In introducing the Lester D. Gardner Lecture for 1968, it is proper that I say something first about the man whom this lecture honors, Major Lester D. Gardner.

Major Gardner was graduated from MIT with a BS in 1898. After a year of graduate study in Administrative Law at Columbia Univ., he was employed successively on the editorial staffs of the New York Times, New York Tribune, New York Sun, Collier’s magazine, and other publications. In 1915, with the encouragement of Glenn L. Martin, Grover Loening, and Jerome C. Huntzeker, he organized the Gardner Publishing Company, which started Aviation, Who’s Who in American Aeronautics, and The Rubber Age.

In WW I, Gardner became a lieutenant in the Aviation Section of the Signal Corps, organized 89 aero-squadrons for overseas service, and served on the Control Board of the U.S. Air Service.

It was in 1932 that Gardner and several friends who were leaders in American aviation organized the Institute of the Aeronautical Sciences. He was its executive officer for 14 years.

Our lecturer, Arthur Raymond, was born March 24, 1899, in Boston, Mass., and grew up in Pasadena, Calif. He was graduated from Harvard in 1920, and in 1921 he received an MS in aeronautical engineering from MIT.

Returning to California, Raymond first went into the hotel business with his father, but took courses at Caltech and in 1925 accepted a shop job with the Douglas Aircraft Co. in Santa Monica. A few weeks later, Donald Douglas, needing a good man in stress analysis, asked Edward P. Warner at MIT to recommend his best student in that field. Warner wired back: “He is Arthur Raymond. He works in your shop.”

Douglas immediately transferred Raymond to the task of analyzing stresses in a pontoon strut in Douglas’ engineering department, then consisting of about a dozen engineers including Douglas himself. In 1927 Raymond was promoted to Assistant Chief Engineer, and became Chief Engineer in 1936.

Under Raymond, an impressive list of aircraft was developed, including the DC series from DC-1 to the jet-powered DC-8, as well as missiles and experimental planes. In 1939 he became vice-president in charge of engineering at Douglas.

From 1927 until 1934 Raymond also served as Assistant Professor of Aeronautics at Caltech, and there followed closely the wind-tunnel tests of the DC-2 transport and other outstanding aircraft.

Apart from aircraft developments associated with his company, Raymond has given many other valuable services to aviation. During WW II he undertook studies for the Secretary of War relating to the bombing of Japan. In 1954 he was appointed a member of the Kelly Committee to study defense against atomic attack.

Raymond has served as a member of DOD’s Steering Group for the Technical Advisory Panel of Aeronautics; from 1946-56, as a member of NACA; and a member of the USAF Space Systems Division Advisory Group.

Following retirement in 1960, he has served as a consultant and member of the Research Council of RAND and as a trustee of Aerospace Corp. For the past five years he has been a special consultant to James E. Webb, NASA Administrator.

He is a past President and Honorary Fellow of the Institute of the Aeronautical Sciences (now the AIAA), a member of NAS, and a founding member of NAE.

RAYMOND BISLINGHOFF, MIT

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Toward Aircraft of the 1980s

Aeronautical and socio-economic issues, once seen together, give new perspective to a field in the midst of a neoclassic period, but verging on a Wellsian era.

By GEORGE N. CHATHAM
NASA Headquarters
The aviation industry has emerged from a period in which survival, not service, was the dominant concern. Now, at a time when the industry is not only healthy but expanding at a maximum rate, there are claims that aeronautics has not fulfilled its earlier promises in transportation—that its technology lags and that the aviation industry may soon choke itself in the tangle of its growth.

In this projection of the aeronautical environment of the 1980 period, the reasons for these criticisms will be examined. Designs for the near future and early 1970s are seen as products of successful trends of the past, continuing for a time on the impetus of success, although new conditions can be foreseen which will speed their obsolescence. Designs of the 1980s are far enough into the future for these new conditions to have their effect. We will examine these new conditions. Designs of the 1980s will be projected as a response to the demands of the socio-economic environment.

The Promise of Air Transportation

Air transportation promises freedom from the circumspect pathways imposed by the Earth's topography. It promises direct travel between any two points regardless of the surface barriers between them. It promises channels of transport with complete freedom from the arduous tasks and massive investment in time and money that would otherwise be required in preparing a surface connection.

Early prophets of aeronautics, such as Jules Verne and H. G. Wells, applied this promise to its fullest extent. Their aerial vehicles could provide transportation to any desired point on Earth. They needed no prepared runways or airports to land—hence, were free of all surface restraints and consequently, had no problems of air-terminal congestion.

The distinction between these ideal vehicles and the ones we have today is simply a matter of power. Neither Verne nor Wells visualized the prospect of flight evolving as power became available. They both built their vehicles around sources of unlimited power.

Flight to them was therefore a matter of using enough power to support a vehicle and applying additional power to move it forward. Flight to us is still primarily a byproduct of forward velocity. By applying power to gain forward speed, we can generate lift with wings.

Through more than 60 years of development, forward speed and flight have become almost synonymous. Whereas forward speed was originally only a means to an end—a device which permitted flight with limited power—forward speed rapidly became an end in itself.

When its wheels touch the runway, an airplane is still in flight. At that instant, a machine designed to operate in the open expanse of the sky must perform on the ground with the stability and certainty of a well-designed racing car. At touchdown the speed it needed to sustain flight becomes a liability, a quantity of energy which must be dissipated before the wings will transfer the weight of the plane to the wheels. At touchdown the fate of the airplane rests on the outcome of a race to use up its own momentum before it uses up the available runway.

The modern air transport could neither take off nor land without the runway. The runway is as much a part of the flight system as the airplane itself. Consequently, the modern airplane can use only a small part of the potential three-dimensional freedom of flight. It is constrained to routes which terminate on suitable landing fields. For example, only 5% of the existing airports are large enough to receive jet airliners. Aircraft of sufficient size that require paved runways are restricted to about 21% of the nation's 9490 airports.

Only the lighter general-aviation aircraft have the full 9490 options for destination. Commercial air industry and general aviation are both growing at accelerating rates. But the path of general aviation tends to keep its flexibility, whereas the path of the air carriers heads rapidly toward higher congestion.

The Divergent Paths of General Aviation and the Air Transport Industry

Both more aircraft and more airports characterize the growth of general aviation. The emphasis has been on point-to-point convenience—a geographic base which broadens to match a rising level of activity.

Air-carrier development shows an opposite trend. Growth here emphasizes ever higher use of existing airports. Fleet size was forestalled for a while by the use of larger and faster aircraft. In the decade beginning in 1958, revenue and load capacity doubled while
the number of aircraft and number of operations has not changed significantly.

The higher efficiency of the larger transports plus the rising market brought sudden prosperity to the industry. Profits were a new sensation, and the trend that brought it was understandably pursued. Airplanes on order have doubled and tripled the payload capacity of those now flying. And now, the fleet is growing numerically as well.

As aircraft grow larger and heavier, they find fewer places they can land. New airports of a size adequate for large transports seldom appear. Instead, runways on older airports are lengthened, but at a pace far slower than the growth rate of aerial service. The result is an ever-increasing concentration of service. Thirty-nine airports accounted for two-thirds of all passenger traffic in 1964.

Traffic saturation in the air and on the ground has begun to slow service and cut profits. The Air Transport Association estimates that delays due to congestion cost the industry $28 million at the 23 major "hub" airports in 1966. Success has accelerated the industry into a cul-de-sac. Nady.

Airplane and Airport—An Uncoupled System

Although the airplane and the airport are parts of the same system, their development is not spurred by the same forces. The public air terminals emerge tortuously from a matrix of municipal and national funding, bond sales, legal involvements, and ever higher land costs. Already formidable construction and maintenance costs make so much as a lengthened runway an issue filled with controversy. Terminal development at best is tedious and uncertain. In contrast, the aerial component of the system can and is responding aggressively to an insatiable public demand — proceeding with confidence that more and longer runways will be provided — proceeding down a technological path in which each advancement in the aerial part of the air-ground system increases the required investment in the landing facilities.

Growing Government Concern about Transportation

The long concern of the government over the growing congestion, rising investment requirements, and ineffectiveness of all transportation networks brought a beginning of corrective action at the national level in 1967. The Department of Transportation (DOT) was established. Numerous Congressional hearings which preceded and followed the establishment of DOT served to expose the status and problems confronting the nation's public transportation systems.

National transportation was found to be a fractionated conglomerate of competitive entities. The modes, and systems within each mode, had developed historically as competitive enterprises. Although legislative control of public carriers was well established, it pertained to each mode separately and did not examine their interdependence. Systems analysis, an old concept, but one which had never before been applied to a public service, suddenly became a byword. Slowly, the concept of studying the interdependence of system elements, the essence of systems analysis, opened a new perspective.

Innumerable studies, sponsored at the national level, confirmed repeatedly certain main points:

- Transportation determines to a major extent how well the nation can put its resources to use. Transportation services tie its economic regions together. The effectiveness of these services determines the extent to which economic regions must exist as semi-independent provincial entities or may act in a mutually complementary way.

- Historically, transportation systems have shown the capacity to improve themselves—the more-effective solutions surviving and the less-able systems vanishing—a kind of Darwinism. However, the development of the nation is proceeding too fast to leave transportation so gross a "natural selection." Transportation systems have become a factor of such importance that they now pace continued national development.

These studies, in general, repeated certain recommendations which have formed the philosophy for broadening the government role in national transportation. In essence they suggested that—

—existing transportation systems must be integrated to the extent that one mode can complement another;

—technology and innovations should be sought and promoted;

—guidance and active participation at a national level is required to avoid the pitfalls of random growth.
Aeronautics Examined as a National System

In May 1966, the Senate Committee on Aeronautical and Space Sciences released its now famous Document 90-1, a staff report called "Policy Planning for Aeronautical Research and Development." An historical compendium as well as a critique of aeronautics in the U.S., this document precipitated a fundamental change in the status of aeronautics as a national asset. The document raised many questions which were further explored in Committee hearings early the following year.

In essence, all facets of aeronautics were challenged. Why had civil aeronautics developed in the technological shadow of military aeronautics? Why had the technological gap between civil and military aeronautics grown larger over the last 15 years? What is the national policy toward the field of aeronautics? Were the people in the field aware of the socio-economic role of aeronautics? The gist of the examination revealed that:

- Research and development for civil aeronautics has no central planning or forecasting mechanism.
- Research and development for civil aeronautics has slipped technologically as a result of a shift in military research toward missiles and highly specialized aircraft.
- Aircraft manufacturers served aircraft users and would not undertake major research and development for advanced aircraft without user endorsement.
- The air-carrier industry was reluctant to gamble with innovations in its present system, which was now paying off.
- The national air-transportation services were facing a traffic-saturation crisis and would soon be unable to provide the service the nation required.
- Military aviation has a well-developed system leading in an orderly fashion through planning, research, and development to useful production of vehicles for specific military missions.
- Air transportation took its place along with all other commercial carriers as one among other independent networks, each of which developed in competition with the rest, serious attempts to coordinate outmoded schedules or service.

The Senate Committee had no intention of providing solutions to any of these issues, only of exposing and underscoring the importance of solving them. But, for the first time, research and development in civil aeronautics gained real recognition as an area demanding timely progress for the national welfare. The nation's development patterns were seen as inextricably related to and dependent upon the health and growth of a civil aeronautical system.

The implications of this new recognition profoundly affect the future of aeronautics. The financial success of recent years appears more of an expected consequence of economic change and development than a hallmark of business perspicacity. Yet, as startling as the success has been, it is clearly only a token of what is to come.

Future Systems—The Selection of a Transportation Mode

Only four primary considerations affect what mode of transportation will be selected for a new system:

1. Initial outlay. The first costs of the equipment and terminals, and the cost and preparation of the right of way. The right-of-way costs dominate the picture in all modes except air.

2. Time to completion. Again, except in air transportation, preparation of the right of way dominates all other considerations.

3. Flexibility of routing and growth potential. Automotive traffic has a potential flexibility equal to the entire network of available roadways. However, its actual flexibility decreases sharply with the number of cars in use. Streets, essentially one-dimensional pathways, can easily get overloaded. Time of transit becomes a consideration of more importance than distance traveled. Surface and sub-surface rail systems are also one-dimensional. The isolation of their pathways allows high usage with relatively small congestion. However, their rights of way are rigidly fixed—the most limited of all modes. Only air-transport routes can be changed without concern for loss or new construction of rights of way.

4. Operation costs and maintenance. Aircraft cost more to operate and maintain than surface vehicles. The higher costs are reflected in higher passenger fares and freight rates. However, time

For the first time, research and development in civil aeronautics gained real recognition as an area demanding timely progress for the national welfare.
is also a valuable commodity; and time saved offsets the higher rates of air transportation. In 1963 the airlines passed the passenger-mile total for railroads and inter-city buses combined. Many firms find the higher freight costs of air cargo more than offset by the closer scheduling and reduced inventory made possible by air shipments. At present, air cargo is growing 25% per year, a slightly higher rate than the increase in passenger traffic. In fact, air-cargo tonnage exceeded passenger tonnage in 1967. The DOC of new aircraft, e.g., the C-5, are calculated to be under 4-1/2¢ per ton mile—a rate competitive with surface trucking.

A quick survey of these points is enough to show that air transportation holds the potential of dominating all other modes.

A Quick Look at Fares from a Systems Viewpoint

The costs of airports and navigation and traffic-control systems are not paid for by airline ticket purchases or air-freight billings. Gasoline taxes do not cover the costs of surface transportation facilities. The user pays a vehicular fare (or total vehicular cost in the case of the automobile), but the rest of his transportation costs are paid from his general taxation.

It is a little early for a systems analysis to contrast a new highway with an air terminal in terms of the tax levy. However, there are some obvious points favoring this approach. As the use of all modes of transportation increase, the vehicular ton-mile costs decline; but the general tax burden related to the maintenance or new construction of surface facilities steadily rises. It seems inevitable that total-cost analyses will be made in the future. Such an analysis would weigh the required service against the total user costs—that is, cost in time and dollars per vehicular ton-mile plus the cost of related surface facilities included in general tax burden.

Applying this total-cost concept to a more limited example will further illustrate the implications. Economy in air transportation rises with increased vehicular payload. Larger and heavier conventional airplanes require longer and stronger runways. The higher cost of these runways, however, is not a significant factor in the vehicular operation cost, although landing fees couple them to a degree. In the quest for ever-lowering operating costs, air transportation therefore has become a high-density commutation between a relative handful of major airports.

One of the issues raised in the hearings of the Senate Committee on Aeronautical and Space Sciences in February 1967 pertained to the cautious view most air carriers took of VTOL aircraft.

It is an obvious argument that if present aircraft had VTOL capability there would already be enough landing sites to solve the traffic crisis. One common argument against the development of the VTOL was higher fuel consumption—perhaps 25% higher than conventional airplanes. If all aircraft had consumed 25% more fuel in 1967, the air-carrier fuel bill would have been about $100 million higher.

In terms of the total cost, however, this sum would be a fantastic bargain as an entree for commercial service to even a portion of the nation's 9000 minor airports. FAA estimates that adequate conventional airports would require $6 billion by 1975—nearly a billion dollars a year!

Of course, there are more complex reasons for the slow development of VTOL and STOL technology. But this illustration makes the point that, in a total-cost analysis, the ground-support and vehicle-component costs must be considered together, not left isolated. In this case, higher fuel costs and the use of smaller existing airports would prove far less expensive than a growth pattern requiring more large air-terminals.

Aeronautical Trends for the Future

Begin to Form

By 1970, the United States will have 13 airports capable of accepting the "jumbo" jets. According to the Air Transport Association this number will grow to 23 by 1973. FAA made aviation forecasts through 1979, based on growth of the present systems (Aviation Forecasts—Fiscal Years 1968-79, DOT/FAA Office of Policy Development, Economics Division). It foresees the number of passenger airplanes rising by 170% and the number of enplane-ments rising by 350%. These figures assume transports twice the present size, on the average, by 1979.

The FAA forecasts do not discuss the ground- and air-saturation problems. However, it is clear that
From Aircraft of the 1980's, by George E. Chatham

p27 - 1 question statement: industry healthy & expanding at mod. rate.

- Ma-Dog. merger
- VNA-Rockwell merger
- NAR-Aero Commander merger

I agree that technology lags.

- Boeing-SST dilemma
- FFX - poor showing
- Business Aircraft - still designed on 1935 basis, cost increases not as to other items autos, etc.

p28 - Airplane & airport - A series of facts - understood

- Grow, grow, concern - statements OK for overall transportation system but certainly not for air system in which only 2-10% of population use.

p32 - Environment - Too optimistic for VTOL

I see no end in sight for high-speed-honing craft. - Large airports may stabilize but not diminish

1980 too early for 200 pass VTOL commercial
The trend toward suburban and inner-city V/STOL terminals will become a major movement throughout the 1970s...because alternative solutions to filling transportation requirements are too costly, too difficult, or just not available.
probably not into the growing air-freight service of conventional airplanes.

—the placement of orders for machines capable of handling up to 200 passengers. These machines will be of two types—high-speed inter-city vehicles and low-speed "buses" for suburban and inner-city commutation.

The Environment
The environment of the 1980s for aircraft systems may be anticipated in a gross way from trends already visible:

Total system merits vs. total system costs will be a dominating consideration in new developments. Methods of reducing vehicular operating costs at the expense of multiplying ground-service costs will be rejected.

Civil and military aeronautics will share technology but will have independent R&D cycles.

Central planning at the national level for national and international requirements (aircraft market studies) will be a well-established routine.

Point - to - point transportation will be a feasible goal toward which the greatest step will have been taken—namely, the breaking of aircraft dependency on long runways.

Aeronautics will dominate the field of transportation as the most cost-effective total system (aerial plus ground support) for the movement of goods and people.

The end of the high-speed-landing aircraft will be in sight. Passenger service will migrate rapidly toward VTOL craft. Conventional airports and high-speed-landing vehicles will be left to finish their era through air-cargo services.

Large airports will begin to diminish in size and decline in number as air traffic shifts toward VTOL and city growth demands their acreage.

All-weather operation in instrumented VTOL craft will be routine.

Air-traffic area control as well as local control will be largely converted to coupled computer systems. The human operator, thus released from this unnerving routine, will be able to monitor the system and handle unusual events.

Aerial traffic within terminal control zones will also be handled by automatic systems from entry into the zone through the completed landing.

The aeronautical community consists of various distinct groups, each with special interests and goals:

1. User groups
   a. The military
   b. The air-transport industry
   c. General aviation

2. Research and development groups
   a. The military
   b. The manufacturers
   c. Civilian government agencies

3. Long-range planners
   a. The military
   b. The manufacturers
   c. Civilian government agencies

Long-range planning in civil aviation is at present more of a newly recognized obligation than an established routine. Although the nine groups listed have certain goals in common, they have other goals quite distinct. Since goals are more enduring than technology, they are handy guidelines to predict the directions of technical development over a long period. The goals can be weighted to some extent because the groups originating them serve somewhat different roles in the development of the security of the nation.

Finally, there is the matter of innovation. We expect improvements with time, and we know worthy innovations may gather dust on a shelf or may immediately overwhelm an area of technology. But about all that innovations in common is the surprise they cause when they appear.

Goals in 1980

All user groups will seek point-to-point flexibility—minimum dependence on surface facilities.

The military, the largest investor in helicopters and VTOL research and development, has already begun to reduce its dependency on super runways. The F-111, for example, will use about 2000 ft of runway to land and requires no drag chute. (Older operational fighter-bombers capable of supersonic speed require over a mile of concrete even with a drag chute. The C-5 also has short-runway capability. This trend toward elimination of the runway means development of air-logistic support and strike aircraft that can operate without regard to surface facilities.

By 1980 the air-transport industry will apply the true "air bus," 75-200-passenger VTOL craft, to expand its geographic base rapidly. The trends toward this today may be seen in the moves of air carriers to underwrite helicopter feeder services, in STOL-route analysis studies, and in the fact that nearly all major aircraft com
Great emphasis will be placed on simplicity of operation and safety, this being essential to the development of the mass market.
In supporting the weight of an aircraft against gravity, the wings deliver a thrust equal to the aircraft's weight; but in doing so, they consume very little of the available power.

The total thrust of the engines of a Boeing 707, if directed against gravity, would not lift a fourth of this plane's weight. By moving the airplane parallel to the pull of gravity, however, the engines can transfer a portion of their energy to the wings, allowing them to disturb a great mass of air. Because of their shape, the wings produce a net downward vector in the disturbed air. By the time the aircraft reaches takeoff speed, its wings have generated a pressure gradient of about 1/20th of an atmosphere—enough to cause a slow downward movement of an enormous mass of air. The continuous momentum of this flowing air provides enough reaction to lift this 150-ton plane easily.

The design challenge of the wings is not in creating a shape which provides the lift needed; the challenge is in preventing the wing from wasting energy as the speed rises above that needed to remain airborne—i.e., to retain a favorable ratio of lift to drag.

An aircraft lands at the lowest speed permitting it to maintain a stable flying attitude. As speed increases beyond this minimum, less and less of the wing area is needed to support the plane. As surplus
The relegation of the wing to the role of an ancillary support system, in contrast to the dominating role it now holds, requires more than improvement in engine systems.

The Engine—An Active Thrust System

In 1933, a 2500-hp Fiat A.S.-6 engine powered the Macchi M.C. 72 seaplane to a speed of 423.57 mph. The following year, the engine was modified and rated at 3100 hp. The additional 600 hp along with certain airframe changes added 17 mph to this speed. With this demonstration, the propeller and reciprocating engine system approached the upper limit of its performance capability. Over the next 10 years, steady improvements in the art boosted this record only slightly. Significant gains had to await the jet engine's development.

The low yield of 17 mph for the additional 600 hp should have been expected, for thrust requirements rise exponentially with speed. The total power required to produce enough thrust for this speed is of more concern. There are two general considerations:

1. Moving from the wing, a passive thrust device, into the regime of the engine as an active thrust device, requires a machine of manageable size and weight—a device much smaller than a wing.

2. The mass of air into which the machine can transfer energy is proportionately reduced. As the table on page 34 illustrates, a reduction in reaction mass brings an exponential increase in energy for a given thrust value.

One design criterion for the aircraft engine emerges: the energy needed for a given thrust falls exponentially with the increase of the air mass receiving the energy.

The reciprocating-engine-and-
propeller system puts its available energy into a far greater mass of air than the higher-performance jet engines. For a given thrust value, the propeller/engine system therefore proves proportionately more economical. However, the upper speed of the propeller is limited. The propeller loses efficiency if part of its blade operates above the speed of sound. Although studies were initiated on propellers designed to operate supersonically, the appearance of the jet engine cut them short.

The Early Jet Engines

The limitations of the piston/propeller system were known long before the record flight of the Macchi M.C. 72, and these were accepted by most of the aeronautical world as the realm within which they would have to live. But there were a few who did not accept these limits.

The search for ways to augment or supplant the power of the piston engine began in Italy as early as 1930. The Italian engineer, Campini, felt that if the slipstream of the propeller could be heated, the air would expand and increase in velocity. Thus, the kinetic energy cost would be high, but thrust values beyond the potential of the propeller proper could be attained. Campini founded his own research firm to pursue the idea in 1931. His association with the Caproni firm led to the development of several experimental aircraft. The most advanced of these, the Caproni N.1 (referenced in Jane’s as the Caproni Campini CC-2), flew in 1940. The N.1, like the preceding Campini efforts, used a conventional reciprocating engine as a source of primary air. Burning fuel warmed the air before it was finally discharged. The N.1 flew poorly, and subsequently Campini proposals along this same approach were never built.

A German, Ernst Heinkel, and an Englishman, Frank Whittle, took another and more successful route to the objective of adding heat as well as kinetic energy to the reaction mass of the aircraft engine. It is probable that both Whittle and Heinkel knew of Campini’s work. However, it’s quite clear that neither Heinkel nor Whittle knew of each other’s progress. Both pursued the gas-turbine jet engine. The gas turbine was far from a new concept as a source of power. Their application, however, was new. The gas turbine was to furnish power by means of its own exhaust.

Heinkel’s interest in more potent powerplants than the piston engine extended back into the mid-1930s. He flew the first successful rocket-powered aircraft in 1937, the He 112. His turbojet engine was flying as an auxiliary power unit in 1938. In 1939, he flew the world’s first successful jet-propelled aircraft, the He 178.

Whittle’s progress with his turbojet paralleled but followed Heinkel’s. Whittle watched the first flight of his engine in a Gloster E-28 in 1941.

From that point forward, developments were extremely rapid. By 1942, the United States had begun testing the Bell XP-59A powered by General Electric engines based on Whittle’s design, and Messerschmidt completed the flight tests of the twin-jet fighter, the Me 262. However, the major impact of the jet engine was on aeronautics, not on the war. The war ended before the jet-powered aircraft could do much more than frighten the Allied Air Command.

Diverging Developments: Speed Vs. Utility

In aeronautics the turbojet engine pushed back three of the main barriers to propulsion systems:

- Its turbine could operate subsonically and still produce enough power to drive an aircraft to supersonic speed.
- Its principles provided a method of converting fuel into power at a rate far beyond any conceivable reciprocating engine.
- It opened the door to applying the high power of the gas turbine as a drive for high-thrust systems, i.e., conventional propellers and auxiliary fans.

The two objectives which have always been with us—the pursuit of speed, and the achievement of higher utility—still are with us. In recent years, the rising importance of the aircraft for civil applications has led to a stress on developments for utility. There is every reason to expect that utility, not speed, will be the major impetus for development through the next two decades.

The proliferation of all types and sizes of gas-turbine thrust systems is to be expected. Some primary directions for development:

- Toward larger subsonic turbojet engines which stress higher thrust for fuel consumed. Some elevation in operating temperatures is to be expected, but the gains in economy are primarily a matter of higher bypass ratios and use of...
fewer but larger engines.

- Toward smaller turbo-propeller engines of sizes suitable for the lighter general-aviation aircraft.
- Toward high-static-thrust vertical-lift engines, considered a permanent part of the airframe. They will be designed for the highest possible thrust-to-weight ratio. Their single operating regime requires short, intermittent rather than continuous periods of operation. Their construction can therefore be extremely simple—built for discarding rather than repair.
- Toward thrust-conversion systems in which a turbojet may be used either as a primary propulsion system or as a source of high-energy gas to drive secondary thrust devices, e.g., fans built into wings, pods, or side plenums.

Fans in wings or side plenums offer an appealing solution to VTOL flight. They are light in weight and can be totally shielded from the airstream when not in use.

New aircraft using the enclosed fans for VTOL take the path of least change in design. They have essentially the same shape, speed, and power levels as present conventional aircraft. On an average, commercial jet aircraft have an engine thrust level equal to 23% of takeoff weight. When this power is applied through lift fans, the thrust can be amplified to the level desired—e.g., multiplied by a factor of 7 or 8—and will lift the aircraft as well as provide an adequate safety margin.

Of the four listed directions for development, only the latter, the lift-fan system powered by diverted engine exhaust, is still highly experimental. As mentioned elsewhere, rapid exploitation of this concept is paced by two other needed developments—powered stability and control methods. Adequate solutions to all of these problems should be expected by the mid-1970s. The use of power-dependent lift, stability, and control systems will become common practice in commercial aircraft developed in the 1980s.

Without question, speed has been an end in itself to those who have worked for it. However, to the field of aeronautics, as mentioned earlier, the speed itself has been less important than the developments which made it possible.

If one seeks speeds beyond the state of the art, he also seeks thrust levels beyond the state of the art. He seeks refinements and new principles in aerodynamics, new tolerance levels, and strengths in materials. He must measure new levels of stress, heat, and velocity. A higher speed is a single objective, the achievement of which requires that the entire field be advanced.

Until the first space flight, each new speed record represented the highest absolute velocity ever achieved by man and equipment. The upper speed limits of atmospheric flight were uncertain and always open to challenge. With space flight, however, the aerodynamicist suddenly had data from both ends of the speed spectrum. Higher speeds in atmospheric flight could then be regarded as filling in the gap between present performance and the orbital velocity.

The challenge to propulsion systems can be simply put: As speed advances, the production of thrust becomes increasingly difficult. The reaction mass an engine can produce is relatively constant, but the energy which must be added to it rises exponentially. Since the fuel is the source for energy, ways are sought to use fuel at higher rates and higher operating temperatures.

At a speed close to the upper limit of the propeller/engine system, the turbojet enters its best performance regime. At about Mach 3, ram-air temperatures begin to climb, decreasing the amount of energy which can be added. At this point, the ramjet enters its best operating regime. The ramjet is essentially an open tube. Fuel burned inside the tube heats and expands the air passing through, causing it to leave at a velocity higher than it entered. It is simple and light. Large ramjets have been proposed, theoretically able to reach speeds of Mach 12 or higher. These, however, are no longer simple tubes. The air would enter an annular space between a large outer sleeve and a football-shaped body serving primarily as a fuel tank.

The ramjet is the simplest of all internal-combustion engines. For speeds above Mach 5 or 6, however, an even simpler approach has been proposed—the external-combustion engine, or the “surface-burning” engine. In this case, the exterior of the airframe serves as the engine wall.

The airframe in the “surface-burning” engine, as in the large ramjet, is essentially a fuel tank. The aircraft releases fuel into the air. It is ignited as it fills a region aft of a wedge-shaped fuselage. Burning there, it increases the pressure behind the shock wave left by the fuselage, so increasing thrust and lift. Theoretically, this mode of propulsion can produce speeds beyond Mach 15.

Each engine scheme has a speed range in which it works best. The ramjet and the “surface-burning”
Engines require high speed to work at all. Obviously, a useful aircraft employing the ramjet or "surface-burning" system would also have to carry engines for the lower-speed portions of its flight.

Beginning with the turbojet, each engine, operating efficiently in its particular speed regime, burns fuel at a rate which is at least one order of magnitude higher than an engine in the speed regime below it in order to get the same thrust. If we duplicated the thrust of the surface-burning engine with a rocket, fuel consumption would go up by yet another order of magnitude. The extra fuel, in this case, is the oxidizer which the rocket must carry but which all the preceding systems extracted from the air. However, in the quest to convert the fuel carried by the vehicle into energy at the fastest useful rate, the rocket has no peer.

In the rocket and, to a lesser extent, in the surface-burning engine and the ramjet, we have systems which can produce power at rates that must be likened to a "controlled explosion." (The Saturn-V rocket engines use fuel at the rate of 15 tons/sec.) Of these three systems, only the rocket has reached a high degree of development. Its great power can be controlled to a fine degree, making it an engine system of unparalleled merit for research in high-speed flight.

The extensive application of the rocket engine will therefore be a vital tool toward the achievement of hypersonic flight. Research in aerodynamics, structures and materials, as well as airbreathing-engine design, will apply the rocket engine as a means of reaching test velocities. At the present rate of development, however, a useful hypersonic vehicle will probably not become available before the mid-1980s.

A discussion of fuel-using devices alone does not cover the area of propulsion. It is clear that the art of releasing energy from chemical fuel is farther advanced than the development of more-potent energy sources for aircraft. In examining engine and fuel systems like the rocket and ramjet, one begins to look at fuel in a different light.

Except in research vehicles, which require only a short burst of power, the fuel supply dominates all other considerations. Indeed, were fuel to be used at a lesser rate than a "controlled explosion," its energy would be entirely expended in moving its own mass. The aircraft becomes, in effect, a guided fuel tank. Even conventional turbojet transports, such as the DC-8, demand energy levels corresponding to a fuel consumption of 5 lb/sec. Although this is a miserly rate compared to the ramjet's at equal thrust, fuel places a burden on the conventional aircraft equal to almost half its total weight.

The sheer bulk of fuel that must be carried by the larger aircraft becomes awesome. The normal fuel load of the C-5, for example, would spread an inch deep over an area of two acres.

The larger aircraft, however, provide a ton/mile economy that smaller aircraft can not match. The future for larger aircraft is attractive not only for this reason but also because they hold the key to the growing problem posed by the volume of chemical fuel.

The Nuclear Future

The C-5 borders the size range where nuclear power becomes practical for aircraft. The nuclear powerplant, fully shielded and strengthened against bursting in the event of a crash, has a high fixed weight—about the weight of the fuel carried by a C-5—but this weight remains almost constant, even for power-output levels adequate to drive aircraft many times the weight of the C-5.

Even at low efficiency, the cost of nuclear power falls far below the cost of using chemical fuels. Power becomes so plentiful that it can be wasted. Airplanes may be made heavier and wings may be made shorter—less efficient but stronger. Stay time in the air ceases to be a critical balance between trip length and fuel supply. The nuclear-plant can be fueled for a large fraction or even the total life of the airframe. Stay time in the air is entirely a matter of convenience or crew rotation, not fuel supply.

With nuclear-powered aircraft, the aeronautical engineer achieves the performance potential of the fictional airships of Jules Verne and H. G. Wells.

Developing nuclear-powered aircraft, however, will be costly, and therefore keyed to the economic requirement for planes larger than the C-5.

One may expect the traffic in air freight to require civilian versions of the C-5 by the mid-1970s. By the late 1970s aircraft larger than the C-5 will be economically desirable. By the early 1980s, the development of the nuclear-powered aircraft should be underway. Toward the end of that decade, their economy should be established, making the use of chemical or fossil fuels economically unfeasible on aircraft in the size range of the C-5.

Developments which could place nuclear power at the disposal of smaller aircraft are not in sight at this time. It would be unwise, however, to eliminate this possibility. Time has a way of reversing the odds against developments in the nuclear field; or for that matter, in any field, as we move toward aircraft of the 1980s.
Major Lester Gardner was the father of the Institute of the Aeronautical Sciences; a major component of what has now become the American Institute of Aeronautics and Astronautics, the most comprehensive technical society in its field in this country. He was a close friend of mine, a unique and lovable character, and I am pleased and honored to join those who have preceded me in giving this lecture, established by him and bearing his name.

Obviously, I cannot hope, without exceeding your patience and my allotted time, to cover the history of air transportation except in a very fragmentary way. I realize there will be many omissions, and if my remarks are superficial or unduly personal at times, please forgive me.

Actually, in discussing the subject of air transportation, it is not necessary to go any farther back than the 1920s. There was very little before that.

When I got my Master’s degree in aeronautical engineering at MIT in 1921, the aviation industry in this country was just beginning to recover from the cutback to near zero which occurred in 1918, at the end of World War I. At MIT, the aeronautical courses were given in the Department of Naval Architecture. Most of the students were officers of the Army and Navy, detailed to come back to school for advanced work after several years in the service. Our professor, Edward P. Warner, was scarcely any older than most of them.

As you may know, he went on to a distinguished career on the Civil Aeronautical Authority, as Assistant Secretary of the Navy for Aeronautics, and ultimately for 10 years as President of the Council of the International Civil Aviation Organization, with headquarters in Montreal.

Until 1925, when I joined Douglas, I found no opportunity to work in the field for which I had been trained. Then the Douglas World Cruisers had just completed their spasmodic flight around the globe. This had taken more than six months. Four planes started; two were lost en route; three finished, one a replacement. But they did serve to focus world attention on the possibilities of long-distance travel by air.

Douglas won a production order, shortly after I started there, for a single-engine, two-place Army observation biplane. It had wooden wings, a steel-tubing, truss-type cloth-covered body, and wire bracing throughout. For several years, this was its major product line. Employment was around 200, with a dozen or so in engineering. Mr. Douglas did detail design on the board, did stress analysis and weight estimation, handled sales (such as there were), and did his best to rustle up the payroll every week.

In 1927, Lindbergh flew the Atlantic in the Spirit of St. Louis, giving further impetus to public interest in air travel. Civil aviation began stirring.

Late in the 1920s, Douglas converted some of its observation planes into mail planes such as the M-1. These were used between Los Angeles and Salt Lake, with an occasional intrepid passenger sitting on the mail sacks. I recall that on one occasion a passenger got loose, so to speak; and in his enthusiasm over the beauties of flight on a moonlit night, started walking out on a wing, causing a hasty forced landing.

This was the era of the Ford and Fokker trimotors and the Boeing 247, the first metal-skin, bimotor, internally braced monoplane built for passenger use. But none of these was quite efficient enough, or carried enough payload a long enough distance, to make money; and the 247, in case of an engine failure, had marginal ceiling.

Still, the state of the art was advancing on many fronts. Almost simultaneously, it seemed, the all-metal, stressed-skin, cantilever monoplane superseded the externally braced biplane of wood, steel tubing, and fabric; adjustable-pitch metal propellers were introduced; the NACA’s low-drag cowl enclosure for engines was developed; and engine efficiency and reliability improved. We also learned how to install wing flaps to reduce landing speed or, what was more usual, to get faster cruising speeds with the same landing speed.

Just at the psychological moment came a request from TWA (then Transcontinental and Western Air), sent to several manufacturers, for 10 or more transport planes, built to meet a rather simple but farsighted specification. Shown on page 62, together with the specification, as received by Douglas in August of 1932, this letter became a major milestone in transport aviation.

The most critical requirement was that last pregnant sentence. It was written, and the specification was written, around a three-engine plane, because nobody thought it could be met with a two-engine plane flying with one engine dead.
But we thought it could. If we were right, the engine in the nose of the fuselage could be dispensed with, improving the pilot's environment considerably as regards vision, noise, dirt, and vibration, and making the plane much simpler.

So we decided to submit a bimotor, and I was detailed to go to New York to TWA—together with Douglas' general manager—to try and sell it. We traveled by train (significantly!) and I worked all the way refining weight and performance calculations.

Lindbergh was TWA's chief technical advisor. I spent several days with him in New York trying to convince him of something I'm afraid I wasn't completely convinced of myself—that we could build a two-engine plane to meet their specification for flight on one engine, a spec which finally took the form of calling for flight between any two stations on TWA's line with one engine out.

Anyway, we won the competition and I decided that I had better prove my confidence in air travel by flying home to Los Angeles via TWA, which I did in a Ford trimotor, stopping at the maintenance base in Kansas City for a few days to work out a longer and more definitive spec.

New York to Kansas City took all day, bumping along at low level, but I thought it was wonderful to leave the Atlantic Ocean in the morning and actually cross the Mississippi River before nightfall.

On a Ford trimotor, ventilating air for each passenger came in through an S-shaped ventilator, something like one on a boat, directly from the outside. We landed at Kansas City after a rainstorm and the airport was covered with puddles. As we touched down I got a liberal dose of muddy water directly in the face.

I spent several days with the TWA service and engineering groups getting a first-hand grasp of their problems and desires, then flew on to the West Coast and we started designing the DC-1.

I had for several years been moonlighting at Caltech, teaching airplane design. One of the first things I did, after returning to the factory, was to hire one of my students who had specialized in aerodynamics and performance estimation. You see, I was still worried about the single-engine-flight question. The student's name was Bailey Oswald.

During construction of the airplane, we also hired a former MIT student and airmail pilot, Eddie Allen, who had already established a reputation as a test pilot, and he and Oswald worked out on paper a concept of efficient high-altitude cruising flight which became routine in airline operation, but was then somewhat unorthodox.
The DC-1 finally met its performance guarantees—including a demonstration of single-engine flight over the highest segment on TWA’s route, Winslow to Albuquerque—and we all heaved a sigh of relief, because it would never have done so without a certain amount of luck. It was several thousand pounds overweight, but propeller and engine advances which occurred while it was being built pulled it through.

We had several problems with the DC-1, some fairly amusing in today’s perspective.

It nearly came to grief on its first flight because the engine carburetors had mistakenly been installed backward and the floats shut off fuel every time the pilot tried to climb.

The wing flaps and landing gear were hand-operated at first, and it took an unconscionably long time to lower them. In fact, experienced as Eddie Allen was, he made one belly landing.

We had problems with that landing gear. Its weight was counterbalanced by rubber bungees so that it could be raised manually; but this made it hard to lower, and it wouldn’t come down by itself. Once down, it had a tendency to come unlatched and collapse when weight was put on it. On one occasion, with several airline presidents and other dignitaries assembled on the field preparatory to taking a demonstration flight, the airplane, which was standing quietly on the ramp, suddenly squatted as the gear on one side folded up. That demonstration had to be postponed while we unbent a wing and propeller.

But these weaknesses were corrected and airline orders started coming in, for the DC-1 really did represent a step forward to within striking distance of having low-enough operating costs to be a moneymaker. It needed a bit more payload, so in the first production version, the DC-2, we lengthened the body and put in another row of seats; and in the second, the DC-3, we widened the body, making possible three seats abreast and even, if you didn’t mind being squeezed, four abreast.

The DC-3 hit the market at exactly the right time, and captured it. For years it really had no competitor.

The second half of the 1930s saw an enormous expansion of air-transport services and systems throughout the world. The market was there and the vehicle existed. At Douglas, it took us some time to realize the full extent of the revolution in travel that had been sparked by the DC-3. I remember the argument we had among ourselves as to whether to design the tooling for a total of 25 airplanes or to be courageous and design it for 50. We decided to be bold. Actually, we built 350 on that set of tooling and 350 more on a duplicate set, just to meet the commercial demand. Of course, the military demand created by the war of 1940-45 came along to augment this, and by that war’s end we had three factories turning out the airplane as fast as possible. Total production reached over 10,000; and subsequent to the war, many of the military version were put into civilian use. A good many of them are still there over 20 years later. A strange quirk is that recently several have been converted to combat use as gunships in Vietnam.

The truth is that the DC-3 literally never wears out as a whole. Only replaceable parts do, and the design is such that replacement is easy; for there are almost no heavy members or fittings deeply imbedded in the structure. I flew in one the other day that had logged over 80,000 hr and it looked literally as good as new. Of course, it had worn out several sets of engines, wheels, etc., and several skin plates had been changed, but it retained much of the original structure, equipment, and furnishings. I was astonished to hear that Douglas sold over $3 million worth of DC-3 spares as late as last year.

The DC-3 made travel by air much more comfortable than it had been. Thanks to Allen, Oswald, and others, it normally flew at higher alti-
tudes where the turbulence was less. It had a better ventilating and heating system—but not good enough. It was even produced in a sleeper version, with berths.

But transcontinental trips at 180 mph took a long time, especially since there had to be several stops. Flight over mountainous terrain was hampered by low cabin air pressure, and flight over long ocean stretches was hampered by range and the safety limitations of a bimotor.

More speed, more range, more engines, and pressurization were clearly needed. The impetus of the war brought about the first three in the DC-4s, of which we built 1200 or so, and the phenomenally good record of this land plane in over-water service for the military proved the feasibility of dispensing with flying boats on such routes. By war's end, pressurized aircraft were ready and there ensued a second period of great airline expansion, worldwide, built in large meas-

ure on the DC-6 and the Constellation.

Succeeding versions, with longer fuselages to carry more payload, more-powerful and more-reliable engines having lower fuel consumption, and other logical improvements, introduced nonstop services where they had not before been possible, and brought flying costs down to the point where they were more nearly competitive with other forms of transportation. Finally, the polar routes began to be utilized to shorten flight distances between widely separated points.

This brings us from the late '40s up into the late '50s. In the meantime, a revolutionary engine had found its way into military use, the jet-driven turbine.

The large piston-engine transports had almost doubled the speed of the DC-3. The jet-engine transports of the '60s again almost doubled operating speeds.

There is no doubt about it, air travel over long distances tends to be boring, especially if it lasts more than five or six hours. Movies, piped music, and gourmet meals can help to while away the time, but the sooner the trip is over, the better the traveling public likes it. Yet, not only does the jet transport bring a big stepup in speed, it also has other characteristics the public appreciates.

The jet engine has proved to be extremely reliable, even more so than the most optimistic sales-talk forecasts. On-time departures are now routine, and forced landings—or what are now somewhat euphemistically referred to as "unscheduled landings"—are very rare. Vibration is unnoticeable and there are no visibly moving parts. Fuel consumption is so low that practically all important trips or trip segments can be covered nonstop.

So we have been experiencing for several years a third great period of expansion in air travel, during which the number of passenger miles flown has been going up at a rate of around 20% a year. And, more impressive perhaps, air-cargo volume has been going up at almost twice that rate.

This has caused the major manufacturers in the United States to bring out a still proliferating series of jet transports.

All of these airplanes have sweptback wings, of course, dictated by their high speed. (You may have wondered why the comparatively low-speed DC-3 wing was swept. I'll let you in on a little secret: In its original configuration, which was the DC-1 as laid down, it did not. But during the design process we found that the center of gravity was going to be farther aft than we had thought, so we swung the wing back (on paper, that is) to compensate. This was simpler to do than shifting the entire wing on the fuselage.)

Looking back, one sees, ever since the 1920s, nothing but rapid progress in speed, range, reliability, operating altitude, carrying capacity, and volume of operations. It is tempting to extrapolate these trends indefinitely into the future; but seldom if ever in human affairs does this kind of growth continue without a slowing at some point, and there is no reason to expect an exception here.

Let me lead into this by first reviewing the predicament in which the supersonic transport finds itself. Obviously, since one of the major advantages of air transportation has been speed, it has appeared sensible to consider as a next logical step the development of a plane which would again double, or even triple, the speed of the current fleet.

For a long time, the sonic barrier was a limit, and the current fleet indeed recognizes that limit. As the speed of sound is approached, aerodynamic drag starts to rise abruptly; flight becomes uneconomical until the barrier is passed, and this rise levels off to the point where the effect of speed upon economy again predominates.
At about double the current operating speeds, one runs into another barrier, created by the thermal limit for the use of aluminum-alloy materials. This is where the British-French supersonic transport, the Concorde, will operate. By substituting titanium and other heat-resistant materials, it is possible to push this thermal barrier up to as much as three times current speeds at an increase in cost but with a gain in efficiency, and this is where the U.S. Boeing-built supersonic plane will operate.

But, in either regime, and in fact whenever sonic speeds are exceeded, pressure waves are generated which cause the sharp, explosion-like noise known as the sonic boom. Nothing has yet been found that will reduce the intensity of this noise to a point where it will be clearly acceptable for flight over populated areas. Consequently, it is generally accepted that, initially at least, SSTs will have to be limited to operations over water or sparsely populated regions.

The North Atlantic has the highest volume of over-water travel—not just coast-to-coast, but including inland cities. It looks at present as though both SST projects will be hard-put to cover the North Atlantic route with economically adequate payload, especially when winds are adverse, or temperatures much above standard.

Actually, the time advantage from supersonic speeds is of real significance only over the longer ranges, and this is where the current SST designs are most deficient compared to the current subsonic jets, which now routinely handle ranges of 5000 mi. or better. It does not make sense to introduce the SST on a route, now being covered nonstop by the subsonic jet, where it will have to make an intermediate stop for fuel.

In time, advances in supersonic technology, particularly in the propulsion system, will overcome this range imbalance. In time, also, ways may be found to bring the sonic boom under control. In the meantime, the SST market is bound to be limited.

Next, let me turn to the so-called jumbo jet
and the Airbus. The rationale for these has at least three facets:

1. As traffic increases and air space becomes more crowded, it is logical to carry more payload per unit and thus reduce the number of units.
2. The more payload, the lower the seat-mile or pound-mile cost.
3. The more internal space in the fuselage, the more amenities can be provided, thus competing, through more comfort and distractions to overcome boredom, with the advantages of shorter travel time accruing to the SST, which, as we have seen, currently has problems.

In each of these three items, there are, in fact, interesting competitive tradeoffs:

First, in putting more payload in each unit, we reduce the traffic-control problem in the air, but increase the problems of ground-terminal congestion.

Second, economy requires high-density seating. Comfort and luxury require more space per passenger.

Third, as I have already said, greater speed, greater economy, and greater comfort are all features that attract traffic, but each is achieved somewhat at the expense of the others.

So compromises and choices have to be made, and much thought and analysis is presently going into arriving at reasonable answers. In the meantime, the current jet fleet is being expanded in all directions and traffic is growing. If one postulates conservatively a 15% increase per year, volume will double in five years. It becomes more and more apparent that the critical parts of the aircraft system will not be the vehicles themselves, but terminal congestion in the air and on the ground.

Actually, while important and desirable, it has not been essential, up to now, to consider travel by air in the complete system sense and plan all elements concurrently. Now it is. The days are gone forever when airplanes could be designed and purchased without simultaneously making provision for solving the problems introducing them will create. (I remember when, coming into La Guardia on a DC-2 delivery flight in the early '30s, we had to circle the field several times, gunning the engines, to wake the custodian and get
him to turn on the runway lights!) There is a limit to the amount of crowding, congestion, and noise the public will take before rebelling. The result of failing to give these problems adequate attention can only be restrictions, legal and otherwise.

Perhaps this is a good point to introduce the subject of vertical- or short-takeoff and landing aircraft, VTOL and STOL as they are called. Anyone who has suffered through the ground-traffic tieups of the automobile age—and who has not?—must have dreamed of sometime being able just to pull back on the steering wheel and soar over the whole mess. A great deal of money, effort, and ingenuity has already gone into advancing the V/STOL art, and a number of promising techniques are emerging.

At one end of the spectrum, the conventional helicopter has certainly demonstrated its practicability and utility, but is hampered by high operating cost, stability problems that inhibit its use in bad weather, and a natural speed limitation. At the other end, the lightly loaded airplane with sophisticated and powerful high-lift devices is rough-air sensitive and is incapable of vertical or hovering flight.
One solution—in a direction already indicated by the Lockheed Cheyenne (now operational in its military configuration and in the proposal stage commercially)—would use a rigid rotor, coupled gyroscopically and articulated only with respect to blade pitch, that overcomes the stability problem and a wing that permits the rotor to be offloaded as speed increases, thus extending the speed range. Ultimately, a way should be worked out to stow the rotor entirely, thus further increasing the high-speed capability. The next few years will undoubtedly see some form of compound machine emerge as practical.

So here again, I do not see vehicle technology as being the most critical element.

No, here again we must face the problem of noise, which will make low-flying vehicles over congested areas extremely unpopular, and the problem of terminal congestion, in the sense of airspace and traffic control. As I have said, the jumbo jet and the Airbus will reduce congestion in the air at the expense of congestion on the ground. The V/STOL will do the reverse.

Thus far, I have covered the more immediate prospects. Taking a longer view, one thinks of such things as nuclear-powered aircraft with practically unlimited range, and hypersonic or orbital transports, with not unlimited, but at least greatly increased, speed. I am bearish on these, unless we begin to talk about voyages away from this Earth, because of the limited geography with which we are dealing. Aside from the technical difficulties, which are many, it is patently useless to extend transport ranges indefinitely, when one considers the distance between major cities in the world. The realities of range, moreover, imply a limitation on useful speed, associated with time required for ascent and descent, considering the extremely high operating altitudes. And there is small advantage to be gained in shortening trip length after it has been brought down to non-boring dimensions. And if one goes too far with this, there will not be enough time for the meal and the movie!

Over all comes the economic question. These far-out devices are bound to be extremely expensive. The 747 is about the limit of what can be financed without government assistance.

I might close by alluding to the inhibiting effect on business travel that will surely result from the advances being made in the field of communications. It is easier and cheaper, as well as quicker, to transmit ideas and information while sitting in one place than while moving about, and the rapidly advancing arts of ground and satellite communication surely will revolutionize many social habits in the next decade or so. Sight, sound, and the written word will be instantaneously transported over virtually unlimited ranges without requiring the movement of weighty physical objects, animate or inanimate.

To recapitulate, if we confine ourselves to practical, utilitarian air-transport systems, I see:

Not much advantage in speeds above those currently associated with SSTs.

Not much advantage in ranges above those currently associated with subsonic jets.

Eventual coupling of these two.

Not much advantage in putting more payload in each vehicle over what will be carried in the 747 or C-5 because of problems of terminal congestion and high airplane cost.

Growing irritation on the part of the general public with the annoyances associated with heavy air traffic—namely, noise and delays due to congestion in the air and on the ground.

A need for advance over-all systems planning, taking due account of competing and complementary systems.

I would anticipate continued rapid technical and operating advances, accompanied by a rapid increase in number of passenger and cargo miles.
thrown per year, gradually slowing down as a variety of practical limitations start to be felt.

It might be interesting at this point to compare some current performance figures against those of the 1932 TWA specification as an indication of the progress which has generated the remarkable growth indicated by the graph on page 68. I am taking the long-body DC-8 as illustrative of where we are now.

The first item in the TWA spec called for three engines at 550 hp each, or a total of 1650 hp. In contrast to this, the four engines of the DC-8 each produce 19,000-lb thrust, or a total of 76,000 lb. Converting this to horsepower at 100 knots speed, we get a total of 21,000 hp.

The next item was gross weight, 14,200 lb. The DC-8 has a gross weight of 355,000 lb.

Cruising range specified was 1080 mi. at 150 mph. The corresponding figure for the DC-8 is 4030 mi. at 350 mph with full payload. It has fuel capacity for 5530 mi. with a reduced payload consisting of 170 passengers plus their baggage.

The TWA spec called for 12 passengers. The DC-8 has a passenger capacity of 251.

The DC-8 can carry a payload of 66,400 lb, compared to 2300 lb in the 1932 spec.

Top speed, 600 mph against 185 mph.

Cruise speed, 557 mph at 30,000 ft against 146 mph at sea level.

Landing speed. Here is where the comparison might seem adverse, for it is 160 mph against 65. But with current runways and approach aids, this has become routine and quite acceptable.

Rate of climb, 2250 ft/min at sea level against 1200.

The service ceiling called for in the TWA spec was 21,000 ft, but an unpressurized airplane could not be expected to carry passengers above 12,000-15,000 ft without supplying them with oxygen. The DC-8 has an operating ceiling of 42,000 ft and can fly at 37,000 ft with one engine dead, compared to the 10,000 ft which TWA required.

Altogether, the state of the art has come a long way since 1932. And this is by no means the end.

In conclusion, I might say that I believe improvements in communication and transportation have been, and will continue to be, potent influences for peace. Ignorance of one's fellow man and his milieu breeds bigotry, isolationism, neglect and distrust. So, in civilization's all-too-slow progress toward better days, air transportation has a vital and impressive role to play. Participation in its introduction and expansion has been an exciting and most satisfying experience.

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CAPTAIN J. LAURENCE PRITCHARD:
His Passing Marks an Era
By Nicholas J. Hoff
Stanford University

With the death of Captain J. Laurence Pritchard on April 23, 1968, a great era of the aeronautical history of the United Kingdom came to an end. His decease followed the death of most of the pioneering flier-inventors who had built up great industrial concerns (e.g., Sir Frederick Handley Page), the vanishing of some of the most honored names from the list of aircraft manufacturers (e.g., de Havilland) through mergers into surviving super-organizations, death of the great designers of such planes as the Hurricane and Spitfire, and even, to a large extent, replacement of the airplane by missiles and spacecraft in military operations.

Pritchard started his career in aeronautics at the beginning of this era, held important positions when the British aircraft industry reached its greatest heights, and began himself to decline as the era approached its end.

Born on February 25, 1885, John Laurence Pritchard received a degree in mathematics from Cambridge University and served in the Royal Naval Air Service during World War I. Immediately after the war, in 1919, he published Aeroplane Structures, the first textbook on airplane structural analysis, which he wrote jointly with A. J. Sutton Pippard. This volume, together with its second edition of 1935, was used all over the world, and served as a model for many later books on the subject. In 1919 Pritchard became editor of the Journal of the Royal Aeronautical Society, a post he held for 26 years. He obtained for the Journal papers of general interest on airplane design and operation, as well as highly mathematical articles meant for the specialist.

From 1925 to 1951, he served as RAeS Secretary and insisted that industry and university people should both have a voice on the Council. He helped Lester D. Gardner with his advice when the IAS was organized. Pritchard also was instrumental in getting U.S. and U.K. aeronautical men together in the joint Anglo-American Aeronautical Conferences.

Pritchard had a gift for writing, turning out detective stories as well as articles on all manner of topics for Fleet Street when he was short of cash in the twenties. He devoted his last years to the history of aeronautics, publishing books and articles on the subject, particularly on Sir George Cayley and in the RAeS.

He married a witty and gay woman, Wynde Ross, who survives him. Their only child, John, served in the Royal...