Powered Lift Systems

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PROFESSOR J A J BENNETT (*Chairman, Lecture Committee*)
occupying the Chair

The CHAIRMAN, in opening the meeting, said that Mr Zimmerman, a member of the scientific staff of the National Advisory Committee for Aeronautics, at Langley Field, Virginia, had long been concerned with the development of S T O L aircraft, having originated and developed the Chance-Vought circular-wing project during the war at Stratford, Connecticut In the rotary wing field, he was perhaps best known as the originator of the Flying Platform, having designed and built at Nicholls, Connecticut, shortly after the war, his so-called " Aerial Motor-cycle," which had two side-by-side lifting propellers of disc loading about 20, interconnected by a tiny platform which he strapped to his feet like skis By 1947, he was able to demonstrate to his satisfaction that this device required no controls other than a throttle for the two engines, and that he could hover safely by applying the same reactions to his feet as he used for balancing himself when standing on the ground

It was merely a matter of getting used to the feel of the machine, like learning to ride a bicycle When later he returned to Langley Field he built another flying test rig on the platform principle This could be flown with no controls except a valve controlling the supply of compressed air through flexible tubing to a jet nozzle from which the device derived its lift

After such a convincing demonstration at Langley Field, it was necessary for a platform to be built with a self-contained power system, and the Hiller ducted-fan project was a spectacular result of this

Tonight's lecture was the first to be given before the Association on powered-lift systems other than those incorporating rotating wings, and the Association was very much indebted to Mr Zimmerman for coming over from America to give an authoritative and first-hand survey of the work that was taking place in this field, in which the N A C A was playing an important part

SUMMARY

An aircraft capable of competing in time, convenience, and economy as a means of transportation between metropolitan centres 100 to 300 miles apart will necessarily utilize a powered lift system in order to operate from very small airports or heliports Three aircraft utilizing such systems and suited to such service are described for the purpose of bringing out the problems and compromises involved

Subsonic intercontinental jet transports must either operate from very large airports or carry installed thrust greater than that required for cruise in order to take off from runways of moderate length (5,000—6,000 ft) A 300,000 lb jet transport using retractable high thrust-to-weight ratio engines in conjunction with an external-flow jet-augmented flap is described and discussed to bring out the problems involved

It is concluded that powered lift systems can be used to provide aircraft suitable for operation between city centres and to permit operation of large intercontinental jet transports from fields of moderate size It is pointed out that there are serious problems to be overcome of which high cost and extreme noise are probably the most important

INTRODUCTION

The increased size and speed of modern transport airplanes have resulted in an increase in the time required to travel by air between metropolitan centres less than 300 miles apart to such an extent that it is becoming once again more convenient and quicker to make the trip by train This apparently paradoxical situation arises, of course, from the fact that larger, faster airplanes require larger airports and these, in turn, tend to be located at greater distances than in the past from city centres There is, therefore, a growing need for economical, high-performance transport aircraft which can operate from very small airports, or heliports, near city centres

Jet transport airplanes designed for high efficiency when cruising at high subsonic speeds have relatively high wing loadings and relatively low values of thrust/weight ratio for take-off This combination of characteristics results in requirements for large airports and may seriously limit operational utility and flexibility Projected long-range jet transports, for example, need airports having runways 10,000 feet, or more, in length Relatively few cities have such runways The best solution may be the construction of more large airports However, it seems of interest to examine other possibilities

The development of turboprop and turbojet engines in recent years has made it not unreasonable to consider the use of power to increase the ability of aircraft to produce lift at low speeds and hence to operate from smaller airports There have been, as a result, a great deal of interest and notable developments in this field When asked to prepare a paper for the Association, the author had at first intended to attempt a discussion of all the more promising powered lift systems It soon became apparent that time and space limitations would not permit such an ambitious undertaking It did not seem worthwhile to attempt a brief review which could in large measure only repeat what is already available in the literature It was finally decided to prepare specific designs to meet definite requirements utilizing certain of the more promising powered lift systems with which the author is familiar in order to bring out the problems and compromises involved These designs are not offered as being the best solution They are offered to stimulate your thoughts on the subject These designs utilize two general types of powered lift systems, namely, propeller-wing combinations and jet-wing combinations Three airplanes have been designed for STOVL (short take-off, vertical landing) operation between heliports, or very small airports , a fourth is a large, long-range, jet transport capable of operating from airports of moderate size These aircraft will be described and discussed in turn

Propeller-Wing Powered Lift Systems

The classical ways to reduce airplane take-off and landing runs are to decrease the wing loading and/or increase the capability of the wing to develop a high lift coefficient by use of slats, slots, and flaps Both of these approaches have practical limitations as you well know Low wing loadings result in low cruising speeds, or low lift/drag ratios at high cruising speeds, and high ratios of structural to gross weight, especially in larger aircraft High maximum lift coefficients are attainable by use of slats, slots, and flaps only at the expense of structural weight and, even with the most effective of these devices, the maximum lift coefficient attainable is of the order of 4

High lift coefficients can, however, be achieved by utilizing the slipstreams of propellers located ahead of the wing as has been well known for many years Some 20 years ago the Crouch-Bolas airplane made use of this concept to achieve short take-offs and landings About 1947 Breguet embarked upon a programme to develop a wing-propeller combination having a number of propellers disposed along the span of a heavily flapped wing with the objective of attaining high usable lift coefficients In 1950 the NACA embarked upon a programme to explore the possibilities of an airplane in which this concept would be carried to the ultimate of deflecting the slipstreams substantially 90° so that with the developed thrust equal to the weight, the aircraft could support itself in hovering flight and could hence make take-offs and landings without ground run This too was not a new idea A brief search of the literature revealed a patent covering a feasible means of doing this issued in 1921 As in many similar cases, however, a device which was completely impractical with the powerplants available in 1921 may be quite practical with the powerplants of 1965 or 1970

I will not bore you with the details of the NACA investigation which is rather thoroughly covered by McKinney in Ref 1 From it have come two basic wing-propeller combinations which appear to offer the possibility of practical high-speed air transportation between points having landing areas permitting little or no ground run These are the deflected-slipstream airplane, very similar to the Breguet development, and the tilt-wing airplane In order to give point to this discussion, sketches and rough weight and performance estimates have been prepared for one airplane of each type to meet a common requirement

The requirements used as a basis for the airplanes to be discussed are

(*a*) A passenger payload of 13,500 pounds ,
(*b*) Still air range 1,000 statute miles at 300 knots at 20,000 feet altitude ,
(*c*) Hover 3 minutes at sea level with full gross load ,
(*d*) Retain full control and the ability to land safely in the event of failure of a power unit

The major assumptions, aircraft dimensions, and estimated weights are given in Appendix I

These designs are not presented as optimum or recommended airplanes Neither the time nor the experienced manpower is available to your speaker to prepare highly accurate, refined designs or to make optimization studies Certain of the assumptions as regards weight and drag are believed to be optimistic but not out of the realm of possibilities

Description The deflected-slipstream airplane is shown in Fig 1 This airplane is estimated to weigh 79,000 pounds and is powered by four 2,650 horsepower turboprop engines These engines drive six 16-foot-diameter propellers through a common line shaft By means of suitable clutches, each engine and each propeller may be individually disconnected from the system in case of failure The two outboard propellers are designed for high static thrust and are stopped and feathered in cruising flight The engines deliver 2,650 horsepower at 300 knots at 20,000 feet and are restricted to this output at lower altitudes

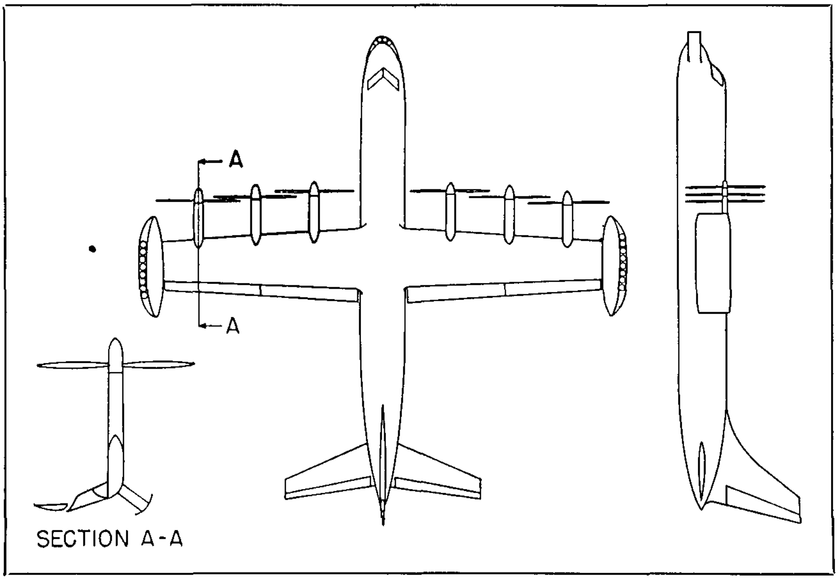

Fig 1 Deflected slip stream STOVL

The slipstream-deflecting wing is of the type described by Kuhn and Draper in Ref 2 and in co-operation with the propellers will produce a resultant force vector in hovering flight equal to 90 per cent of the propeller static thrust and acting upward at an angle of 70° to the wing chord plane Note that this wing utilizes an auxiliary turning vane which retracts into the wing just forward of the flap

The turboprop powerplant is just sufficient to provide the power required for cruising at 300 knots at 20,000 feet and will provide only about 46,000 pounds of static thrust or 40,000 pounds of lift in hovering flight In order to make VTOL performance possible, 20 high thrust-to-weight ratio turbojet engines are provided, four at the aircraft nose and eight at each wing tip Although not shown in Fig 1, these jets are inclined so that their thrust vector makes an angle of 80° with the wing chord plane This is done to partially compensate for the failure of the wing to turn the slipstream the full 90° and will permit hovering with the wing chord inclined approximately 10° nose up referred to the horizontal

The turbojets at the fuselage nose serve to trim the otherwise large unbalanced pitching moment produced by the heavily flapped wing and also provide longitudinal control at speeds below the speed at which the conventional elevator surface becomes inadequate for this purpose Control in roll in hovering flight and at very low speeds is provided by differential pitch control of the two outboard static thrust propellers Control in yaw in hovering flight and at very low speeds is provided by differential deflection of the outboard portion of the rear wing flaps which serve as ailerons in airplane flight

This airplane is fitted with tip tanks since there will not be space for the fuel in the heavily flapped wing which also houses the propeller interconnecting shafting and gearing These tanks also serve as end plates and as structural members to support the outboard ends of the wing flaps

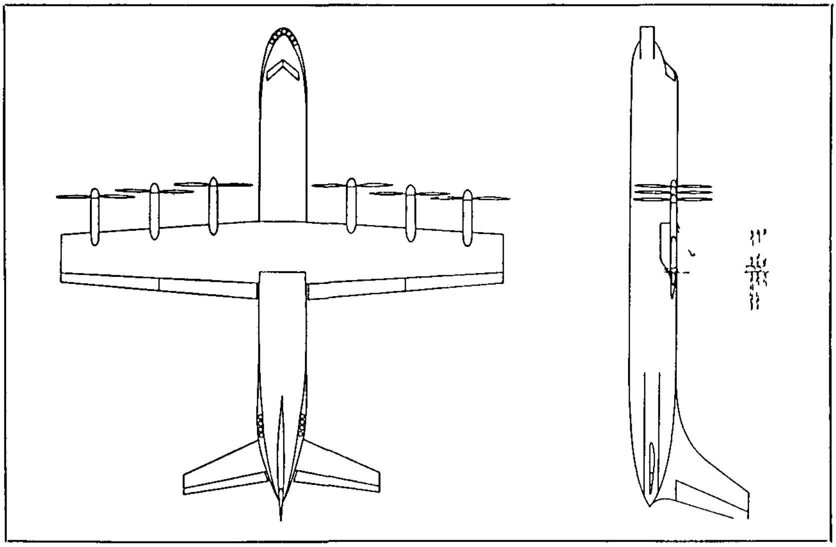

Fig 2 Tilt-wing STOVL

The tilt-wing airplane is shown in Fig 2 This airplane is estimated to weigh 72,000 pounds and is powered by four 2,350-horsepower turboprop engines The propellers and propeller drive systems are as described for the deflected-slipstream airplane

The wing of this airplane is hinged so it can be rotated 90° relative to the fuselage about an axis along the rear main spar With the thrust axis perpendicular to the fuselage, the full static thrust of the six propellers is available for support in hovering This is not sufficient to support the weight, however, and 15 high thrust-to-weight ratio turbojet engines are provided, 7 at the nose and 8 near the tail to provide VTOL capability

Controls are as described for the deflected-slipstream airplane The turbojets are used for pitch control at very low speeds but are not required to compensate for a large wing pitching moment as in the case of the deflected-slipstream airplane

It is assumed that there will be room in the wing for the necessary fuel More complete design studies might indicate the need for tip tanks

Performance Each of the airplanes under discussion was designed to meet the requirements set forth earlier A great deal is required of a practical transport airplane, however, in addition to its capability of meeting cruise and, in this instance, hovering performance requirements Its ability to fly and land safely after failure of a propulsion unit, its rate of climb, its endurance or range under conditions which preclude immediate landing at the destination are all of very major importance

The values of horsepower required and available for the deflected slipstream airplane at sea level are shown in Fig 3 It will be noted that the horsepower available at sea level at zero speed is given as 70 per cent of the installed horsepower This is based on an assumed figure of merit of 73 per cent for the propellers in static thrust and a 3 per cent loss in the propeller drive system The horsepower required in hovering is that indicated by the Froude momentum theory for ideal actuator disks

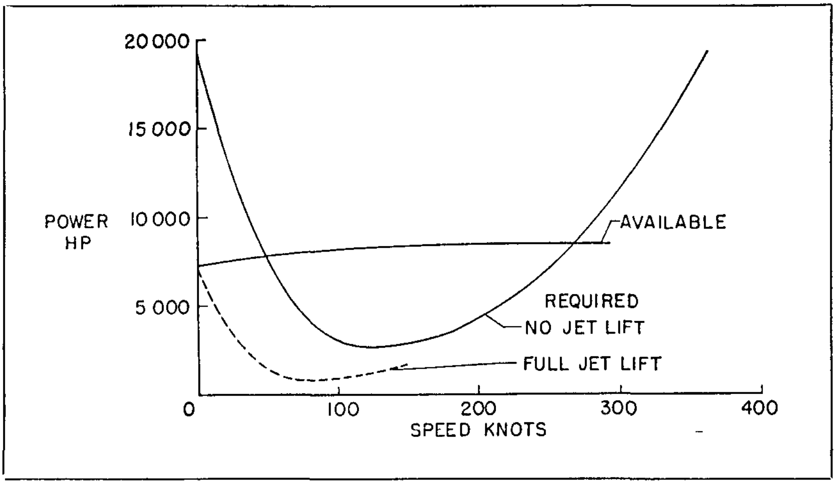

Fig 3 Power characteristics at sea-level, deflected-slipstream STOVL airplane

The horsepower-required curves of Fig 3 are typical for a deflected-slipstream airplane if stalling of the wing is avoided and the wing acts to produce lift by circulation at all speeds as a result of its interaction with the propeller slipstreams This is not necessarily the case at low speeds as was pointed out by Kuhn in Ref 3 When the auxiliary lifting jets are supplying 40,000 pounds of lift, the power required of the turboprops is of course greatly reduced at low speeds and is indicated by the dashed curve in Fig 3

Considering first the power required and available with the lifting jets inoperative, it will be seen that the level flight speed range at sea level is from 50 to 270 knots   The maximum rate of climb occurs at about 140 knots and is 2,300 feet per minute   The airplane will climb at 550 feet per minute with two engines inoperative   The fuel consumption at the speed for maximum endurance, about 130 knots, is 2,390 pounds or 18 6 per cent of the normal fuel load per hour

With the lifting jets supporting 40,000 pounds of the airplane's weight, the horsepower required from the turboprop powerplant is greatly reduced   In fact, if the lifting jets are provided with means for deflecting their exhausts backwards from the vertical approximately 5° with the wings at an angle of attack sufficient to give the necessary lift coefficient of 1 05, the airplane will maintain level flight with the turboprops inoperative at 100 knots   This would, of course, be very uneconomical as the jets would consume about 600 pounds of fuel per minute on the basis of rather optimistic fuel consumption assumptions   Actually it is envisaged that the normal procedure for an airplane of this type operating from a heliport would be to take off and land with a ground run of the order of 200-300 feet, utilizing the full power of the turboprop powerplants for acceleration during take-off and for high lift coefficients during landing and using the thrust of the turbojets only as necessary to provide lift-off and climb at low speed during take-off and to regulate the rate of descent during the landing   The full thrust of the jets would then only be used for very short periods, that is, of the order of 15 seconds, during take-offs   During landings, except in those cases in which coming to a full stop before touchdown should be necessary, the full thrust of the jets would not be used   Calculations indicate that the airplane would approach at 40 knots along an 8   1 path at full turboprop power and the turbojets would be used normally only momentarily to brake the descent and permit a tangential landing

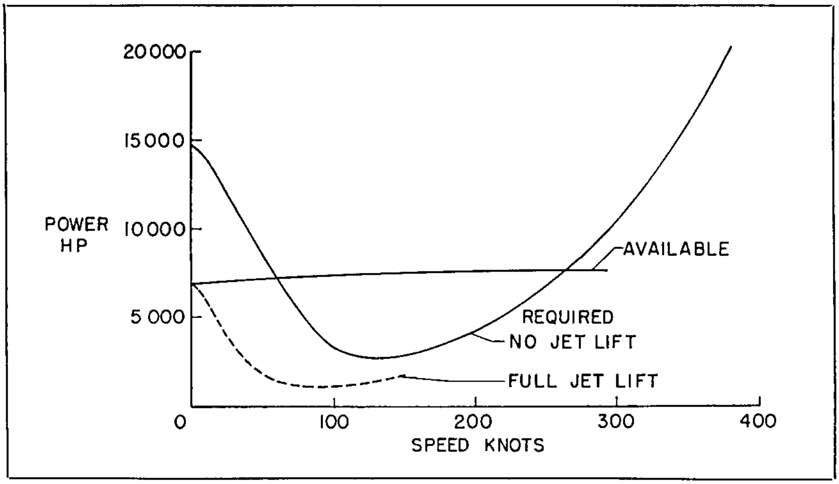

Fig 4   Power characteristics at sea-level, tilt-wing STOVL airplane

The horsepower required and available for the tilt-wing airplane at sea level is shown by Fig 4   Level flight without the aid of the lifting jets is indicated to be possible from 60 knots to 260 knots   The best rate of climb at sea level is about 2,200 feet per minute at 140 knots   The airplane will climb at approximately 480 feet per minute with two of the turboprop units inoperative   The fuel consumption at the speed for maximum endurance, 130 knots, using two turboprop units, is 2,320 pounds or 20 5 per cent of the normal fuel load per hour

The use of the auxiliary turbojet powerplants results in a large reduction in the turboprop power required for flight at very low speeds although the reduction is not quite as pronounced as for the deflected slipstream airplane This, of course, results directly from the lower ratio of jet thrust to weight necessary for hovering flight with the tilt-wing airplane

There are certain very obvious general comments that can be made about both these hypothetical airplanes   They are both relatively expensive compared to conventional airplanes because of the additional cost of the auxiliary turbojets, the propeller drive systems, and propellers   They are both relatively complicated and hence more difficult and expensive to maintain than conventional airplanes   They both require the pilot to master the art of flying in the transition speed range between hovering and conventional airplane flight, making the configuration changes and cutting in or out the additional turbojets as required   They are both certain to be noisy because of the jet exhausts during the take-off and landing operations

The most significant difference between these designs and the tilt wing and deflected-slipstream configurations which have been discussed by NACA authors in previous papers (Refs 1, 3, and 4) is in the use of small light-weight turbojets to provide STOVL capability rather than to provide excess power in the main propulsion powerplants   It is not the purpose of this paper to advocate the use of the turbojets as resulting in a superior configuration   Rather the purpose has been to attempt to estimate the characteristics of an STOVL airplane taking the extreme opposite point of view and installing only enough turboprop power for a moderate cruising speed and altitude, developing as much STOVL capability as reasonably possible with that power through use of large propellers and then using turbojets to give VTOL capability under standard sea-level conditions   Certain points appear worthy of further discussion

The use of turbojets permits the avoidance, to a large extent, of the problem of wing stall during slow, steep approaches discussed in detail by Kuhn in Ref 3   It also minimizes the ground effect problem with deflected-slipstream airplanes discussed by McKinney, Kuhn, and Hammack in Ref 4   These phenomena have to be considered, of course, when operating near the minimum speed possible with a given amount of turbojet lift   The essential difference is that the dynamic pressures, both in and out of the slipstream, are reduced at a given lift coefficient by the ratio, $\left(\frac{\text{weight—jet lift}}{\text{weight}}\right)$ and the disturbing effects of wing stall caused by either steep approach or ground proximity are correspondingly lessened by unloading of wings   Also, and probably more important, low enough speeds for landing within a heliport are attained without requiring extreme values of C_L from the propeller-wing system   The jets themselves produce ground interference effects which must be considered but should not be harmful for the aircraft shown in Figs 1 and 2

One of the annoying problems which arises in the design of propeller STOVL designs is that brought about by the necessity of providing reaction control in pitch In the case of the deflected-slipstream airplane, this is aggravated by the further necessity of providing a fairly large amount of reaction force to trim the large wing pitching moment at low speeds This has resulted in the use of auxiliary jet engines on the Hiller X-18 airplane for pitch control, use of small propellers at the tail on the Vertol tilt-wing test bed, and use of the turboprop exhaust piped to the tail on the Ryan deflected-slipstream test bed (See Fig 1 of Ref 5) Use of auxiliary jets, as in the present case, for supplementary lift at slow speeds provides a means of taking care of these problems and does not additionally complicate the airplane as might appear to be the case The auxiliary jets actually give the designer more freedom to proportion his airplane to provide good stability in forward flight without excessive horizontal tail area and to accommodate a large c g travel

The assumptions which have been made in estimating the weights of the subject airplanes (see Appendix I) result in a powerplant weight of about 0 2 pound per pound of static thrust for both the turbojets and the turboprop-propeller powerplants Hence the ratio of static thrusts provided by the two systems can be varied considerably without marked changes in weight (if the assumptions are reasonable) However, it should be noted that if all, or nearly all, of the weight were to be borne at zero speed by the propellers, it would either be necessary to use larger propellers, and hence larger wings, or to use counter-rotating propellers with their attendant complications In either case, the powerplant plus wing weight per pound of thrust would be increased over the value assumed

The use of auxiliary jets for VTOL is not new, especially to a British audience The pioneering work in this field is believed to have been done by Griffiths , certainly the work by Rolls Royce and by Short Brothers and Harland stemming from Griffiths' ideas in this field has become widely known The essential difference of the approach described herein is the utilization of the primary propulsion units to the fullest extent reasonably possible to keep to a minimum the lifting jet capacity required There are, of course, certain disadvantages of the jets Their fuel consumption is very high and hence it is desirable to use them only for a very minimum of time during take-off and landing They are extremely noisy They present serious soil erosion and dust and debris problems unless they can be kept well away from the ground by being mounted high on the aircraft All of these things have to be considered in evaluating the relative merits of the airplane described as compared to those having the power for VTOL applied solely to the propellers

An additional problem which appears to be very serious but can conceivably be satisfactorily solved is that of starting and controlling large numbers of small jet engines simultaneously and accurately This problem has appeared to be almost insurmountable to some engineers but is believed by the author to be capable of satisfactory solution

A discussion of STOVL airplanes is not complete without consideration of the safety problem, especially when the aircraft under discussion is to be used for commercial operation from small fields in congested areas Such an airplane can be either extremely dangerous or extremely safe The difference will lie in the amount of design skill and effort employed and in the relatively small weight penalty required to provide for interconnecting power shafting, mechanical interconnection of propeller pitch control mechanisms, and suitable clutching to permit disconnection of disabled power or propulsion units Assuming these safety requirements to have been met, propeller-wing type STOVL airplanes having adequate reaction control units should prove very safe and reliable because of their very rapid decrease in power required with increase in speed near zero speed, and the large amount of excess power available at flight speeds from 20 knots to 200 knots As pointed out earlier, if controllable nozzles are provided on the lifting jets, these airplanes can be flown and controlled using the jet engines alone and landed on a small airport should there be a complete failure of the turboprop system

JET-WING POWERED LIFT SYSTEMS

Nearly 20 years ago a wind-tunnel investigation by Schubauer (Ref 6) revealed that large increases in lift coefficient could be achieved if relatively large amounts of air were blown from a slot along the wing trailing edge The practical application of this principle was not apparent, or possible, at that time In recent years, Davidson in England and Poisson-Quinton in France independently rediscovered this principle and pointed out its practical significance The possibility of using the exhaust from jet engines, or the output of turbine-powered gas generators, to supply the large amount of air required, brings this type of high lift device into the realm of practical possibility The application of this type of powered lift system to aircraft to achieve large reductions in take-off and landing speeds and runs is now of great interest

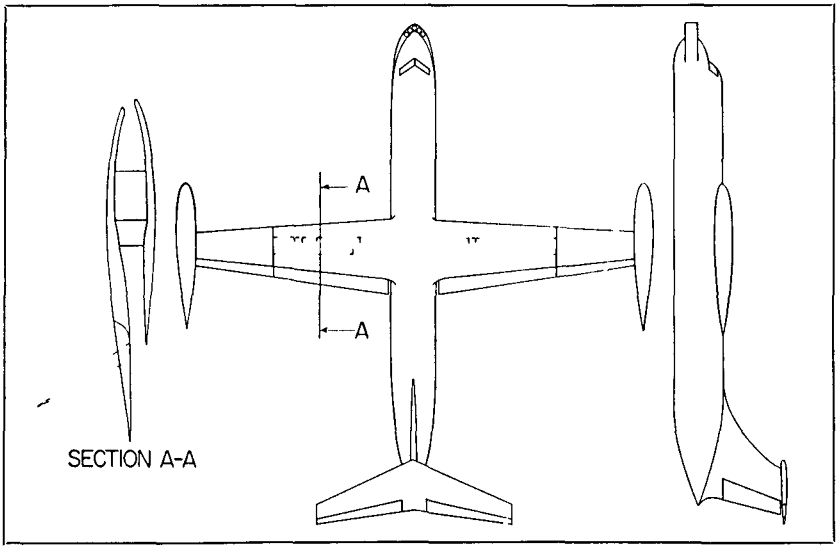

Fig 5 Jet STOVL

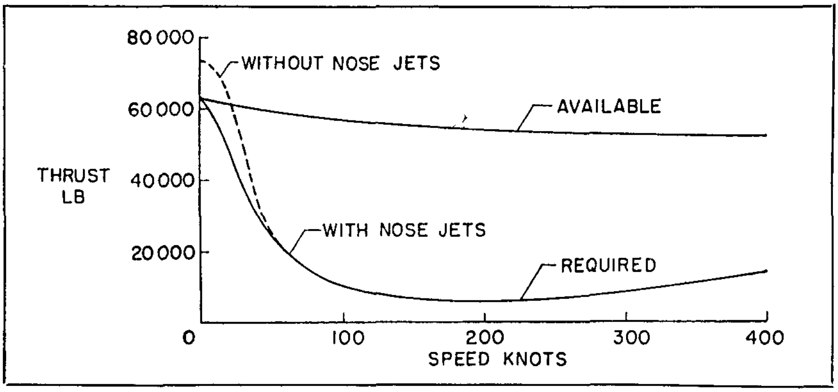

Fig 6 Thrust characteristics at sea-level jet STOVL

In order to bring out some of the characteristics and problems encountered when jet powerplants are used in conjunction with wings to produce large increases in the wing maximum lift coefficient, two different designs have been considered One is an STOVL airplane to meet substantially the same requirements as for the propeller STOVL airplanes previously discussed, the exception being that it is permitted to cruise at 350 knots at 30,000 feet The other is a large inter-continental jet transport designed to operate from fields of moderate size, that is, runway lengths of the order of 5,000—6,000 feet These two aircraft will be described and discussed in turn

Jet STOVL airplanes An STOVL airplane utilizing a large number of small, high thrust-to-weight ratio engines mounted in the wing for propulsion and to supply the major portion of the thrust required for vertical take-off and landing performance is shown in Fig 5 and its major characteristics are given in Appendix II The thrust of the wing jets is turned through substantially 90° for hovering flight Additional jets mounted at the fuselage nose provide longitudinal trim and control and also provide the additional lift required to support completely the weight of the airplane in hovering flight In cruising flight, only the number of wing engines required when operated at their optimum cruise thrust will be used The outermost wing engines will be used for this purpose Provisions are made for closing and fairing the inlet and exhaust openings of the inoperative jets during cruising flight

In laying out this airplane the same fuselage and passenger accommodations are assumed as for the previous cases The straight wing is mounted high on the fuselage and carries fuel tanks at its tips A thick section is necessary to house the jet engines, the greatest thickness ratio of nearly 0 2 occurring in the vicinity of the outermost engine The horizontal tail is mounted at the top of the vertical tail where it is out of the jet exhaust at all times

Curves of thrust, required and available, versus speed at sea level for this airplane are given in Fig 6 Immediately obvious is the large amount of excess thrust available at all speeds of interest except near zero Rough calculations indicate that if passengers will accept the large acceleration (of the order of 0 6g or 0 7g) and the steep climb angles (nearly 45° at 350 knots at sea level) required, this airplane can be airborne at 50 knots after a ground run of 171 feet and can be cruising at 350 knots at 30,000 feet 2¼ minutes after start of the take-off run After having travelled 500 miles, it will have fuel remaining for 52 minutes' loiter at sea level at 200 knots plus 3 minutes' hovering

It is apparent from Fig 6 that hovering landings should be resorted to only when necessary If a heliport having 400 feet of runway is available, the airplane can be landed at 40 knots and braked to a stop never having used more than approximately 50 per cent of the available thrust This is obviously a much more economical procedure than coming to a complete stop while airborne and making a hovering landing

The author must confess to having been surprised by the results of his own calculations in respect to this airplane This airplane looks extremely attractive at first glance and the author has a feeling he must somewhere have made a seriously unconservative assumption However, the picture is by no means all favorable Let us consider some of the practical problems which are presented

Obviously the same objections apply to this airplane as to the propeller STOVL types previously discussed The subject airplane will be powered with 30 to 40 high thrust-to-weight ratio turbojets which will certainly be expensive unless someone develops a manufacturing process which will greatly reduce costs over those now envisaged These engines must be capable of being stopped in the air and started as needed during the approach and landing manoeuvre They must be capable of precise control during hovering flight and hovering landings These problems are not insurmountable , neither can they be dismissed lightly

The noise output of this airplane will be very great during take-off, initial climb, and landing The solution of this problem is not apparent It may very well be the major deterrent to the development and use of such airplanes In this connection, it is possible that a profitable approach would be investigation of the possibility of designing heliports to have acoustic properties which will minimize propagation of jet noises to the heliport terminal passenger facilities and to the surrounding neighbourhood The noise output to the surrounding community can be minimized and localized somewhat at some sacrifice of economy by using the very steep climb-out angles possible with this type of airplane

Realization of the full potential of this airplane requires subjection of the passengers to relatively high acceleration and to large fuselage nose-up attitudes during take-off and climb and to fairly high rates of deceleration during the approach, landing, and ground run To what extent this is a serious problem is not known, and may depend on the approach taken by operators in presenting such performance to the public

It is probable that the airplane described is quite far from the optimum A jet airplane having a thick, straight wing is in itself an abnormality Somewhat higher speeds would be possible if the wing were swept This would require location of the fuel tanks inboard A wing of lower aspect ratio would, of course, permit smaller wing thickness ratios and hence a higher drag-rise Mach number The effective thickness ratio is considerably reduced over that portion of the wing span housing the turbojets used for cruise thrust. Because of this, it appears advantageous to use the outermost engines for this purpose.

The horizontal tail has been placed on top of the vertical tail to get it as far as possible from the region of extreme downwash (see Refs. 7, 8, and 9) associated with the very large lift coefficients at very low speeds. Using the nose jets for trim and control at low speeds also permits a relatively forward c.g. location. These two measures may permit avoidance of serious longitudinal stability deficiencies in the low speed range but this is certainly an area of possible deficiency in the subject design.

The high-wing design is used to minimize ground effects which have been shown by wind-tunnel tests to have serious adverse effects on the capability of a jet-augmented flap to produce high lift coefficients as is shown in Fig. 7 taken from Ref. 7. Ground effect should not be serious during take-off with this airplane because of the low flap deflections required but may be quite serious during landing.

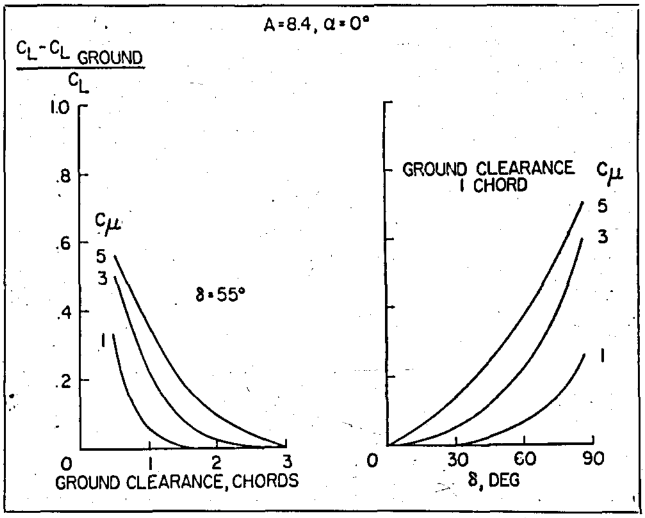

Fig. 7. Effect of ground proximity on the lift coefficient.

The author has not attempted to present a wing section configuration with an arrangement of flaps, vanes, hinged or sliding sections, etc., which will give a faired wing section at cruising speeds, efficient inlet and exhaust passages during take-off and climb, and efficient turning of the exhausts through angles up to 90° during the approach and in hovering flight. This appears to be a fertile field for research, invention, and development.

An aircraft of this type will depend for safety on the large number of powerplants, and the large excess of thrust available at all speeds above 20 or 30 knots. This airplane should be capable of flying to and landing on even the smallest airport used by conventional airplanes after losing half of its turbojets in either or both wings.

Long-range jet transport for moderate field lengths : In a paper by Lowry, Campbell, and Riebe (Ref. 7), it was shown that a jet-augmented flap system will not significantly improve the take-off and landing capability of a jet transport unless the T/W ratio is of the order of 0·3 or larger, if the aircraft

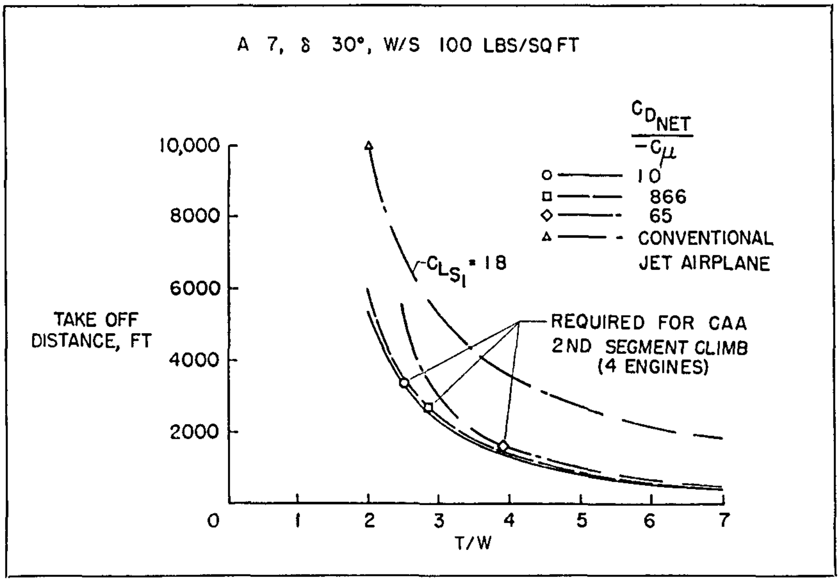

Fig 8 Estimated take-off distance for a conventional jet airplane and an airplane with an internal-flow jet-augmented flap

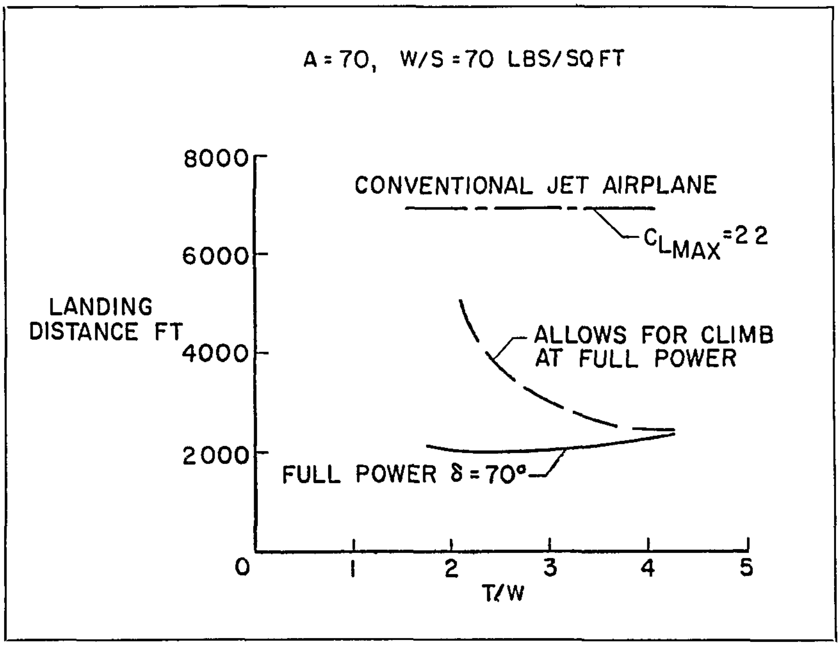

Fig 9 Estimated landing distance for a conventional jet airplane and an airplane with an internal-flow jet-augmented flap

is required to meet CAA requirements for performance following a powerplant failure during take-off or approach Their results are summarized in Figs 8 and 9 On the other hand, the thrust required for cruise at high subsonic speeds results in the need for an installed thrust of only about 0 2 of the take-off weight The manufacturer and the operator are therefore faced with the necessity of either installing more thrust capacity than is needed for cruise or of operating only from airports having very long runways

If it be assumed that it is desirable for long-range transports to be capable of hot-day operation from airports having runways of moderate length, 5,000 to 6,000 feet, it can readily be shown that an installed thrust of the order of 0 3 of the take-off weight under standard conditions is required Also it will be necessary, with the wing loadings in current use for such transports, to develop a lift coefficient of the order of 4 during the final approach with the capability of climbing out with such a lift coefficient in the event of a baulked landing This, of course, can be achieved with various arrangements for boundary-layer control or jet-augmented flap configuration Fig 10 shows one such arrangement This configuration is presented as a basis for discussion and to illustrate problems involved It is not presented as either the author's or the NACA's conception of the best solution It does illustrate a number of points

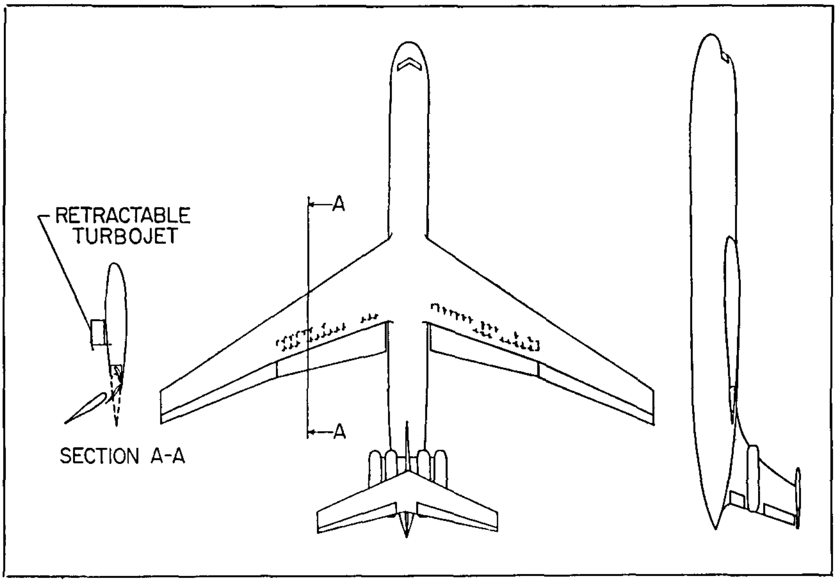

Fig 10 MTOL (Moderate Take-off and landing)

As will be seen from Fig 10, the propulsion engines are mounted at the rear of the airplane on the vertical tail and are proportioned for maximum economy in cruising flight In order to bring the installed thrust up to a value of greater than 40 per cent of the take-off weight, a number of small, high thrust-to-weight ratio engines are carried to supply the thrust capacity required for moderate length take-offs and landings These engines are carried retracted into the wing during cruising flight For take-off, they are extended below the wing and exhaust beneath the partially extended double-slotted flap to give the thrust required These engines are again extended during the approach, serving as sources of drag until required for lift augmentation During the final stages of the approach and the landing, these engines are operated full throttle and exhaust through the external-flow type of jet-augmented flap described by Campbell and Johnson in Ref 9 With the installed auxiliary thrust, a lift coefficient of 4 can be developed permitting a landing on a 4,000 to 5,000 foot runway under standard conditions after the consumption of fuel has reduced the wing loading to 70 pounds per square foot Ample thrust is available to meet CAA requirements for climb-out in the event of a missed approach, assuming failure of no more than one of the propulsion units or two of the auxiliary turbojets

The disadvantages and problems associated with this configuration are apparent One of these is the use of a high wing location, generally agreed to be undesirable for reasons of safety, structural weight, and convenience in laying out the passenger accommodations In this case, it appears to be necessary if the lifting capability of the jet-augmented flap is to be fully realised There is, of course, some question as to the true importance of the reduction of lift due to ground effect during a landing but if it is as important as has been indicated earlier, use of a low wing is ruled out

The use of retractable auxiliary engines introduces problems of control, flexible fuel lines, etc , which could be avoided by a fixed installation The drag of an exposed, fixed installation of auxiliary engines would be prohibitive, however If the engines are fixed in the wing, on the other hand, the necessary inlet and outlet passages would eliminate the possibility of carrying any substantial amount of fuel in the wing It will probably be necessary to provide for some external tankage even with the design illustrated The use of the external-flow type of jet-augmented flap has the further disadvantage of requiring approximately one-third more engines than would be required for the same lift coefficient with an internal-flow arrangement (Ref 10)

The propulsion engines and the horizontal tail are mounted high on the vertical tail This is certainly not advantageous from the standpoint of weight but is necessary to keep them well out of the exhaust blast from the auxiliary jets and away from the worst of the downwash from the jet-augmented flap at high values of C_L and C_μ The thrust moment of the propulsion engines will add to the nose-down pitching moment of the jet-augmented flap and may require corrective measures Their far aft location may also present a difficult problem in avoiding a c g location undesirably far aft on the fuselage

The overall economics of adding auxiliary turbojets to permit use of moderate-sized airports by large jet transports is outside the scope of this paper The fuel cost and maintenance costs will certainly be increased It may be possible to compensate partially for the additional weight of the auxiliary jets by decreasing the reserve fuel load It will, of course, permit greater flexibility of operation of such aircraft since they will not be constrained to operate only from the few very large fields in the world

CONCLUDING REMARKS

The increased size and speed of airplanes have resulted in a need for larger airports which has caused airports to be located farther from cities which has resulted in increasing the time to make short trips, such as from New York to Washington, until the train has once again become the fastest and most convenient means of transportation There is a growing need for economical, high-performance aircraft which can operate from small airports, or heliports, near city centres Such aircraft will of necessity utilize engine power to permit flight at the low speeds necessary for operation from such airports or heliports

Modern turbine powerplants are bringing into the realm of technical possibilities both propeller and jet types of STOVL airplanes capable of operating with reasonable payloads for short ranges, of the order of 300 miles, from heliports near city centres Development and use of such aircraft will require solution of a number of problems including noise, ground interference effects on both propeller-wing and jet-wing powered lift systems, operation and control of large numbers of turbo-jets, and the high costs of small, high thrust-to-weight ratio turbojets

The jet-augmented flap, together with an adequate thrust/weight ratio, can be used to reduce landing field size requirements for long range jet transports This will involve compromises in design and some additional costs Whether these compromises and additional costs will be counterbalanced by the advantages of the ability to operate from moderate-sized airports is an interesting area for further study

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APPENDIX I

Propeller-Wing STOVL Transports

The weights, dimensions, power and thrust installed, and major assumptions used in arriving at weight and performance estimates for the propeller-wing STOVL airplanes are as follows

Deflected-slipstream

Weights, lb		
Empty		50,377
Useful load		28,423
Operational	2,155	
Payload	13,500	
Cruise fuel	10,650	
Hover fuel	2,118	
Gross		78,800
Dimensions		
Wing area, sq ft		1,125
Wing span, ft		100
Overall length, ft		98
Propeller diameter, ft		16
Installed power and thrust		
Turboprop , h p (4 at 2,650)		10,600
Auxiliary thrust, lb (20 at 2,000)		40,000
Major assumptions		
Zero-lift drag coefficient		0 0339
Effective wing span, ft		89 1
Specific fuel consumption		
Turboprop , lb /h p /hr		0 6
Jet, lb /lb /hr		0 9
Specific weights, powerplant		
Turboprop propulsive system, lb /h p		0 8
Jets, installed, lb /lb		0 2
Propeller efficiency at cruise, per cent		80
Propeller figure of merit in static thrust		0 70
Weight of fixed equipment, lb		11,524

Tilt-wing

Weights, lb		
Empty		44,990
Useful load		26,910
Operational	2,155	
Payload	13,500	
Cruise fuel	9,650	
Hover fuel	1,605	
Gross		71,900
Dimensions		
Wing area, sq ft		1,125
Wing span, ft		90
Overall length, ft		98
Propeller diameter, ft		16
Installed power and thrust		
Turboprop , h p (4 at 2,350)		9,400
Auxiliary jet thrust, lb (15 at 2,000)		30,000
Major assumptions		
Zero-lift drag coefficient		0 0291
Effective wing span, ft		76 7

Specific fuel consumption	
Turboprop , lb /h p /hr	0 6
Jet, lb /lb /hr	0 9
Specific weights, powerplant	
Turboprop propulsive system, lb /h p	0 8
Jets, installed, lb /lb	0 2
Propeller efficiency at cruise, per cent	80
Propeller figure of merit in static thrust	0 70
Weight of fixed equipment, lb	11,524

APPENDIX II

Jet STOVL Transport

The weights, dimensions, power and thrust installed, and major assumptions used in arriving at weight and performance estimates for the jet STOVL airplane are as follows

Weights, lb		
Empty		42,105
Useful load		31,895
Operational	2,155	
Payload	13,500	
Cruise fuel	12,900	
Hover fuel	3,340	
Gross		74,000
Dimensions		
Wing area, sq ft		1,000
Wing span, ft		96
Overall length, ft		96
Installed thrust, lb		
Wing jets (32 at 2,000)		64,000
Nose jets (5 at 2,000)		10,000
Major assumptions		
Zero-lift drag coefficient		0 0257
Effective wing span, ft		81 5
Specific fuel consumption, lb /lb /hr		0 9
Specific weight installed thrust, lb /lb		0 2
Weight of fixed equipment, lb		11,524

Discussion

The **Chairman,** in expressing thanks to Mr Zimmerman for his excellent presentation of the subject, said it seemed that jet-lift and the jet-wing principle were not in general competitive with rotor-lift It appeared that their field of utilisation was very different, although they might have the common objective of independence of airfields for take-off and landing Their application was mainly to long-range aircraft capable of flying at high subsonic or, perhaps, supersonic speed, whereas the role of the helicopter was for relatively short-range operation Did Mr Zimmerman agree with this generalization ?

The Author in his paper had considered the lifting turbojet almost exclusively as an auxiliary power system Did he consider this to be its appropriate application in the future, or did he think that eventually a battery of turbojets would take over the whole responsibility of power for take-off and landing and not merely be used as a source of auxiliary power ?

Mr Zimmerman expressed agreement concerning the role of the helicopter For operations in which hovering was itself a primary part of the mission and where