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PRELIMINARY REPORT
AFFTC FLIGHT EVALUATION OF THE XV-3

WALLACE H. DECKERT
Lieutenant, USAF
Project Engineer

ROBERT G. FERRY
Major, USAF
Project Pilot

Air Force Flight Test Center
Edwards Air Force Base
California

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SUMMARY

A limited flight evaluation on the XV-3 convertiplane was conducted at Edwards Air Force Base between 21 May and 3 July 1959. Thirty-eight test flights were made during this period for a total of 29.6 hours of flight time. A brief STOL evaluation was conducted at Bakersfield, California, on 30 June 1959. Forty complete conversions to airplane flight and twenty gear shifts to the more efficient low propeller rpm were made.

These tests were conducted at the request of Headquarters Air Research and Development Command, Directorate of Systems Management, reference ARDC letter RDZSCM dated 1 May 1959.

The XV-3 demonstrated that the tilt-rotor VTOL concept is operationally practical with safety and complexity comparable to helicopters. The versatility while operating at intermediate conversion angles was excellent. During the flight evaluation there were no maneuvers attempted that were not safely completed. Full deflection aileron rolls, steep turns, and stalls were easily accomplished. Rotor-propeller operation was successfully accomplished over a wide range of rpm (250 to 600), power on and off, without any apparent rotor-propeller instability. Additional features that are considered to provide highly desirable characteristics for any VTOL aircraft are the power-off reconversion capability, good STOL capability, very low vibration levels, non-dependence on electronic augmentation for stability, low downwash velocity and excellent reliability.

Several unacceptable deficiencies were noted during the test program. The most important question, however, is whether these deficiencies are hardware problems peculiar to the XV-3 itself, or whether they are inherent deficiencies in any tilt-rotor VTOL design. It is felt that caution must be exercised in assigning any deficiency to a basic configuration before all the data has been reduced and analyzed in detail. Furthermore, some of the problem areas must

be investigated in more detail before they can be completely defined.

Some of the unacceptable deficiencies of the XV-3 are: the lateral instability in hovering flight in ground effect; the sudden requirement for a large increase in power as hovering flight is approached; weak lateral-directional dynamic stability and longitudinal and directional controllability in the low speed, low conversion angle regime; excessive blade flapping during longitudinal and directional maneuvering in airplane flight; weak longitudinal dynamic stability in airplane flight at dive speeds; and the high parasite drag.

Correction of the present deficiencies in a future design should yield a practical VTOL, capable of operating from unprepared landing sites, with good low speed handling qualities and performance (comparable to modern helicopters), and satisfactory stability and performance characteristics in airplane flight.

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DESCRIPTION OF THE AIRCRAFT

The XV-3 convertiplane is a fixed mid-wing monoplane with a two-bladed semi-rigid rotor mounted in each wing tip pylon. The rotors may be tilted 90 degrees by electrically powered, linear actuators in the wing tip pylons. The convertiplane maintains a conventional attitude in all flight regimes. It has a conventional empennage with an added ventral fin and uses skid landing gear. A single R-985 Pratt and Whitney reciprocating engine, mounted in the fuselage, provides power. Power is transmitted from the central transmission to the rotor masts by torque tubes located in the wing. The cockpit contains typical helicopter controls plus conversion controls and instruments. The longitudinal, lateral, and collective controls are hydraulically boosted. There are no "black boxes" for stability augmentation in the XV-3.

OPERATION

The XV-3 flight envelope is divided into three basic regimes: helicopter, partial conversion, and airplane. Take-off and landing, hovering, and low speed flight are accomplished as a helicopter. The airplane configuration is used for cruise and high speed flight. For some particular low level missions it is possible that flying at an intermediate conversion angle will prove advantageous from the standpoint of safety and maneuvering flexibility.

In helicopter flight the laterally displaced twin rotors, turning at 532 rpm, provide forward thrust and lift. For hovering and low speed, longitudinal control is provided by cyclic pitch, directional control by differential cyclic pitch and lateral control by differential collective pitch.

A switch on the cyclic stick operates the electrical, linear, wing tip actuators which tilt or convert the rotor masts. During conversion, as airspeed increases, the wing provides an increasing proportion of the lift. The high rotor rpm gear ratio, used for helicopter flight, is maintained throughout conversion. As the rotor tilts forward from 0 degrees, the longitudinal cyclic control and the differential cyclic control diminish linearly to a locked-out position at 90 degrees conversion angle. Conventional surface controls, ailerons, rudder, and elevator are used for airplane flight. These surface controls operate at all times.

For airplane flight, a large amount of collective pitch is required. Most helicopters require about 15 degrees of rotor blade pitch change compared to about 45 degrees for the XV-3 convertiplane in airplane flight. This 45 degree change in rotor blade angle is provided by three mechanical features. First, the pilot can change the blade pitch a total of 15 degrees by operating a typical collective pitch stick. Secondly, a mechanical linkage linearly and automatically adds 15 degrees of blade pitch as the rotor masts are converted from helicopter to airplane configuration. Thirdly, the pilot can change the blade pitch by 15 degrees by operating a mechanical system incorporated in the collective control system called a collective pitch "range shift". The pilot can "beep" or can continuously add blade pitch by operating the range shift toggle switch which operates an electrically driven actuator that drives the mixing linkages in the collective control system.

In airplane flight it is desirable, for most missions, to shift gears to a lower more efficient rpm range. The gear shift procedure is to reduce power, disengage the hydraulic clutch thereby allowing the overrunning clutch to drive the rotors, lower rotor rpm by applying collective pitch, and then restore power.

LIMITATIONS RELATIVE TO THE TEST PROGRAM

The original design gross weight, approximately 4700 pounds, was not realized. With one pilot full fuel load (600 pounds) and AFFTC's instrumentation installed (160 pounds) the XV-3 would have grossed 5200 pounds. This high gross weight definitely prohibited hovering. In an effort to reach a hovering capability, the gross weight was reduced to 4600 pounds by using only partial fuel load and by removing the heavier instrumentation components. However, even by overreving the engine 300 rpm, only a very marginal hovering capability was realized at Edwards Air Force Base (elevation 2300 feet) during the warm month of May (approximately 20 degrees Centigrade). Furthermore with the instrumentation installed, a practical fuel load (275 pounds for 1 hour endurance), and with increasing temperatures, it was apparent that an STOL technique was required regardless of the test location. A short qualitative hovering evaluation was conducted at Fort Worth in the cool month of January with the gross weight reduced to about 4600 pounds.

Earlier the contractor had briefly evaluated the STOL performance of the XV-3 using four sets of dual rubber wheels externally attached to the landing skids. Due to the weight of these wheels (about 90 pounds) and the added parasite drag, it was deemed advisable to develop new small metal wheels and incorporate them inside the skid tubes. In this regard, the contractor fabricated four 5 inch OD metal wheels weighing a total of only 20 pounds. These metal wheels were installed and checked out at Edwards Air Force Base by the contractor. Except for the STOL evaluation at Bakersfield, California, these metal wheels were utilized throughout the limited flight evaluation.

Due to the lack of a hovering capability, marginal performance in airplane configuration, and the limited nature of the test program it was impractical to try to determine the effects of weight or center of gravity changes. Except for the STOL evaluation, all tests were conducted at approximately 4850 pounds gross weight and at essentially a mid-center of gravity

All test work was conducted with the wing struts on and rigidly locked*. The high parasite drag of these wing struts reduced

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*The contractor had previously conducted some tests using a mechanism which permitted in-flight locking and unlocking of the wing struts.

performance, especially at high speeds.

SYMBOLISM FOR CONFIGURATIONS

Due to the multitude of variables that change the test configuration of this convertiplane, the following symbolism is included for ease of discussion:

H	Helicopter, 0 degrees conversion angle, high rotor rpm gear ratio (532 rpm at 2300 engine rpm), optimum flap position (up for take-off, landing, and autorotation, 20 degrees down elsewhere).
C30	(or C15, C45, etc.) -- Rotor masts converted 30 degrees (or 15, or 45, etc.) from vertical, high rotor rpm gear ratio, optimum flap position (20 degrees down).
AH	Airplane flight, 90 degrees conversion angle, high propeller rpm gear ratio, optimum flap position (20 degrees down).
A	Same as AH except low propeller rpm gear ratio.

TEST RESULTS

COCKPIT

In general the cockpit is satisfactory for a research test-bed vehicle. Entrance is accomplished without undue difficulty; the seat is comfortable for short range missions. The pilot had access to all controls with shoulder harness locked with the exception of the pedal adjustment levers which had to be positioned on the ground. The over-all visibility was good in all directions except downwards over the nose. This lack of visibility is serious for any VTOL or STOL aircraft that is designed to operate from unprepared sites. The cockpit is roomy enough to easily accommodate a 200 pound pilot. The instruments are well placed. Noise levels (118 decibels when hovering with maximum power) are satisfactory when normal helicopter ear protection is used. Noise levels in forward flight were qualitatively judged to be less and the pilot reported noise levels quite comfortable. Ventilation during ground operation or during hover was poor. In forward flight, ventilation was provided by an intake in the nose that directed air flow on the inside of the canopy which proved very satisfactory.

Two unsatisfactory areas, especially for a production version, are the large number of pilot controls required for normal flight operation and the ejection system. In routine flight the pilot must operate the collective stick, the throttle twist grip, the collective pitch range shift switch, and the gear shift switch with the left hand. The right hand operates the conventional cyclic stick, flap position button, lateral trim button, radio switch, and conversion button. In addition there are the usual engine, engine accessory, and radio controls; and the controls for emergency reconversion, and emergency collective pitch range shift. The primary objection is not the fact that there are too many controls installed in the cockpit; it is that the pilot is required to manipulate too many controls and watch too many instruments during some flight maneuvers, for example during a gear shift. It is questionable whether even an above-average pilot could correctly manipulate all the controls during emergency situations. It should be mentioned that several of these controls and cockpit procedures could be eliminated or simplified by mechanical design in a production vehicle. The use of free turbine engines with speed governors in future designs may also offer advantages for cockpit procedures.

The escape system, the second unsatisfactory item, is a downward escape system with seat and pilot egress assisted only by a bungee cord system. As in the F-104 it is unsatisfactory because ejection is downward; the pilot must free himself from the seat; and it is improbable that the bungee cord system would even fire the pilot and seat out of the cockpit if the aircraft is rolled on its side or inverted to any degree. The pilot would stand the chance of encountering the large rotors when escaping during uncontrolled rolling or sideslipping. An upward ejection system appears desirable for this configuration.

STARTING AND ROTOR ENGAGEMENT

All starts were made using an external power source. A battery is installed in the aircraft which theoretically will start the engine. However, this battery was kept at its highest potential in case of an in-flight emergency where it would be used for range shifting and reconversion. The starting procedure is standard for an R-985 engine. Engine starting was usually accomplished with the clutch control in low rpm position where the rotors are driven directly by gearing which by-passes the clutch (this increases clutch life) and then positioning the clutch to the high rpm position after rotor speed had reached approximately 300 rpm.

GROUND HANDLING

With either the large dual rubber wheels or the small metal wheels, directional control on the ground was almost nonexistent. Consequently, all take-offs and landings were conducted into the wind except for crosswinds of less than 5 knots. During one landing in a 5 knot crosswind (touchdown at about 20 knots IAS), full rudder pedal did not prevent the aircraft from weather vaning into the wind. Landing on a narrow runway in a 5 knot or more crosswind could lead to a dangerous situation.

On either set of wheels the aircraft could easily be taxied forward or backward in a straight line using cyclic control or, for forward taxi, by using 5 to 15 degrees of conversion. When using the small metal wheels, attachable dual rubber ground handling wheels proved satisfactory for ground handling. When the large rubber STOL wheels were installed, the ground handling wheels could not be utilized.

Due to lack of hovering performance and directional control, no attempt was made to evaluate the characteristics of the skid tubes sliding on the ground.

Rotor clearance between the ground and the rotors was satisfactory. Ground personnel should exercise normal caution when approaching the cockpit as the rotors are decelerating to a stop. Care must be used by the pilot when ground checking the conversion units so the rotors do not strike the ground or personnel. A maximum of C25 was used during ground check with rotors operating.

HELICOPTER CONFIGURATION

Hover:

The high test gross weight (4850 pounds) and test elevation (2300 feet) prevented free hovering flight. To obtain hovering performance a hovering rig was used. This rig consisted of a small loading platform that could be raised from ground level to a height of 13 feet (which put the XV-3 out of ground effect), and the skid tubes of the aircraft rigidly attached to a piece of boiler plate which rested on four load cells. The four load cell readings were recorded on an oscillograph. This hovering data shows that at full throttle (about 450 BHP), 2400 engine rpm (555 rotor rpm), at 3650 feet density altitude with flaps up, the XV-3 can (1) lift-off the ground at approximately 4730 pounds gross weight, and (2) hover at 4200 pounds gross weight at a 13 foot skid height. Under the same conditions, lowering the flaps 60 degrees at the 0 foot skid height permits lift-off at about 4780 pounds gross weight. Thus it appears that 60 degree flaps decreases the load of the downwash on the wing by about 50 pounds. (The contractor estimates that the total hovering download on the wing (flaps up) is about 400 pounds.)

The following qualitative statements were obtained from the AFFTC pilot during familiarization flights at Fort Worth (elevation about 692 feet) where a hovering skid height of 6 to 8 feet could be sustained during the cool month of January (approximately zero degrees Centigrade).

When hovering close to the ground, the XV-3 exhibits an erratic tendency to dart laterally. In addition to this phenomenon a roll oscillation persists when hovering close to the ground. It is believed that these characteristics are due to non-uniform changes in the downwash flow pattern. Above a 5 foot skid height, these phenomena disappear and stabilized hover over a spot can be accomplished without difficulty. Hovering turns over a spot and low speed sideward and rearward flights were accomplished.

When hovering with a 10 knot tail wind, a large amount of back cyclic control was required to hold position over the ground.

The differential cyclic used for directional control was insufficient in initial response. This is characteristic of tandem helicopters and it is questionable whether this configuration would ever attain optimum response in yaw, however, control would be improved by increasing the total differential cyclic available plus changing the mechanics of the control system to provide an increased response for a given pedal input.

When nearing the power required for hovering lift-off the aircraft reacts with a lateral oscillation that is disturbing to the pilot. During the tests at Edwards Air Force Base full take-off power was not applied until a ground roll was established. As translational lift was entered, full power was applied. This technique was used to avoid the aircraft lateral instabilities in the hovering regime.

It was noted by the pilot that increased power was required for hovering with a 10 knot crosswind as would be expected with the rotors in this "tandem" position.

Transition:

At low forward speeds (15 to 20 knots) there is a longitudinal stick position reversal. This characteristic was anticipated for safety by the pilot for each take-off. The backside of the speed power curve (speeds between hover and best climb speed) is very steep, providing good forward acceleration and STOL capability. It is believed that this sharp drop in power (from hovering power) results from the reduction in induced power which occurs due to the aspect ratio effect of the side-by-side rotor configuration.

The reverse effect encountered when landing was even more pronounced. As hovering flight is approached (approximately 10 knots IAS) there is a sudden requirement for an additional 9 to 10 inches Hg MAP. Even though anticipating this condition, the pilot found it nearly impossible to prevent the aircraft from suddenly losing 2 or 3 feet of altitude before sufficient power for stabilized hover could be obtained. This characteristic is undesirable and should be considered a safety of flight item for aircraft combining marginal hovering performance and poor low speed control characteristics. The pilot is given some compensation from the damping provided by the rotor in descent plus the low power required during an approach. Furthermore, rotor inertia can be used to reduce the descent rate in the event the aircraft starts to "fall through". But in any case the combination of the sudden demand for power, poor low speed stability and controllability, and skid landing gear dictate that this be labeled a safety of flight item for the XV-3. This sudden power requirement has been noticed on the H-21 and HSL during a 90 degree sideslip approach and in the McDonnell XHJD-1, which had laterally displaced rotors. In fact, XHJD-1 pilots found that this condition could be avoided by approaching hover with large sideslip angles.

Take-off and landing performance is discussed under STOL evaluation.

Level Flight

At 4850 pounds weight, 5000 feet density altitude, using 20 degree flaps, V_{max} is 75 knots TAS and V_{min} about 15 knots in configuration H. Minimum power required occurs at 45 knots. The backside of the speed-power curve is very steep due to the aspect ratio effect previously mentioned; the high speed side of the curve is also quite steep because of the large parasite drag (high speed requires severe nose down fuselage attitude) and negative lift on the wing. At higher airspeed (about 60 knots IAS) a two per revolution vibration becomes apparent, believed to be retreating blade stall. The magnitude of this vibration increased as airspeed increased to an unsatisfactory level at 70 knots IAS. A small conversion angle greatly improved this condition as will be discussed later*.

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*It should be noted that the contractor does not consider configuration H a normal flight condition in the higher speed regime but recommends [illegible] of at least C10.

Stability and controllability are satisfactory except at low speeds (below 35 knots IAS). At low speeds a divergent long-period directional oscillation is apparent. The amplitude of this oscillation can increase to the point where the tail swings into the rotor wash, promptly inducing pitch-up. This oscillation can be suppressed by constant manipulation of the directional control. The dihedral effect is negative. Longitudinal dynamic stability was excellent above 40 knots . At 25 knots or lower a pitching oscillation was present. It was virtually impossible for the pilot to longitudinally stabilize the aircraft in this low speed regime. The lateral control response was good. The directional control response was poor. This condition plus poor directional stability resulted in a poor control balance about all three axis. Even though the flying qualities are poor in the low speed region the XV-3 can be safely operated in all normal maneuvers.

Autorotation:

The best configuration for autororation appears to be with the masts vertical and the flaps up, although insufficient quantitative data was obtained to positively determine the best flap position. Typical values of rate of sink are as follows:

Configuration	Flaps	Altitude ft	Rotor rpm	IAS kt	Rate of Descent fpm
H	Up	4750	570	45	1780
H	Up	4750	570	55	1695
H	Up	4750	570	65	1750
C10	Up	4750	560	55	1910

It is seen that minimum autorotative descent is about 1695 fpm at 55 knots IAS with the mast vertical. The above tests were conducted at 570 rotor rpm for consistency. At C10 however, only 560 rpm could be obtained. Maximum rotor speed which can be realized with the masts vertical and at 55 knots is 600 rpm. However, stabilized rotor speed decreases as airspeed is increased above 55 knots due to the wing carrying more lift, thereby unloading the rotors. At the lower autorotation rpm and higher speed conditions (above 75 knots) the aircraft has an annoying shake. At C10 this condition is worse. This may be caused by excessive blade flapping. Lateral stability deteriorates in low speed autorotative flight, possibly because stalled flow from the wing passes through the rotors. Directional control is reduced and a roll oscillation is very pronounced.

An actual autorotative landing was conducted with the masts vertical. Touchdown speed was approximately 30 knots IAS on the dual rubber wheels. The flare from about 60 knots was effective and no problem area was noted.

Autorotations were qualitatively evaluated at C15. Though no critical problem developed at this higher conversion angle, it is considered undesirable for autorotation because the sink rate is higher, rotor rpm is lower, and there is a lack of sufficient longitudinal control, especially for flares (the longitudinal cyclic control washes out linearly with conversion angle).

Entry to autorotation from airplane flight is discussed under "Conversions and Re-conversions".

The XV-3 tail configuration with ventral fin removed approaches the ideal for autorotation landings. The swept-up tail allows maximum flare possibilities and rotor-ground clearance is sufficient to make it nearly impossible for the rotors to strike the ground. The laterally displaced rotors gave very good performance for stopping sink rate and forward speed. Rigid skid gear is a decided disadvantage for autorotations when making nose high landings.

SOME CHARACTERISTICS OF THE XV-3 AT THE INTERMEDIATE CONVERSION ANGLES

Climb:

With the added variable, conversion angle, many climb configurations are possible. The following table summarizes climb performance at one altitude, 6000 feet, 4850 pounds gross weight, and using 20 degree flaps (optimum).

Configuration	Speed for Best Rate of Climb IAS - kt	Rate of Climb fpm
C15	57	450
C25	60	650
C30	60	725
C35	65	685
C45	75	535
C55	80	350

At all altitudes from 4000 to 9000 feet, maximum rate of climb was obtained using C30. The highest recorded rate of climb at 4850 pounds gross weight was 1000 fpm at 4000 feet altitude and 60 knots IAS. Even though the wing will stall at about 55 knots IAS using C30, 400 to 500 fpm rate of climb could be obtained with the wing stalled. For conversion angles greater than C30, the best climb speed was just above the wing stall speed.

Reasons for not climbing at conversion angles greater than C55 were:

1. Longitudinal control was decreased to a marginal level due to cyclic washout with conversion angle.
2. Fuselage attitude became uncomfortably nose high at low speeds.
3. Visibility was poor.
4. Rates of climb were poor.

Stability during climb was acceptable. Responses to longitudinal pulse inputs were essentially deadbeat, except in the low speed, small conversion angle regime as previously mentioned.

Adverse yaw-roll coupling was apparent and was more pronounced in the lower conversion angles.

Level Flight and Stalls:

The XV-3 can easily be flown in level flight at any conversion angle. At the lower conversion angles at low altitudes, and at the large conversion angles at all altitudes, maximum speeds are limited by power available. At higher altitudes (7000 to 10,000 feet) and at the lower conversion angles (H to C15 degree) retreating blade stall occurs, as evidenced by increased vibration, prior to full power but does not affect control or stability. Minimum practical speeds should be considered to be limited by wing stall above C25 and by power available below C25, although level flight may be continued below stall speeds at intermediate conversion angles by additional power. In this case the rotors are dragging the wing "along for the ride". Typical values of maximum and minimum level flight speeds at 5000 feet altitude, 4850 pounds gross weight, 20 degree flaps are as follows:

Configuration	V_{min} TAS - kt	V_{max} TAS - kt
H	15	75
C15	23	100
C30	65	106
C45	78	107
C60	88	106
C75	94	103
AH	98	101
A	95	112

It is noted that V_{max} is essentially the same from C15 to AH. That is, the speed power curves essentially fall on top of each other in the V_{max} regime in this power limited aircraft.

At speeds above 35 knots stability and controllability are acceptable at C30. There is some pronounced adverse yaw-roll effect at this conversion angle. At C60 this adverse yaw effect is still apparent but is diminished to an acceptable level. Lateral control appears most effective at C30.

Wing stall characteristics are good from C25 to AH (the wing cannot be noticeably stalled below C25). A typical mild buffet occurs with stall and the stall is mild with no rolling tendency. It is not necessary for the pilot to cautiously safeguard against stall because it is inconsequential if the wing does stall. Slight conversion angles provide tremendous improvement over the helicopter configuration in stability, control, vibration levels and speed capability.

Descents:

Partial power and power-off descents were conducted at C15, C30, C45, C60 and C75. With partial power the characteristics were satisfactory. With power-off severe buffet due to wing stall was the primary limiting factor. The pilot was forced to abort some steep power-off descents at C30 to C75 due to severe buffet, although the rotor rpm could be maintained. During descents at mid conversion angles with the wing stalled, lateral stability and controllability was reduced. If the airspeed is maintained at 90 knots IAS or greater the stall buffet is absent or minimized. At C15 or below the aircraft shakes in a high power descent at low airspeeds, probably from being in its own rotor wash as is common to all helicopters.

As previously mentioned at C15 and low speeds, longitudinal and directional control are inadequate, preventing a precision low speed approach.

Steady state and transient blade flapping were as high in partial power descents as in any other regime (9 to 10 degrees out of possible 11.5 were recorded).

Conversions and Reconversions:

One outstanding feature of the XV-3 is that conversions and reconversions can be made, either in "beeped" steps or continuously from any flight condition. There is no limiting combination of airspeed, conversion angle, fuselage angle, altitude, wing stall, power setting or trim position schedule required for conversion. In addition to a myriad of conversion steps, the following continuous conversions and/or reconversions were conducted.

Conversion and reconversion holding altitude.

Conversion holding airspeed (starting from C15).

Conversion and reconversion adding collective pitch range shift at intermediate angles.

Conversion and reconversion without adding collective pitch range shift.

Conversion and reconversion during a standard rate turn.

Conversion and reconversion started during a climb.

Conversion and reconversion during descents.

Conversion and reconversion with the wing stalled.

Conversion and reconversion by a pilot during his first flight in the XV-3 (made by Captain W. J. Hodgson using the step technique).

Reconversion, power-off, from C45 to H without a flare.

Reconversion, power-off, from C45 to H with a flare at C25.

Reconversion, power-off, from AH without flare.

Reconversion, power-off. from A with flare at C25.

Conversion at 10,000 feet altitude.

Conversion and reconversion at 600 feet altitude.

None of these tests revealed a serious problem area. Rotor behavior and aircraft behavior were very satisfactory. No large control changes, stability changes, or prohibitive blade flapping effects were noted. A continuous conversion requires about 11 seconds.

Additional comments are in order for the power-off reconversions. After conducting numerous full throttle reconversions reduced-power reconversions were made at 25, 20 and 15 inches Hg MAP. Prior to this testing, the major concern was whether the rotor rpm would drop to a dangerously low value as the mast angle went from C45 to C30. In this area the flow must change from driving a windmilling propeller to upward flow through the rotor for autorotation. There is thus an area where the rotor is not being driven aerodynamically. The reconversion at only 15 inches Hg MAP indicated that there was a tendency for the rotor rpm to drop in this area; however, the rotor decay was not of a prohibitive magnitude.

The first power-off reconversion from airplane flight, high rotor rpm ratio, to autorotation in helicopter configuration was conducted at about 4775 pounds gross weight, a cg 0.3 inches aft of neutral, 20 degree flaps, power at idle with an engine rpm of 1700, starting at 90 knots IAS, 7800 feet pressure altitude, OAT 16 degrees C. The reconversion was continuous. From AH to C60 the wing was stalled due to the low starting IAS. At the smaller conversion angles (C30 to H) the rotor rpm dropped from the 550 starting value to about 440 rpm and then increased to the normal value (600 rpm) as helicopter autorotation was entered. Several seconds after autorotation was entered and stabilized the altimeter read 6300 feet. Thus the first power-off reconversion and entry into stabilized autorotation required about 1500 feet. The pilot made no attempt to flare the ship during the reconversion to increase the rotor rpm and decrease the altitude loss.

The second power-off reconversion was started from airplane flight operating in the low rotor rpm gear ratio (324 rpm). Conditions were 4790 pounds gross weight, a cg 0.3 inches aft of neutral, 20 degree flaps, idle power at 1450 rpm, starting at 5000 feet altitude, OAT 23 degrees C and 90 knots IAS. Stall buffet again occurred during the first part of the reconversion. There were no control, stability, or vibration problems. The lowest rotor rpm during the maneuver was 435, occurring at about C10. Autorotation was established at 4200 feet altitude. Rate of sink was 2000 fpm from AH to C25 and only 600 fpm (due to flare) at H. The two factors which minimized the altitude loss (only 800 feet this time compared to 1500 on the first attempt) where a flare at the lower conversion angles (started about C25) and the fact that 4200 feet altitude corresponds to just entering helicopter autorotation -- not a stabilized autorotation as in the first test.

It is thus concluded that power-off reconversion and entry into stabilized autorotation can be made comfortably with a 1000 foot altitude loss provided a flare is executed during the reconversion.

It is recommended that the airspeed at the start of the reconversion be at least 95 knots IAS. At slower speeds the wing will stall during the first part of the reconversion. The stall is accompanied by buffeting and a high sink rate which increases the blade flapping.

Power loss was simulated at intermediate conversion angles by reducing the power to idle. It was expected that the most critical area for rpm behavior would be from approximately C45 to C30 This was not the case, since rotor rpm decay did not become appreciable until C25 or less, progressively increasing as H was approached In H the rotor decay following power loss is average for a helicopter.

SOME CHARACTERISTICS OF THE XV-3 IN AIRPLANE FLIGHT

Level Flight at High Propeller RPM Gear Ratio:

At test gross weight (4850 pounds) level flight could not be obtained at altitudes above 5000 feet. At lower altitudes wing stall occurred at 98 knots TAS with V_{max} about 101 knots. Thus the level flight speed envelope was only about 3 knots. In smooth air the vibration level is low. The aircraft responds peculiarly to gusts in that the aircraft seems abruptly disturbed rather than "riding through" a disturbance as do most airplanes. These abrupt disturbances consist of accelerations along the longitudinal axis. Pilots found this unusual phenomenon quite weird but not frightful after familiarization. In addition, the aircraft responds to gusts with a yawing motion. In low propeller rpm this phenomenon was reduced. One possible explanation for this effect is that the gusts are imposed on the propellers unsymmetrically.

There was essentially no climb capability in this configuration under test conditions during the warm month of June.

Stability was excellent about all axes. Response to control pulses were essentially deadbeat. A slight bank is established in the proper direction when pulsing the rudder pedal (right pedal produces right bank)

Gear Shift:

Twenty gear shifts into low rotor rpm (324) were accomplished during the evaluation. Prior to gear shifting the collective pitch range shift must be used. This device allows more pitch to be applied to the rotors than the normal range of collective operation could provide. The reader may think of this in either of the following manners:

The collective pitch control stick is allowed to move to a new low position from its physically high position in the cockpit while holding constant blade collective pitch setting as the range shift switch is held forward. From this point the pilot may get a new "bite" on the system

If the collective pitch control is held fixed then holding the range shift switch forward will put in about 15 degrees of collective pitch.

The gear shift procedure is as follows:

1. Starting from AH configuration, the collective pitch range shift is put in either by "beeping" or by a continuous operation. If done continuously, a little practice is necessary to coordinate collective stick movement to maintain rpm.
2. Holding 90 to 95 knots IAS, cut power to idle.
3. Throw the clutch switch to disengage the hydraulic clutch and thus permit the overrunning clutch to drive the rotors.
4. Pull up on collective stick to slow propellers to 324 rpm.
5. Apply power.

The reverse procedure applies when shifting back from low to high propeller rpm The average time required to complete the gear shifting operation was about 10 seconds.

Though conversions were made without altitude loss, some altitude must be lost in gear shifting the XV-3 because of the necessity to cut power. This altitude loss was generally about 400 to 500 feet

Other than altitude loss, no problem areas were noted during the twenty gear shifts This was also accomplished, on occasion, during wing stall.

Level Flight at Low Propeller RPM Gear Ratio

Gear shifting to the more efficient low rotor rpm added about 11 knots to V_{max} (112 knots TAS in configuration A at 7900 feet density altitude) and enabled level flight above 9000 feet density altitude. V_{max} was limited because of power available

At lower altitudes a small 100 to 200 fpm climb capability existed

Stability appeared good at level flight airspeeds. Responses to control pulses were essentially deadbeat, similar to those obtained in high rotor rpm. Since the rudder is unboosted, directional control forces were high.

Steep turns were accomplished with no adverse effects.

Sideslips to 15 degrees were made without excessive blade flapping.

Rolling maneuvers were satisfactory. Maximum lateral stick displacement was accomplished. The resulting roll rates were a acceptable (20 degrees per second maximum). Rolls to 60 degree bank angles were conducted. During these maneuvers blade flapping remained low.

Vibration levels were low.

During the program the aircraft was flown in this low rpm regime for a total of 3 hours and 15 minutes.

No problems were encountered in this regime except at the higher dive speeds as discussed under "High Speed Dives".

STALLS

Though there is no stall warning in configurations A or AH, the stall characteristics are nevertheless good. The stall is mild with only slight pitching at all power settings. There is no tendency to roll or yaw. Stall speeds were 95 knots TAS in A and 98 knots in AH at 5000 feet.

HIGH SPEED DIVES

The high speed regime was incrementally extended from 110 knots TAS in level flight to 155 knots in a dive using low rotor rpm gear ratio. The test work terminated at 155 knots because all the available collective pitch was utilized. Faster speeds could only be obtained by overspeeding the rpm (or modifying the collective system to increase available pitch).

In the 120 to 140 knot TAS regime the pilot of the chase ship reported that the horizontal stabilizer and elevator were buffeting although the XV-3 pilot could not detect this tail buffet. Accelerometers were installed in the tips of the horizontal tail to define this phenomenon. Results showed that in AH a 4/rev (34 cps) frequency predominated with some 2/rev (17 cps) evident and in A the 2/rev (11 cps) predominated with some 4/rev evident. Double amplitudes were a maximum of about 1/2 inch. The mode of the horizontal tail was the asymmetric see-saw type. The amplitudes increased only slightly with airspeed. Because tail flutter was not evident and airspeed not an important factor, the high speed investigation was continued. The pilot was still unable to detect any tail buffet at the maximum 155 knot TAS dive point.

A stability and controllability investigation was conducted in incremental steps up to and including 150 knots TAS. The stability and controllability characteristics deteriorated in this high speed region. The dynamic characteristics were excellent at 105 knots. Above 120 knots a weakly damped pitching oscillation (the short period mode) begins to appear.

At the time of this writing insufficient data has been reduced and analyzed to positively define this phenomenon.

One possible reason for the weakness of the short period longitudinal dynamic stability is the short distance on this airplane between the horizontal tail and wing. Another is the destabilizing effect of the relatively large propeller blade area.

The vibration level at 95 knots IAS is very low. At 100 knots this level increases but builds up only slightly with further increases in airspeed. An aft pulse of the stick produced a weakly damped oscillation. When the nose raised, following an aft pulse, there was no blade flapping apparent; however, as the nose lowered there was noticeable blade flapping which was apparent in aircraft roughness and on the oscillograph records. Blade flapping could also be felt in yawing maneuvers but was not a factor in rolling maneuvers. Full deflection aileron rolls were accomplished without approaching blade flapping limitations. Blade flapping is a design problem in this configuration and represents a possible limiting factor in maneuvering longitudinally (nosing down) and in yaw. To minimize this factor the contractor has used 20 degrees delta 3 (pitch-flap coupling angle between blade flapping "hinge" and blade feathering "hinge") which mechanically reduces blade pitch as that blade flaps up. Increased delta 3 appears to be required. However, as delta 3 is increased, control is decreased during helicopter operation unless additional cyclic control is provided. Therefore, in future designs using an increased delta 3, it must be determined if there are any limitations in providing the additional cyclic control.

It may also be desirable to droop the masts below 90 degrees, say 92 or 93, since the upwash, ahead of the wing, causes aft flapping.

STOL EVALUATION

On 30 June 1959, a brief STOL evaluation was conducted at Bakersfield, California. The tests were conducted at Bakersfield because of favorable wind conditions and because the low elevation (492 feet) increased performance, and thereby safety in this low speed region. Twenty-four take-offs and landings were photographically recorded with a Fairchild Theodolite camera. The large dual rubber wheels were attached to the skids, the ventral fin was removed (to permit higher flare angles), and wing tip skids were installed (to protect wing tip pylons in case of roll). Conditions were 4570 pounds gross weight, a cg 1.0 inches aft of neutral, 490 feet pressure altitude, OAT 23 degrees C average, flaps up, full throttle and 2400 engine rpm. Under these conditions, the aircraft should have been capable of hovering inches off the ground. The runway was hard surfaced and had no slope.

Configuration	Climb Out TAS kt	Distance Over 50 Foot Obstacle - ft
H	30	470
H	40	625
C7½	40	550
C15	40	515
H	45	770
C7½	45	635
C15	45	585
C7½	50	745
C15	50	670

Test work was limited to a minimum of 30 knots TAS because of the marginal stability and controllability characteristics in the low speed regime plus the acceleration resulting from the steep slope of the backside of the power curve made it nearly impossible to avoid accelerating past a low climb speed once transitional lift was obtained

From a performance standpoint the airspeeds were too high to define the airspeed for minimum take-off distance. Consequently, minimum distances over a 50 foot obstacle may be much lower than the distances given in the preceding table Furthermore there was insufficient time to develope an optimum take-off or landing technique In any case, the results show that the distances decrease as conversion angle is increased to 15 degrees, at least in this higher airspeed regime (above 30 knots TAS). C15 was taken as the practical test limit although the rotors will convert to about C30 before contacting the ground.

Below climb speed the H and C15 speed power curves coincide This implies that STOL performance should be essentially independent of conversion angle in the 0 to 25 knot regime.

ENVIRONMENTAL PRACTICABILITY

The XV-3 has a low disk loading which is a highly desirable feature for operational suitability. The XV-3, with a 5.5 pound per square foot disk loading, should be capable of operation in and out of unprepared areas with minimum hindrance to the ground crew. During the test program the aircraft was operated off the edge of the taxi-way and from the lake bed at Edwards Air Force Base. These areas should not be considered typical unprepared areas; however, the feature was indicated by take-offs and landings that were conducted on an area in the lake bed that was covered with a heavy layer of fine dust. No adverse effects other than a dusty aircraft were noted. The pilot did not have to "go IFR" as was frequently necessary in the H-37 and its 7.7 pounds per square foot disk loading. Downwash behavior was typical of helicopters. At the time of this writing it is very questionable whether VTOL's (except for the XV-1 and XV-3 type) will actually be suitable for operation from unprepared areas. Even the tilt-rotor will lose its operation suitability if future designs incorporate high disk loadings. If disk loading above 10 pounds per foot (approximately) are used, the tilt-rotor configuration then assumes the disadvantage of increased downwash velocities plus compromised safety in the areas of autorotation and slow speed operation where large rotors provide inherent safety.

AIRCRAFT AVAILABILITY AND RELIABILITY

The XV-3 compiled the best availability record in the history of rotary wing test work at Edwards Air Force Base. Starting on 21 May 1959 (date of check flight by contractor) the aircraft was available for flight test work between 0530 and 0730 hours on each of the next 44 consecutive calendar days. Thirty-eight tests were actually conducted during the 44 calendar day period (38 working days). Maintenance requirements during the program were modest. It should be pointed out that an experienced Bell crew consisting of 3 mechanics, 1 inspector, 1 instrumentation technician and 1 foreman, maintained the XV-3 during AFFTC's evaluation, and that this crew, on several occasions, worked more than an 8 hour day as required for daily inspections and/or for changes in the test configuration. It can be justifiably argued that a 44 day period is too short for firm statements regarding the availability and reliability of a tilt-rotor VTOL.

CONCLUSIONS

Several unacceptable deficiencies were noted during the limited flight evaluation. The most important question is whether these deficiencies are hardware problems peculiar to the XV-3 itself, or whether they are inherent deficiencies in any tilt-rotor VTOL design. It is felt that caution must be exercised in assigning any deficiency to a configuration before all the data has been reduced and analyzed in detail. The following unacceptable deficiencies are known to be peculiar to the XV-3 itself. The final report will discuss whether they are or are not inherent in the tilt-rotor design to the degree warranted by a limited flight evaluation.

1. Instability in hovering flight.
   a. Erratic lateral darting tendencies in ground effect.
   b. Persistent roll oscillation about the longitudinal axis in ground effect.
   c. Sudden requirement for a large increase in power as hovering flight is approached.
2. Weak lateral-directional dynamic stability and longitudinal and directional controllability in the low speed, low conversion angle regime.
3. Excessive transient blade flapping during longitudinal and directional maneuvering in airplane flight.
4. Weak longitudinal dynamic stability (short period) in airplane flight at dive speeds.
5. High parasite drag.

Additional unacceptable deficiencies that are peculiar to the XV-3 itself and which are known to have straight-forward solutions are as follows:

1. Unduly complicated pilotage required due to multitude of cockpit controls.
2. Ejection system - because it is downward and is powered by

bungee cords.

3. Skid landing gear.

4. Poor performance due to low installed power (actually the propulsion system utilizes the low installed power efficiently).

The XV-3 exhibited the following good features that are considered to provide highly desirable characteristics for any VTOL aircraft.

1. Ease of conversion and reconversion. No scheduling of variables, such as airspeed, conversion angle, etc., is required.

2. Safety:

   a. Rotor damping and inertia.

   b. Autorotational capability.

   c. Power-off reconversion capability.

3. Operational practicability primarily because of low disk loading, and reasonable noise levels.

4. Aircraft and rotor propeller control and behavior during wing stall.

5. Good STOL capability.

6. Non-dependence on electronic augmentation for stability and control.

7. Excellent reliability and availability. Modest maintenance requirements.

8. Low vibration levels.

During the flight evaluation there were no maneuvers attempted that were not safely completed. No aerobatics were attempted. Full deflection aileron rolls, steep turns, and stalls were easily accomplished. Operation over a wide range of rotor rpm (250 to 600), power on and off, without any apparent rotor instability was commendable. The XV-3 demonstrated that the tilt-rotor VTOL concept is operationally practical with safety and complexity comparable to helicopters. The versatility while operating at intermediate conversion angles was excellent. Correction of the present deficiencies in a future design should yield a practical VTOL, capable of operating from unprepared landing sites, with good low speed handling qualities and performance (comparable to modern helicopters), and satisfactory high speed capability. Some of the problem areas must be investigated in more detail before they can be completely defined as discussed in "Recommendations". Thus it would be premature to conclude that all deficiencies are of the hardware type and none are inherent in the tilt-rotor principle.

RECOMMENDATIONS

Due to the limited nature of the AFFTC flight evaluation it was impossible to investigate all detailed problem areas. It is recommended that additional flight testing be conducted on the XV-3 in its present state to supplement the AFFTC evaluation as follows:

1. Remove the wing struts. Characteristics with a flexible wing should be investigated to determine if a tilting rotor is compatible with a flexible wing as necessarily required (from a weight standpoint) on a large aircraft. Removing the wing struts on the XV-3 would be an important first step in establishing these characteristics.
2. Investigate autorotational touchdown capability in more detail. AFFTC did conduct an actual autorotational touchdown without difficulty. However, touchdown was initiated at about 30 knots IAS. The usefulness of this apparently excellent configuration for flare-out landings should be further explored.
3. Investigate the adverse yaw-roll coupling in configuration C30. Presently the differential collective control (roll control) is linearly washed out with conversion angle. In the XV-3 it is very simple to disconnect this control washout feature. Thus it would be relatively simple to establish whether disconnecting the collective washout for the first portion of the conversion would eliminate the yaw-roll coupling problem.
4. Investigate the hovering regime in detail to define the lateral aircraft instabilities. This would necessarily include rotor downwash behavior in ground effect.
5. Investigate the effects of a large increase in directional control for hovering. This does not require a modification. Additional directional control can be obtained by rerigging

the present XV-3 control system although longitudinal control will decrease as directional control increases.

6. Investigate the effects of increasing the conversion angle to 92 or 93 degrees. It is believed that the upwash ahead of the wing causes aft blade flapping in the present airplane configuration of 90 degrees conversion angle. A 2 to 3 degree increase of conversion angle can be obtained, without modification, by re-rigging without changing the 0 degree mast angle setting. Further increases of conversion angle for airplane flight can also be obtained, without modification, by re-rigging but only by limiting the helicopter configuration to a small conversion angle instead of the present 0 degree mast angle.

7. If the tilt-rotor principle is considered for a production VTOL aircraft it is recommended that the XV-3 be considered for modification as required to evaluate the effects of a higher disk loading (say 10 pounds per square foot), parasite drag reduction, wheel landing gear, simplification of pilot controls, and if possible higher speed airplane flight. Such data would be valuable for construction of a prototype tilt-rotor vehicle.

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