

THE DANIEL AND FLORENCE GUGGENHEIM LECTURE

THE DYNAMICS OF STOL

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Abstract

This paper is concerned with factors which influenced the design of STOL/Utility aircraft in Canada. These included the early research work, experience with bush aircraft and the stimulus of the Guggenheim Safe Aircraft Competition. The acceptance of STOL in remote areas and for low density traffic on 'short haul' routes is compared with the many obstacles that exist to acceptance in transportation systems on a national scale. Areas in need of more advanced development in high lift aerodynamics, drag and propulsion are described. The paper concludes with observations on the potential of the STOL aircraft to reduce energy demands in transportation.

It is a great privilege to be invited to contribute to the series of lectures dedicated to the memory of the Guggenheim family, and upon this occasion - the tenth Congress of ICAS - I am most conscious of the honour. Today, when the value of advances in technology is seriously questioned and the merits of research in the aeronautical sciences are under scrutiny, we do well to recall the steadfast support and the far-sighted benefactions of the Guggenheim family to aviation at a time when it was in its infancy.

Your Council leaves the choice of a subject for this lecture to the author, and I have chosen for the title 'The Dynamics of STOL'. In choosing STOL, the acronym for 'short take-off and landing', as the topic I was guided by the thought that this Congress would be the first to be held on the North American continent, and for many delegates it would represent the first opportunity to visit this country. Accordingly, I selected a somewhat parochial theme. The word 'dynamics' is taken in many contexts. In physics, it pertains to 'forces in action', it is used in biology

to describe 'patterns of change in growth', and in philosophy it relates to 'the reason for the existence of an object of experience'. I would like to view STOL from all of these points of vantage in my remarks this morning.

STOL has provided a focus for much aeronautical research activity in this country and I hope there will be no misunderstanding if my remarks highlight that fact. I am aware of the size of our contribution in relation to the world pool of knowledge in the aeronautical sciences. All of the countries represented here by the participating societies of ICAS have contributed extensively, and I am most cognizant of that fact.

In the aeronautical sciences we are pictured as having our eyes firmly fixed on the future. That is probably the right general direction, but we should also occasionally look backwards. In this country we have made some very costly mistakes with major programs in research and development because we failed to profit from the lessons of history.

Contributions to the science of aeronautics, and efforts to fly, date back a long way in Canada. In a well reasoned lecture⁽¹⁾ that was delivered to the Engineering Society of the University of Toronto in January 1895 by C.H. Mitchell, the early work of Lilienthal, Langley, Hargrave, Wenham, Maxim, Zahm, and many others, was summarized to deduce that heavier than air powered flight was indeed practicable. The lecturer pointed out that most attempts to fly had been made by artisans and enthusiastic amateurs who did not understand the theory. Advances in the science were more recent and there was a tendency for it to develop in parallel with the technology. What was now needed was someone who could bring the two together. These were prophetic words, for within a few years the Wright brothers demonstrated powered heavier than air flight. Unfortunately, despite the example of the Wright

brothers, and many others during the past 80 years, we still have a lot to learn about the problem of bringing science and technology closer together.

C.H. Mitchell later became Dean of Engineering at the University of Toronto, and in due course that institution became the first in Canada to regard aeronautics as sufficiently respectable to be included in courses of study. The university acquired a wind tunnel in 1918 and J.H. Parkin who came to Ottawa later to establish the aeronautical laboratories of the National Research Council, did his early work there. Considerably later, in 1949, an institute with which I am sure many members of this audience are familiar - the Institute of Aerospace Studies - was established at the University of Toronto.

It is not my intention to trace the whole course of aeronautical history in this country, but two other contributions which were made at the turn of the century are noteworthy. Wallace Rupert Turnbull is considered by many to have been the first aeronautical scientist in Canada. He built the first wind tunnel in Canada, maintained systematic records of his research, and published in the scientific journals of the day.⁽²⁾ His investigations included the mechanics of the flight of birds and the lift of an aerofoil near the ground, a problem which troubles us even today in the design of STOL aircraft. In his work on propellers he recognized the importance of scale effects and constructed a large outdoor test track. This was used in the design and development of a controllable pitch propeller - possibly the first in the world. He had to contend with the sceptics, there were many delays, and it was not until 1927 that a full-scale prototype propeller equipped with an electric drive for blade adjustment was test flown by the Canadian Air Force.

On this continent we associate the name of Alexander Graham Bell with the invention of the telephone - his fascinating experiments in the design and construction of aircraft are less widely known. It was at the suggestion of Mrs. Bell, who provided the funds, that Bell assembled a group of young engineers and formed what he described as the Aerial Experiment Association at his summer home in Baddeck, Nova Scotia.⁽³⁾

The first aircraft constructed by this team was flown from the ice of a lake near Hammondsport, N.Y., and is believed to be the first flight made in public in North America. The first machine to fly in

Canada was built by this group and piloted by J.A.D. McCurdy, who flew it from the ice of the Bras Dor Lakes near Baddeck in 1909. Among the many artifacts which are now in the Bell Museum as a tribute to the genius and untiring efforts of that group, is a co-axial contra-rotating propeller. The story behind this development is that Bell became concerned about a type of failure that occurred in many of the aircraft of that era. It was common design practise to mount twin propellers, which rotated in opposite directions to balance torque, well outboard on the wings. Since the structure was very flexible, the propellers not infrequently fouled the rigging, or the chain drives failed. Lt. Selfridge, a former member of Bell's team was killed in a Wright biplane due to an accident of this kind. Following that tragedy Bell decreed that propellers should be used in a more compact arrangement, and, as a solution, proposed the co-axial drive.

This was typical of Bell who had no patience with the rather human tendency to cover up or forget mishaps as quickly as possible. In insisting that accidents be thoroughly investigated, the causes analyzed, documented in detail, and given the widest possible publicity, he anticipated by many years the procedures which we now take for granted.

Looking back one may feel twinges of envy at the euphoric environment in which the Aerial Experiment Association flourished. Bell, at the height of his prime, was an inspiring leader. Each person could assimilate all of the literature that had been published on the subject of aeronautics, and carry out his own project - with Bell as a friendly advisor. The materials of construction and methods of assembly came readily to hand. Money seems to have been no problem - anything more in contrast with our bureaucratic procedures today is difficult to imagine. No doubt we view the past through rose tinted spectacles, but the Aerial Experiment group is credited with many firsts, and for those of our visitors who have the time and inclination for a holiday in Canada I can recommend a visit to the Bell Museum at Baddeck in the highlands of Nova Scotia.

You will appreciate that due to the large land mass of this country, the resource based economy, and a relatively small population, we are more dependent than most upon transportation - and particularly transportation by air. Most Canadians live in a narrow band of territory which is 200 miles wide and extends 3000 miles along our border with the United States. This is not so much due to the hospitality of the Americans -

although we get along with them very well - as to the nature of the Canadian winter. As a result, the population density in the rest of Canada - an area of some three million square miles north of this narrow band from east to west - averages out at about two hardy souls for every one hundred square miles of territory.

Despite the small number of people who live in this area it is rich in resources, and the boom came in the 1920s with the discovery of gold and other minerals in the north. This created a large demand for air transport, and for a number of years the quantity of passengers plus freight transported by air was probably greater than that of any other country. To understand how that could be accomplished in the rather small and primitive aircraft of that era, equipped with floats and skis and a legal payload of less than 1000 lbs, we must appreciate that the alternatives - depending on the season - were canoes and dog sleds. In these circumstances, and particularly during the spring break-up when surface transport would be at a standstill for months, the attractions of air travel were strong.

The need for aircraft that were rugged, easy to maintain and would operate reliably in this rather demanding environment had a marked influence on design. Many modifications that were incorporated 'in the field' would not be approved by our airworthiness authorities today. There is little evidence that the classic paper on the Streamline Aeroplane, published in England by Professor Melvill Jones in 1929, had any influence on the design of aircraft for the Canadian bush. This is not surprising for the aircraft were encumbered with pontoons during the summer months. And indeed, with freight which was too large to go inside the cabin, it became common practise to strap on the outside of the aircraft such items as canoes and lumber - even pianos were transported to frontier camps in this cavalier fashion.

The early bush airplanes were equipped with open cockpits, a design feature which derived from the opinion - widely held at that time - that the pilot should feel the wind on his face in order to be fully aware of the attitude of his aircraft. Pilots, not unnaturally, questioned the need for so intimate an association with the environment - particularly when it was 40° below zero - and I recall an encounter with an astonished bush pilot who had built a rudimentary cockpit enclosure for reasons of comfort and discovered the cruising speed of his airplane was noticeably

improved. On the maps of Canada there are some 60 northern lakes and rivers named after the early pilots of bush aircraft, and for their role in the development of this country we owe them an enormous debt.⁽⁴⁾ The aircraft they helped to develop became the basis of an important industry and prepared the way for the evolution of STOL.

In the decades of the 1920s and 1930s there were many spectacular flying achievements around the world, and in many countries solid technical progress was evident. By comparison, advances in aerodynamics were slow and many flying accidents - loosely attributed to 'pilot error' - were due to serious shortcomings in stability and control. Early in 1927 the Guggenheim family agreed to sponsor a competition in America for the development of a 'safer aircraft'.⁽⁵⁾ Characteristically, the Guggenheims got to the heart of the problem. They did not offer to support research on slotted wings or flying controls or whatever was deemed necessary to patch up deficiencies in the design of existing aircraft. A simple specification was issued to describe what was required of the end-product, and it was the responsibility of the aircraft designer and manufacturer to determine the best means to that end. For modern research proposals we should be reminded of that approach!

The most interesting requirement of the contest was for the aircraft to take off and climb from a field which was 500 feet square and bounded by trees 25 feet high. As a safeguard against engine failure during the take-off and climb the pilot was required to demonstrate a landing within the field from any point on the flight path. The winner - the Curtis Challenger - accomplished this. It was no mean feat, and I vividly recall efforts to match that performance, albeit with a somewhat higher wing loading, many years later.⁽⁶⁾

Today, with the lengths of runways at metropolitan airports specified in statute miles, I suppose it is not inconsistent to accept flight path gradients on the approach to a landing that place the conventional transport aircraft at tree-top height one-quarter mile short of the point of touchdown. For STOL we feel that the performance requirements should be more demanding, and a few years ago, as the result of a considerable effort in flight testing, it was concluded that the optimum flight path would place the aircraft at tree-top height about 200-250 feet short of the touchdown.⁽⁷⁾ That corresponds almost exactly to the glide path angle of 13° specified in the Guggenheim competition some three decades earlier.

The importance of low-speed performance to minimize the risk of accidents in take-off and landing requires little by way of justification. But what is so often ignored, even today, is the importance of the handling qualities and the ability of the aircraft to manoeuvre at those minimum speeds. We should remember that, primitive as were the rules, the organizers of the Guggenheim Safety Competition did not fall into this error. Indeed, the emphasis on high lift and controllability at low airspeeds produced a wide variety of shapes and sizes in aerofoils, flaps, slats and slots. One design even anticipated the form of the augmentor wing we are so interested in today.

In all, the contest attracted approximately 30 entries, although many fell by the wayside during the course of the tests. Two aircraft only survived the competition. The Curtis Challenger design was the outcome of an extensive series of investigations in the wind tunnel, followed by test flights, and embodied a number of advanced ideas. It satisfied all the conditions and was declared the winner. The Handley-Page entry was a close runner-up.

It is unfortunate that the results of the Guggenheim Safety Competition were not accepted widely, and the important lessons to be learned on aircraft handling and manoeuvring at low airspeeds were largely ignored. The popular emphasis was on performance, not safety, or cost, and in due course the economic disasters of the 1930s became a major distraction. We paid a high price for that neglect, and it was not until the urgent necessities of World War II became apparent that the problems of stability and control began to receive serious attention in the aeronautical laboratories of the world.

If I may now turn to the Canadian scene again - you will recall that in order to make use of the airstrips provided by nature the bush aircraft I referred to earlier typically operated on skis and floats. In the take-off with skis the sliding resistance may be very low or very high, depending on snow conditions. With wave-making at low speeds and planing at high speeds, floats produce a substantial drag force in the take-off. As a result the take-off of early bush aircraft tended to be somewhat prolonged, and operations from small lakes were hazardous. The introduction of more powerful engines, large diameter geared propellers, and relatively sophisticated flap systems in the 1940s and 1950s, effected a marked improvement - and if the change in seaplane performance was

significant, it was likely to be spectacular in the land plane version of the same aircraft. Indeed, bush/utility aircraft designs that evolved by that process were capable of clearing a 50 ft obstacle at the end of a 1000 ft airstrip. This enabled many bush operators to abandon floats, and, operating from improvised airstrips, to use land planes all the year round. In course of time these aircraft demonstrated that the STOL/utility requirement was not peculiar to this country, and today their lineal descendants are providing useful services in many parts of the globe.

This is not to say that demand for air services to remote areas of Canada has diminished since the early days of bush aircraft. On the contrary, there are few roads in eastern Canada north of the 50th parallel, or in western Canada north of the 55th parallel. The prospect of providing access to three million square miles of territory with roads that may cost \$1 M/mile is intimidating.

In this vast area there are at least 200 permanent communities with a population ranging from 100 to 1000 persons where there is no regular year-round access by surface transportation.⁽⁸⁾ In addition, there are many mobile and semi-permanent activities concerned with mineral surveys, drilling rigs and resource development generally. The problems of providing air services to these communities are primarily economic and social, rather than technical, and government assistance is usually required to provide a minimum of facilities. As the community may have to construct the airstrip from its own resources, and the volume of traffic is small, large airfields are out of the question and the small STOL aircraft is the logical choice of vehicle.

Regional and commuter airlines employing STOL aircraft are more recent in origin, and, by contrast to services in remote areas, are expected to become economically viable and operate in competition with surface transportation. Having led the world with air services to remote areas, and, somewhat later, having developed a respectable network of air carriers to serve major cities, it is ironic that we have failed to provide support for regional air services between the smaller cities and larger towns a few hundred miles apart. The basic problem is economic. There is always the fear, usually justified, that in the early stages of operation the volume of traffic will be too small to provide the revenue required to justify the capital investment. As a result, when initiatives of this kind have been undertaken in the past there has been inadequate backing, a tendency

to provide obsolescent equipment, aircraft that were too large, a low frequency of service, and time schedules that were inconvenient. In the outcome, many short haul services have acquired a bad public image. On the other hand, a number of successful services will attest to the fact that with a realistic appraisal of the market, and a sensible investment in modern aircraft and facilities, airlines of this type can pay their way after a reasonable 'introductory' interval.

A recent example has been the introduction by the Ontario Provincial Government of a northern air (NOR-ONTAIR) service.⁽⁹⁾ In the beginning, light twin-engined STOL aircraft were used to link four communities in northern Ontario. The population of these communities ranged from 20,000 to 85,000 and the stage lengths from 90 to 200 stat miles. The planning for this service was thorough, and the relatively simple models that were used to project passenger growth and distribution, operating costs and revenues, have proven to be reasonably accurate. The success of this enterprise has encouraged the sponsor to expand it to other communities and to bring in a number of commercial operators to provide the services.⁽¹⁰⁾

Bearing in mind that our railroads have reduced passenger services to the smaller communities, and that the cost of three or four miles of modern highway will provide a STOL-port, I believe the northern Ontario experiment could be repeated to advantage in many parts of Canada. A few major additional airports are not the solution - the concrete used in the construction of the 12,000 foot runways of a single modern 'metropolitan' airport would provide STOL runways for every community in Canada with a population of 10,000 people.

In contrast to the regional type of service I have just described there are a number of examples on this continent where commuter air services operate a 'hub and spoke' system. These feed passengers from the surrounding communities into a central airport where they can connect with the main airlines. With STOL aircraft it is feasible to operate between a small community airport and special assigned runways at a major centre without conflict with heavy traffic.⁽¹¹⁾ Although a number of commuter airlines are catering to vacationers, and services of this type are growing rapidly, the majority of travellers are on business. Accordingly they expect the commuter airline to meet the standards of the major carriers in the reliability and regularity of the services they provide.

Facilities for navigation and communication that will permit operations in any kind of weather are therefore essential.

Much of the resistance to the introduction of new air services stems from the concern that it would impose an additional burden on existing traffic systems. It never ceases to surprise me that in an age when we can pin-point with great accuracy a landing spot on another planet we continue to rely essentially upon visual OMNI range (VOR) stations for guidance in aerial navigation. The limitations of the present system which funnels all traffic through channels between VOR stations and overloads the control capabilities in terminal areas, are well known. They present a particularly serious handicap for short range STOL where the need is for each aircraft to have a simple, direct flight profile from take-off to touchdown, without interference with the 'mainline' traffic and with navigation the responsibility of the pilot. 'Area Navigation Systems' of this kind exist and have been demonstrated.⁽¹²⁾ It is to be hoped that the problems of complexity and cost will be overcome and that they will soon come into routine service.

I remarked earlier on the importance of a steep landing approach for STOL, and that precise guidance on the glide path is essential. Existing facilities for instrument landings with conventional aircraft are obsolete, and for some time there has been an active search underway for a successor. Microwave Landing Systems (MLS) are the leading contenders, and at least six different systems developed independently by six countries have been proposed as candidates. I hope this surfeit of riches will not be too severe a test of international harmony and that an agreed standard, compatible with the requirements of STOL as well as conventional aircraft, will soon be adopted.

The modern versions of STOL/utility aircraft which operate in remote areas and provide short haul regional services of the type I have described above bear little resemblance to the early bush plane. Notwithstanding products of modern technology, such as turbine engines and propeller controls, for example, that are incorporated in these designs, I think it is fair to say that technical progress has been evolutionary rather than revolutionary. Indeed, with these aircraft it may well be that the technology has reached a plateau where efforts to produce further improvements will be very costly. I would suggest that the need in this class of aircraft is not so much for advances in propulsion and aerodynamics, where the knowledge already exists and is awaiting application,

but in new materials and highly organized advanced methods of manufacture. These advances will not be achieved with materials and methods of forming and assembly that are traditional in light aircraft.

Accordingly, I would argue that the focus should be upon the development of new materials which would permit structures of the required shape and stiffness to be assembled with a minimum of joints. I am not thinking of the high strength fibre reinforced composites that are beginning to find application in military aircraft, but rather of the low density materials that have invaded the high performance sailplane design field in Europe. A great deal remains to be learned about how to use these materials to best advantage, and these lessons will have to be learned in the field and on the shop floor, as well as in the laboratory. The objective is the elegant simplicity that is the hallmark of good design.

While technical advances help, I believe it is even more important to find new and better ways of doing business. To realize the potential of small feeder airlines we must establish closer ties between main and subsidiary airlines, common use of certain facilities, and, perhaps above all, better cooperation with and between the various agencies of government.

If we accept the thesis that new and radical aircraft technology is not likely to appear in the near future, we may well ask what happened to the spectacular advances that were predicted for this decade of STOL? You will recall the ferment of technical activity a few years in the aviation world. Analytical studies and papers reporting on the results of research projects were appearing in respected publications at a rate of 15-20 per month.⁽¹³⁾ Large-scale wind tunnel models were lined up awaiting a turn in the wind tunnel, and many kinds of full-scale aircraft, ranging from vestigial test rigs to prototype transports, were taking to the air. Passive high lift devices were passé - we had examples of powered lift through boundary layer control, slipstream deflection, jet flaps, wings and powerplants that tilted, fans buried in wings, compound helicopters, and the augmentor wing accompanied, I need hardly add, by annual expenditures on the related R&D approaching \$100 M/year.

In addition to a number of STOL projects in this country⁽⁷⁾ several tilt wing aircraft were developed by Canadair which could also take off and land in the vertical mode. These have now accumulated

nearly 500 hours of flying time.⁽¹⁴⁾

A few years ago many cities designated STOL-port sites. In the New York area a 40,000 lb STOL transport aircraft demonstrated take-offs and landings from city parks. A major airline conducted an extensive series of tests on a 4-engined transport to demonstrate STOL and examine system requirements. Despite this great activity, and the development of small air services along the lines I described earlier, STOL has made no major impact upon intercity transport services.

We now know that our expectations of the widespread adoption of STOL for major air services was unrealistic. There are many explanations, and the problems are not all peculiar to the aircraft industry. The public distrust of new technology is a familiar phenomenon - what is more disturbing is a growing loss of confidence in the abilities of scientists and engineers to come up with answers that are in the public interest.

This growing loss of confidence by the public may well be the biggest challenge we face in science and engineering. It is now quite clear that in order to find the answers we will have to learn a great deal more about the social and behavioral sciences. With about 40 million people on this continent living in a noisy⁽¹⁵⁾ environment, and about 20% of that number exposed to aircraft noise, we should not be surprised when we meet resistance to the conception of STOL-ports in urban centres. One may also wonder if we have our priorities right when all public concern seems to centre on the case for transportation in major cities. As a stimulus for the economic and cultural growth of this country, should we not be concerned with services to smaller communities?

A part of the problem of winning public support for the main issues is in the difficulty of persuading all of the multiplicity of government jurisdictions to work together. To this there is no easy answer - perhaps we may hope that in learning more about human behavior we will also devise better ways of conducting our affairs at the various levels of government.

We have learned to our cost that the spur to industrial progress is in the marketplace and not, simply, in developing new technology. In the business climate that has prevailed lately, and with the questions that have been raised about the public acceptance of STOL, the new markets that are needed to justify a substantial capital investment have been slow to appear.

In the face of these difficulties I believe it is clear that we will have to pay far more attention to the economic justification for STOL. The data and the analytical techniques exist - the problem is to extract the data from all of the sources and to assemble it in a form we can understand. Until we can do this with STOL and with competing transportation systems, and make some valid comparisons of capital and operating costs, the prospects for significant advances in efforts to rationalize transportation systems are not very bright.

If there are no short-cuts to solutions of these problems, at least we can detect some positive trends at this time. A few commercial services are providing meaningful costs and operating data. Government sponsored demonstration services, when they are conducted by commercial operators in realistic situations, can also help in 'spreading the word' and winning the confidence of the public. During the final year of operation of the STOL demonstration service between Ottawa and Montreal - sponsored by the federal government - more than 90,000 passengers were carried.

While it is apparent that research in the more traditional fields of science and engineering cannot provide answers to many of the problems I have described, we must be careful not to relax our efforts. Today, with science budgets severely strained, research is often discouraged on the grounds that our society is not willing to accept new technology and that the market is not ready. If that thesis is adopted we can be sure that the market never will be ready. STOL is a case in point; the problems that must be solved to ensure social acceptability or economic viability cannot be treated separately from the research required to reduce the noise of the powerplant or the drag of the airframe.

Let us consider the realm of high lift for example. In choosing a wing small enough for comfort and speed in cruising flight, and large enough to permit landings on conventional airport runways, the aircraft designer must make a compromise that is difficult under the best of circumstances.

It is even more difficult in aircraft designed to use the short airstrips appropriate to STOL, and the practise in the small airplanes I described earlier has been to use a relatively large wing and accept the penalties of a reduced cruising speed and a rough ride in turbulent air. With the next generation of STOL the aircraft will be larger, the cruising speeds will be higher, and a more comfortable ride will be

essential. As a result, the designer will be forced to use wing loadings approaching those of conventional transport aircraft. To satisfy the low-speed requirements he will have to accept the need for high lift devices of considerable complexity.

Research on high lift devices has been active since the beginning of flight. As far back as the 1930s the winning aircraft in the Guggenheim safety contest demonstrated a power-off lift coefficient of 2.4. That was quite an accomplishment - some two decades later we found it no easy task to match that figure in the design of a single engine monoplane which had to satisfy an ICAO requirement, long forgotten, for a minimum flight speed of 56 m.p.h. Today, through a better understanding of the theory,⁽¹⁶⁾ and vastly improved testing facilities, values well in excess of a lift coefficient of 4 are being demonstrated in the wind tunnel with modern air foils and conventional passive high lift devices.

In defining STOL I assume that we have in mind runway lengths of less than 2000 ft and approach speeds well under 80 knots. To satisfy these conditions with a usable lift coefficient of 4, the maximum wing loading that can be used is about 60 psf. This is probably the lower limit for a comfortable ride at the speeds to which the modern airline passenger has become accustomed. As a method of reducing aircraft response to gusts, aerodynamic devices which are capable of modifying lift have been proposed. Direct lift controls may also be used to advantage in the landing manoeuvre⁽¹⁷⁾ and further research on applications to STOL aircraft would appear to be warranted.

These devices have yet to be proven, however, and it is now generally accepted that in the larger sizes of STOL aircraft lift coefficients higher than those available from the best of passive high lift devices will be required, and that power must be used in some way to augment lift. The requirement for powered lift is the characteristic that distinguishes STOL from conventional aircraft. The energy of the powerplant is used to increase lift and permit flight at low air speeds. While it sounds simple in principle, powered lift has a profound influence on stability and control, and introduces many problems in the handling qualities of the airplane.

The most straightforward way to accomplish powered lift on a propeller driven aircraft is to use large chord flaps on the wing in the wake of the propeller and deflect the slipstream downwards. At high power settings the gain in lift is impressive - unfortunately

in the landing manoeuvre, where we require drag in the horizontal direction, thrust can become a distinct embarrassment. A number of schemes have been proposed to provide the required drag in the landing manoeuvre and to offset the related problems in stability and control. One of the most successful solutions, demonstrated by De Havilland, has been the use of a small 'booster' powerplant to provide positive or negative thrust at will⁽⁷⁾ without disturbing the lift, and hence the speed on the glide path.

If you are wondering at the reference to propeller driven aircraft I should hasten to explain that propellers are not going to disappear from the scene in the near future. From many standpoints - high thrust for take-off, powered lift for landing, low fuel consumption in the cruising flight, a fine thrust control on the glide path and reduced noise - the modern propeller has distinct advantages. De Havilland Canada, in concert with the Canadian Government, had demonstrated confidence in the future of propeller driven aircraft with the development of the DASH-7 STOL transport.

The principal drawback of the propeller is the reduction in efficiency at high airspeeds. With modern developments it appears possible to delay this to speeds well above those of interest to short range aircraft. With long range aircraft, and cruising speeds above 70% of the speed of sound, the by-pass turbine is superior, and may be an acceptable compromise despite shortcomings in its ability to generate lift.⁽¹⁸⁾ The United States Air Force has adopted this solution for the advanced medium STOL transport (AMST) prototype aircraft currently under contract.⁽¹⁹⁾

With a jet engine, an elegant solution to the problem of high lift is to pipe the hot efflux from the powerplant to the wing trailing edge and to eject it downwards and aft. No complex flap systems are required, the high velocity gas performs the function of a flap as well as supplying propulsive thrust for take-off. A drawback is in the problem of handling the high temperature gases, and with the modern turbofan engine it appears that the augmentor wing, as developed by De Havilland, is a preferred solution.⁽²⁰⁾ The augmentor wing has been the subject of many technical papers and I will not attempt a description here, but the basic principle you will recall is to tap air from the compressor, or the fan of the main powerplant, and eject it at a high velocity over the entire wing flap system. The mass flow of air involved is large and

provided the engine is matched to the requirements, and the duct losses are not excessive, the momentum of this air contributes lift at low airspeeds and thrust in cruising flight. In addition, there is the possibility of using the effluent for a measure of boundary layer control to reduce the profile drag of the wing and to postpone a drag rise at the high end of the speed range. Recent research on new aerofoil shapes has shown that a relatively thick wing can be used on high-speed aircraft. This has interesting implications for the augmentor wing because it could provide additional space for air ducts or, alternatively, a larger span of wing for a given weight and a reduction in the drag due to lift.

The drawback to the augmentor wing is the requirement for an engine developed specifically for the task - engine manufacturers are understandably reluctant to produce engines tailored to a particular airplane. While a great deal of work remains to be done in stability and control, for example, the augmentor wing represents an attractive solution to the problem of integrating the powerplant with the aerodynamics of the air frame.

We have become highly conscious of the importance of conserving energy. For the choice of transportation systems the efficiency of the system in terms of energy requirements - rather than speed - may well become decisive. In my remarks earlier I stated that 'high' cruising speeds necessitate high wing loadings, and these in turn dictate the use of powered lift to satisfy low speed demands. In this context 'high' speed is a relative term: it must be high enough to compete with ground transport and conventional aircraft operating between major airports and high enough to provide a saving in time that justifies the fares. However, the STOL mission is essentially short range, and with increasing speeds a limit is approached where the reduction in the time of the total trip is negligible. An increase in cruising speed from 65 to 79% of the speed of sound, for example, represents a significant technical advance and may compromise the design of the aircraft in many important respects. At the lower speed, for instance, it is quite feasible to use a propeller - rather than turbofan - with the possibility of saving fuel. At the higher speed the gain is about 100 miles/hour and represents a difference in block time of less than five minutes in a 300 mile flight.

In a recent lecture delivered in honour of Rupert Turnbull⁽²¹⁾, Cockshutt has proposed a dimensionless ratio - the energy

content of fuel, in units of work, divided by payload times distance - as an index of transportation efficiency. On this basis the automobile, the subsonic transport aircraft, and the current generation of STOL aircraft are comparable in energy cost, and it depends on the number of passengers, i.e. the load factor, to determine which mode is superior.

In view of discussions about revivifying the railroads and restoring passenger services in this country, it is interesting to observe that STOL aircraft are competitive on an energy cost/passengers mile basis with the volume of traffic using the railroads today. For the transport of bulk cargo, rail is an order of magnitude superior, but it will require a substantial increase in load factors for the railroads to become more efficient in terms of energy demands for passenger services. We should of course note that this does not take into account the energy required in the first instance to set up or maintain the system as a whole, and no doubt this assessment would be favourable to the air mode.

In his lecture Cockshutt shows that whereas the present generation of 'wide body' transport aircraft is efficient on stage lengths of more than 1000 miles, there is a considerable margin for improvement in the efficiency of aircraft used for shorter trips. This point is noteworthy since it is the short haul services - 400 miles and under - which attract the maximum number of passengers.

Efforts to introduce new technology into the older and well established ground modes of transportation in order to save energy have not been highly successful, and it appears that substantial improvements are unlikely. By comparison, STOL is at an early stage of development, and if it can compete with older systems today it should face a very bright future when the benefits of further advances in aeronautical technology become available. With the rate of increase of fuel prices to demonstrate the need, it should not be difficult to justify renewed efforts in R&D to improve aircraft design, placing particular emphasis on improvements in propulsive efficiency and reduction of aerodynamic drag and structural weight.

The fuel consumption figures for the engines most recently placed in service are a significant advance, and the pressure ratios and temperatures of advanced technology engines now on the drawing board show promise of further gains. These advances projected for the high by-pass fan

engine apply equally to the propeller turbine, and, in the light of recent advances with both propellers and fans, it is an open question which will be adopted for the STOL aircraft of the future. Perhaps the distinction between propellers and fans will disappear as fans expand in diameter and shrouds shrink in chord.

Concerning drag, we have come a long way since the Melvill Jones' lecture I referred to earlier, and substantial progress has been made in our understanding of boundary layer phenomena and the influence of the shape of a body on drag. Efforts to reduce body drag by suction and blowing have not been notably successful, and the best prospect for progress, I submit, will be found in a closer integration of the powerplant and the air frame. This is not easy to accomplish because the cost of modern engine development is prohibitive if the anticipated application is limited to any single type air frame. A promising trend is the development of 'basic' powerplants with 'building block' modules that can adapt to a wide range of applications. This will assist, one hopes, in developing the close cooperation between the creator of the powerplant and air frame which is vital at an early stage of a new design.

Concerning air frames. It would appear that radical changes in the design of aircraft in the transport category are unlikely and weight savings will probably be modest. Improved composite materials, reinforced with high strength filaments, are being used to an increasing extent in military aircraft and no doubt will find applications in some highly stressed components of civil aircraft where the weight savings will justify the costs. (I referred earlier to the possibility of using moldings and low density materials in the structures of small and medium sized STOL aircraft.)

It seems likely that the greatest structural gains, and hence potential weight savings, will come from further advances in aerodynamics. I mentioned recent work on aerofoils which permits thicker sections to be used at high speeds and may reduce the need for a swept wing. These developments may be used to save weight, or to increase performance. If we wish to be more daring we may contemplate the use of an 'active' control system in the aircraft to reduce loads on the structure when a gust is encountered.⁽²²⁾ This would permit the use of smaller tail organs or possibly eliminate them altogether. With active controls the airplane is deliberately made unstable. The prospect of relying entirely upon electronics to constrain the vehicle is somewhat

daunting - but I have no doubt that we will come to it eventually.

I would conclude that the potential of STOL for a national transportation system will not be realized until further work is done on propulsion, aerodynamics, materials and methods of construction. In parallel with research on technical problems it is essential that we acquire a better understanding of the social and economic implications of new developments. For STOL air services to become viable and expand we will have to acquire better cost data, better working arrangements with government agencies, and better methods of doing business.

No matter how challenging the problems we see ahead, Mr. Chairman, we can continue to profit from the example of the pioneers whose knowledge, insight, understanding and motivation, established the foundations of the science. Although I have mentioned a few, only, no list would be complete without the name of the founder and first honorary chairman of ICAS, Dr. T. Von Kármán. It is typical of his foresight that he published jointly with Gabrielli a paper which anticipated by 25 years the concerns I expressed on energy costs in transportation.⁽²³⁾ If we plan our endeavours with the foresight of Von Kármán and the wisdom of the Guggenheims I believe we can look forward with confidence to the future of the aeronautical sciences.

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