into use. Fourth, there are several advanced jet powered concepts which appear promising. These concepts include the internally and externally blown flaps, and the use of lift fans to provide direct-lift augmentation. And, finally, demonstrator flight vehicles are urgently needed in order to explore the practical and operational problems associated with the more advanced jet type STOL aircraft. Continued development and refinement of the technology in the various technical disciplines is obviously required.

V/STOL Aircraft

For many years, vertical takeoff and landing aircraft have been thought to hold high promise for commercial and military application. V/STOL aircraft have been the subject of extensive study and research and a number of V/STOL flight vehicles of varying degrees of sophistication have been built and flown. Yet, today, the helicopter is the only operational V/STOL type available. The helicopter has, of course, proved highly useful as a military machine and for special purpose civilian work, but has been only marginally successful as a commercial passenger carrying transport. An attempt will be made to review and assess the present state of the art in V/STOL technology and to offer some thoughts on future directions of research activity in this area.

The classes of vehicle concepts encompassed within the definition of V/STOL are indicated in Fig. 11. This figure, taken from Ref. 4, indicates a matrix of aircraft in which the propulsion system is indicated across the top of the figure,

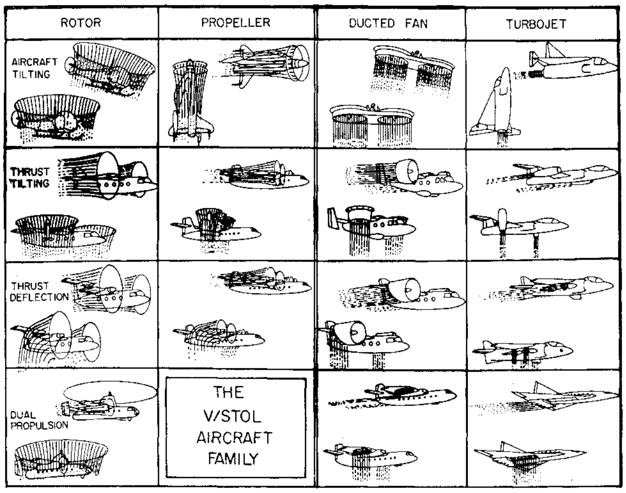

Fig. 11 The V/STOL aircraft family.

and the manner in which the propulsion system is utilized to produce lift and thrust is shown along the side of the figure. Momentum may be imparted to the air by a rotor, propeller, fan, or jet, as indicated along the top of the figure. Lift and forward thrust, as indicated along the side of the figure, may be achieved from the momentum imparted to the air by tilting the vehicle, tilting the thrust, deflecting the thrust, and finally, by uncoupling the propulsive lifting system from the forward propulsion system. A large number of these combinations has been explored and tested in wind tunnels, and many of them have been built and flown in full-size man-carrying vehicles.

The question might be asked why so many different concepts have been proposed and investigated. One answer might be found in the search for a reduction in complication, or perhaps a more optimized relation between control and performance. A very fundamental reason why a number of configuration concepts must be considered is offered in Fig. 12 in which the fuel required per minute in hover, as a fraction of gross weight, is plotted against design cruise speed in knots. The fuel required to hover is seen to be a minimum for a helicopter, increasing as configurations capable of higher speed are chosen, and becoming a maximum for the lift-jet configuration. The reason for this trend lies in the fundamental principle that a given lift can be achieved more efficiently by imparting a small acceleration to a large mass flow of air, rather than imparting a large acceleration to a small mass flow of air. Thus, the particular concept chosen for the V/STOL aircraft depends critically upon the hover time and the cruise speed requirements for the particular mission. Although many mission studies of V/STOL aircraft have been made, there appears still to be an important need for market/vehicle trade studies in order to define what kind of aircraft is required in order to accomplish what mission. The lack of definition of the mission has been one of the difficulties which has prevented focusing on a particular type of V/STOL aircraft and pursuing its development into a commercially feasible vehicle.

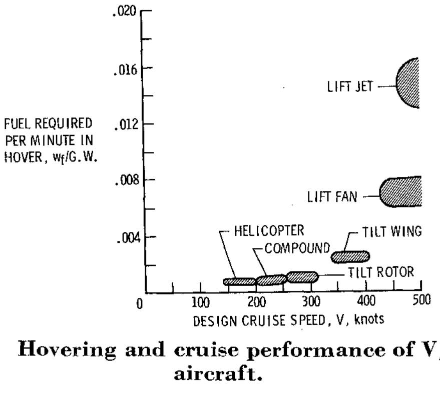

Fig. 12 Hovering and cruise performance of V/STOL aircraft.

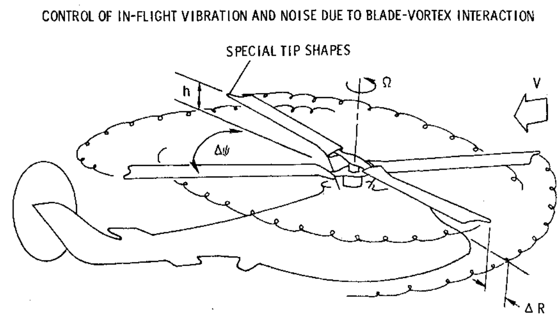

Fig. 13 Variable-geometry rotor.

The types of V/STOL aircraft which appear most promising are helicopter, compound helicopter, tilt rotor, tilt wing, and fan lift. The helicopter is a versatile and useful aircraft and is the only operational V/STOL machine available at the present time. Some of the problems associated with the present-day helicopter are poor flying qualities, undesirable vibration characteristics, high maintenance cost, high noise level, and low efficiency. The helicopter has relatively poor flying qualities, a fact that becomes particularly evident under instrument flight conditions in the approach and landing maneuvers. The vibration characteristics of the helicopter are undesirable from the point of view of passenger comfort and also contribute to the high maintenance cost associated with operation of the aircraft. The high noise level is particularly annoying to the community within which the helicopter operates. The efficiency of the helicopter is also relatively poor. Directions of future research and development which appear promising are: technology development—vibration, fatigue, materials, control and maneuverability, IFR flight, and efficiency; new concepts—variable-geometry rotor, ABC rotor, and structural configurations. In basic technology, a number of areas of fundamental work are indicated which will help solve the problems previously discussed.

Innovative rotor and vehicle concepts aimed at solution of some of the problems of the helicopter are also needed. For example, the variable-geometry rotor, shown in Fig. 13, offers the possibility of reduced noise and vibration. In this concept two of the blades operate in a plane displaced from that of the other two blades. The blades also vary in length and are at an angle other than 90° to each other. The hope for the variable-geometry rotor is based on the concept of controlling the interaction of the rotor blades with the vortices from preceding blades. NASA flight studies are planned with a rotor test vehicle in which the effects of changes in the design parameters can be systematically studied. Other new approaches, such as the advancing blade concept rotor proposed by Sikorsky, and other new concepts should be studied. New structural configurations and methods of blade structural design should also be considered.

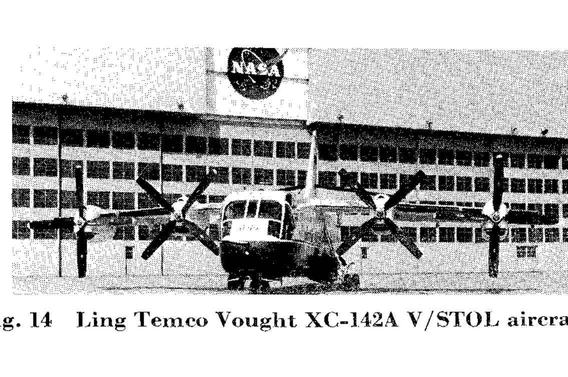

Fig. 14 Ling Temco Vought XC-142A V/STOL aircraft.

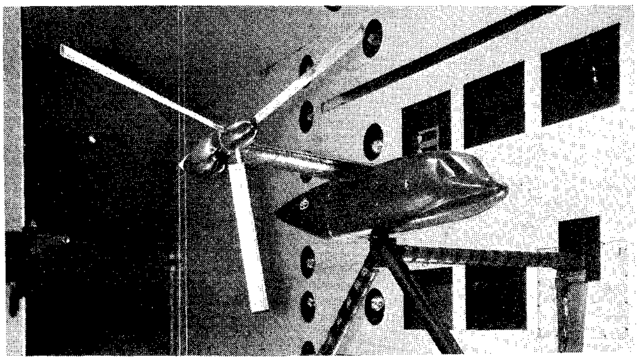

Fig. 15 Bell tilt-rotor model in Langley transonic dynamics tunnel.

The state of technology for the other types of V/STOL aircraft previously listed is less well defined at the present time, and except for the compound helicopter, is not sufficiently advanced to permit initiation of the development of prototypes for airline use even if the desired mission were clearly defined. The technology for the tilt-wing concept, illustrated in Fig. 14 by the 35,000 lb LTV XC-142A aircraft, is fairly well in hand. More work is required on the tilt-rotor concept. A tilt-rotor machine was flight tested in the late 1950's and was found to have serious dynamic problems. Theoretical analysis and model tests over the past few years provide hope that the problems of the tilt-rotor aircraft have been overcome. A model of a Bell tilt-rotor concept is shown mounted in the NASA Langley transonic dynamics tunnel in Fig. 15. A demonstrator aircraft employing the tilt-rotor principle would appear to be desirable. The pure jet-lift principle has been successfully applied to the Hawker Siddeley P.1127 aircraft shown in Fig. 16. This aircraft is now being purchased by the Royal Air Force, and a number of such machines are on order by the United States Marine Corps. The German Dornier DO-31 V/STOL transport aircraft also employs the jet-lift principle and has been flown quite successfully in experimental studies. This aircraft, however, like the XC-142A, appears to be destined for a museum. The use of the lift fan as a means for providing VTOL capability is illustrated by the model in Fig. 17. The Ryan XV-5 aircraft is being utilized by the NASA Ames Research Center for flight studies of the lift-fan principle as applied to V/STOL aircraft.

An assessment of the status of V/STOL aircraft follows. First, the helicopter is the only available commercial V/STOL vehicle. Improved helicopters appear to be possible in the future as a result of the application of advanced technology. Second, there are several advanced V/STOL vehicles which appear to be technically feasible, but all require further technology advancement prior to prototype development. Research is required in many technical areas. Particular attention must be directed toward the noise problem since the particular type of V/STOL aircraft to be utilized in a given situation may well be dictated by the noise level which can be achieved. Study of the operational characteristics and problems of V/STOL aircraft should also be cited as needing continued attention. Finally, a combined technology development and market/vehicle trade study program should be pursued in order to resolve areas of uncertainty and identify the most promising concepts.

Table 5 Size of long-haul subsonic transport activity[a]

	Calendar year 1969	Calendar year 1980
Passengers on domestic airlines	154,400,000	437,500,000
Number of passenger miles—domestic	95,945,000,000	312,000,000,000
Number of passengers from JFK to overseas	8,341,318	25,000,000
Number employees JFK	44,867	— — — —
Number of jet transports	2,068	3,679

[a] Jet transports produced in 1969 cost \$2.9 × 10^9 (estimate). Total number of passengers from JFK in 1969—19.5 × 10^6.

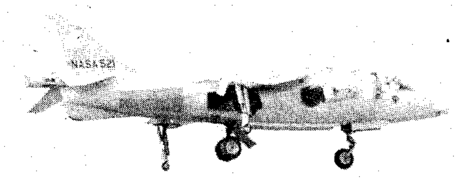

Fig. 16 Hawker Siddeley P.1127 V/STOL aircraft.

Long-Haul Systems

Subsonic Jet Transport

There is no doubt that the long-haul subsonic jet aircraft represents the highest level of vehicle development yet achieved in air transportation. An indication of the size of the modern scheduled air transportation activity is indicated in Table 5. Although Table 5 is entitled, "Size of long-haul subsonic transport activity," a significant amount of the activity indicated is associated with the present schedule short-haul system. The data shown are for the year 1969 and include projections for the year 1980. Note that over 154 million passengers were carried on domestic airlines in 1969. By way of comparison, some 3 million passengers were carried on domestic airlines in the year 1940. The number of passengers departing from Kennedy Airport for overseas destinations was over 8 million in 1969 and is projected to be about 25 million by 1980. The introduction of the jet transport has essentially eliminated the ship as a serious means of overseas travel. In addition, as indicated by the large number of passengers leaving Kennedy Airport for overseas destinations, more passengers are traveling abroad today as a result of efficient air transportation than was the case when the ship provided the sole means of overseas travel. For example, in 1939 about 500,000 people left the United States by way of steamship bound for overseas destinations. Some of the other data in Table 5 provide additional insight into the size and importance of the scheduled airline activity today.

The design, development, production, and sale of United States jet transports, both at home and abroad, is an important element in our economy. Today, it is hardly possible

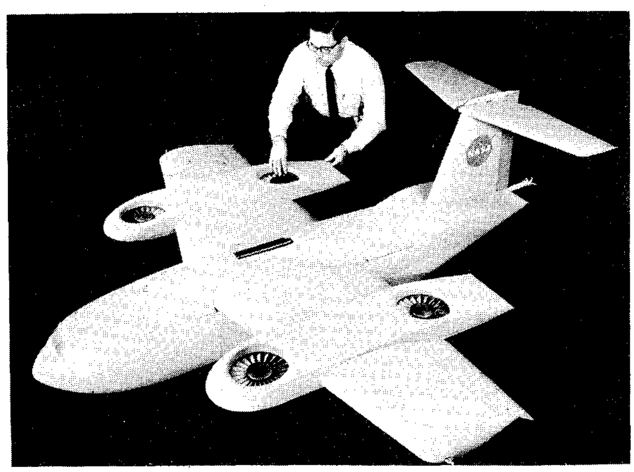

Fig. 17 Model of a lift-fan V/STOL aircraft.

Fig. 18 Flight line at Seattle.

to visit any major air terminal in the world without witnessing the arrival and departure of the products of U.S. aircraft manufacturers which bear the names of both large and small foreign and domestic airlines. Some indication of the international aspects of United States aircraft production can perhaps be gained from the photograph shown in Fig. 18. This photograph, taken in Seattle, shows new Boeing transport aircraft destined for various domestic and foreign airlines.

Modern air transportation has become such an accepted part of modern life that many tend to forget how far air transportation has advanced in a relatively short period of time. The fantastic growth in air transportation capability can be illustrated by the photograph in Fig. 19. This photograph was taken from the August 1929 issue of a long-defunct magazine entitled, "Air Travel News." Shown is a Boeing model 40-B single-engine biplane in which the pilot sits in an open cockpit and four passengers are carried in a small enclosed cabin behind the engine. The caption on the figure states that it depicts an early morning scene at Oakland Airport from which four people are about to depart for Seattle. The scheduled airlines carried about 130,000 passengers in 1929. In contrast, a photograph of the first-class section of the new Lockheed L-1011 Tri-Star is shown in Fig. 20.

Indeed, commercial air transportation has come a long way in the past 40 years. In fact, so much progress has been made and today's jet transport provides such a good basis for air transportation that many feel there is little left to be done in the way of improvement in the long-range subsonic jet transport. There appear, however, to be three major areas in which distinct improvement is desirable and possible. These areas are: greater efficiency, greater safety, and lower noise. The order in which these characteristics are listed does not imply a priority. Greater efficiency can mean greater convenience and economy to the passenger, greater return on investment to the operator, and, of course, greater efficiency means sales to the manufacturer. Travel by scheduled air transport planes today is one of the safest forms of transportation, as was indicated in Table 3. As the passenger capacity of our transport aircraft approaches and passes the figure of 500, however, the consequences of a fatal crash are indeed sobering. One still reads accounts of the sinking of the steamship Titanic. This disaster occurred in 1912 and was accompanied by the loss of about 1500 passengers. It seems self-evident that continued work is necessary to improve the safety of our transport aircraft. Noise must be regarded as one of the most serious problems in air transportation today. Progress is being made toward reducing the noise levels of new aircraft, but further work is necessary. More detailed discussion of the areas of efficiency, safety, and noise follows.

Fig. 19 Air transport in 1929.

Fig. 20 Interior of Lockheed L-1011 Tri-Star transport.

Three areas of future research and development aimed toward increasing the efficiency of long-haul subsonic transports are: supercritical aerodynamics—better fundamental understanding, generation and test of new shapes, and flight study and demonstration; durable, high-temperature engines—materials and cooling concepts; reduced structural weight—new structural materials and automated methods of structural design. Recent explorations in the field of supercritical aerodynamics by R. T. Whitcomb of NASA point the way toward the possibility of flying transport aircraft very close to the speed of sound. Much work needs to be done to obtain a better fundamental understanding of how to configure shapes to operate at and near the speed of sound. New shapes need to be generated and evaluated. Finally, all of the work to date on supercritical aerodynamics has been accomplished in wind tunnels on very smooth, carefully contoured models. Experiments need to be made in flight on real aircraft whose wings are not always smooth and do not always conform exactly to the desired contour.

In order to explore the application of supercritical aerodynamic technology to an actual flight vehicle, NASA is at the present time modifying an F-8 airplane to incorporate a supercritical wing. The wing bears no relation to the original wing on the F-8 aircraft, but has been laid out to simulate the geometry of a high-speed transport wing. In addition, the fuselage is being recontoured in order to provide the neces-

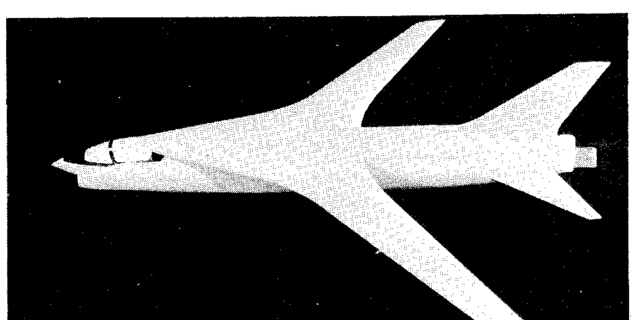

Fig. 21 Model of modified F-8 with supercritical wing.

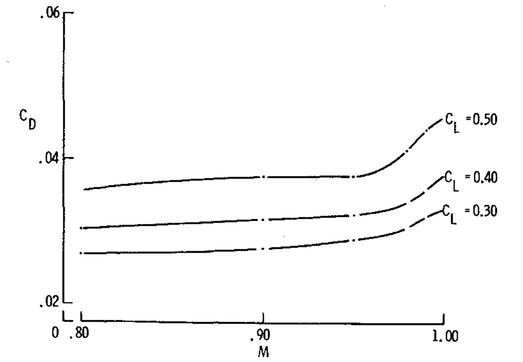

Fig. 22 Drag characteristics of F-8 model with supercritical wing.

sary area-ruling for flight near Mach 1. A photograph of a model of the configuration is shown in Fig. 21. A plot of the drag coefficient against Mach number for the F-8 model of Fig. 21 is shown in Fig. 22 for lift coefficients of 0.3, 0.4, and 0.5. For the design lift coefficient of 0.4, the drag break is seen to occur at a Mach number of about 0.98. Recent work on an entirely new transport shape has indicated the possibilities of delaying the force break Mach number to a value between 0.99 and 1.0.

Another area in which future research and development may be expected to contribute to improved aircraft efficiency is that of propulsion. For example, the use of increased turbine inlet temperatures can be expected as the result of the development of improved materials and improved blade cooling techniques. Reductions in structural weight of the aircraft can be expected as a result of new and improved automated methods of structural design and through research and development on new lightweight, high-strength, high-stiffness structural materials. Work has been under way for a number of years on various composites as materials for aircraft construction. Shown in Fig. 23 is an experimental center wing box for the C-130 aircraft which is being built by Lockheed under contract to NASA. The wing box will be constructed of aluminum alloy reinforced with boron composites, and will serve as a test specimen.

There are a number of directions of future research and development aimed toward the improvement of safety. These include a better definition of the air and ground environment in which the aircraft must operate and a better definition and understanding of operating practices in relation to the environment. One area which is receiving increased attention today as a result of the introduction of very large 747 and C-5A types of aircraft is that of the wing trailing vortices. Wing trailing vortices constitute a hazard to encountering aircraft as indicated in Fig. 24. The hazard exists for the cruise condition at high altitude and has an effect on the required separation distances between aircraft, and is also a major concern in the takeoff and landing patterns around airports. Work is required in at least three directions. First,

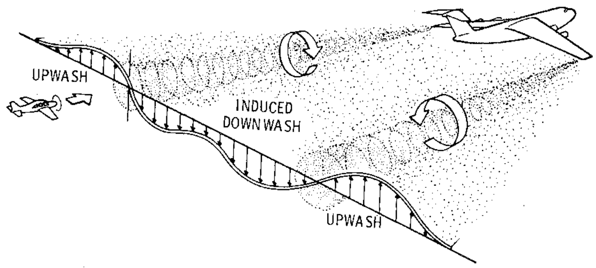

Fig. 24 Wing trailing vortices present a hazard to encountering aircraft.

safe separation standards must be determined. Second, the development of means for detection of the vortices is required. Third, explorations are required in order to determine if methods can be found for increasing the instability of the trailing vortex system so that the large vortices will break up into a number of small and relatively harmless vortices at a short distance behind the aircraft.

The understanding of structural fatigue and how to design to avoid fatigue failures must be the subject of continued research and development. Concepts and criteria for stability and precision control and guidance with minimum compromises in aircraft performance must be pursued. For example, the use of full-time stability augmentation systems and command control systems must be studied. Low visibility takeoff and landing, collision avoidance, clear air turbulence detection and avoidance, and upsets are all matters that require continued research and development. Methods of gust alleviation need exploration, both for passenger comfort and for the avoidance of excessive loads on the aircraft. Finally, ground operations which include skidding, braking, and directional control must be further studied.

As has been indicated previously, the reduction of aircraft noise to the point where aircraft operations are socially acceptable within the community is probably one of the most challenging problems facing aeronautical engineers. Some of the directions for future research and development leading toward the solution of the aircraft noise problem are: basic understanding of noise generation and propagation; methods of noise attenuation—acoustic treatment and choking; engine design to minimize noise—turbine and exhaust nozzle; and aircraft operating practices. Attainment of a better basic understanding of noise generation and propagation, and of the reaction of people to noise must continue. A new laboratory is being planned for the NASA Langley Research Center to provide the facilities necessary for an expanded fundamental noise research program. An artist's concept of the noise research laboratory is shown in Fig. 25.

Acoustic treatment in the nacelles of jet engines, and inlet choking, have been explored as means for reducing noise and will continue to be the subject of research and development. A program has recently been completed by the McDonnell

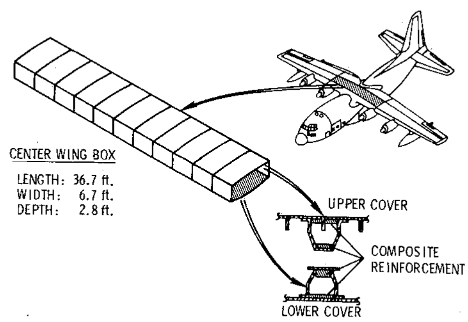

Fig. 23 C-130 airplane center wing box reinforcement with composites.

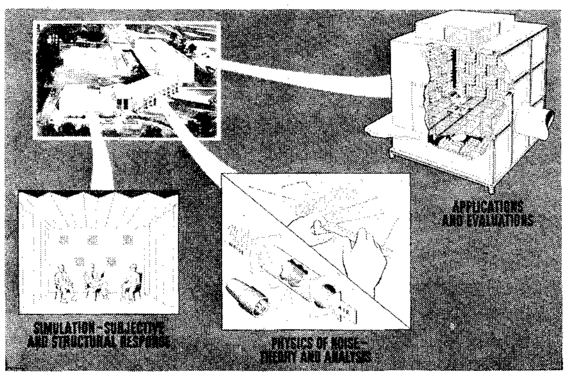

Fig. 25 Langley aircraft noise reduction laboratory.

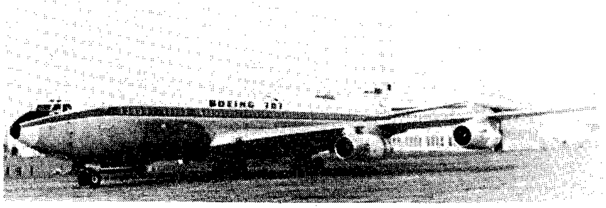

Fig. 26 Boeing 707 with acoustically treated fan-jet nacelles.

Douglas Corporation and The Boeing Company, under contract to NASA, in which the use of acoustic treatment for quieting the fan engines during the landing approach was explored. The program included modification and flight tests of acoustically treated nacelles on a McDonnell Douglas DC-8 aircraft and a Boeing 707 aircraft. Figures 26 and 27 show the Boeing 707 aircraft equipped with modified nacelles incorporating acoustic treatment for noise reduction. The use of acoustic treatment on the Boeing aircraft resulted in a reduction of 15 EPNdB for the approach condition. The annoying fan noise which emanates from the engines utilized on this aircraft was essentially eliminated. Acoustic treatment is being employed on the nacelles of several new commercial transport aircraft.

In addition to nacelle treatment, work is now in progress and will continue on the design of the basic engine to minimize noise. The compressor and fan, the turbine, and the exhaust nozzle must be studied. The quiet engine program at the NASA Lewis Research Center is an example of work on the basic engine. Finally, work is continuing on the development of aircraft operating practices to reduce noise. For example, steep approach procedures are being studied as a means of reducing the extent of noise exposure under the approach path of the aircraft. At the present time, the state-of-the-art suggests that the noise from the fan can be controlled to an acceptable level; however, little progress has been made in recent years on controlling the noise from the hot exhaust of the engine. As the proportion of the total generated energy absorbed by the fan increases, however, the noise associated with the hot exhaust becomes relatively less important.

Supersonic Transports

Supersonic flight was first achieved in October 1947, and the military have been flying at supersonic speeds for about 15 yr. The age of commercial supersonic transportation is now about to begin. Even in 1947, however, before Charles E. Yeager's historic flight in the X-1 airplane, thought was being given to the possibility of a supersonic commercial aircraft. The NACA concept of a supersonic transport, as depicted in a January 1947 issue of Life magazine, is shown in Fig. 28. The aircraft was intended to carry 10 passengers at

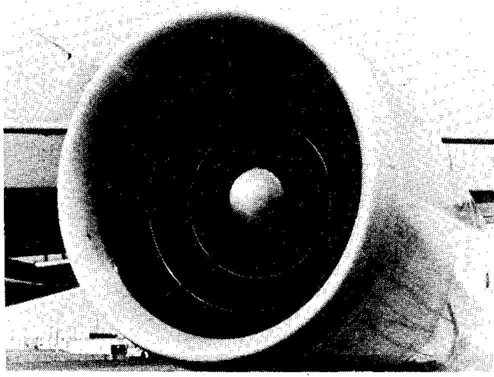

Fig. 27 Closeup of inlet of acoustically treated fan-jet nacelle on Boeing 707.

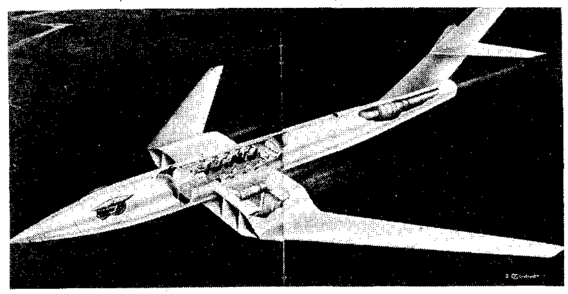

Fig. 28 1947 concept of a supersonic transport.

Mach 1.5 for a range of about 1500 miles. The present Boeing supersonic transport concept is indicated in Fig. 29. A comparison of the aircraft configurations in Figs. 28 and 29 suggests that predictions of future aircraft designs on the basis of meager technology can indeed be misleading.

Research on the problems of long-range supersonic cruising aircraft has its origins in the United States in the work which was undertaken in support of the Air Force XB-70 program in 1954 or 1955. Focused research on the supersonic commercial air transport began in this country in about 1958. The British began studying the supersonic transport at a somewhat earlier date. The time period in which the Russians began considering the supersonic transport is not known. The situation today is that both the French/British Concorde and the Russian TU-144 aircraft are undergoing flight tests.

On the other hand, unfortunately, money for the construction of the U.S. supersonic transport has not yet been appropriated. Both the French/British and Russian supersonic transports are relatively small aircraft designed to carry about 125 passengers and to weigh in the range from 350,000 to 400,000 lb. Both aircraft are constructed primarily of aluminum alloy and, hence, are restricted to cruise Mach numbers slightly in excess of 2. Studies in the United States have indicated that cruise Mach numbers of 2.5 to 3.0 yield an aircraft which is more attractive than one designed to cruise at lower Mach numbers. The higher Mach numbers are desirable for increased productivity of the aircraft as well as for improved flight efficiency. The higher cruise Mach numbers, of course, preclude the use of aluminum as a structural material. Titanium will be used for the structure of the U.S. supersonic transport.

The United States supersonic transport is much larger than either the French/British or Russian machine. The passenger capacity of the U.S. aircraft reflects airline experience in this country and, depending upon the particular seating arrangement, varies between 250 and 300 passengers. The resultant aircraft weighs in the order of 750,000 lb. The United States supersonic transport gives promise of being a highly successful commercial aircraft.

The present state of supersonic aircraft technology suggests that follow-on second-generation supersonic transports can be significantly improved in comparison with the aircraft being designed and constructed today. Future research on supersonic technology should be aimed toward achieving a better payload fraction, longer range, and lower noise and sonic boom. The better payload fraction and longer range imply the development of aircraft having improved lift-drag

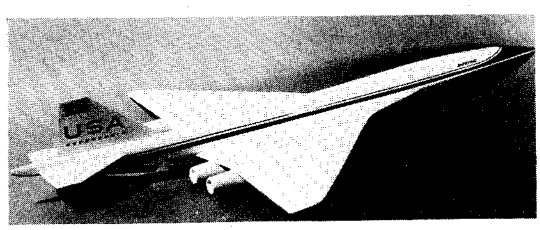

Fig. 29 The Boeing model B2707-300 supersonic transport.

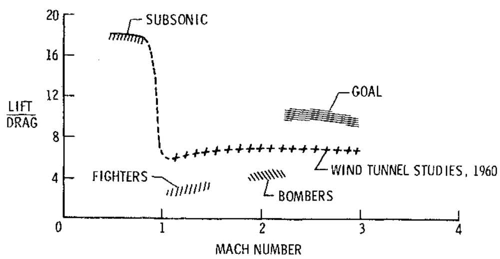

Fig. 30 Trends in supersonic L/D ratio.

ratios, better structural fractions, and better engine specific fuel consumption. Lower noise implies improved engine design and nacelle treatment, and lower sonic boom implies refinement of the aircraft configuration.

Future research and development directed toward reductions in the structural weight fraction will encompass: automated methods of structural design; development of new materials; interaction of aeroelasticity, stability, and control; active elastic mode suppression; engine-inlet exhaust-nozzle optimization; reduction of noise and sonic boom; and improved configurations. Automated methods of structural design suggest more precise definition of the structure and thus reductions in weight. New materials, such as the composites, offer the hope of better strength-to-weight ratio and stiffness-to-weight ratio. The interaction of aeroelasticity with stability and control implies a reduction in the amount of weight added to the structure to provide the stiffness necessary for adequate control power. Perhaps the deformations of the aircraft can be utilized as a means for increasing control power. Active elastic mode suppression implies a reduction in the amount of structural weight required to prevent flutter and to withstand the loads imposed by gusts. Engine-inlet and exhaust-nozzle optimization, together with the development of improved engines, suggests a reduction in specific fuel consumption.

Reductions in the amount of engine noise suggests both nacelle treatment and improvements in engine design. With regard to the sonic boom and the possibilities of its elimination, consideration must be given to the fact that in order to produce lift air must be given a downward component of momentum. The formation of a shock wave is necessary at supersonic speeds in order to provide the turning required to produce the downward momentum. Hence, the notion that the sonic boom can be caused to disappear completely through some as yet undiscovered invention ignores the physical fact that the formation of a shock wave is necessary for the production of lift. Nevertheless, the overpressure due to the shock wave experienced near the ground or on the ground can be controlled, to some extent, by careful tailoring of the aircraft configuration so that several small shock waves impinge on the ground rather than two large ones. Furthermore, reductions in the weight of the aircraft required to accomplish a given mission can cause significant reductions in ground overpressure. Those factors which contribute to a reduction in gross weight for a given mission are exactly those factors, previously discussed, which contribute toward improved aircraft efficiency.

The last item, "improved configurations," means the development of aerodynamic configuration concepts with increased supersonic cruising efficiency. Significant progress has been made in the development of methods for designing improved aerodynamic configurations and in evolving configurations which have improved lift-drag ratios at supersonic speeds. A plot of lift-drag ratio vs Mach number is shown in Fig. 30. On the left-hand side of the figure are shown the lift-drag ratios achievable by present-day operational subsonic jet transports. In the Mach number range between 1.0 and 2.0, the hatched regions indicate the lift-drag ratios achieved by military fighters and bombers. The

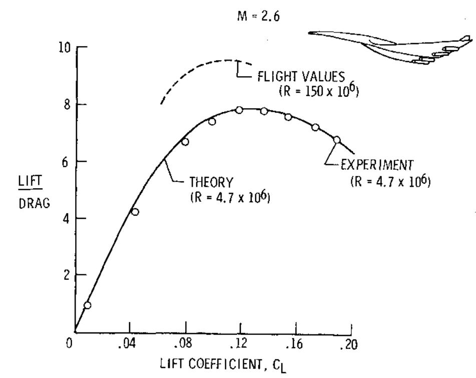

Fig. 31 L/D ratios of integrated SST design.

crosses indicate the values of lift-drag ratio extrapolated from wind-tunnel studies in about 1960. The region labeled "Goal" indicates the values of lift-drag ratio which were chosen in 1960 as a goal for supersonic cruising aircraft. In the Mach number range between 2.0 and 3.0, these desired ratios are about 10. Values of the lift-drag ratio near 10 have been projected for future flight vehicles on the basis of theoretical calculations and wind-tunnel experiments conducted in recent years. The lift-drag ratio is shown in Fig. 31 plotted against lift coefficient for a conceptual aircraft configuration. The solid line indicates the values predicted on the basis of theoretical computations made with the use of high-speed digital computing equipment. The circles indicate values obtained at a Reynolds number of 1.7 million in the wind tunnel. The dashed line at the top of the figure illustrates the values of lift-drag ratio extrapolated to a flight Reynolds number of about 150 million. These values of lift-drag ratio are trimmed and include the effects of roughness drag on the real vehicle.

Two points are worthy of mention in regard to Fig. 31. First, theoretical methods are now available which permit detailed aerodynamic design of supersonic cruising aircraft by means of high-speed digital computers. These theoretical methods have been repeatedly checked by experiment. Second, flight values of the lift-drag ratio of the order of 10 appear to be possible with configurations which, though perhaps not practical today, may be practical in the future. A model of the configuration for which the data of Fig. 31 were obtained is shown in Fig. 32. This configuration has been extensively studied by industry, but does not appear to form the basis of a practical airplane at this time.

Thus, although the presently proposed United States supersonic transport appears to offer every promise of being a good and commercially viable airplane, advances in tech-

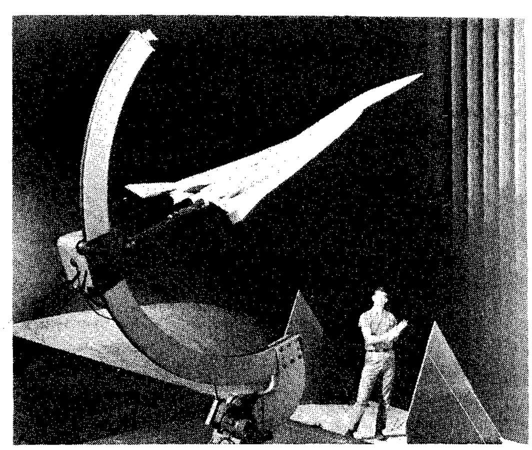

Fig. 32 SCAT-15F supersonic transport model in the Langley full-scale tunnel.

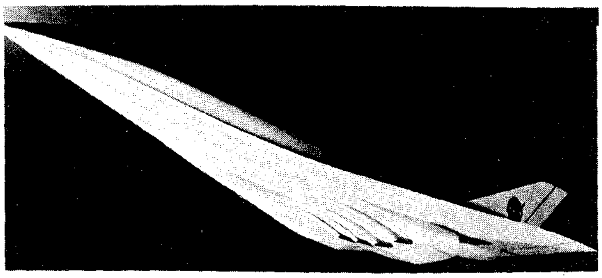

Fig. 33 Hypersonic transport concept.

nology hold the promise of producing an even better second generation supersonic transport at some time in the future.

Another kind of supersonic transport, one that is designed to fly below the threshold Mach number for which the sonic boom shock wave reaches the ground, has recently received attention. The aircraft, which cruises at a Mach number between 1.0 and 1.2, is in competition with the subsonic and nearsonic transport rather than the Mach 2.7 supersonic transport. The advantages of such an aircraft can be found in reductions in trip time and increases in productivity. For example, one recent study has shown that an aircraft cruising at a Mach number of 1.2 on the nonstop transcontinental route could reduce the flight time westbound by an hour and 45 min and eastbound by about 50 min, as compared with the present subsonic jets. Whether or not such an aircraft could be made economically viable, however, remains an open question. A large reduction in lift-drag ratio occurs as the Mach number is increased past 1.0 as shown by the curve in Fig. 30. A lift-drag ratio in excess of that shown at Mach 1.2 in Fig. 30 can no doubt be achieved.

Since the Mach number range between 1.0–1.2 has not been thoroughly explored from the point of view of evolving configurations with high cruise lift-drag ratios, the practicality of a slightly supersonic airplane cannot be assessed on the basis of the technology now in hand, but must await further research and study. In addition, the extent to which the slightly supersonic transport can be predictably flown below the threshold Mach number for sonic boom across the country on a day-to-day basis and under all types of weather conditions has not yet been fully explored. No final judgment seems possible on the slightly supersonic transport at this time; however, work should proceed so that the role of this aircraft in the transport spectrum can be evaluated.

Hypersonic Aircraft

The X-15 hypersonic research airplane was conceived in the early 1950's, was first flown in 1959, and now has been retired to museum status. The definition of a practical mission for hypersonic aircraft, however, remains vague. The possible applications of such aircraft, which have been studied in varying degree, are: transport aircraft, recoverable booster, and military aircraft. A very long-range high-speed

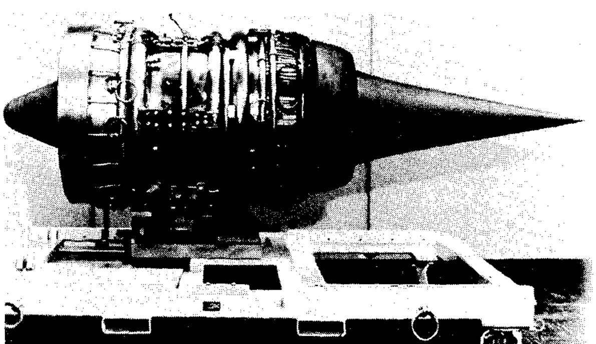

Fig. 34 The hypersonic research engine.

Fig. 35 Hypersonic structures model mounted in the Langley 8-foot high-temperature structures tunnel.

transport such as might be used to connect California with Australia is one possible application of a hypersonic aircraft. Another application is the recoverable booster, or what might now be termed an air-breathing first stage for the space shuttle. Finally, consideration has been given to some type of hypersonic vehicle in the military reconnaissance role. The design Mach number has not been established for any of these applications, but would no doubt be in excess of 5.

Studies made to date have indicated certain design principles of the hypersonic air-breathing machine. First, hydrogen fuel is required in order to provide the low specific fuel consumption needed to compensate for the reduction in lift-drag ratio at hypersonic speeds, and to provide the necessary heat sink capacity for cooling the engine and perhaps other parts of the structure. Second, some sort of dual propulsion system involving an accelerator engine and a ramjet for cruise flight is required. Two separate engines or a compound engine such as the turbo-ramjet could be utilized. Supersonic or subsonic combustion might be employed in the ramjet. Third, a highly complex structure will be required in order to contain the liquid hydrogen at a temperature of approximately −420°F and to sustain temperatures which may vary from 1500° to 2500°F on the outside of the aircraft depending on the Mach number, altitude, and the area of the aircraft involved. Both passive insulated structures as well as active cooling systems are under consideration for the hypersonic aircraft. Fourth, depending on the degree of optimism involved in the aerodynamic, structural, and propulsive assumptions made, the hypersonic cruise aircraft can be made to look either attractive or unattractive.

Because of uncertainties in the basic engineering information necessary for hypersonic aircraft design, the directions of future research and development are aimed primarily at establishing a basic quantitative technology in all of the technological areas involved: basic fluid mechanics, configuration aerodynamics, engine-airframe integration, propulsion systems, materials evaluation, structural concepts, and flutter. Finally, there is a need for novel and imaginative new design concepts in the hypersonic aircraft activity.

Some examples of hypersonic aircraft research are indicated in the next three figures. A hypersonic aircraft configuration concept is illustrated in Fig. 33. The configuration has been under study by both industry and the various Centers of NASA. A question might be asked as to whether the configuration shown in Fig. 33 will bear any more resemblance to actual aircraft which may finally evolve than the 1947 supersonic transport concept shown in Fig. 28 bears to the presently proposed United States supersonic transport design.

A mockup of the hypersonic research engine, being developed by the Garrett Corporation under contract to NASA, is shown in the photograph presented in Fig. 34. The research engine was originally designed to be flown in the real environment of hypersonic flight on the X-15 research airplane. The engine is designed to operate over the Mach number range from 4 to nearly 8 and to utilize both subsonic and supersonic combustion. The fuel used is hydrogen and the structure is regeneratively cooled. The research engine had as one of its major purposes the experimental determination of what can actually be achieved by a hypersonic air-breathing propulsion system in the real environment and over a range of conditions appropriate to flight of an actual aircraft. The termination of the X-15 research airplane program, however, will prevent the actual flying of the research engine. Nevertheless, tests will be made of the engine in ground facilities for a variety of conditions. A great deal has been learned from the Hypersonic Research Engine project which has again shown that a time comes in any technological evolution when actual hardware must be designed and built in order to determine what is really possible as compared with what paper studies seem to show is possible.

A very complex, insulated, hypersonic structural model is shown in Fig. 35 mounted in the NASA Langley 8-foot high-temperature structures tunnel. Studies of this model are intended to advance the technology of aircraft fuselages containing hydrogen fuel tankage.

Technology development is proceeding in the hypersonic area in all the technical disciplines. The rate of progress, however, has been relatively slow because the resources committed to the hypersonic program have not been large. It seems evident that at some time in the future, the development of an air-breathing hypersonic research aircraft, or demonstrator aircraft of some type, must be undertaken.

Concluding Remarks

Aeronautical research in the decade following World War II was devoted to achieving higher speeds, higher altitudes, and longer range. Great and spectacular technological progress was made in these directions. The technological advancements which have been discussed herein have concentrated primarily on such matters as efficiency, safety, dependability, economics, convenience, and social acceptability. The advances to be achieved in these areas may not be as spectacular as those advances made in the 1940's and 1950's; nevertheless, the technological challenge and the importance of the results to be achieved are every bit as great.

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