AIAA/SAE William Littlewood Memorial Lecture

Our Amazing Air Transportation System

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OUR air transportation system is *vital* in today's social and economic world. This reality is probably more astounding to those of us who have been involved in aviation since the late 1920s and early 1930s. When we reflect upon the sacrifices and struggles which have resulted in safe, reliable, and comfortable civil air transportation available to all at reasonable fares, it is difficult for us to comprehend that this marvelous achievement is taken for granted by so many. Perhaps it is just as well. You have to have lived through it to really appreciate it. We have the satisfaction of remembering some particular contributions by which we have participated in this great evolution.

World dimensions have been drastically reduced timewise. In one hour, today's jet travels about as far as an ocean liner does in one day. This time saving has provided the opportunity for travelers to visit distant lands more easily and more often. Today's young people have travel opportunities that could never have been contemplated one generation ago. In today's world few persons have the time for, or can afford to indulge in, surface transportation over long distances.

This lecture will relate some personal impressions gained during a forty-six year association with airline engineering activities. The value of competition between manufactures, suppliers, and airlines; the contributions of airline development engineering; and the input of operational experience—all have played a significant part in the achievement of "Our Amazing Air Transportation System."

Franklin Kolk and William Littlewood

Some of you know that Mr. Franklin W. Kolk, Vice-President Technological Development Operations of American Airlines, was originally selected to give this Sixth William Littlewood Memorial Lecture. His untimely death prevented him from carrying out this assignment. In late September I received an invitation to present the lecture in his stead. I am greatly honored and hope that the following observations will be useful as well as informative.

In November 1959, the Institute of Aeronautical Sciences sponsored a Fourth National Turbine Powered Air Transportation Meeting in San Francisco to consider the initial experiences obtained in civil operations of jet aircraft. The first paper was given by Franklin Kolk. The session chairman was Marvin Whitlock, then Senior Vice-President for Maintenance and Engineering of Capitol Airlines. Let me present Marv Whitlock's introduction of Frank Kolk and some excerpts from Frank's paper as transcribed at that meeting:

"Our first speaker this morning is Mr. Franklin W. Kolk, Director of Aircraft Research of American Airlines. Mr. Kolk is an unusual person in several respects. First, not only is he an outstanding engineer, but also he is one of the few native New Yorkers that I have ever known in many years in New York. Frank took his B.S. in Aeronautical Engineering at MIT, went with the Glen L. Martin Company as Senior Aerodynamist, came with American Airlines in 1943. And

Ray Kelly, a Purdue BSME (Aeronautical) graduate in 1925, began his career with the U.S. Air Corps in June as a Junior Aeronautical Engineer at McCook Field, Dayton, Ohio. He was transferred to the new Wright Field with the Aircraft Instrument Branch of the Equipment Section. In July of 1928 he moved to Los Angeles to become Aeronautical Engineer for the American Paulin System to assist in the development of a precision aircraft altimeter. However, the company did not survive the 1929 depression.

In October 1930 he was employed by Boeing Air Transport as Foreman of their Instrument Repair Shop at the Cheyenne, Wyoming, Base. With his technical background he was soon involved in engineering and flight test work. BAT soon was to become part of the United Air Lines system. In 1936, United established an Engineering Department at its headquarters in Chicago. Mr. Kelly was transferred there as Supt. of Engineering Development. He and his group were involved in the development and testing of new aircraft and equipment. In 1948 he was transferred to Denver as Director of Technical Development. In 1952, the Technical Development Staff was moved to the UAL Engineering and Maintenance Base in San Francisco, where he remained until retirement on March 1, 1966.

He was continuously engaged in professional activities of the SAE, AIAA and ASTM. He is the author of a number of papers. He became a member of SAE in 1929 and was elected a Fellow of the AIAA in January of 1963. In 1965 he was given a "Distinguished Service Award" by The Flight Safety Foundation. During his active career he served on numerous NACA and NASA Committees, the last of which was NASA's Research Advisory Committee on Aircraft Operating Problems.

After retirement from UAL, Mr. Kelly served as a Consultant to Boeing on the U.S. Supersonic Transport. However most of his consulting activities to date have been with R. Dixon Speas Associates, primarily in the areas of airline aircraft operations, costs, and performance.

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I'm sure whatever you have good to say about American, you certainly will all concede that they have never been outgunned in equipment. That, to a large degree, is a credit to Frank Kolk.

"There has been a lot of fact and fiction having to do with the turbo-fan engine, so we have asked Frank to separate fact from fiction and give us a presentation entitled, 'A Realistic Significance of the Turbo-Fan Engine.' Mr. Frank Kolk."

"The turbo-fan engine, in the form now available to the industry, is basically a jet engine. That is to say, its installation and its control and the type of flight characteristics produced by it are very, very similar to those of the jet engine. It can be interchanged with the jet engine in aircraft originally designed and built for jet engines. It cannot be reasonably installed in aircraft originally laid out for the use of propellers as a basic power plant.

"Why, then, is the turbo-fan a better unit for aircraft propulsion than the turbojet? Simply because at the speeds we now fly, it is more efficient. The fan must be added to the engine to use surplus energy extracted from the main propelling gas stream in order to make the mainstream more efficient. The turbo-fan uses it to pump up a secondary air stream so that it may be ejected rearward at a higher speed, as does the main jet. Thus, the turbo-fan provides a means of using an efficient gas generator to the utmost advantage while still using a very low pressure ratio across the propelling nozzle."

Later in these meetings I was asked to sum up the significant thoughts which had been generated. Today it is my pleasure to quote William Littlewood as he introduced me, some thoughts from my talk, and Bill's closing remarks:

"Well, I am going to proceed now to not the serious but very pleasant business of introducing Ray Kelly, who is going to give us, I don't know exactly what, but probably a recap of this meeting, problems, all sorts of things."

"Thank you, Bill, Members of the Institute, and guests. I am inclined to be overwhelmed by all of the good information which has come out of these meetings in the past two days. The number one thing we have seen emphasized is that these new transports are just a part of the system. To most of us that is no surprise, but I am sure that there are a lot of people who think that you just go out and buy an airplane and start flying it like you would drive an automobile. It requires the concerted and continuing contributions of many organizations to have air transportation at all.

"References were made to the increased complexity of the airplane and all its systems. There was this question, "Can't we simplify?' Now that has been asked at every technical meeting I have attended in the past twenty-five years. We should try to simplify and do things the easy way whenever we can, but we must recognize that we have a vehicle and a system which are both very complex. Simplicity of operation comes largely from improvement in reliability. Whenever you get something that is 100 percent reliable, nobody worries about its complexity.

"One other general thought I would like to give you: there is no ultimate goal... only plateaus. The only thing that is constant is change. What we know today, or think we know, will not be gospel tomorrow, or next week, or next year, or ten or fifteen years from now. Maybe we do not know exactly where we are going, but we try to look beyond the trees to see the hills; to establish a course which we think is right. We have got to be realistic about this and let our people know that there is a future which we are trying to attain but which we cannot be positive about today.

"Marvin Whitlock mentioned that the airlines are not running scared. They show confidence in our present equipment and in the future. This is a credit, he thinks, to the airlines and to the manufacturers. The airlines are quite happy, and certainly the public response to these new turbine powered airplanes has been most encouraging. It really is only the beginning."

Then Bill Littlewood closed the meeting with the following:

"Thank you, Ray, for a stimulating review of our last two days' activities. I think that we would all agree that these two days have been extremely profitable to all of us and I, of course, as an airline person, have been delighted that the airlines and the air transport people had a chance to dish it out and some of you captive audience had to sit there and take it. We are usually in the reverse position, but we have learned to bear up extremely well under your blows. Thus, it is inspiring to review all these things and to see where we are, and perhaps where we are going; but we must recognize that the simple development of an antigravity device and the simple application of atomic energy for propulsion would solve all our problems. So, if you fellows will just get to work on that between now and our next meeting..."

The foregoing, excerpted from the 1959 IAS meeting in San Francisco, are included in recognition of William Littlewood and Franklin Kolk.

Early Airline Experience

My connection with the airline effort began in October 1930, when I joined Boeing Air Transport in Cheyenne, Wyoming, as Foreman of the Instrument Shop. At that time Boeing Air Transport was operating the Boeing 80-A fifteen-passenger tri-motors, plus single-engined 40 B-2 and 40 B-4 biplanes. The latter were used primarily for the carrying of mail, but they could also accommodate either two or four passengers in very crowded seating. National Air Transport was using Ford tri-motor all-metal planes,Curtiss Carrier Pigeon mail planes, and Travel Air two-passenger monoplanes. I dug up a June 15, 1931, timetable for United Air Lines, comprising the four subsidiaries: Boeing Air Transport, Pacific Air Transport, Varney Air Lines, and National Air Transport.

For that time the services offered were quite advanced. There were fifteen scheduled stops on the transcontinental route which originated in Oakland, California, on the West Coast and in Newark, New Jersey, on the East Coast. The eastbound flight required twenty-seven hours, while the westbound flight was scheduled at thirty-two hours. The fare was $258.00 or 8.2 cents per mile.

So with that as a starting point and remembering the problems and the advances which have been recorded in air transportation from 1930 to 1977, I will relate some recollections and impressions which have particular significance to me in the evolution of air transportation as we know it today. Emphasis will be given to the benefits of competition and the achievements of engineering and operations expertise. I am still amazed at the unbelievable progress which has been produced in technology, in safety, in acceptance, and in economic impact.

Achievements

During the 1930s, 40s and 50s, most airlines engineers were on the defensive. We had to say, "Yes, *but* we will eventually demonstrate the validity of our belief in the importance of civil air transportation." We were questioned first about safety. We had an extremely difficult time in justifying air transporation on that account. Figure 1 is based on data taken from annual *ATA Facts and Figures* from 1941 to 1976. It illustrates the tremendous improvements which have been made in airline passenger safety. It also gives comparative data for automobile and taxi, railroad, and bus passengers. Scheduled air transporation is now among the safest forms of public transportation. It offers a much lower hazard to the rest of the population from the standpoint of injury to pedestrians and/or to other people than do other forms of public land transportation.

Reasons for the dramatic improvement in scheduled airline safety during the period of 1941 to 1959 were numerous. There was the continuing development of additional navigational aids both for the airway traffic system and for

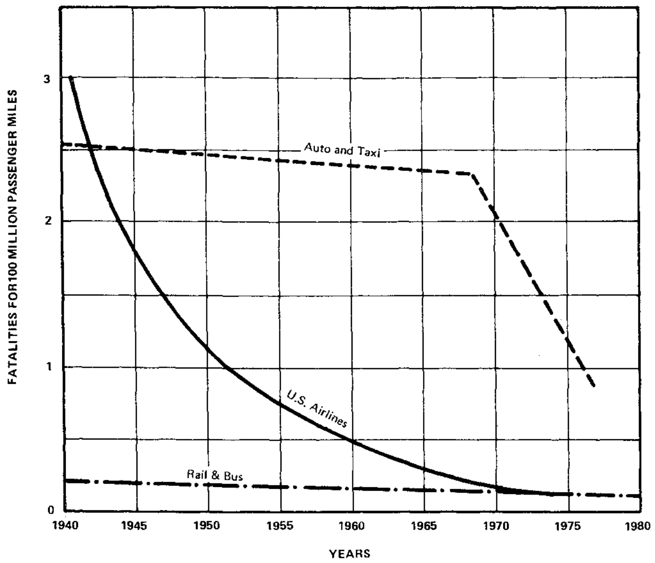


Fig. 1 Comparative safety trends (from ATA annual reports).

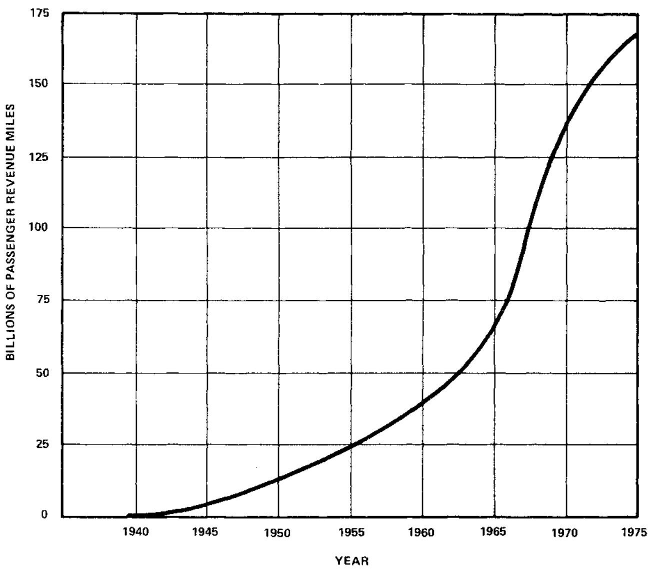


Fig. 2 U.S. scheduled airline passenger traffic trends (from ATA Facts and Figures).

the aircraft itself. The pressurized cabin, permitting more overweather flights, was a big asset. Thunderstorm avoidance radar, first tested by United, increased safety and comfort. With the introduction of jet aircraft in 1959, the improvement in safety continued. This, despite the fact that a great many people, including me, had some doubts as to whether the continued decrease in "fatalities per 100 million passenger miles" could be maintained. You will note from the chart that, happily, this has been so. From 1969 through 1975, scheduled U.S. carriers were on the same level of safety as that achieved by bus and rail transportation.

For that seven-year period, bus average is 0.08, airline 0.11 and rail 0.17. The private automobile and taxi average is 1.77 fatalities per 100 million passenger miles or 16.1 times the airline hazard. It is encouraging to note that there has been a dramatic improvement in auto safety since 1968. However, to be truly reflective of the effect upon the total population, such charts should indicate the number of related deaths and/or injuries which occur to persons other than passengers.

The increasing usefulness of civil air transportation can be demonstrated by plotting the total U.S. scheduled airline passenger miles generated during this same period, from 1941

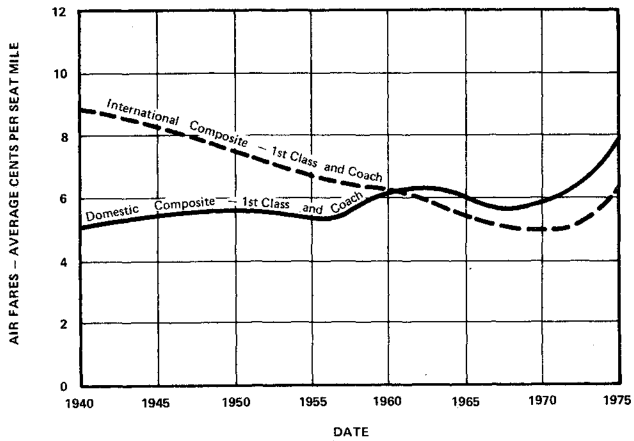


Fig. 3 U.S. scheduled airline fare history (from ATA Facts and Figures).

to 1975. Figure 2 shows how much the acceptance of the airplane as a transportation vehicle has been increased on scheduled U.S. carriers.

No one in the 1930s could have anticipated that civil passenger air transportation worldwide would far exceed that of surface carriers between the major cities of the world. Yet this has come about. The answer is simple. When the public's fear of flying was overcome, and the time-saving, comfort, and schedule reliability had been amply demonstrated, most travelers accepted the airplane as the most reasonable mode of long distance transportation.

During all of this time there was continuing rise in the cost of all goods and services. It is interesting to plot the average seat-mile fares occurring during the same period (see Fig. 3). Despite greatly increased prices for equipment, labor and fuel, airline fares have been kept within reasonable limits. I have no doubt but that the recent tripling of fuel costs was a primary factor in the need to increase fares. This, in turn, probably had an effect on the rounding off of passenger trends, as shown on Fig. 2.

Evolution of U.S. Airline Aircraft

Direct competition between the manufacturers, coupled with engineering and operation input from the airlines, has been a major factor in the achievement of "Our Amazing Air Transportation System."

In 1928 the Boeing Company brought out the Model 80-A tri-motor biplane to compete with the Ford-Stout all-metal tri-motor monoplane and the Fokker tri-motor monoplane with its plywood wing structure. These aircraft demonstrated that the traveler preferred embarking upon his journey without the necessity of donning helmet, goggles and flying suit. The public's acceptance of these three cabin aircraft plus some smaller single-engined airplanes gave sufficient encouragement to the manufacturers to proceed with new designs.

United introduced, in June 1933, a radical change, the Boeing Model 247 all-metal low-wing ten-passenger airplane with a cruising speed of 150 mph. It was powered with two Pratt and Whitney Wasp engines. Immediately it became very popular with passengers and United personnel, and some sixty of these planes were put into service on the transcontinental route. The elapsed cross country flying time was cut to nineteen and one-half hours.

The superiority of the 247 was not to be of long duration. In a letter dated August 2, 1932, Jack Frye, Vice-President Operations of Transcontinental and Western Air, wrote to Donald Douglas expressing an interest in purchasing "ten or more all-metal tri-motored twelve-passenger airplanes, with a top speed of 185 mph and a range of 1080 miles." Douglas responded, proposing to build the DC-1. This evolved into the DC-2 and eventually the DC-3.

The story of Bill Littlewood's and American Airlines' participation in the development of these airplanes was well documented in The First William Littlewood Memorial Lecture, authored by Peter G. Masefield, British Airports Authority. He credits the airlines for many of the changes and improvements made in the DC-3 airplane which made it readily available and very useful to the military effort in World War II.

To go back to my own experience at the UAL Maintenance Base at Cheyenne in the early 1930s...due to my engineering background I was soon involved in conducting flight tests. This gave me an opportunity to explain some of the elements of "instrument flying" to our basically "seat of the pants" type pilots. Success was marginal, to say the least, but it was a start. It gave me an insight into the problems and needs for the future, if airlines were ever to achieve all-weather flying with safety.

While the Boeing 247 had opened the gates for the advent of two-engined all-metal low-wing transport airplanes, the DC-3 with its superior speed and larger size soon demonstrated better economy and passenger appeal. United quickly followed other airlines in buying these planes. However, with the Wright Cyclone R-1820 engines as installed in the first DC-3s, performance for operation out of United's higher airports at Cheyenne, Salt Lake City, Elko, and Reno, was disappointing.

It was determined that the Pratt and Whitney R-1830 twin-row fourteen-cylinder Wasps rated at 1200 horsepower would be more suitable engines. Even with these there was need to find the best combination of take-off rpm, propeller blade length, and pitch to give optimum performance at our higher airports, especially on hot days. Consequently, I was delegated to take one of our first DC-3's and a flight crew to Hartford, Connecticut, in late December 1936 to conduct tests with Pratt and Whitney engineers to improve performance.

DC-3 Problems

Early in the introduction of these aircraft we incurred some unfortunate accidents and some of the pilots complained that the stalling characteristics were critical. It was considered to be a very "hot airplane." Their concerns increased when flying in icing conditions, even though the airplane was equipped with deicer boots on the wings. There was further complication of loss of engine power under atmospheric conditions conducive to ice accumulation in the carburetors. Windshield ice was also a problem. These combinations could become critical and justified an extensive investigation.

In October 1937 I was instructed to take an airplane and UAL flight crew to Langley Field in Virginia, where the National Advisory Committee for Aeronautics had agreed to assist in comprehensive stall tests. The object was to ascertain exactly how and under what flight conditions the airplane became critical in its control characteristics.

These tests were very revealing and demonstrated how the airplane must be flown in order to increase the margin of safety. The air flow over the upper surface of the wing was observed and analyzed by attaching silk tufts to the upper wing skin at frequent intervals. In addition to visual observation, the tuft action was recorded by a movie camera. The airplane was stalled under all conceivable conditions short of spinning.

With the information gained from these tests and more day-to-day flying experience, it was determined that these airplanes must be taken off and landed in a manner different from the traditional "three point" technique, i.e., accomplished at speeds safely above the stall. This was now a practical method thanks to improved wheel brakes and longer airports runways.

The problem of icing was still present. In spite of the use of inflatable boots, the leading edge of the wings sometimes retained residual amounts of ice. Later, in Chicago, simulated ice accretions (cemented wood chips) were placed on the wings to determine the relative effects of varying deposits. Increased carburetor heat capacity was also provided and flight crews were instructed on how to anticipate carburetor ice so as to apply heat in time to avoid loss of power. Propellers and windshields were protected with alcohols.

There were other problems with the DC-3s that only extensive airline service could reveal and which required the cooperative efforts of manufacturers' and airlines' engineers. These related to such items as propellers, spark plugs, carburetors, brakes, heating systems, lubricants, etc. I particularly recall seven weeks of intensive testing out of Burbank, California, to obtain, with "cut and try" methods, an improvement in the fuel/air mixture distribution to all fourteen cylinders of the Pratt and Whitney R 1830-S1CG engines equipped with the Bendix PD injection carburetors. These flight tests were run under all possible operational variations of ambient temperature, altitude, power, throttle settings, engine speeds, etc. With the continued cooperation of Pratt and Whitney and the Bendix companies, we arrived at a basic combination which served so well for subsequent DC-3's and the military C-47's and R-4-D's.

The eventual DC-3 designs required the input of extensive airline experience and engineering coupled with ready cooperation of airframe, power plant and accessory (including communications) equipment manufacturers to make those modifications and improvements which eventually produced great reliability and safety for airline and military applications.

DC-4 Airplane

For the next step, to acquire a larger four-engined airplane, five airlines collaborated with Douglas in the development of the proto-type of the original DC-4. It will be of interest to quote here from a paragraph of an Equipment Agreement dated March 23, 1936:

"16. Participation in Engineering and Development Costs—The Air Lines agree among themselves that if $80,000 becomes due and payable by the Air Lines pursuant to paragraph 14 hereof, said sum shall be paid to Douglas by the Air Lines by the time required by paragraph 14 in the following proportions and amounts:

United	(40.322%)	$32,257.60
Transcontinental	(24.193%)	19,354.40
American	(16.130%)	12,904.00
Pan American	(11.290%)	9,032.00
North American	(8.065%)	6,452.00
	TOTAL	$80,000.00"

Thus the major airlines were, even in 1936, very anxious to participate actively in the engineering and financial development of more suitable civil transports. The DC-4 prototype did complete its CAA test program and was flown rather extensively in service tests by United in 1939. William Mentzer, Chief Engineer of United, had served as the chief airline coordinator at Douglas during the construction.

In the production DC-4, the prototype design was modified considerably, especially for increased speed. However the original airline engineering input and flight testing of the prototype were very valuable in determining the criteria for the production DC-4 and its military counterparts, the C-54 and R-5-D. Again one cannot help but wonder how much the U.S. World War II effort would have been impeded had it not been for the ready availability of the airline influenced DC-3 and DC-4 civil transports.

Operational Costs Formula

It was recognized in the late 1930s that there was need for a uniform and comprehensive method of computing and comparing the operational costs of airline aircraft. Bill Mentzer and Hal E. Nourse, United's Vice-President for Economics, collaborated on the development of a formula which would do just that. On January 26, 1940, at the winter meeting of the Institute of the Aeronautical Sciences in New York, they presented a paper titled, "Some Economic Aspects of Transport Airplane Performance." This became a classic and was the basis from which succeeding Air Transport Association formulas and many private cost calculation methods were derived. It was a very definite contribution by an airline to the better understanding and assessment of aircraft operating costs.

Stabilized Approach System for Pilot Training

In 1942 a series of tests were run by our Technical Development Group in Cheyenne, Wyoming, during which our Engineering Test Pilot, Mr. Ralph S. Johnson, developed a manual outlining simplified procedures for making consistent DC-3 stabilized approaches and landings, with power being the only variable. This method was used in training novice pilots to fly C-47s and R-4Ds. Test Pilot Johnson determined that if, in the event of poor visibility or for other reasons, the DC-3 type airplane were flown onto the runway at a 3-degree approach angle at the stabilized approach speed and flap configuration, the landing gear could absorb the shock without any undue hazard.

So far as I know, this was the primary basis for the establishment of the long accepted 3-degree glide slope. This method of pilotage, much more simple for the novice, eliminated the necessity for making last-second changes in attitude and/or air speed. The pilot, under visual conditions, would normally flare the airplane appropriately to soften the landing, cut the throttle, retract the flaps, and apply brakes as required.

Pressurized Cabin Airplanes

With the ending of World War II, it was evident that cabin pressurization, to permit passenger airplanes to operate at higher altitudes, was a must. This had first been demonstrated with the Boeing B-307 Stratoliners operated by TWA. Howard Hughes' and TWA's input to Lockheed led to the development of the first Constellation, which began flying in 1943, and later contributed greatly to the war effort and then to post-war civilian use, especially in long-haul operations.

The obvious advantages of cabin pressurization meant that Douglas followed suit with their post-war version of an advanced DC-4 (C-54 military) civil airplane. This became the 300 mph DC-6 (powered with the P&W R-2800 18-cylinder Twin Wasp engine), one of the most economical and useful of the piston powered craft.

The DC-6 and the Constellation stimulated long-haul travel, with a much higher degree of comfort, because they could operate at altitudes of 15,000 to 20,000 feet, thus avoiding much of the turbulence prevalent lower down. Then the Boeing Company designed and built the Stratocruiser, a still bigger airplane, using the larger Pratt and Whitney R-4360, 28-cylinder engine. It was a very fine airplane from the passenger's standpoint, with a lower deck lounge and more quiet cabin than either the Constellation or the DC-7. However, it was not a profitable airplane except on long hauls and with high load factors. Cooling problems developed with the engines, and it was evident that we had reached the limit in size of the piston engine that could be cooled properly without incurring very high drag. However, the military did use the tanker version (KC-97) for refueling jet fighters with good success for a long period of time.

The longer range capabilities of the Constellation and the Stratocruiser influenced Douglas to design the DC-7, using the more powerful Wright 18-cylinder Cyclone engine. This increased the speed to 350 mph and boosted the weight 10,000 pounds. The range became 2,500 miles or more. DC-7's were used primarily for transcontinental and overseas flights.

Turbine Engine Potentials

In 1946 Mr. John A. Herlihy, Senior Vice-President of Enginering for United Air Lines, had requested me to being studying the potentials of the turbine engine for airline applications. Wartime turbo-jet engines, some of which had been built here in the United Sates by our own engine manufacturers, all used centrifugal compressors, generally not very efficient. The centrifugal compressor was rugged, however, and much less expensive than the more recently proposed axial flow compressor designs, which would not only be more efficient, but would also incur less drag at high speed, due to its smaller diameter.

In Europe in the meantime, they had begun to plan for the use of turbine engines in civil aircraft. These were still of little interest to U.S. airlines or manufacturers who dominated the international long range transport arena with Constellations, DC-6s, Stratocruisers, and DC-7s. The airlines were, for the most part, making a profit. Worldwide travel had become a reality. Engine and aircraft reliability had reached new heights. Passengers were happy with the comforts of flying at higher altitudes. Why gamble with something as new and untried as the jet engine, having fuel consumption so high that its range was shorter than that of the larger, piston engine powered aircraft?

However, the British were going ahead with the jet powered DeHaviland Comet and the Vickers-Armstrong Viscount Turbo-prop. Even the Canadians were building the Avro Jetliner in Toronto. In the the spring of 1950, Mr. Herlihy, his assistant Mr. Frank F. Davis, and I made and extended trip to find out first hand more about the real potentials of gas turbine engines for aircraft propulsion. First, we went to Toronto and saw the Jetliner being built and tested by A.V. Roe Canada Ltd. Then we visted Great Britain to see and fly in the prototypes of the Viscount and the Comet. So far as I know, we were the first Americans to be accorded these privileges. The following excerpts from a memorandum report by Mr. Herlihy at the conclusin of our trip demonstrated our conviction that the turbine engine had a definete place in the future of civil air transportation:

"We are frequently asked, 'Are the British really ahead of the United States in the developement of advanced transport airplanes?' After an intimate view of their work, we must conclude that they are. The new aircraft which they have designed and the engines which power them are much more nearly ready for commerical service than are any parallel projects in America. It must be recognized, of course, that the British have had the advantage of substantial government support in these endeavors.

"A conclusion which we found inescapable is that the medium and large transport airplanes of the near future will be powered by turbines. This applies to planes in the present Convair-Martin class and larger. Abroad, all present thinking starts from this premise. The principal controversy remaining is whether the propeller-turbine or the jet-turbine is the more suitable, and this is going to be difficult to resolve. All turbine power plants bring to transport airplanes the advantages of low weight and drag, negligible oil consumption, higher operating speeds, and quiet, vibrationless flight.

"Summarizing our reactions to the advanced transport airplanes described above, I do not consider that our company can safely undertake the financial risk of buying any additional types of conventional piston engine aircraft, inasmuch as they are already rendered technologically obsolescent by these turbine powered transports. This comment extends to aircraft intended for 400-mile segments and longer; piston power plants may still be suitable for small, DC-3 class transports."

We thus came away from those experiences with the firm conviction that the gas turbine engine would have a most important place in future airline operations. It was self-evident that the public would appreciate the much greater speeds and the smoothness of operation. The possibility of changing from gasoline to a cheaper and less volatile fuel, kerosene, was also enticing.

On November 29, 1950, the A.V. Roe Canada Ltd. brought the Avro Jetliner to United's Executive Offices in Chicago, to demonstrate the characteristics of a jet transport plane to the top management people. This was part of a tour of major U.S. airlines arranged by Mr. R. Dixon Speas, who was just establishing his Aviation Consulting firm. United's management was quite impressed with the obvious passenger appeal and our pilots seemed assured that the piloting and flight operations transition would not be too difficult.

However, when my Technical Development Group made a careful analysis of the possible application of the Avro Jetliner to our route structure, it became apparent that with a range less than that of our DC-6s its speed advantage was not great enough to compensate for the number of refueling stops it would have to make on a transcontinental trip. The DC-6 could make the trip in shorter elapsed time and with much less fuel. This conclusively demonstrated that practical and economically viable turbine powered airplanes must have as good or better range capabilities than current piston powered craft.

The need for lower fuel consumption was very important for military applications as well. So all aircraft engine manufacturers began to develop new designs employing axial flow compressors, and combustion chambers and turbine blades which could withstand higher operating temperatures, to gain efficiency. In England, Rolls Royce pursued similar leads, while in the United States, Pratt and Whitney, General Electric and Allison carried out extensive research and development programs. Out of this effort came the P&W J-57 engine, which was the first to have extensive U.S. Military application.

United's "Paper Jet" Exercise

United's Technical Development Group continued their studies. A successful jet airplane for United must have transcontinental non-stop capabilities with a reasonable payload. Mr. Herlihy said that the only engine that he would recommend to United's management as having enough operational experience to justify application to airline operations was the Pratt and Whitney J-57. The Technical Development Group then began to study its potentials for application in a jet transport for use on United Air Lines.

Using "state of the art" aerodynamics and structural design criteria, specifications were established for a hypothetical aircraft. It turned out to have a passenger capacity of seventy-five to eighty with a maximum payload of 22,000 pounds and a maximum gross weight of 200,000 pounds.

In 1952 and 1953, with the cooperation of United's Operations Department, six daily simulated flights were planned for out hypothetical airplane, as follows:

1) Depart San Francisco 0725 PST for Chicago.
2) Depart Chicago 1345 CST for New York.
3) Depart New York 1310 EST for Chicago.
4) Depart Chicago 1450 CST for San Francisco.
5) Depart San Francisco 0830 PST non-stop for New York.
6) Depart New York 1310 EST non-stop for San Francisco.

These flights were conducted daily for a period of fifteen months. Dispatch and flight following procedures were as though the airplanes and flights were real. Cruise altitudes were 35,000 to 40,000 feet and speeds were 520 to 561 mph, depending on gross weight, altitude, and temperature. The results of this extensive operation were reported in paper before the Society of Automotive Engineers in New York, April 15, 1954. It was prepared by me and United's Research Meteorologist, Howard B. Kaster.

Results from the first year of this operation provided very encouraging answers to several important concerns about the practicality and realiability of jet transport operations into and through existing weather and air traffic situations. It was demonstrated that the much higher speed of these aircraft made scheduling easier and more accurate. Additionally, it was shown that combinations of adverse circumstances, which were not anticipated or planned for (weather changes, traffic problems, etc.), were very rare. Again the much shorter flight times were a distinct advantage in this regard. It is my recollection that during the entire fifteen months there were only six or eight diversions to alternate cities.

This tedious program did result in increased confidence, within United's Management and Flight Operations, that the jet transport would have many advantages. In Engineering our only concern was about the engines. We could neither honestly assure our superiors that the overhaul and maintenance costs would be reasonable nor that the reliability would be equal to that of our well-proven piston engines. We could not help but be concerned that the military was only averaging about 500 hours between engine removals. They were having a great amount of trouble with foreign object damage. Maybe we would suffer likewise. But the engine manufacturers were confident that the airline experience would be much better. Finally, Pratt and Whitney agreed to guarantee that the hourly overhaul and maintenance costs for the J-57 engine in United's service would not exceed a stipulated amount.

This was an important assurance. Our Operations Simulations had demonstrated operational reasonableness and even advantages. It is interesting now to recall that the primary objection within United to the hypothetical design used in our simulated exercise was that seventy-five to eighty passengers represented too large an airplane. Our economists and passenger service people said United did not need or want any craft larger than the DC-6 with a passenger capacity of about fifty to fifty-five. "It is essential to maintain frequency of service," they said. "We will not be able to carry good load factors on so large a craft." I tried to explain that it was not technically possible to have a smaller jet aircraft with transcontinental non-stop capabilities that would be profitable on United's system.

"That's your problem," they replied. I was requested to go back to the "drawing board" and come up with a practical design with fifty to fifty-five passenger capacity. You all know how that turned out. In 1955 UAL placed an order with Douglas for thirty DC-8s having a passenger capacity of one-hundred twenty-five.

Prior to this time there had been considerable talk about government underwriting the cost of the building and testing of a U.S. jet transport prototype. This received a lot of discussion in the Congress but failed to get enough support even though, as I recall, the appropriation was to be on the order of only one million dollars. I have in my files a UAL Technical Development report dated April 1951, "A Proposal for Testing of a Prototype Transport Aircraft." I quote from the Introduction:

"History of development of air transport equipment consistently demonstrates a substantial improvement to the product after a period of airline service. This is due to the extreme need for safe, reliable and economical service...The plan for government sponsorship for testing of prototype aircraft is most important for national defense and maintenance of leadership in the transport field. United Air Lines is uniquely prepared to conduct such a testing program on any selected prototype and to provide full information for all interested parties." However, no opportunity for such a test ever came about since Congress never approved the funds.

Jet Competition in the U.S.

Shortly thereafter, in 1953, Boeing decided to take on the development of a large jet on their own. They believed that they could design a basic dual purpose fuselage that could serve the military as a tanker plane (to replace the relatively slow KC-97s) and at the same time have suitable space and structure to serve the airlines as a passenger and cargo transport. They proceeded to build a prototype, the Model 80, powered with four Pratt and Whitney J-57 military type engines. It was very successful in its first flights in 1954 and made important demonstrations to the airlines. Based on this experience the specifications for the B-707 evolved.

At that time there was a great deal of discussion in this country about the actual need for a civil jet transport. The Comet airplane, after enjoying initial success, had run into problems due to the in-flight explosions at high altitudes. This caused a drastic setback to further developments in Great Britain and also was reason for questions in the minds of many people in this country about the ultimate safety of jet aircraft. Fortunately, the metal fatigue problem of the Comet was discovered in time so that it could be avoided in U.S. aircraft.

The Douglas Company was also proceeding with their own studies. They came up with specifications for the DC-8, also using four of the J-57 engines. These were reviewed with the airlines. At the same time Boeing approached the airlines with the B-707. It was still structured so that the basic fuselage tooling could be used for either civil transport or military tanker. The diameter was smaller than that of the DC-8.

It may seem surprising that this would become a very important difference between the two airplanes. The DC-8 could accommodate six abreast seating, while the 707 could only take five. The head room in the cabin was somewhat better in the DC-8, as was the cargo space below the cabin floor. To determine whether the DC-8 diameter was of sufficient advantage to justify the added weight and drag. United constructed an expensive plywood mockup at its Maintenance Base in San Francisco. Two fuselage halves, one for each diameter, were abutted to each other. Then tests were carried out by Stewardesses from galleys designed by United. Other cabin and cargo loading duties were simulated.

The result was that United definitely preferred the DC-8. Both Douglas and Boeing were privy to these tests and results. It was thought that Boeing would be convinced of the need for a larger diameter fuselage, but they did not make that decision until after United decided to place its initial jet transport order with Douglas, for thirty DC-8s. After both United and Pan American had placed orders for DC-8s, Boeing decided to increase the diameter of the B-707 to be the same as the DC-8.

Both Boeing and Douglas then set about to produce the very best transports possible. Boeing, with their military jet bomber experience, plus the information gained from the Model-80 prototype. were able to promise earlier deliveries. The direct competition was a very important stimulus to each company to produce a superior airplane. They each accepted the engineering input and operational expertise of their respective airline customers.

Douglas, in spite of their lack of experience in building large jet aircraft, elected to forego the production of a prototype. This was viewed with some concern by me. However, they did have access to the latest aerodynamic information and were very knowledgeable about the construction of large airline airplanes. They put their design directly into production so as not to be too far behind their competitor in deliveries.

As it turned out, the B-707 was used in transcontinental operations by TWA and American in the 1959 summer season. TWA, with only one airplane, operated their initial schedule for seventeen days without experiencing any significant delay, accumulating 173 hours of flight time. This performance was a great credit to TWA. It also gave us added confidence in the likelihood of jet operational reliability. United's first jet operations with the DC-8 did not begin until September 18, 1959. Thus we had lost all of one important "summer season."

But the point that I wish to make here is that the traveling and using public gained much from the direct competition that resulted from the simultaneous development and production of these two great aircraft. Both initially had marginal long range performance and economics, as originally powered with the civil version of the J-57 engine, the JT3D-6. It took larger and more fuel-efficient power plants, particularly the turbo-fan, as mentioned in the beginning of this lecture, to really produce a profitable vehicle.

TWA was also deeply involved in the development of the Convair 880, delivered to its first airline customer late in 1959.

In fact it was that threat of C-880 competition on the intermediate haul operations that influenced United to lose interest in the Lockheed Turbo-Prop Electra. We considered the C-880 very seriously, but with Pratt and Whitney's proposal to reduce the weight of the J-57 type of power plant and Boeing's offer to redesign the basic B-707 to take advantage of the reduced engine weight and fuel load, the B-720 evolved and was purchased by United. This was another example of how competition worked to improve civil aircraft.

Of course, the competition which did so much to produce safer, more reliable and efficient machines, was also present between airlines in the services they provided to customers. This was perhaps first reflected in cabin services, with the institution of Stewardess service on United Air Lines in 1930. From that time on there was continuing effort on the part of all carriers to cater to the physical comfort and convenience of the passenger. It was not long until such efforts were instrumental in overcoming the almost total aversion to flying that was prevalent in the 1930s.

Engineering Cooperation

One of the greatest satisfactions that has come out of my career in airline engineering has been the objective and cooperative realtionship which was existed between all elements of the technological fraternity. Perhaps this was the outgrowth of a common loyalty to make this new and thrilling mode of transportation safe, comfortable and economically important to society. It was especially challenging in view of all doubters; and the all too frequent instances of tragedies which were so costly in lives and money. At the technical level there was never any reluctance to share problems and successes with one's peers in another organization. There were few "trade secrets." particularly if safety might be involved.

When airline safety is mentioned, the name of Jerry Lederer, of the Flight Safety Foundation, comes to the minds of most of us. As the "Safety Disciple" for the entire industry, he had no peer. He never let up in his efforts to exhort every individual in our industry to be conscious of his responsibility to reduce all potential hazards, no matter how improbable. As a group, I think that airline engineers over the past forty-six years have felt that it was up to them to achieve the greatest possible advancements in safety, reliability, comfort and economy. And, as was started earlier, the progress has far exceeded our greatest expectations.

Professional Societies and Committee Work

The technical committees and meetings made possible by the American Institute of Aeronautics and Astronautics and the Society of Automotive Engineers have been of great importance in providing a forum for the exchange of experience, needs, viewpoints and information between the airlines engineers and manufacturers. Quite often representatives of government agencies, such as the FAA, NASA, and the military, are also contributors.

I'm sure you know that the William Littlewood Memorial Lecturers are made possible through the joint participation of those two great organizations, the AIAA and the SAE. Bill Littlewood was the only individual to date to have been honored as President of both. He was President of the SAE in 1954 and of the IAS (predecessor of the AIAA) in 1959. He died in 1967.

It is obvious from the name that the AIAA should be active in matters relating to airline activities. The SAE had been sponsoring and publishing papers discussing aviation technology prior to 1929 when I first became a member. The AIAA has established many committees and sponsored many meetings for the purpose of bringing about a clearer and objective revelation of airline operational and engineering advancements and needs. Unlike the SAE it does not publish specifications. AIAA activities do relate to operations but more often concentrate on research and long range potential developments. The two societies complement each other very well, and both have been very useful in assisting the airlines and the manufacturers of equipment in the achievement of "Our Amazing Air Transportation System."

Airline engineers have also contributed to Government Agencies, particularly to the FAA and to NASA. For example, Bill Littlewood, other airline engineers and I were privileged to be members of NASA's "Research Advisory Committee on Aircraft Operating Problems." I was also designated by the Air Transport Association in 1963 to represent my own views about the potential application of the supersonic transport to airline applications and to join the FAA team in the development of the requirements for a U.S. supersonic transport.

Now, I would like to emphasize a number of criteria relating to civil aircraft applications. These are general in nature, but individually and collectively they all have important connotations in the achievement of effective and efficient airline operations.

Energy Requirements

On the matter of energy expenditure: Aeronautical engineers have always understood that the airplane and helicopter require a constant expenditure of energy to overcome the acceleration of gravity, whenever the craft is airborne. For airplanes, this expenditure of energy is greatest for speeds just above the stall and lowest for speeds somewhat less than normal cruise, i.e., at the speed of best lift over drag ratio (L/D). For helicopters the greatest expenditure of energy is associated with hovering.

By contrast, with wheeled or buoyant marine and lighter-than-air vehicles, gravity is opposed by direct mechanical support or displacement. There is no expenditure of energy when the machine is not moving. When moving over a level surface, the energy expenditure is only that required to overcome the associated friction and heat losses.

Thus, the airplane's best utilization of energy is associated with is greater speed capability to transport payload as far as possible, while overcoming its added burden of continuous energy expenditure to offset the acceleration of gravity. It is not my intention to deal further with this basic phenomenon. I merely wish to say that the lay public does not often understand that a "slow" subsonic airplane operates at an economic disadvantage. Even in 1936 the 180 mph speed of the DC-3 was an economic plus over the slower Boeing 247 aircraft.

Airline Fuel Specifications

One of my early responsibilities after joining United Air Lines in 1930 was to run distillation and other laboratory tests on the gasoline being purchased for our aircraft. It was obvious that specifications must be written so that we could be assured of a consistent product across the entire system and from various producers. Military aviation fuel specifications were not entirely applicable. In time it was apparent that there would be an advantage in having a common specification base for all airline aircraft. The SAE provided the first avenue through which representatives of the major airlines, engine manufacturers, and suppliers could meet as a committee to draft such requirements as would provide the most consistent, available and economical aviation gasoline supplies throughout the United States.

However, as with all such SAE specifications, in contracts between any airline and a supplier, these specifications were not binding unless so agreed. Later the American Society for Testing and Materials (ASTM) took over the writing of civil aviation fuel specifications, since petroleum products were more in the area of that society's expertise. But the same type of supplier-user cooperation and representation has prevailed. Thus, airline technical and economic needs remain a very important aspect of our civil fuel quality and safety specifications. I was active in those first SAE specifications and later served on Technical Committee J of the ASTM up until my retirement from United in 1966.

It is fortunate for air transportation that we have been able to purchase as many energy units per pound of fuel as have been available in kerosene and gasoline. In spite of a great many proposals to use a basically different fuel for air transportation, at the moment it appears that except for the possible use of liquid hydrogen, we are at a loss about how to obtain more BTUs per pound of fuel carried. There is such a gap between our present 18,000-19,000 BTUs per pound for kerosene and 52,000 BTUs per pound of liquid hydrogen, that it would seem that someone may find a means whereby the basic molecular structures of fuel can be somehow modified to increase the number of hydrogen atoms in the molecule. I would not rule out the possible use of pure liquid hydrogen; but that has problems too, with respect to the tankage volume required, safety and cost.

However, so many things have happened in the last forty-six years beyond the comprehension of those of us who started in air transportation in the 1930s, that we are not about to say that any particular thing cannot or will not be accomplished within then next generation or so.

Productivity

A civil aircraft's productivity may be defined as its rate capability to produce useful transportation, when used in a specific operational situation. That productivity can be revenue dollars, seat miles, passenger miles, ton miles, etc., produced *per* hour, day, year, etc. The formula is written as:

$$\text{Productivity} = \text{Payload (Revenue)} \times \text{Block Speed} \times \text{Block Hours}$$

Since each of these three factors is a multiplier in the above formula, they each effect the other two. Therefore, it is necessary to consider the combined effect when determining productivity.This is especially important in the application of civil aircraft to airline routes. I often use four charts to

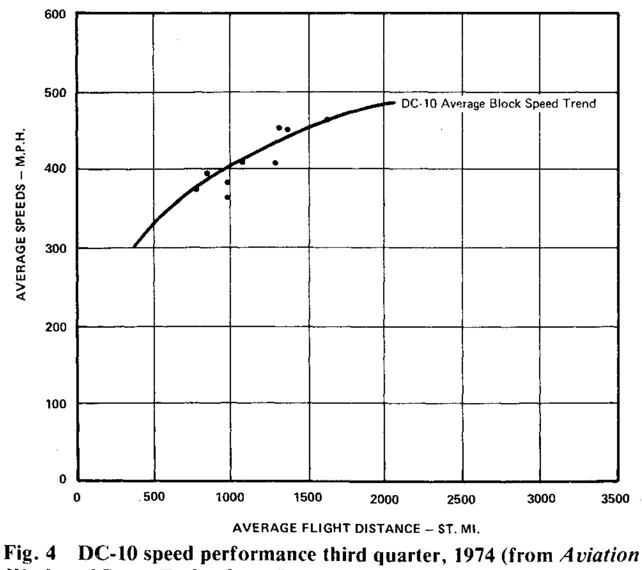


Fig. 4 DC-10 speed performance third quarter, 1974 (from *Aviation Week and Space Technology*, Jan. 6, 1975).

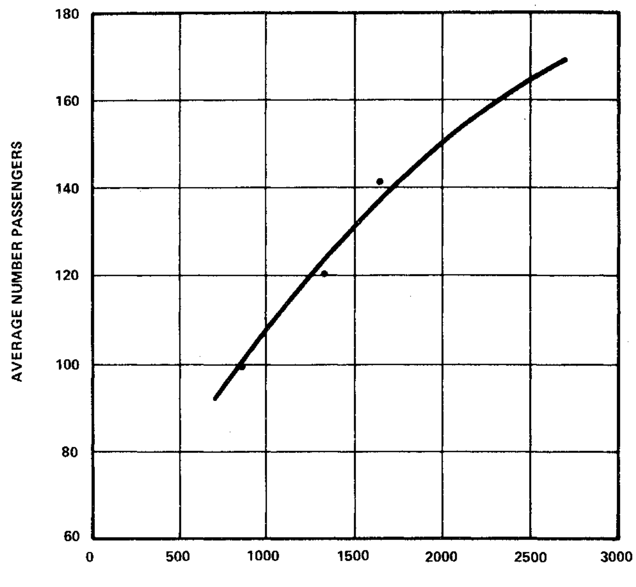


Fig. 5 DC-10 average passenger load (from *Aviation Week and Space Technology*, Jan. 6, 1975).

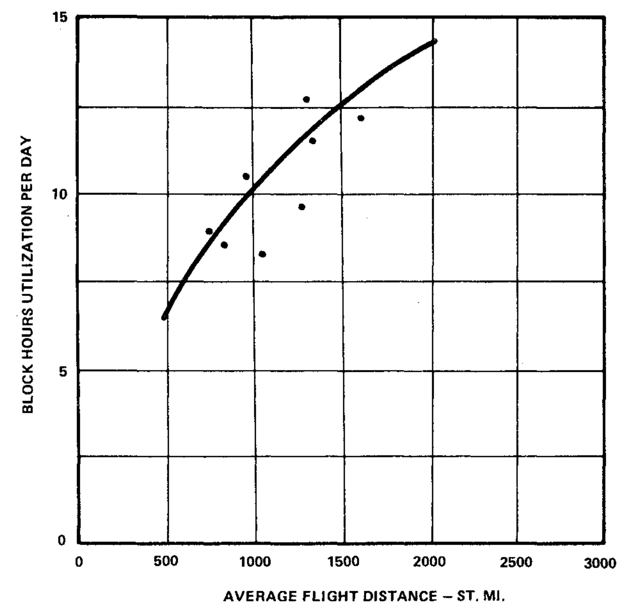


Fig. 6 DC-10 utilization trends third quarter 1974 (from *Aviation Week and Space Technology*, Jan. 6, 1975).

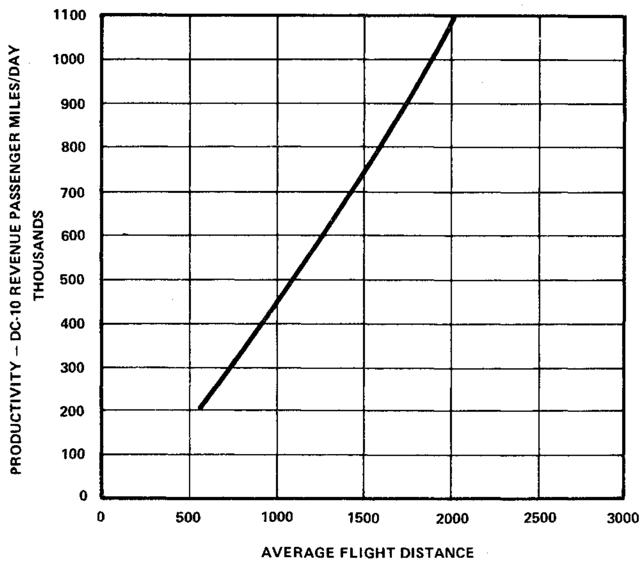


Fig. 7 DC-10 average passenger seat miles per day third quarter 1974 (from *Aviation Week and Space Technology*, Jan. 6, 1975).

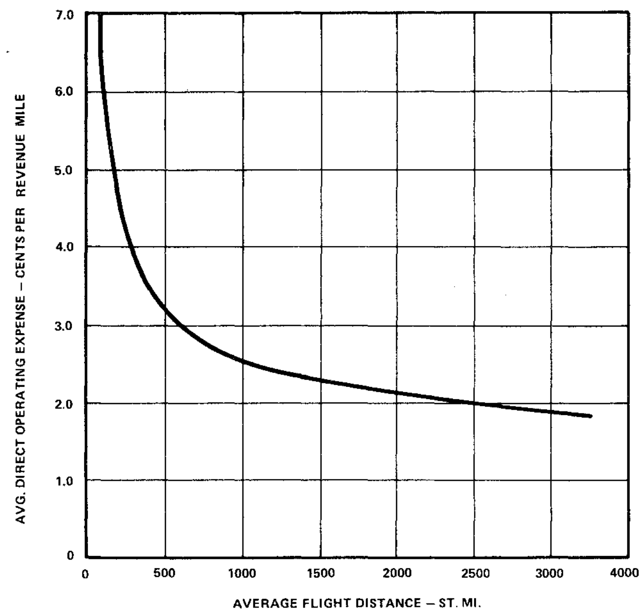


Fig. 8 Average airline unit operating cost trends: U.S. domestic composition fleet (from CAB data).

demonstrate the difficulty of getting high productivity when aircraft are limited to short haul operations.

Figure 4 is a speed chart wherein the block speed made good for a given trip length is plotted against trip length. These trend lines were constructed from DC-10 airline experience data. You will note that as the distance for flights increases within the range capability of the airplane, the block speed comes closer to the cruising speed of the aircraft. Conversely, as the trip distances are shortened, the block speed made good begins to drop off rapidly, until at zero distance the block speed is likewise zero.

Figure 5 is similar except that payload carried is plotted against trip length. Here again the average experience is that load factors tend to be less as the distances are shortened within the range limit of the airplane.

In Fig. 6 block hours of utilization are plotted against trip length. By and large the utilization of an aircraft increases to its maximum when it can be continuously used for flights that are substantially near its upper range limit. Again, utilization drops off as the distances are shortened.

The last figure of this series, Fig. 7, shows total productivity for the airplane, plotted against the various trip lengths over which it was used. The basic data for all of these figures was taken from CAB reports, so the curves represent actual average values in airline experience.

It becomes evident why the total decrease in productivity can be dramatic for short flights when each of the three factors suffers as stage lengths become shorter. The example, shown for DC-10 aircraft, demonstrates that the productivity, on average, for 750 mile flights was only about one third that achieved on 1750 mile flights.

Revenue vs Costs

Productivity can be calculated in terms of payload generated per time unit, but in the final analysis of the airline financial situation, productivity must be converted to the actual revenue required to overcome the high airline operational costs.

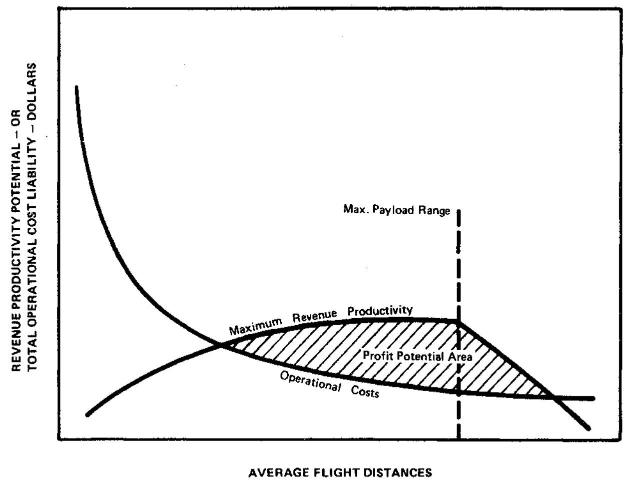


Fig. 9 Revenue vs costs (from Speas Associates' analysis).

With depreciation and other fixed costs being a very sizable portion of the direct operating costs, it is apparent that the problem of achieving profitable operations is compounded on short flights. Unit costs escalate for the same reasons that productivity decreases.

A typical unit cost trend line averaging CAB data for all U.S. airlines operating various aircraft in late 1970, including the B-747, is shown on Fig. 8. I did not have the latest CAB data, but the characteristic has not changed significantly (although costs are probably somewhat higher).

Figure 9 illustrates a simple graphical representation that can be developed to depict the economic potential or problem, for a single type of aircraft (or for a fleet of aircraft), as applied to a given airline system. Costs versus revenue production can be studied to analyze operations to maximize profits.

These basic factors and relationships have always existed and should be well understood by airline managements. Still they may not be so obvious either to the lay public or to their political representatives. It is hoped that these illustrations and figures will be useful.

Obviously these several figures represent generalizations which cannot be applied *in toto* to any specific airline's operations. Most of the segments of a given system are of different lengths, and airplanes cannot often be scheduled to carry the biggest payloads over the most reasonable distances and operate for the maximum hours per day or per year. Nevertheless, these trend graphs should help everyone understand the basic causes for rapidly escalating unit costs in short haul transportation and associated reduced payload and revenue production potentials.

Conversely, the only reason why we can have long haul air transportation at such reasonable rates is due to the great revenue productivity possible by taking advantage of the airplane's speed over long distances, where there has been good response from the public so as to maintain relatively high load factors. Increasing the size of the aircraft wherever and whenever there is sufficient traffic, is an obvious means to reduce unit costs and/or increase revenue.

Timing is Crucial

When the B-747's were first operational and shortly thereafter, coincident with the recent recession, there was an oversupply of capacity. Many thought this airplane much too big. At that time the need did not generate enough traffic to maintain high load factors and utilizations even over the long hauls. It was disastrous to use the B-747's on short distances. For that reason a number of them were mothballed.

However, the economic picture worldwide has improved during the past two years and the situation has changed. Recently, I made some phone calls to determine where a client might find a surplus B-747 for lease. I went directly to the Boeing Company who, I felt, should be most knowledgeable. I was surprised to learn that they knew of only three aircraft possibly available at this time, and my client already knew about them.

Energy Conservation vs Human Resources Utilization

At the time of my retirement from United and for sometime thereafter, it was assumed that the price of kerosene for subsonic and supersonic aircraft would likely stabilize at around 11 to 12 cents per gallon. Within the past three years, that price has tripled. This makes for an entirely new ballgame so far as the cost of operation of all civil aircraft is concerned. Table 1, which I began to use a number of years ago, com-

Table 1 Seat mile productivity and fuel consumptions

Vehicle	No. passenger seats	Block speed, mph	Statute seat miles per hour	Seat miles per pound of fuel	Seat miles per hour per pound of fuel	Trip length, St. miles
Volkswagon	4	45	180	23.26	1,047	500
Avg. American automobile	6	45	270	14.93	672	500
Eight-car diesel streamliner	384	50	19,200	47.62	2,381	500
Light airplane	4	150	600	12.05	1,904	500
DC-3 airplane	25	158	3,950	9.01	1,423	500
DC-6B airplane	75	231	17,325	10.31	2,381	500
B-727-200 airplane	123	400	46,740	5.62	2,247	750
DC-8(super) airplane	198	400	75,240	7.35	2,941	750
DC-10 airplane	246	400	98,400	6.94	2,778	1,000
B-747 airplane	358	400	143,200	6.58	2,632	1,000
DC-8 airplane	198	475	93,060	8.70	4,130	2,000
DC-10 airplane	246	490	115,620	8.26	4,050	2,000
B-747 airplane	358	490	168,260	7.81	3,828	2,000
Boeing 2707-300 supersonic[a]	298	1384	412,432	3.97	5,498	4,060

[a] From Boeing Report D6A11850-1 April 1970

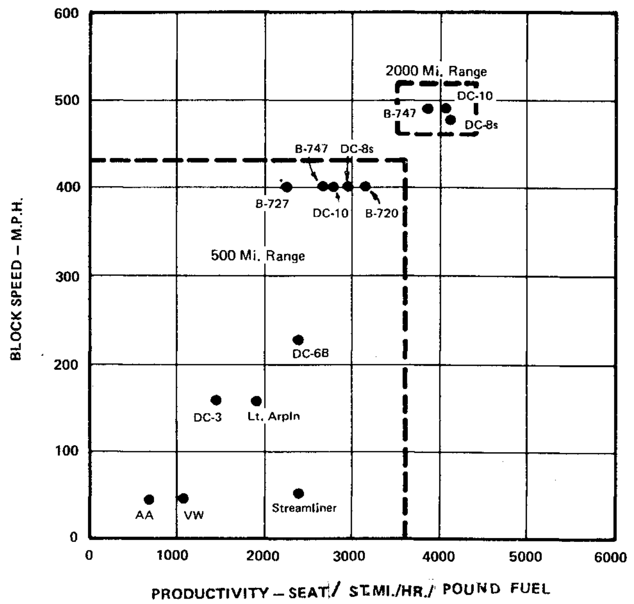


Fig. 10 Speed and productivity (from Speas Associates' analysis).

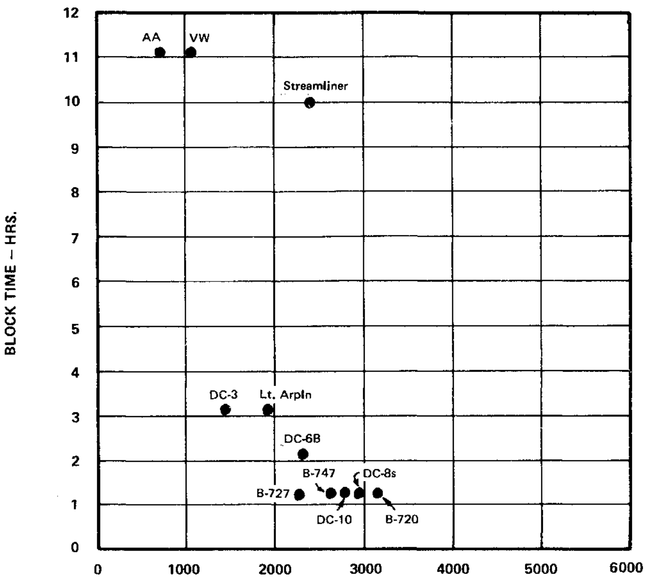
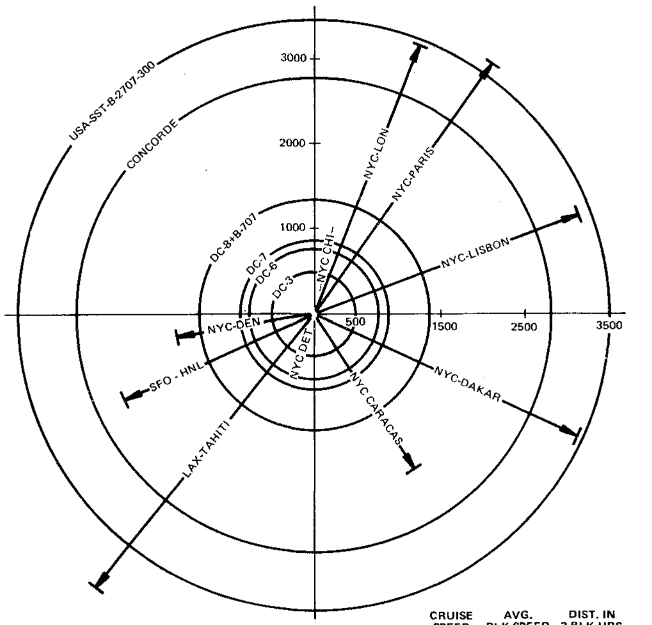


Fig. 11 Time-saving potential: 500 mile trip (from Speas associates' analysis).

pares "available seat miles per pound of fuel burned" for various vehicles.

In comparing the usefulness and unit costs of various transportation systems, the value of time savings has been submerged by the recent concerns relating to energy conservation. At the AIAA Annual Meeting in 1975, I recall discussions in which the only criterion for comparing the efficiency of various modes of transportation was "pound miles, or seat miles per gallon" of fuel. I commented that time saving and/or speed comparisons must be included in the eventual determination of the value of any transportation system.

For that reason I have proposed another measure which I think is significant; that is, seat miles or ton miles per hour per pound of fuel. Thus, we bring the rate factor into the picture, a measure which is very important with respect ot the conservation or best utilization of human resources. I have introduced this factor into Table 1, thus illustrating comparisons of the rate at which the movement of persons, goods



AIRCRAFT	CRUISE SPEED MPH	AVG. BLK SPEED MPH	DIST. IN 3 BLK HRS ST. MI.
DC-3	180	165	495
DC-6	290	250	750
DC-7	345	288	860
DC-8/B-707	560	450	1350
CONCORDE	1380	940	2800
USA-SST	1800	1167	3500

Fig. 12 Equal block time-distance comparisons from New York City for succeeding generations of civil aircraft based on 3 hrs. block time and statute miles (from Speas Associates' analysis).

and services is accomplished per expenditure of a unit of energy (in this case, per pound of fuel). One must draw his own conclusions concerning whether, in today's world, the goal should be to save energy in transportation or to better utilize human and material resources by taking advantage of the speed of aircraft. Figures 10 and 11 show these comparisons in a graphic form. Where time saving is of no significant value, slower surface transportation may be best, probably via rail, barge or tanker where feasible.

Area Accessibility Increases as the Square of Block Speed

A number of years ago I developed a chart which may be of interest for this lecture. Figure 12 depicts the distances, from various points of origin, that airplanes of different speed capabilities can fly during a three-hour period. The passenger has the possibility of access to any city within the circle represented by that time-distance relationship. It is interesting to note that with the DC-3 airplanes it was possible for the traveler to go some 495 miles, say from New York to Detroit.

The next step was from the 180 mph DC-3 to the 290 mph DC-6. The area which then became available to the air traveler, bounded by the next larger circle, is 2.3 times that for the DC-3. Next came the 345 mph DC-7 airplane which increased the circle's area 3.0 times. The following jump was to the 560 mph jet transport, increasing the area available to the traveler about 7.4 times.

Future

At the time that I drew Fig. 12 I was assuming the likelihood of having supersonic airplanes available within a reasonable length of time. The Concorde increases the area 4.4 times that for the subsonic jet and to 32.5 times the DC-3 area. Similar comparisons for the U.S. SST would have been 6.7 and 50.0 times, respectively. As all of you are aware, there has been a decided slow down in SST programs because of the recession, concern about noise and contamination of the upper atmosphere, and rapidly increasing price of fuel. The fuel cost increase has been a very serious blow to the economic viability of the SST.

I cannot predict what will come out of all of this. I can relate that just a little over a year ago I had a flight in the Concorde from London to Gander and return. Insofar as any different sensations to the average passenger are concerned, the flight was not thrilling. However, it was quite a thrill for me, as one who had worked toward the SST since 1960. I still believe that the SST has a vital place in improving the utilizations of man's capabilities and the conservation of his time, which after all, *is extremely important.*

I expect that Figs. 10-12 have little significance to most people today. So many are saying, "Let's slow down. Let's take life easy. Let's don't disturb the environment. Let's stop technological progress."

It is difficult to argue with those who refuse to acknowledge that it has been technological progress that has made possible the civilization we have today. Otherwise we would have had, not only in our country but throughout the whole world, the kind of human existence that has been prevalent in Africa and India during generations.

Most of us engaged in aerospace engineering and development are sure that there cannot be any stopping of progress. We must continue to go ahead, thereby enabling each individual to produce more and better goods and services during his lifetime than they received from society. An important factor in this endeavor will be the increased usefulness of air transportation throughout the world. The challenges for civil aviation are greater than ever before.