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The Army VTOL Surveillance Aircraft Program

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Research Div., U. S. Army Materiel Command

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THE NECESSITY for surveillance or observation of one military force by another has always been a key point of Army strategy since the earliest times. The first use of aircraft by the U. S. Army can be traced to the requirement for observation during the Civil War when hydrogen balloons were used. Surveillance was the military requirement behind the procurement of the first heavier than air craft procured by the U. S. military forces. It can be said that the Mohawk is truly a direct descendent of the Wright Model B.

Previous to World War II, emphasis was placed upon the fighting type of aircraft by the Army Air Corps, which made it necessary to press into service light civilian aircraft, such as the Piper Cub, to fulfill the needs of the battlefield commander for observation and fire control of his weapons. Thus we again see the employment of aircraft as observation platforms, or in reality an extension of the ground commander's weapons system. The employment of aircraft as an organic part of and to improve the effectiveness of surface weapons typifies the Army's use of aircraft.

The versatility of the helicopter, particularly with regard to lack of need for prepared air fields, proved that this type of vehicle was invaluable from the Army's point of view. The advent of sophisticated weaponry has placed a premium on the timely and accurate availability of information about enemy movements. The inherently short range and low speed of the helicopter, currently limits its tactical usefulness to the Army.

With the Air Force responsible for long range reconnaissance, the need arises for an aircraft which can extend the ability of the helicopter out to the effective range of the Army's ground weapons. This was the basic mission for which the Mohawk was developed. Inevitably the requirements for carrying additional unprogrammed surveillance equipment increased the gross weight of the Mohawk to a point where the performance was reduced excessively.

RECENT HISTORY

Over the period of the last 6 or 7 years the Army has sponsored over a dozen flight research vehicles to explore the feasibility of combining a VTOL capability with fixed wing aircraft. The current part of this effort is a program of VTOL surveillance research aircraft. The Lockheed XV-4A (jet ejector) (VZ-10) and G. E./Ryan XV-5A (fan-in-wing) (VZ-11) configurations were selected because of their apparent suitability for the surveillance mission. Later, when tripartite development of the Hawker P-1127 was initiated, the Army evidenced strong interest in this configuration for the same reasons. As a result, responsibility for the U. S. part of the project was assigned by the Dept. of Defense to the Army, and the aircraft was designated XV-6A.

REQUIREMENTS

It should be noted that a number of configurations are possible to satisfy the requirements of VTOL with high speed approaching Mach 1. Table 1 lists the principle configurations by type which will generally provide this capability, together with examples of research aircraft (Figs. 1-4). Fig.

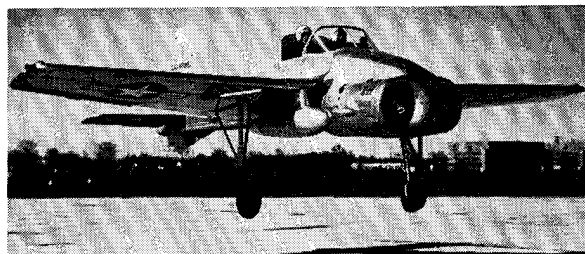


Fig. 1 - Bell X-14

ABSTRACT

Recent studies and developments in VTOL aircraft by the U. S. Army have been to fill the requirement for a surveillance or observation aircraft. The low speed helicopter not being satisfactory for the mission, two recent experimental

craft incorporate the lift fan principle. Answers to many technical problems have yet been answered, in technical research and operational analysis. Actual operation of Army experimental craft may provide the answers needed.

Table 1 - Principle VTOL Configurations

Type*	Aircraft Example	Principle VTOL Features	Fig.
Jet lift	X-14, X-13	Pure jet engines, fan lift and thrust	1
Lift engine	SC-1	Separate jet engines provide lift	
Lift/thrust	XV-6A (P-1127)	Mechanical augmentation, fan and jet lift	2
Jet ejector	XV-4A (VZ-10) Hummingbird	Jet exhaust used with augmentor	3
Lift fan	XV-5A (VZ-11)	Jet engine drives large fan remotely located from gas producer	4

*Listed in order of decreasing effective disk loading.

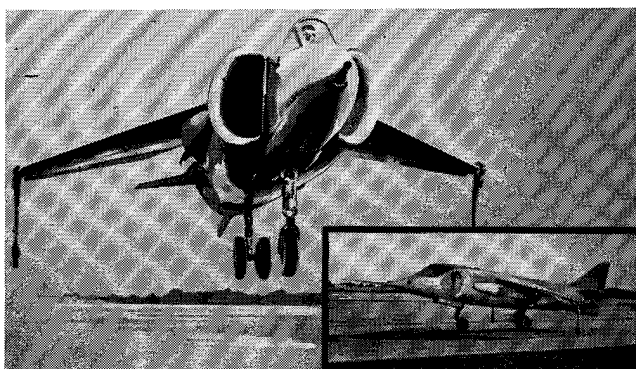


Fig. 2 - Hawker P-1127 V/STOL tactical strike aircraft

5 presents a schematic drawing of the essential elements of these systems.

While a number of configurations to achieve VTOL are possible as indicated by the previous figure, the technical problem of achieving a useful winged VTOL aircraft is that of reasonably matching the thrust or power required for vertical flight with that which is required for an efficient cruise. Thus the helicopter achieves a reasonable match since the rotor accelerates a large mass of air to a relatively low velocity. The jet engine also accelerates a mass of air, but to supersonic velocity, and a jet VTOL is limited in speed essentially only by the characteristics of the engine itself. Thus it can be said that these two configurations bracket the spectrum of VTOL possibilities, and match the power required for vertical flight with that of cruise with varying degrees of efficiency.

Since the winged VTOL's characteristically have the same high lift to drag ratio in cruise and high speed flight as conventional winged aircraft, various schemes have been devised to increase the mass flow of air handled by a jet engine to augment its thrust and improve its static lifting ability for vertical flight.



Fig. 3 - Lockheed XV-4A

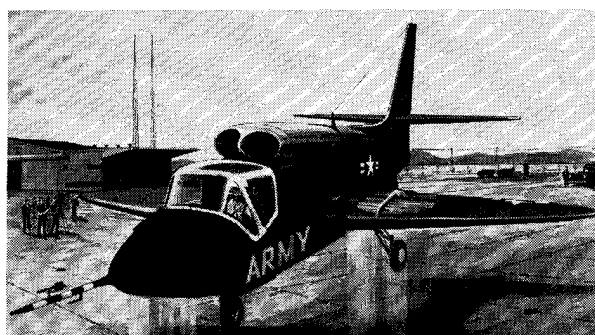


Fig. 4 - G. E./Ryan XV-5A

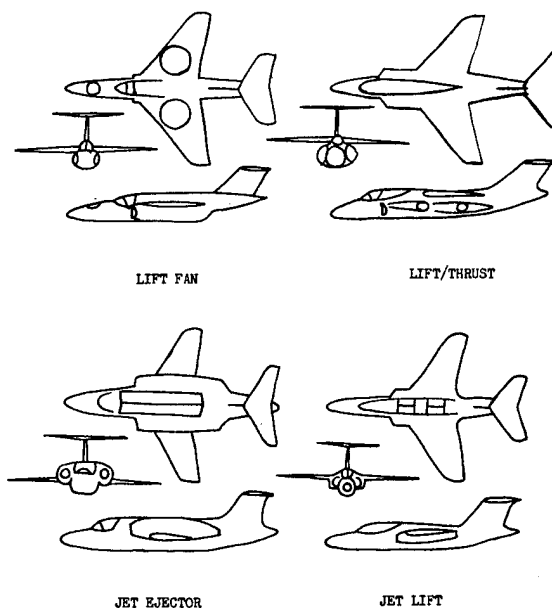


Fig. 5 - VTOL aircraft configurations

Unfortunately no scheme has yet been devised which will augment engine thrust without an appreciable penalty in other areas. When either mechanical augmentation (Hawker P-1127) or aerodynamic augmentation (Lockheed Hummingbird) to a gas turbine is employed, the increased vertical

lift obtained is at the expense of fuselage frontal area and fuselage capacity. If the augmentation system is relocated in the wing as has been done with the XV-5A fan-in-wing, the wing thickness must be increased with an associated penalty of premature wing wave drag increase as Mach 1 is approached. Configurations which use some scheme to augment basic engine thrust generally have higher drag than would an equivalent conventional take-off aircraft.

Fig. 6 presents a typical thrust required curve for a pure jet VTOL employing tip mounted rotating jets. Such an aircraft would have a high speed in the order of Mach 2.5-3.0, but would have very inefficient low level cruise and would have a poor cruise-VTOL power match. If a multiengine design is considered, one way to match widely varying aircraft power requirement characteristics may be to shut down one or more propulsion units. Strictly from an operational point of view, the merit of such technique may be questioned. Engine out cruise at tree top level, or altitudes less than 1000 ft as envisioned by the Army would require that an engine failure be detected, the good engine restarted and brought up to power, all while taking the necessary action to avoid a crash. True, this action could be wholly automatic, however the additional complication of such a system would be undesirable in the light of the Army's needs to keep aircraft as simple as possible.

One European approach, favored by some technical people, particularly those associated with propulsion developments, is to use special engines solely for lift. This system looks particularly attractive in the light of recent advances in the field of light weight gas producers. In addition to the penalty of carrying the additional weight of engine and fuel over the entire mission certain other technical problems arise associated particularly with lift engines. If the engines are installed in the fuselage a volume problem exists similar to that of the augmented jet and the deflected fan jet. Podded lift engines present almost insurmountable aircraft control problems, if the probability of engine failure must be considered.

Obviously the most important consideration in favor of using lift engines is the fact that the thrust engine(s) can be sized ideally to the other mission characteristics.

CURRENT PROGRAM

The current Army program is directed towards providing technical information which will ultimately lead to the development of a service surveillance aircraft. The chosen approaches all employ systems for augmenting engine thrust for VTOL since this general concept appears better suited to the Army type of mission.

Since both the XV-4A and the XV-5A were to be procured as research aircraft and not as preproduction models a definite philosophy was employed in setting down the requirements for them. Both aircraft were to be designed to meet the IFR handling qualities requirements of helicopter specifications of Mil-H-8501A, and to incorporate stability augmentation to operate within the desirable pitch and roll

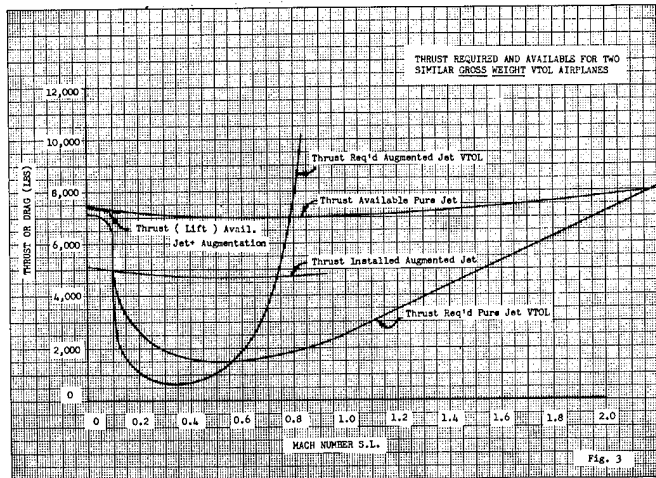


Fig. 6 - Thrust required and available for two similar gross weight VTOL aircraft

boundaries as defined in NASA report TN-D58. In the previous test bed programs, the handling qualities were usually deficient about one or more axes. Some of the aircraft were flown through sheer skill and specific experience of the pilot.

The stability augmentation system in each aircraft is designed to be very flexible and in effect makes a variable stability machine out of the airplane. This not only allows us to optimize the particular configuration, but also enables us to investigate parameters of interest to VTOL operations in general which were mentioned earlier.

The very fact that jet engines are used for conventional flight allows both these aircraft to attain high subsonic speeds. Since that particular end of the speed range is well documented, it is necessary only to reach such velocity as required to demonstrate the flexibility of the propulsion system. Since cost is always an extremely important factor in Army aeronautical research, it was decided that the aircraft should be designed for a maximum airspeed of approximately 450 knots, obviating the need for sophisticated structures, yet producing the desired results at the least program cost. The only requirement was that the aircraft should take off vertically on a sea level hot day, hover 5 minutes, and have a total endurance of one hour when carrying a pilot and copilot, or 300 lb of instrumentation.

It should be kept in mind that the XV-4A and XV-5A were not procured as competitors for any specific mission, but rather as flight research vehicles to produce essential technical data.

During 1958 the Army contracted with General Electric Co. to build a tip turbine lift fan powered by a gas producer in order to establish the potential value of this lift/thrust system. The results were so encouraging that in 1961 a competition was held for design and fabrication of two flight research vehicles incorporating the lift fan principle. From this then, Ryan Aeronautical Co. was selected to build the airframe of the XV-5A under subcontract to General Electric. Ryan had been interested in this means of VTOL for

Table 2 - XV-5A Characteristics

Weight empty, lb	7054
VTOL gross weight (sea level, standard day), lb	12,200
Max speed (25,000 ft)	Mach 0.83
Length, ft	44.5
Span, ft	29.8
Height, ft	15.6

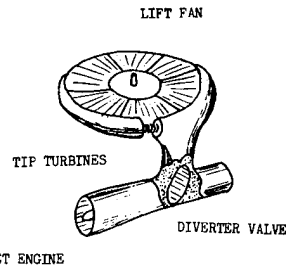


Fig. 7 - G. E. lift fan

sometime, and had acquired a considerable in-house experience through studies and tests. The important characteristics of the airplane proposed and now under construction, are given in Table 2.

It is evident from Fig. 4 that there are two large wing fans and a smaller nose fan. These are used to provide lift, control, and trim during fan supported flight. All three fans and the two J85 engines are cross ducted to afford safety and control in the event of an engine failure. The location of the small fan in the nose is significant in that this fan is normally lifting and only produces a down load when required to overcome a nose-up pitching moment. Roll and yaw control are accomplished by movement of exit vanes mounted under each wing fan. From Fig. 7 you will notice that a diverter valve is positioned immediately to the rear of each gas generator. It is here that the hot gases are directed through the ducts to drive the fans, or aft through the tail pipes for forward thrust. An interesting point arising from cross-ducting provisions, is that the failure of one engine results in a loss of vertical lift of only 40 instead of 50%. This phenomenon is attributable to the power absorption characteristics of the fans. Under standard conditions and normal landing weights it is possible to make a satisfactory landing with one engine out.

The X353-5B lift fan system has a lift augmentation of approximately 3, and other pertinent characteristics as given in table 3.

The Lockheed XV-4A is a markedly different aircraft in background, concept and hardware. Lockheed has studied the application of jet ejectors to aircraft since 1956, but it was in 1959 that a joint Army/Navy program supported further studies by the company. Results were such that Lockheed made an unsolicited proposal to the Army for design and fabrication of two research flight test vehicles. A contract was signed in June 1961, and the first conventional flight was ac-

Table 3 - Pertinent Characteristics of X353-5B Lift Fan System

Lift thrust total, trimmed (SLS), lb	13,946
Lift SFC	0.385
Fan diameter, installed, in.	76
Fan thickness, in.	14.5

Table 4 - XV-4A Characteristics

Weight empty, lb	4 995
VTOL gross weight (sea level, standard day), lb	7200
Max speed (structure limited)	Mach 0.68
Length, ft	32.8
Span, ft	25.8
Height, ft	13.0

complished in July 1962. This airplane's physical characteristics are given in Table 4.

Power is supplied by two Pratt & Whitney JT-12-A-3 turbojets exhausting into a pair of diverter valves. These valves can be switched to direct the exhaust through the primary nozzles of the lift system, thence through the ejector chambers and out the bottom of the fuselage. For conventional flight the gas is allowed to flow aft through a tailpipe. The ejector and engines are cross ducted to afford safety and control in the event of an engine failure. Because of the flow characteristics of the ejector system, failure of one engine still leaves 60% lift available for descent. Pitch and yaw control in hover is provided by reaction nozzles using engine exhaust. Roll control is obtained by using bleed air from the engine compressors. In all cases, the controls meter the flow of gas as required so that the sum total of lift remains unchanged. Ejectors are used on these reaction controls to augment the flow in a manner similar to the main lift system. Design augmentation of the jet ejector is 1.4, but it is expected that a favorable ground effect will be experienced down to about 2-1/2 ft above the ground, the point at which the ejector exits remain when the landing gear is in the static position.

The British Hawker P1127 aircraft is not a research aircraft, but instead was designed from the start as a prototype machine to fill a mission requirement.

It has been publicly stated that the thrust of the British Siddeley BS.53 engine is 15,000 lb, and its thrust/weight ratio is 7.1. Dimensions of the airframe are: length 41 ft; span 24.5 ft; height 10 ft.

Comparison with the XV-5A shows the Hawker has a slightly smaller envelope, thereby resulting in a higher density aircraft as would be expected. Since it is powered by a single engine there is no margin for engine failure during vertical operation. Complete engine thrust is deflected from vertical to horizontal by the rotary nozzles in order to per-

form a transition. Pitch, yaw and roll is controlled, during hover, by reaction jets supplied from the engine compressor. Relatively cool air is supplied from the forward fan to the two forward nozzles and hot gas is exhausted from the aft nozzles. Inflatable engine intake lips provide a novel solution to the problem of matching engine intake low speed conditions to those encountered at high speed.

This aircraft in different versions has completed many flights since it first flew in October 1960, and was dramatically demonstrated at the Farnborough, England airshow in 1962 by having one aircraft hover and another fly by at about 400 knots. Stability augmentation is provided for the P1127, but it has been flown successfully with the system off.

Another configuration suitable for the surveillance mission is that of the pure jet type, which was discussed earlier in this paper. The Bell X-14 (Fig. 1) is currently being flown at the NASA Ames Laboratory and is providing a wealth of information. The stability augmentation system installed in this aircraft can be varied to simulate different damping and response characteristics. A considerable amount of information has been published previously and details will not be repeated here. It should be noted, however, that the use of swiveling nozzles to deflect the exhaust gases provide certain advantages in reducing the seriousness of the downwash problem as well as improving STOL performance.

ANSWERS STILL NEEDED

In the rather extensive test bed program previously sponsored by the Army many questions, of necessity, went unanswered. Solutions are still required in two categories as follows:

Technical Research -

1. Static and dynamic stability requirements.
2. Flying qualities requirements.

3. Instrument flying requirements.
4. Implications of steep descents.
5. C. g. travel requirements.
6. Installed power requirements.
 - a. Thrust-to-weight ratio necessary.
 - b. Power for control.
 - c. Cruise shut down of power.
 - d. Time response for control.
 - e. Matching of take-off to cruise power required.
7. Extrapolation of data to operational sizes.
8. Safety aspects.

Operational Analysis -

1. Need for V/STOL.
2. V/STOL usage evaluation.
3. Study of training and logistics implications.
4. Investigation of noise problems in the field.
5. Investigation of downwash problem.

It is by actual operation of the three Army aircraft previously mentioned that we hope to provide answers to these questions. Funding was made available by the Army to support several promising approaches to VTOL; but we also have a keen interest in what other people are doing, and wherever aircraft are flying we will watch too, for these answers.

As some of you probably know, development of a Mohawk replacement has been delayed somewhat. This delay will be used to better define the technical characteristics of such an aircraft in the Army, the parameters of most importance to the designers and to allow a project manager to integrate the many complex systems, electronic gear, and ground support requirements necessary to make the aircraft a success.

It is wholly fitting and proper that the first winged VTOL to enter military or civilian use will, in all probability, be that having application to the oldest military mission: that of observation and surveillance.