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A Survey of Thrust Control Inceptors for VTOL Aircraft

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November 2017

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SUMMARY

Thrust control inceptors for VTOL aircraft have long been debated—in most cases, over the fundamental issue of throttle versus collective. Some aircraft used throttles with fore and aft longitudinal motion and some used collectives. This report surveys many widely varying types of VTOL aircraft, from the Military Service's "flying platform" concepts, which were actually flown, to proposed designs that never left the drawing board. Although substantial research and development dollars were expended, only two concepts were successful—vectored thrust as embodied in the AV-8 Harrier, and the V-22 Osprey tiltrotor. The tiltwings, tiltducts, and other concepts were discarded. Some of these were evaluated in flight, but they and the others faded into obscurity. This investigation includes some heretofore little-known designs from the Tri-Service VTOL Transport Competition in 1961. There were many "players" in this competition, but the only entry built was the Ling-Temco-Vought XC-142 tiltwing. Five XC-142A prototypes were manufactured, but all but one came to an untimely end. The other entries were a Bell/Lockheed tiltduct, a North American tiltwing, a Vanguard lift fan, and a Sikorsky tiltwing. Additional designs submitted included a Boeing-Wichita direct lift, a Boeing-Vertol tiltwing, a McDonnell compound and a tiltwing, and a Douglas turboduct and a turboprop. A private party submitted a redesign of the Bréguet 941 as a VTOL transport.

INTRODUCTION

During the design phase of an aircraft, the control of thrust should be a straightforward process. If the aircraft is to be an airplane, throttles would be the logical choice—forward to increase thrust and aft to reduce thrust. This holds true for jets or piston-powered aircraft, with some variations in the throttle design. Most use a conventional, vertically oriented throttle(s) operated by the pilot's right or left hand. Many Cessnas, however, use a push-pull rod with a knob to grip, and it is moved forward into the instrument console for increased power and aft to reduce power.

Vertical Takeoff and Landing (VTOL) aircraft, including helicopters, often use a conventional collective "stick" or power lever or throttles of various designs. The convention, "Up is Up and Down is Down" has served the VTOL community well for many decades. There have also been successful designs that use a type of throttle where "Forward is Up and Aft is Down." These designs have worked relatively well. One notable exception, however, was found in the MV-22 Osprey. The original collective design was replaced before the early Full-Scale Development (FSD) aircraft were built. In these cases, "Forward and Down was Up," and "Aft and Up was

Down"—an AV-8 Harrier–type arrangement. Many thought that this was a recipe for a mishap in an emergency and, unfortunately, they were later proven correct. A costly redesign was undertaken to resolve this problem.

Thrust control of VTOL aircraft has been a debatable issue. In most cases, it comes down to the fundamental choice of throttle versus collective. Some aircraft used throttles with fore and aft longitudinal motion, and some used collectives. Many widely varying types of VTOL aircraft—from the Military Service's "flying platform" concepts, which were actually flown, to designs that never left the drawing board—are reviewed in this report. Although substantial research and development dollars were expended, only two concepts were successful—vectored thrust as embodied in the AV-8 Harrier, and the V-22 Osprey tiltrotor. The tiltwings, tiltducts, and other concepts were discarded. Some of these were evaluated in flight but they, and the others, faded into obscurity.

This investigation also includes some heretofore little-known designs from the Tri-Service VTOL Transport Competition in 1961. There were many "players" in this competition, but the only entry built was the Ling-Temco-Vought (LTV) XC-142 tiltwing. Five XC-142A prototypes were manufactured, and all but one came to an untimely end. The other entries were a Bell/Lockheed tiltduct, a North American tiltwing, a Vanguard liftfan, and a Sikorsky tiltwing. Additional designs submitted were a Boeing Wichita direct lift, a Boeing-Vertol tiltwing, a McDonnell compound and a tiltwing, and a Douglas turboduct and a turboprop. A private party submitted a redesign of the Bréguet 941 as a VTOL transport.

THE XV AND X SERIES

XV-1

The XV-1 (fig. 1) was initially designated as the XL-25 (and later as the XH-35) as a liaison aircraft and part of a combined Army/Air Force program started in 1951 to develop a "Convertiplane." The idea of an aircraft that could takeoff and land vertically yet exceed the low speeds of helicopters of that era, was attractive to both Services. The competition included the Bell XV-3 and, for a short time, the Sikorsky entry—the S-57 retractable rotor. McDonnell's entry was a tip jet autogyro, eventually designated as the XV-1. Its overall length was 50 feet with a 26-foot wingspan. Empty weight was 4,300 pounds with a maximum gross weight (GW) of 5,500 pounds. It was powered by a single Continental R-975-19 radial piston engine that ran two air compressors which provided the tip jet thrust for the 31-foot, three-blade rotor for vertical lift, and power for a 6-foot, two-blade propeller mounted at the rear of the fuselage for forward flight. A small rotor was added to the end of each tail boom to provide yaw control in hovering flight. A throttle was used for thrust control. This was a complex control design. The first tethered test was flown in early 1954, and the first free flight was on 11 February of that year. Transition to forward flight was accomplished on 29 April, 1954. The second of two aircraft was damaged in autorotation testing, also in 1954. On 10 October, 1955, the XV-1 exceeded contemporary rotary wing speeds by a wide margin by reaching 200 mph. As conventional helicopter forward speeds increased, the program was canceled in 1957.

Figure 1. McDonnell XV-1 (McDonnell photo).

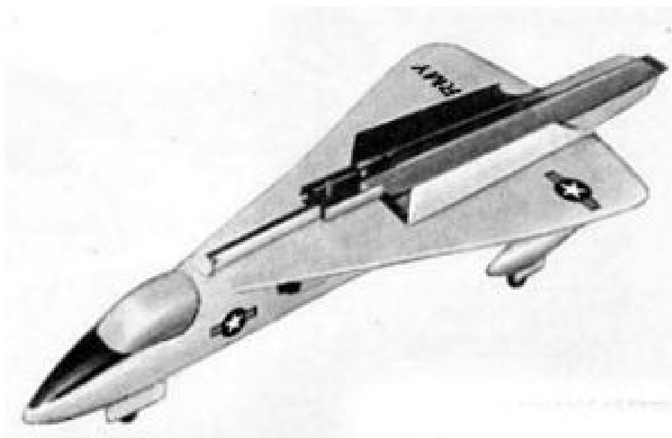

Figure 2. The XV-2 (Sikorsky drawing).

XV-2

This stoppable and stowed rotor concept was never built, and Sikorsky dropped out of the competition for an Army/Air Force “Convertiplane.” It used a single-rotor design with a counterweight to provide stability to the rotor, while a tip jet arrangement powered the rotor that could be retracted into the upper fuselage when stopped. The XV-2 (fig. 2) would then fly as a delta wing with a single jet engine providing propulsion for forward flight. A collective lever was designed to be used for thrust control.

XV-3

The XV-3 (figs. 3 and 4) was the forerunner of three successful tiltrotors—the XV-15, V-22, and Bell/Agusta 609 (later Augusta/Westland). It was designed by Robert Lichten, a Bell engineer formerly with the Transcendental Aircraft Corporation. Two aircraft were built—the Model 1G and the Model 2. Neither aircraft was initially able to complete the transition to full airplane mode flight.

Figure 3. The XV-3 hovering at Ames Research Center.

Figure 4. The XV-3 in tilt mode.

The XV-3 was powered by a single Pratt and Whitney R-985 piston engine that produced 450 hp. It was unable to hover out of ground effect (OGE) in the high-density altitudes of Edwards Air Force Base (AFB) in California. It had to use small metal rollers embedded in the landing skids to allow a takeoff run until it could lift off the runway or taxiway. An unusual feature was a bungee-cord-powered downward ejection seat for the single pilot occupant. It also had a manual "gearshift" to reduce proprotor rpm for the airplane mode of flight. The XV-3 used a conventional collective "stick" for thrust control in all modes of flight.

The XV-3 (or Bell Model 200) first flew in August 1955, however it crashed in October of that year after the pilot experienced severe rotor instability. The second XV-3 also crashed—this time from a hover—after a rotor-pylon coupling failed. A redesign effort was initiated and the fixes were 1) the three-blade proprotor systems were replaced by two-blade systems, 2) the length of the rotor masts was reduced, and 3) the wing was stiffened by the addition of struts. Finally, the XV-3 could make full conversions to the full airplane mode and back. Unfortunately, the crashes were not over. During a wind tunnel test at Ames Research Center, a crack developed near the left pylon that softened the rotor-pylon-wing combination and the aircraft rapidly became unstable. The pylons and rotor blades broke loose on the test stand and the XV-3 was severely damaged. This was the end of XV-3 testing and, after a long period of neglect, the aircraft was rebuilt by a volunteer team of current and retired Bell engineers. It was then moved to the USAF Aviation Museum at Wright-Patterson AFB, Ohio, in 2007 (fig. 5).

XV-4

The XV-4B (originally designated the VZ-10 and then the XV-4A) Hummingbird is shown in figure 6. This VTOL was not successful despite all of its promise. It had six J-85 turbojet engines—two of which provided forward and vertical thrust, and four of which provided vertical thrust only. Its design gross weight (DGW) was 11,607 pounds with a maximum gross weight (GW) of 13,100 pounds. For thrust control, the pilot had both a collective lift lever and a set of three throttles. The copilot had only the three throttles. Both prototypes ultimately crashed.

Figure 5. The XV-3 in the USAF Aviation Museum (USAF photo).

Figure 6. The XV-4 Hummingbird (Lockheed photo).

Figure 7. The XV-5B in fan mode forward flight.

XV-5B

The XV-5B Lift Fan (figs. 7 and 8) was originally the XV-5A and two of a kind. The XV-5A was powered by two J-85 turbojet engines. A fatal crash occurred during a demonstration in the high-speed jet mode at Edwards AFB, California, in early 1965, and the aircraft was destroyed. Later, a second survivable (ejection decision), but fatal crash took place at Edwards AFB during a rescue hoist demonstration. This aircraft was rebuilt into the XV-5B and came to Ames Research Center for terminal area investigations of the lift fan concept. A primary modification was relocation of the landing gear outboard of the wing fans. The gear was fixed down in contrast to the original retractable gear inboard of the fans. The aircraft had an attitude command control system that made it a very stable hover platform. The XV-5 had both a collective "stick" and a twist grip throttle (fig. 9). The collective control allowed more precise control of thrust in the fan mode, although an approach to hover and landing could be conducted using the throttle with less precision and a higher pilot workload.

Figure 8. The XV-5B in hovering flight.

Figure 9. The XV-5B thrust controls (Ryan Operator's Manual).

XV-6A

The XV-6A (fig. 10) was a vectored thrust VTOL design that was also named the P1127 Kestrel. This aircraft was the forerunner of the Marine's AV-8 Harrier. As might be expected, thrust control was accomplished with a single throttle for this fighter/bomber type of aircraft. Forward, up and then down on a short arc to increase thrust, and aft, up then down to reduce thrust (fig. 11). Although apparently not an issue for this concept, it became a serious issue when this type of thrust control was introduced in the early MV-22 Osprey design. The XV-6 and its derivatives minimized time in hover because of high fuel consumption and high noise levels and downwash velocities. Maximum, or near maximum, power was required to hover; therefore, small throttle movements were not required. Whereas in the MV-22, more finesse was required to maintain position and altitude, which required numerous, small control inputs. This photograph of the XV-6 was taken in the outside display area of the Army's Transportation Museum at Ft. Eustis, Virginia. It was chosen because of the background—the Army's Heavy Lift Helicopter (HLH) mockup. It was bulldozed into scrap some years ago and no longer exists. With renewed interest in the HLH concept, it might be of general interest to some readers.

Figure 10. The XV-6A (Army photo).

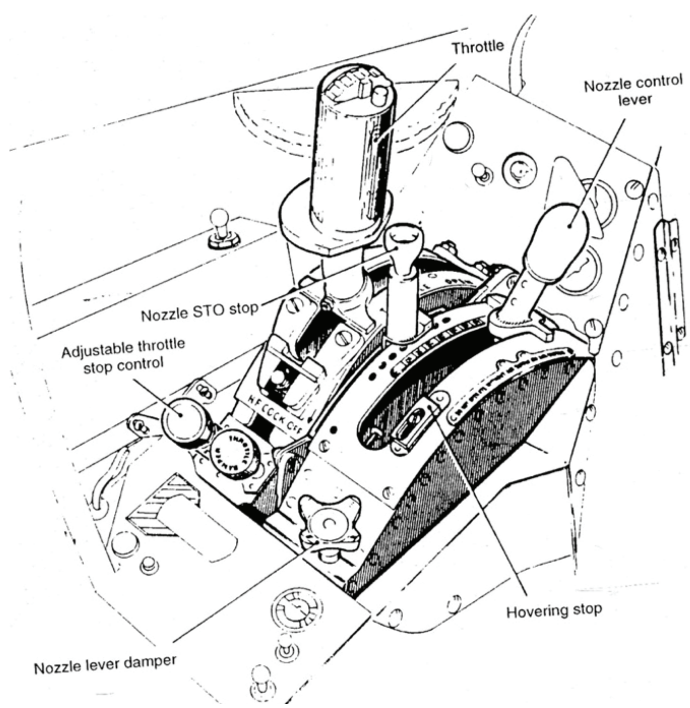

Figure 11. The XV-6 throttle quadrant (Hawker-Siddeley drawing).

X-14A

The single X-14A (figs. 12 and 13) was built by Bell Aircraft Corporation under a United States Air Force (USAF) contract and first flew in 1957. It was an open cockpit, single piloted, VTOL aircraft designed to explore jet-powered hover and transitions to forward flight. The empennage of the X-14 was that of a Beechcraft T-34 Mentor, and the wing was from a Beechcraft Bonanza. In hover, it used engine bleed air nozzles on the wingtips and tail to provide pitch, roll, and yaw control, while two Armstrong-Siddeley turbojets provided vectored thrust through an array of diverter vanes directly behind the engines. Thrust could be vectored from vertical to near horizontal. Two external fuel tanks, holding 50 gallons each, allowed only short research flights—approximately 20 minutes from takeoff to landing at the high-power settings in the hover mode, which was the usual mode for investigations. Later the engines were changed to General Electric J-85s and an onboard computer and digital fly-by-wire systems were added, and it was redesignated as the X-14B. An interesting control system arrangement existed for the X-14; it had a single throttle for the engines and a collective control "stick." One of the modifications of the X-14B was the removal of the collective control. After Air Force testing, it was delivered to Ames Research Center in 1959. Now it could simulate the characteristics of other aircraft, and some of those experiments included the simulation of lunar landings and the development of control systems for vectored thrust aircraft like the AV-8 Harrier. In 1981, it was damaged when a malfunction occurred during a hover flight near the ground. A small fire erupted when one of the main landing gears collapsed and punctured one of the external fuel tanks. It was eventually shipped to Ft. Rucker, Alabama, for display in their aviation museum; however, it was never repaired or displayed. It was later purchased by a private collector in Indiana for eventual display in a museum (fig.14).

Figure 12. The X-14.

Figure 13. The X-14 in forward flight.


Figure 14. The X-14 retired (owner’s photo).

Figure 15. The XV-15 Tiltrotor Research Aircraft.

XV-15

The XV-15 (fig. 15) was a two-place turboprop aircraft powered by two Lycoming T-53-L-13 turboshaft engines modified for vertical operation (lubrication) and uprated to 1500 shp. Maximum GW was 15,000 pounds. The proprotors were 25 feet in diameter and turned at 589 rpm and 517 rpm in the helicopter and airplane modes, respectively. It was equipped with rocket ejection seats (zero altitude/zero airspeed) and carried enough fuel for 1-hour test flights at altitudes below 10,000 feet. Two aircraft were constructed, and the first flights (3 hours) were flown in May 1977 prior to testing in the Ames Research Center 40- by 80-Foot Wind Tunnel in 1978. One XV-15 was destroyed in 1992 in Arlington, Texas, because of a maintenance error, but both pilots survived without injury. NASA transferred the remaining XV-15 to Bell Helicopter Textron in 1994 when the proof of concept and other testing was complete, and NASA was moving away from VTOL and helicopter flight research. In September of 2003, the XV-15 was transferred to the Smithsonian Institution and is currently on display at the Udvar-Hazy Aviation Museum (fig. 16).

As XV-15 Project Pilot for 14 years, the author notes that the thrust control of the XV-15 Tiltrotor Research Aircraft was never a problem for pilots—up was up and down was down in the helicopter and tilt modes of flight. Once fully converted to airplane mode, the power lever was a throttle only, and pulling it up increased thrust with all collective pitch control washed out. Full travel was slightly less than 12 inches. Note the position of the thrust lever outlined in blue in the cockpit photo (fig. 17). On completion of a conversion to airplane mode, a few pilots were observed to pull up on the power lever when the nose was pitching down with the large center-of-gravity (CG) shift. This only caused acceleration because the pilot had not made the mental shift from helicopter controls to airplane controls, but the pilot soon learned to move the stick aft to bring the nose up. With a little experience, it was an automatic response. The issue is that no pilot ever went the wrong way on the power lever when hovering, taking off, or landing in proximity to the ground. The tiltrotor pilot seat convention is that of helicopters—the primary pilot sits on the right and the copilot on the left—which is just the reverse of airplane convention.

Figure 16. The XV-15 at the Udvar-Hazy Aviation Museum (Bell photo).

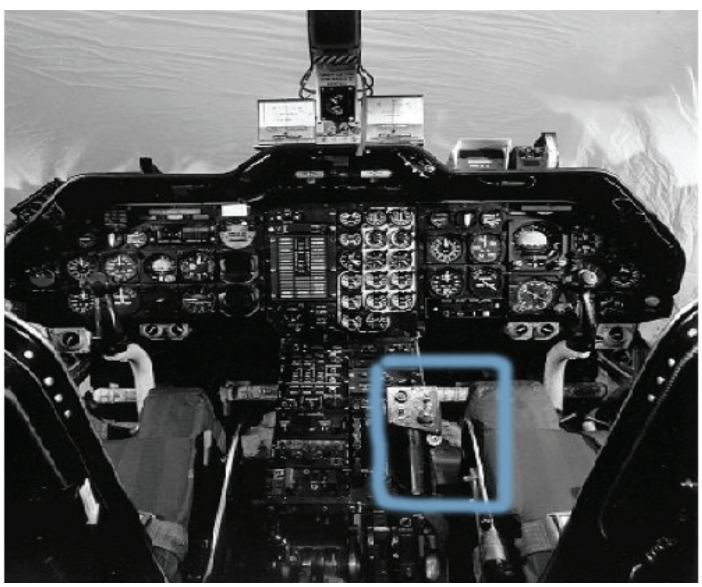

Figure 17. The XV-15 cockpit.

Figure 18. The X-18 on a test stand (USAF photo).

X-18

The X-18 (fig. 18) was a rare and unsuccessful tiltwing concept demonstrator built in the late 1950s. A USAF contract was awarded to the Hiller Aircraft Corporation in 1957, and the design incorporated parts from other aircraft programs—a fuselage from a Chase YC-122C transport and wing-mounted turboprop engines from the Lockheed XFV-1 and the Convair XFY-1 tail-sitter (Pogo) programs. A third engine, a Westinghouse turbojet, was mounted in the tail with thrust diverters for pitch control. Thrust was provided by two sets of three-blade, counter rotating props with a diameter of 16 feet. This allowed the X-18 to takeoff and land in the airplane configuration (fig. 19). There were only 20 flights conducted on this aircraft, the last one being the final flight when control was lost during an attempt to hover at 10,000 feet. After recovering from the resulting spin, the X-18 was grounded and relegated to test stand operation only until it was damaged after a test stand failure.

It never achieved hover, and it was scrapped after the program was canceled in early 1964. Throttle changes were used for thrust control. The requirement for direct prop pitch control was soon apparent because the X-18's use of electric pitch control was slow and inadequate for both height and roll control. Another lesson learned was that the lack of cross shafting between the two engines was unsafe and not acceptable should one engine fail. These lessons were applied in the design of the XC-142.

X-19

The ill-fated X-19 (fig. 20), designed and built by Curtiss–Wright, was originally designated as the X-200 and planned for the corporate market. It was also selected to be part of the Army/Navy/Air Force Tri-Service Assault Transport Program. The USAF contracted for two prototypes of this unusual looking aircraft (fig. 21). It was powered by two Lycoming T55-L-7

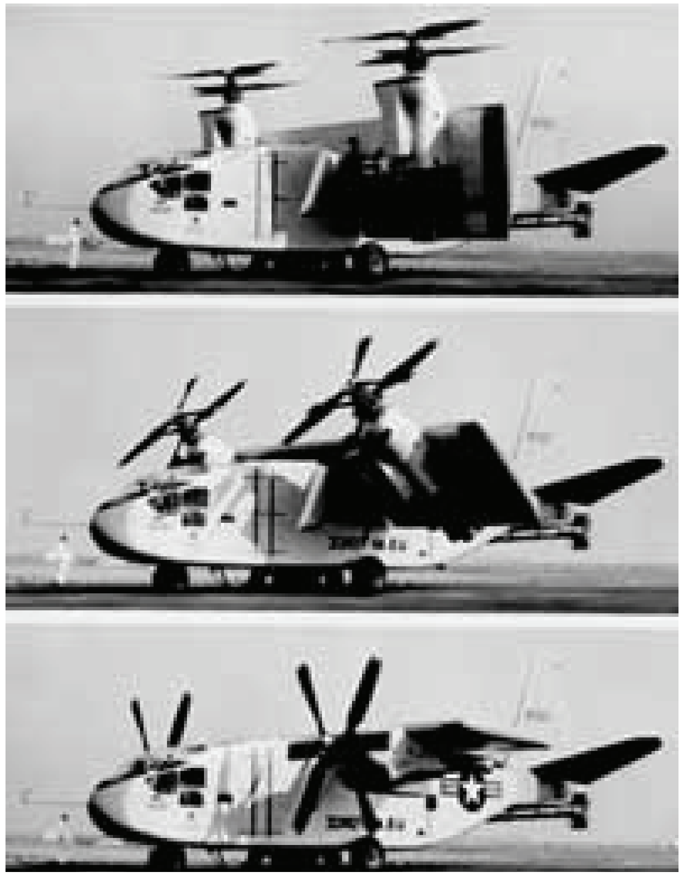

Figure 19. The X-18 in three flight modes (USAF photo).

turboshaft engines rated at 2650 shp each. Four, three-blade, 13-foot-diameter, wide-chord, highly twisted props were used for propulsion in hovering and forward flight. The two front nacelles could be rotated from horizontal to 97 degrees while the aft nacelles could move only to 87 degrees. Each pilot had two throttles for control of thrust, and the X-19 was statically unstable in hover. Precise height control by throttle was difficult, aggravated by a nearly 1-second lag in engine response. The first flight was in November of 1963, and it ended abruptly after a few seconds with the collapse of a main landing gear after the aircraft settled. After other incidents, the aircraft was sent to the Federal Aviation Administration's (FAA's) National Aviation Facilities Experimental Center (NAFEC) near Atlantic City, New Jersey. There, on August 25, 1965, a full transition flight was planned. As the nacelles reached 65 degrees, gearbox temperature warning lights illuminated and the pilots headed back for the airfield. Control began to deteriorate with the onset of both high- and low-frequency vibrations, and when the pilot felt he would not clear trees on the approach end of the runway, the throttles were jammed forward causing the left rear prop to snap off. The X-l 9 rolled left and pitched up, and then the left front prop separated followed by both right props departing. Both pilots ejected inverted at 230 feet and suffered only minor injuries. Total flight time on this X-19 had been 3.85 hours with 129.4 ground run hours. The second X-l9 never flew. The performance of the North American rocket seat (LW-3B) in this "save," along with the saving of the crew of two in another catastrophic accident in the CL-84, led the author to successfully campaign to have that seat integrated into the design of the XV- I5 tiltrotor.

Figure 20. The X-19 (Curtiss–Wright photo).

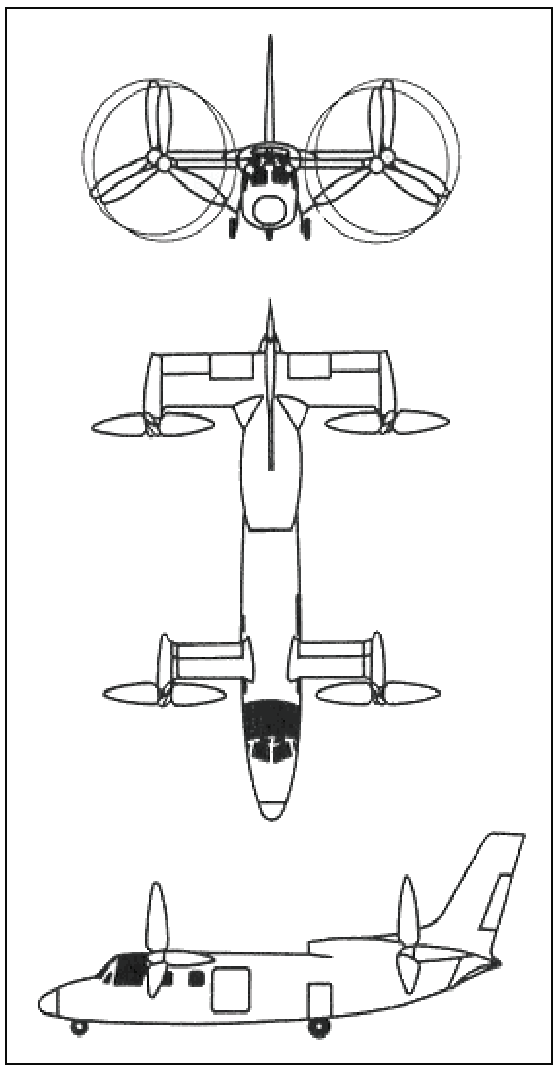

Figure 21. The X-19 three-view (Curtiss–Wright drawing).

X-22A

Another aircraft type researched was the Bell Aerospace X-22 dual, tandem, ducted propeller concept (fig. 22). A rather ungainly and awkward configuration, the X-22A nonetheless satisfied the Navy's interest in the 1960s for pursuing various VTOL concepts. The X-22 was evaluated as a Tri-Service aircraft by the Navy, Air Force, and the Army. This aircraft was powered by four GE T-58 turboshaft engines, each rated at 1250 shp. Altogether, 113 hours were flown on 220 flights during the test program. Unfortunately, the no. 1 aircraft was destroyed early in the program on Flight 15 (hydraulic failures, both pilots survived); however, the no. 2 aircraft flew for many years as a variable stability platform. As was the case for many VTOL configurations of those days, the X-22 had both a height control "stick" (collective) and four throttles that could be ganged to the height controller or disengaged and used as a group of throttles.

Curtiss–Wright X-100

The Curtiss–Wright X-100 (fig. 23) was an earlier attempt to demonstrate "the tilt-prop principle of radial force," which was thought to have an advantage over the XV-3 tiltrotor. To achieve additional lift, the principle was that "as the propeller is inclined toward the vertical from the horizontal, the resultant of the propeller's thrust and the pressure of the relative wind acting on the rotating disk is a force with an additional lift component in the vertical axis." This was attributed to Henry Borst, the chief aerodynamicist for the Curtiss–Wright propeller division. It was thought that short, wide-chord propellers offered an advantage over the longer, more narrow blades of the XV-3. The company began construction of the X-100 in 1958. It was an awkward looking two-place aircraft that included fabric covering of the fuselage. The bulky assembly in the tail was called the "Jetivator," which controlled engine exhaust vents for pitch and yaw control. The props tilted to only within 12 degrees of the horizontal. A throttle was used for thrust control as in the follow-on aircraft, the X-19 (fig. 20), which had a similar blade design. It began tethered hover flights in April 1959, and first flight was in 1960. It was eventually transferred to Langley Research Center where it was only flown in the vertical mode. It sustained moderate damage in an accident in 1961 and had accumulated a total of 14 flight hours when it was retired.

Figure 22. The Bell Aerospace X-22A (Bell photo).

Figure 23. The Curtiss–Wright X-100 (Curtiss–Wright photo).

XC-142

The XC-142A tiltwing (fig. 24) was a Tri-Service aircraft built in the early- to mid-1960s by Ling-Temco-Vought (LTV). It was designed to be a combat assault cargo aircraft to carry 30 fully equipped troops. Powered by four T-64 turboshaft engines with cross-shaft interconnect of the 15.5-foot-diameter fiberglass propellers, the design gross weight (DGW) was 37,500 pounds with a gross weight (GW) overload of 43,700 pounds. The wing could be tilted from 0 degrees through 98 degrees (8 degrees aft of vertical). Thrust control was provided by a collective lever for taxi, takeoff, hover, landing, and Vertical and/or Short Takeoff and Landing (V/STOL) modes of flight. During cruise flight, the collective lever was stowed and conventional throttles were used for thrust control. There was also a small, horizontally mounted tail rotor on the aft end of the fuselage to provide pitch control in the V/STOL mode of flight. This tiltwing aircraft was very noisy in the VTOL mode (personal observations of the author at Edwards AFB) with its high disk loading and rpm required to sustain hovering flight. All of the five aircraft were involved in accidents—four of which either destroyed the aircraft or rendered them not economically repairable. The last accident in May 1967 proved fatal to the crew of three when a bell crank in the tail propeller failed from high vibratory loads, and the aircraft pitched nose-down and could not be recovered. The surviving XC-142 ended up in the USAF Aviation Museum at Wright Patterson, AFB, Dayton, Ohio.

Figure 24. The XC-142 Tiltwing (LTV photo).

Canadair CL-84

Another tiltwing concept investigated was the Canadair CL-84 or “Dynavert” (fig. 25). There were four aircraft built and tested during 1964–1974 and of these, two survived and reside in Canadian museums. Two were destroyed in nonfatal accidents caused by mechanical failures in 1967 and 1973. In the latter accident, a left gearbox failure resulted in the left prop departing the aircraft during a maximum performance climb near Patuxent River, Maryland. Both pilots ejected successfully (the North American LW-3B seat, again). The CL-84 (at one time labeled the CX-84 by the Canadians) was powered by two 1500 shp Lycoming T-53 turboshaft engines with a cross shaft. In the event of an engine failure, the remaining engine would drive both props— just as in the XV-15, which was also powered by two Lycoming T-53 cross-shafted engines. Maximum GW of the CL-84 was 14,500 pounds with hover restricted to 12,600 pounds, and maximum speed was advertised as 279 knots. A single, throttle-type power lever was used for thrust control (fig. 26) in all flight regimes, simplifying he pilot’s control of thrust in the VTOL, transition, or forward flight modes as airplane. The surviving aircraft were placed in Canadian museums.

It is interesting to note that CL-84 gearboxes, cross shafts, and props (cut down), were used in the YOV-10A Rotating Cylinder Flap (RCF) Research Aircraft that flew at Ames in the early seventies. The author flew its last flight in 1979 when static longitudinal stability issues would have required a major modification to fix (changing the incidence of the horizontal stabilizer). That unique Short Takeoff and Landing (STOL) aircraft (the YOV-10A) was retired, and eventually it was acquired by a private party through the General Services Administration (GSA) instead of being placed in a museum.

Figure 25. The Canadair CL-84 (Canadair photo).

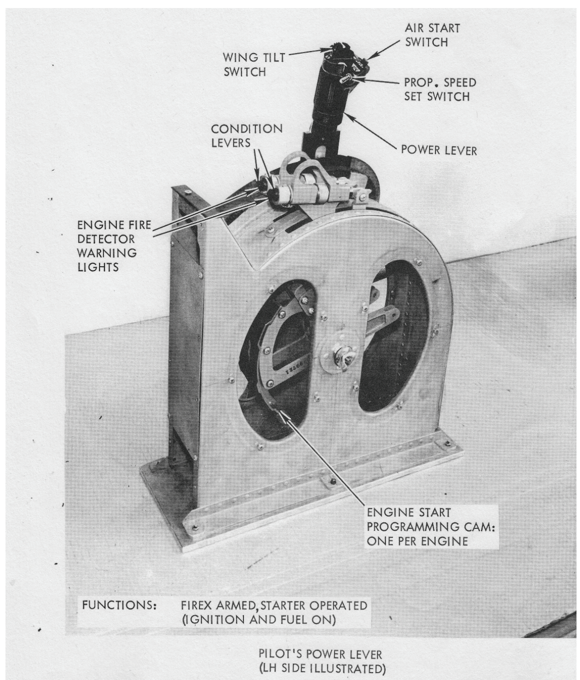

Figure 26. The CL-84 throttle (Canadair drawing).

Fairey Rotodyne

The Fairey Rotodyne (fig. 27) was in a class by itself. It was an unusual combination of helicopter, autogyro, and fixed-wing turboprop. It went through various stages of development and design in the 1950s, and the program was canceled when British government funding dried up. The military had been interested in the concept, and there were even some civil orders considered. The aircraft was considered for short-to-medium distances, and city-to-city transport of approximately 48 passengers. The Rotodyne had rotor tip jets driven by fuel and bleed air from the engines, and two turboprops mounted on the wings. After takeoff using the 90-foot-diameter rotor system, engine power was diverted to drive the props. In this mode, the rotor was autorotated at reduced collective pitch to reduce drag. A combination of collective pitch lever, primarily for VTOL operation, was used in the last design with throttles for thrust in forward flight. Noise from the tip jets was a problem although mitigating modifications were planned. One prototype reached a speed of 191 mph. The aircraft was designed to hover on one engine—something that tiltrotors have been unable to achieve to date.

Figure 27. The Fairey Rotodyne (Fairey photo).

V-22

The V-22 Osprey (figs. 28 and 29) has had an interesting and controversial development history with some fatal accidents along the way; however, the aircraft has been proving itself as reliable, available, and a first choice for many to fly in combat zones because of its low noise signature and speed in the airplane mode. Presidential candidates at the time, Senators Obama and McCain, both flew in the MV-22 in the unfriendly skies of Iraq. The wing has a 0-degree incidence angle relative to the fuselage. At the V-22's design and heavier gross weights, a nose-up attitude is required in airplane mode cruise resulting in a significant drag penalty. The proprotor systems have three-blade, 38-foot-diameter rotors, and the aircraft is powered by two Rolls Royce Allison T-406 or 407 engines rated up to 6150 hp each.

Figure 28. The MV-22 Osprey (Bell photo).

Figure 29. The Osprey in airplane mode (Bell photo).

Many do not realize that the original design for thrust control in the V-22 Osprey was a conventional collective controller (fig. 30). This design did not make it into the first MV-22 Full Scale Development (FSD) aircraft because it was mandated that the thrust control lever (TCL) be configured with a Harrier-type power lever with 4 inches of travel and a forward and downward arc for increasing thrust (fig. 31). As previously mentioned, many saw this as a problem in the event of an emergency. On the first flight of V-22 no. 5 in June 1991, two lateral control “gyros” were improperly rigged and outvoted the third gyro in this triply redundant, digital control system. This resulted in a lateral control phase lag that was to prove uncontrollable by the pilot. The pilot lifted the aircraft to a hover and was immediately in a “fight’ for lateral control of the aircraft. This went on for a couple of minutes until he finally got the aircraft on the ground safely for an instant. Then he quickly applied full thrust, jamming the TCL full forward and down. The fight for lateral control resumed and a short time later, the IR suppressor on the end of the left engine hit the ground and, after an oscillation or two, the V-22 rolled inverted (figs. 32 and 33). Both pilots exited the aircraft without injury. That aircraft was to have been the USAF CV-22 prototype. A lengthy and costly redesign of the TCL was initiated and resulted in a configuration in which the pilot rests his left wrist and hand on a bicycle-seat-shaped TCL and moves it fore and aft with pure longitudinal movements and with some additional travel (fig. 30). The downward movement of the TCL in this mishap had been meant to reduce thrust and was a conditioned response of a pilot with lot of helicopter flight time. In a second case of grave miscalculation, the tragic accident in Marana, Arizona, was fatal to all on board and the V-22 was destroyed. The primary fixed-wing pilot inadvertently drove the right rotor into the Vortex Ring State (VRS), the right rotor lost thrust, and the aircraft rolled inverted near the ground after high sink rates at low speeds. So, the V-22 has had three thrust control designs, and the fore and aft “bicycle seat” design is now found on all production aircraft (fig. 30).

New/Old

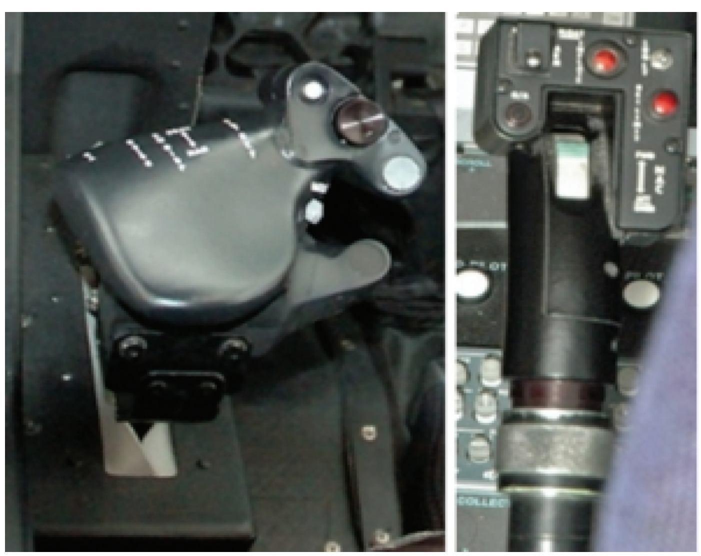

Figure 30. Current TCL with original collective design (Bell photo).

V-22 Old TCL

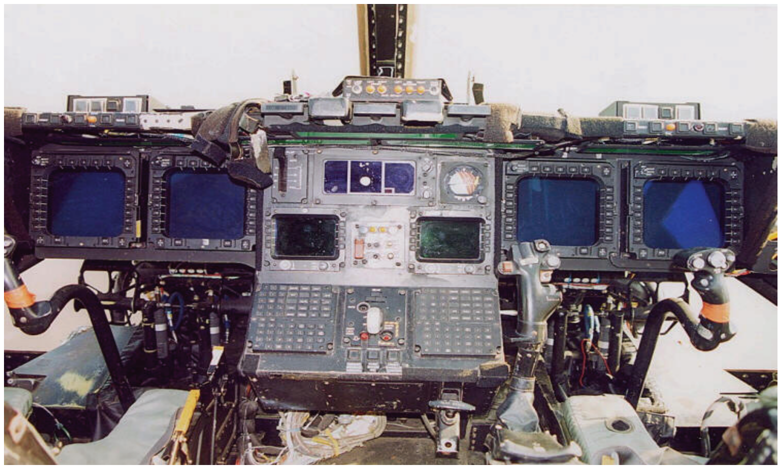

Figure 31. FSD Aircraft TCL before redesign (Navy photo).

Figure 32. The V-22, June 1991, Wilmington, Delaware (Boeing photo).

V-22 #5
Wilmington, Delaware—June 1991

Figure 33. V-22 accident aftermath (Boeing photo).

AW 609

Another look at a tiltrotor thrust controller can be found in the Bell/Agusta 609, now Agusta/Westland 609 (fig. 34)—the world's first production tiltrotor for civil use. As a corporate-sized aircraft, it is slightly larger than the NASA/Army XV-15. It has a GW of 16,800 pounds and is powered by two Pratt and Whitney 1,940-shp turboshaft engines. The proprotor diameter is 26 feet and the AW 609 is designed to carry a crew of two plus six to nine persons. Disk loading is 15.8 psf with a wing loading of approximately 94 psf. It has a digital flight control system and a "glass" cockpit. Wing incidence is 3 degrees as in the XV-15. For thrust control, a conventional collective "stick" (power lever) is used; it is the author's understanding that limited space beneath the floor of the cockpit precluded the use of a power lever similar to that of the XV-15. The power lever grip of the AW 609 is shown in figure 35.

Figure 34. Agusta/Westland 609 (Agusta photo).

BA 609 Grip

Figure 35. Agusta/Westland 609 collective control (Bell drawing).

The ERICA (fig. 36) design is a high-wing, two-engine design with four-blade proprotors. It originated with Agusta, and they teamed with Eurocopter and other European countries on this project. The blades were designed using the Advanced (European Tiltrotor) Dynamics and Noise (ADYN) concept. Wing incidence was to be 3 degrees as in the XV-15, but is now planned for 0 degrees as in the V-22. At the V-22's design and heavier gross weights, a nose-up attitude is required in airplane mode cruise, which results in a significant drag penalty. In the helicopter/tilt modes and in the airplane mode, ERICA's proprotor rpm is to be approximately 550 and 424, respectively. For the XV-15, 457 rpm was desired for maximum efficiency in the airplane mode, but 517 rpm was flown because of blade loads. The XV-15 was flown at 589 rpm in the helicopter and tilt modes. For reference, the helicopter/airplane mode rpm for the V-22 and the AW 609 are 394/333 and 570/479, respectively, when last checked. ERICA's nacelles tilt through an arc of 0 to 95 degrees (as in the XV-15 and V-22), and the outer wing panels tilt independently of the nacelles. At 60 to 70 knots, the wing panels are fully retracted. Their purpose is to reduce the download on the wing in hover and low-speed helicopter mode flight. The proprotor disks are 24.3 feet in diameter, and the aircraft VTOL DGW is 22,050 pounds (disk loading of almost 24 lb/ft^2). This results in downwash velocities higher than the XV-15 or the AW 609, and also those of the V-22 at a DGW of 47,500 pounds (disk loading of 20.9). An original design objective was to have ERICA's proprotors clear the ground to permit landing in the airplane mode. This idea was reconsidered because of ground clearance (approximately 8 inches). That clearance, although statically sufficient, would not be adequate in dynamic cases—crosswinds, hard landings, collapsed strut, and other conditions. The current design incorporates a T tail. Detented flap positions are 0, 10, 30, and 60 degrees. The simulator did not have the 60-degree detent. Detented nacelle positions were 95, 90, 75, 60, and 0 degrees, but the 60-degree nacelle detent was also not implemented in the simulation at that time.

Figure 36. The ERICA design (Eurocopter drawing).

Figure 37. The ERICA simulator cockpit (Eurocopter photo).

The cockpit is a dual-piloted design, roomy, and with the command pilot in the right seat as in helicopter and tiltrotor convention (fig. 37). An interesting feature to the left of the primary multifunction display (MFD) is a large display that depicts the “Conversion Corridor.” It is a wide “corridor” composed of nacelle position on the ordinate and speed on the abscissa—with the stall boundary on the left edge, structural limits on the right edge, and the aircraft’s position in real time in the corridor—an excellent cockpit enhancement.

AH-1

The Army AH-1 series helicopters (figs. 38 and 39) (now retired) had a combination of thrust controllers. A standard collective was located in the aft cockpit for the pilot while the pilot/gunner in the front cockpit had a sidestick control on the left for collective pitch (fig. 40). The design was dictated by the very narrow front cockpit and resulting space constraints. The Army Cobra was only 3 feet wide, excluding the stub wings, and the front cockpit was tapered from that. It took training and practice to hover and land the helicopter smoothly with the sidestick, which had high forces and poor mechanical characteristics. It was a real challenge when the Stability and Control Augmentation System (SCAS) was turned off or was inoperative. On the right side console of the Army Cobra, the pilot/gunner flew with a sidestick cyclic controller. The Army’s attack helicopter was designed in the early 1960s, but today’s technology has made great strides in optimizing sidestick characteristics resulting in much improved handling qualities.

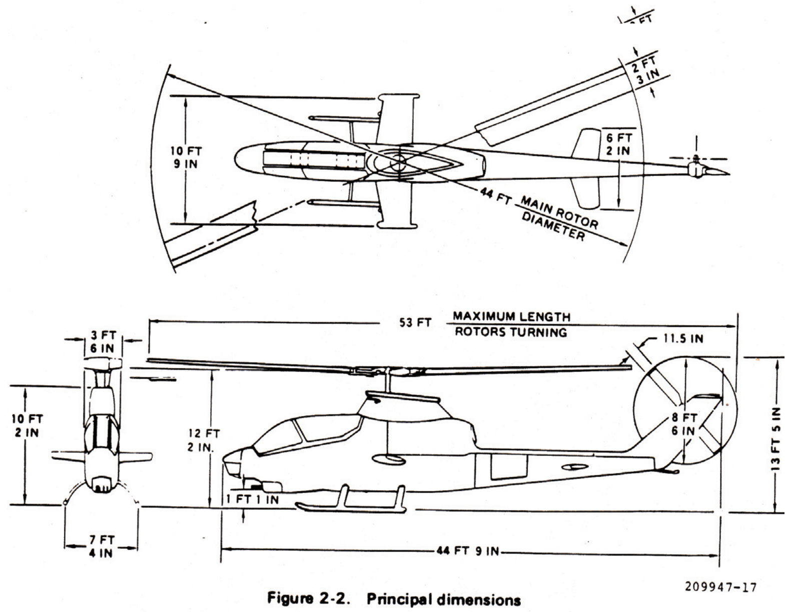

Figure 38. The Bell AH-1 Cobra (Bell drawing).

Figure 39. The AH-1 Cobra (Wikipedia photo).

Gunner's Sidestick Collective

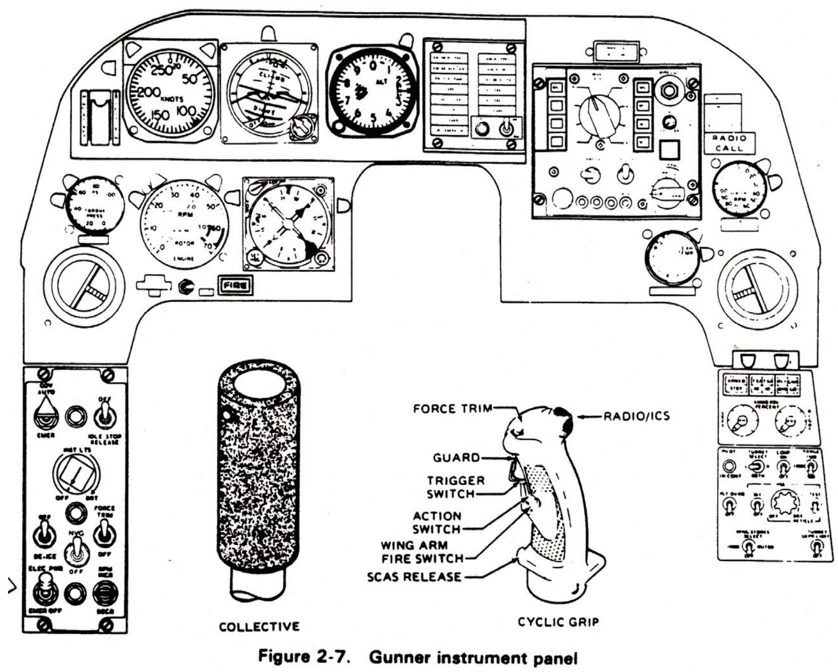

Figure 40. AH-1 Cobra front cockpit (Bell drawing).

AH-64A

The Army AH-64 Apache series of helicopters (fig. 41) uses collective controllers for thrust control in both the gunner/pilot's station (front cockpit) and the pilot's cockpit. Unlike the AH-1 series of attack helicopters, the Apache has sufficient space at the gunner's station to accommodate the same type of collective control (fig. 42). The Apache is powered by two GE T-700-GE701 C engines rated at up to 1880 shp each. The rotor system is a four-blade design with a rotor diameter of 48 feet.

Figure 41. The Army Apache AH-64.

Figure 42. The Apache front cockpit (Boeing photo).

Bell 222

The Bell 222 Helicopter (fig. 43) has a two-blade, 40- to 42-foot-diameter rotor system and is powered by two Lycoming or Roll Royce engines with ratings from 618–700 shp. It uses a standard type of collective lever; however, the "throttles" (more Engine Condition levers) are linked to the collective controller and used as a grip (fig. 44). The configuration was fairly unique but has not posed a problem for helicopter pilots; Bell, however, did not permit V-22 pilots to fly the 222 or the 214 as a precaution to avoid any behavioral pattern that might cause them to go the wrong way with the TCL in the V-22.

Figure 43. The Bell 222 (Bell photo).

Figure 44. The Bell 222 thrust control (Bell photo).

Other VTOL Thrust Control Inceptors

Various controllers for managing thrust of VTOL aircraft have been devised, either by a collective "stick," throttle(s), or some unique applications. There have also been designs that attempt to incorporate a collective function in the VTOL mode, and throttle function in the airplane mode, in a single controller for those aircraft that convert from one mode to the other (for example, a tiltrotor). The three illustrations that follow depict one such design—the Magnum Handle (figs. 45–47). The positions and functions are self-explanatory when referencing the tiltrotor model in the background.

Figure 45. The Magnum Handle—helicopter mode.

Figure 46. The Magnum Handle—airplane mode.

Figure 47. The Magnum Handle—tilt mode.

Another attempt at designing a single controller for a tiltrotor, as a collective in the VTOL mode and a throttle in the airplane mode, can be found in the thesis of a graduate student at the University of Illinois. It was named the Rotational Throttle Interface (RTI). It rotates as the conversion proceeds—from the helicopter mode and a collective function to a throttle function in the airplane mode—as shown in figures 48 and 49.

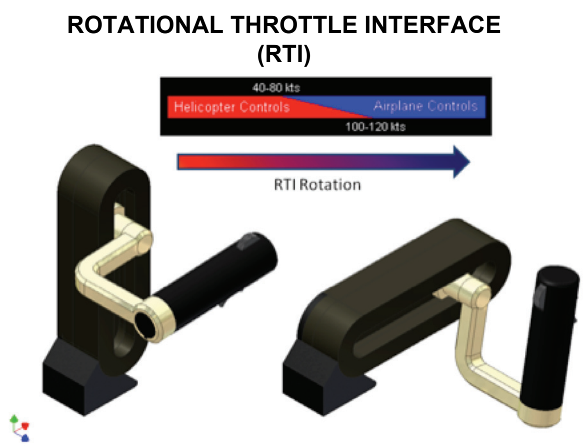

Figure 48. RTI (David Rozovski drawing).

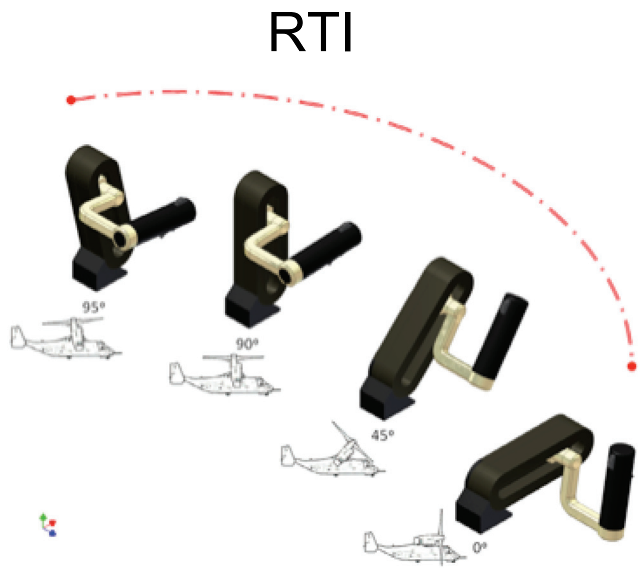

Figure 49. RTI during aircraft conversion (David Rozovski drawing).

THE VZ SERIES

Hiller VZ-1

The VZ-1 had a number of variants as the concept was explored (fig. 50). Starting with the first configuration (fig. 51), funded by the Office of Naval Research (ONR), the VZ-1 was powered by two 40-hp engines, a 5-foot-diameter duct, and two contra-rotating rotors. No cross shafting was included in the design, which was unsafe and unacceptable in the event of an engine failure. Each rotor was driven by its own engine. The second Pawnee had three 40-hp engines, an 8-foot-diameter duct, and a deeper duct for increased lift. A cross shaft was also included. In both of these configurations, the pilot stood while controlling the platform.

The earlier variants had a handlebar grip for the pilot, and a twist grip throttle was used for thrust control. In the final configuration (the VZ-1E) the duct was deeper still, and the pilot was seated and had conventional helicopter controls. The pilot controlled the first two variants by leaning in the direction of desired flight, but this kinesthetic control was inadequate for the larger VZ-1E and vanes were added in the duct to improve control.

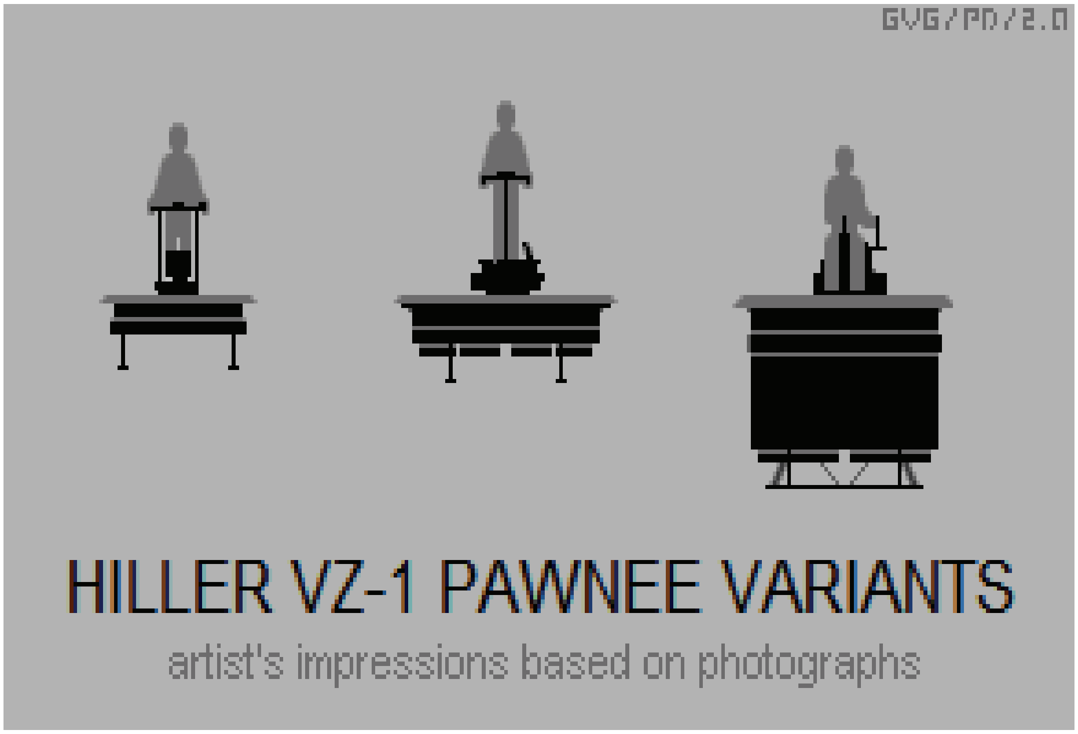

Figure 50. Hiller VZ-1 Pawnee variants (Hiller drawing).

HILLER VZ-1

Figure 51. Early Pawnee Hiller VZ-1.

In the 1950s and 1960s, the Army had significant interest (and the budget to back it up) in both flying Platforms and Jeeps. One of these VTOL aircraft used a concept that was advocated by NACA engineer Charles Zimmerman. He proposed that the rotors of a VTOL aircraft be located on the underside of the air vehicle. That was radical thinking, although the concept was used in more than one research platform (the Hiller VZ-1 Pawnee previously discussed). The control concept was called "Kinesthetic Control," which only required the pilot to lean and shift weight in the desired direction of flight. The Army ordered as many as a dozen of the De Lackner DH-4 Heli-Vector (later the HZ-1 Aerocycle) (figs. 52 and 53). As you might expect, this configuration could be very hazardous to the pilot and on the scary side with the two rotors spinning in opposite directions just beneath the platform. The rotors also kicked up ground debris that could be hazardous in landings, takeoffs, and hovering flight. The pilot was held in place by a safety belt and his grip on the motorcycle-type thrust control on the handlebars (rpm control only—the blades were fixed pitch). It was powered by a 40-hp outboard motor, and the landing gear initially consisted of airbags that were later replaced by skids.

There were two accidents early in the program that occurred when the rotors flexed and entangled. Fortunately, no one was injured and the project was canceled. According to the source (Google, and in the public domain), at least one Aerocycle survived and made it to a museum. It is unknown just how many were actually produced.

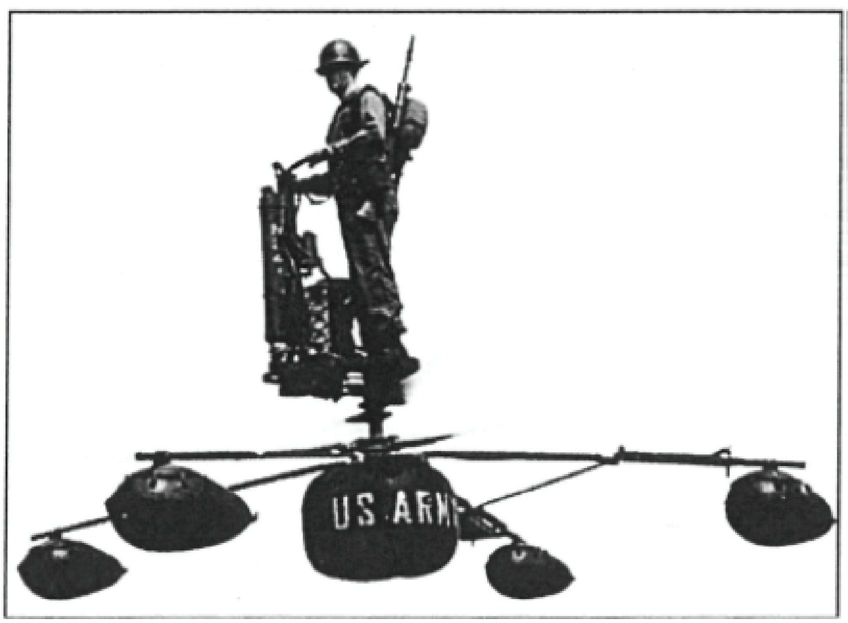

Figure 52. The De Lackner Heli-Vector (Army photo).

Figure 53. The HZ-1 Aerocycle with skids (Army photo).

Boeing VZ-2A (Model 76)

The Boeing VZ-2A aircraft (fig. 54) was designed as an early look into tiltwing technology. It was an odd bird that initially had a tubular airframe with no skin (but the airframe was later covered). It was built by Boeing-Vertol in 1957, and it was funded by the U.S. Army and the ONR. The VZ-2A was powered by a Lycoming YT-53-L-I engine of almost 700 hp. That engine, however, was the forerunner of T-53 engines producing up to 1500 hp. The proprotors were 9.5 feet in diameter, and the VZ-2A had a maximum speed of approximately 134 mph. It had two ducted fans: one located in the horizontal stabilizer for pitch control and one in the vertical fin for yaw control. The pilot and copilot sat side by side.

It was first flown in the late 1950s, and the first transition from vertical mode to airplane mode took place in April 1957. Thrust control was managed by a collective controller (fig. 55). The aircraft was turned over to NASA and it continued to fly until 1965. It is now residing in the Garber Facility of the Smithsonian.

Figure 54. The Boeing VZ-2A (Boeing-Vertol photo).

Figure 55. The VZ-2A collective control (Roger Connor photo).

VZ-3

The Ryan VZ-3 was a one-of-a-kind aircraft built for the U.S. Army in the mid-1950s with its first flight in 1959 (fig. 56). It was an unusual configuration with very large flaps and end plates designed to capture the propellers' slipstream and augment lift. The aircraft was powered by a Lycoming turboshaft engine that produced 1000 hp. The concept was to allow flight from hover to low forward speeds, however neither hover nor vertical takeoff were ever achieved. It required some forward speed to make every short takeoff.

Differential prop pitch was used for roll control, while pitch and yaw control were provided by the engine exhaust at the tail until the aerodynamic controls became effective with forward speed. A throttle was used for thrust control. An early accident occurred in 1959. The aircraft was located at Ames Research Center in the early 1960s. Later, during one "unplanned" maneuver, the pilot ejected over the Bay's salt ponds and the aircraft crashed. The pilot survived with back injuries, and the aircraft was rebuilt and resumed flying in 1961.

VZ-4

The Doak VZ-4 (fig. 57) had a two-place tandem cockpit, although it was always flown by a single pilot. The VZ-4 was powered by a Lycoming T-53-L-1 turboshaft engine rated at either 824 or 840 shp. Later in the program, a 1000-hp T-53 engine was installed. Various components from other aircraft included landing gear from a Cessna 182, seats from a P-51, and duct actuators from the flap mechanism of the T-33. Its estimated maximum speed of 229 mph was demonstrated during the flight test program.

The wingtip ducts were 5 feet in diameter with an inside diameter of 4 feet. A vane in the tail used engine exhaust to provide pitch and yaw control during hovering flight. Conventional flight controls were used in the airplane mode. Testing began in February 1958 in Torrance, California, and the project was transferred to Edwards AFB in October 1958 where it remained until the Army moved it to Langley Research Center. The Doak remained at Langley until August 1972.

Figure 56. The Ryan VZ-3 vertiplane.

The search for the type of thrust control used was frustrating. The aircraft is on display at the Ft. Eustis Virginia Transportation Museum, but the entire contents of the cockpit had been removed and references to the aircraft did not include the thrust control. Finally, a grainy, black and white photo surfaced that showed an early tethered hover flight before the aircraft skin was installed. There it was—the pilot appears to have his left hand on the collective lever (fig. 58).

Figure 57. The VZ-4 (Doak Aviation photo).

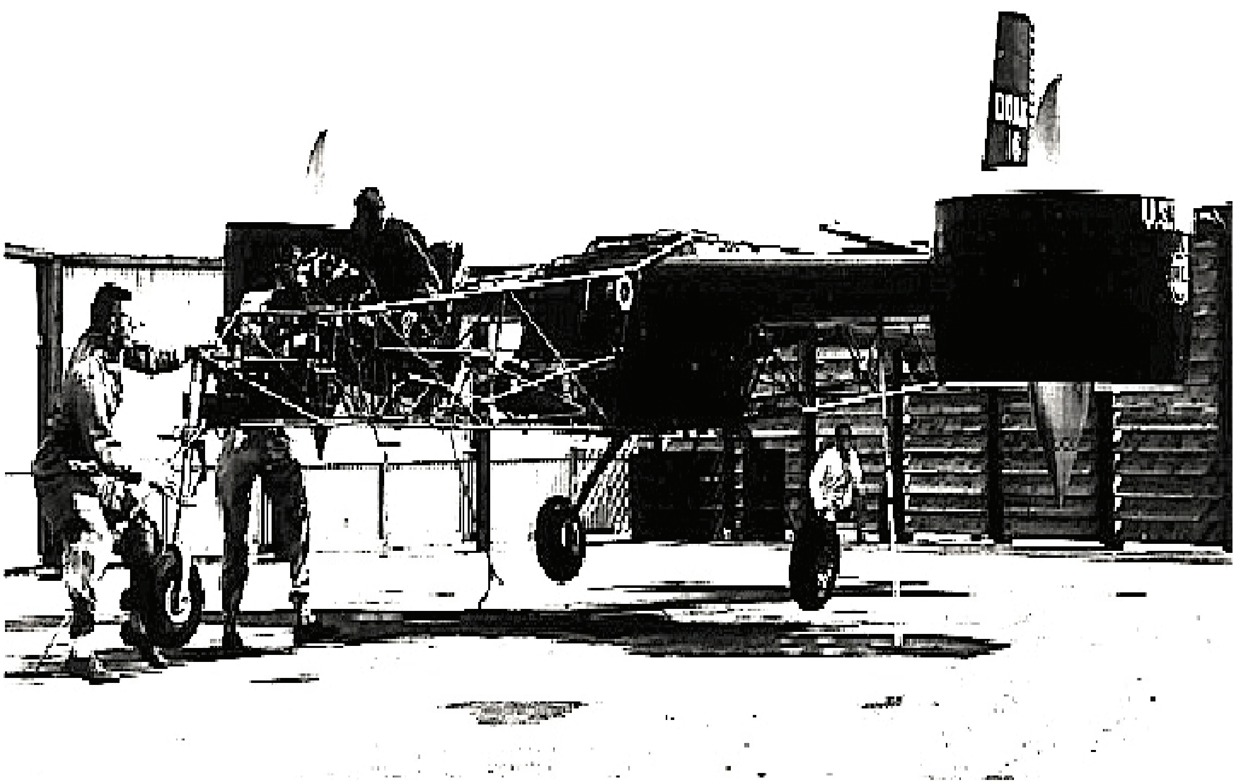

Figure 58. The “skinless” VZ-4 (Doak Aviation photo).

VZ-5

The Fairchild VZ-5 (fig. 59) was another unusual configuration that used the deflected slipstream from the four props mounted on the wing to augment lift (fig. 60)—similar to the concept employed in the VZ-3. It was also known as the “Fledgling.” A GE YT-58 turboshaft engine powered the four, three-blade propellers mounted just below the wing leading edge. The VZ-5 had two, four-blade propellers mounted above the horizontal stabilizer for yaw and pitch control. A throttle was used for thrust control. This concept demonstrator was built for the Army and made its first tethered flight in November 1958. The VZ-5 never proceeded past tethered flight, and the project was terminated.

Figure 59. The Fairchild VZ-5 (Fairchild photo).

Figure 60. Deflected slipstream VZ-5 (Fairchild photo).

Bell Aircraft Test Vehicle

The Bell Aircraft Test Vehicle (ATV) (fig. 61) was another one-of-a-kind VTOL aircraft. It used available parts from a number of aircraft—a Schweitzer sailplane fuselage, a Cessna 170 wing, and a set of skids from the Bell Model 47 helicopter. It was powered by tilting jet pods with Fairchild J-44 engines. A separate Continental-Turbomeca-Palouste gas turbine provided the thrust for the reaction control system used in vertical flight. It had two sets of controls—one for the vertical mode and conventional controls for airplane mode flight. Wingtip exhaust ducts provided roll control, and pitch and yaw control were provided by exhaust ducts on the tail. The first flight was made in January 1954 on a tether. The ATV was damaged the next month from an engine failure and subsequent fire. After repairs flight tests resumed, but the program was canceled in early 1955 after only 4.5 flight hours. The ATV was followed by the successful X-14 discussed previously. An examination by a Smithsonian historian determined that the ATV thrust control was provided by a collective (fig. 62).

Figure 61. The Bell ATV (Bell photo).

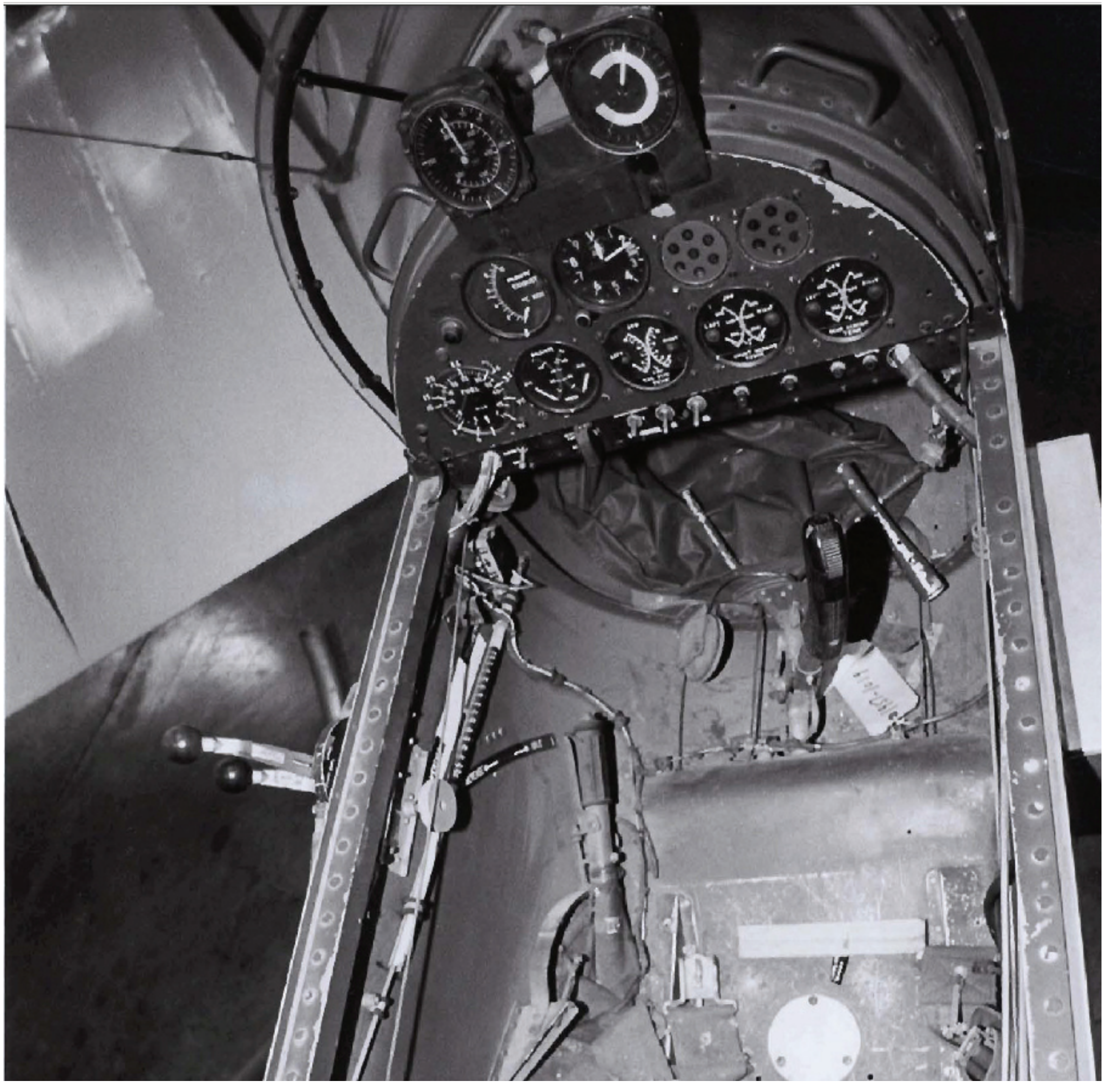

Figure 62. The Bell ATV cockpit with collective thrust controller (Roger Connor photo).

1961 TRI-SERVICE VTOL TRANSPORT DESIGNS

A Tri-Service Transport Competition to build a VTOL transport was put out for bids by the Army, Navy, and Air Force, with entries to be submitted in 1961. Eleven entries were submitted by individual companies and teams: Bell-Lockheed, North American, Sikorsky, Vanguard, Boeing-Wichita, Ling-Temco-Vought (LTV), Boeing-Vertol, McDonnell (2 entries), and Douglas (2 entries). Designs included tiltwings, tilt-props, tiltducts, and even a lift fan. Of this myriad of designs, one was selected to be built—the LTV XC-142 tiltwing. Five were built, and one survived to be sent to the USAF Museum in Dayton, Ohio.

Douglas proposed both a tilting, ducted fan entry (fig. 63) and a tilting turboprop (fig. 64).

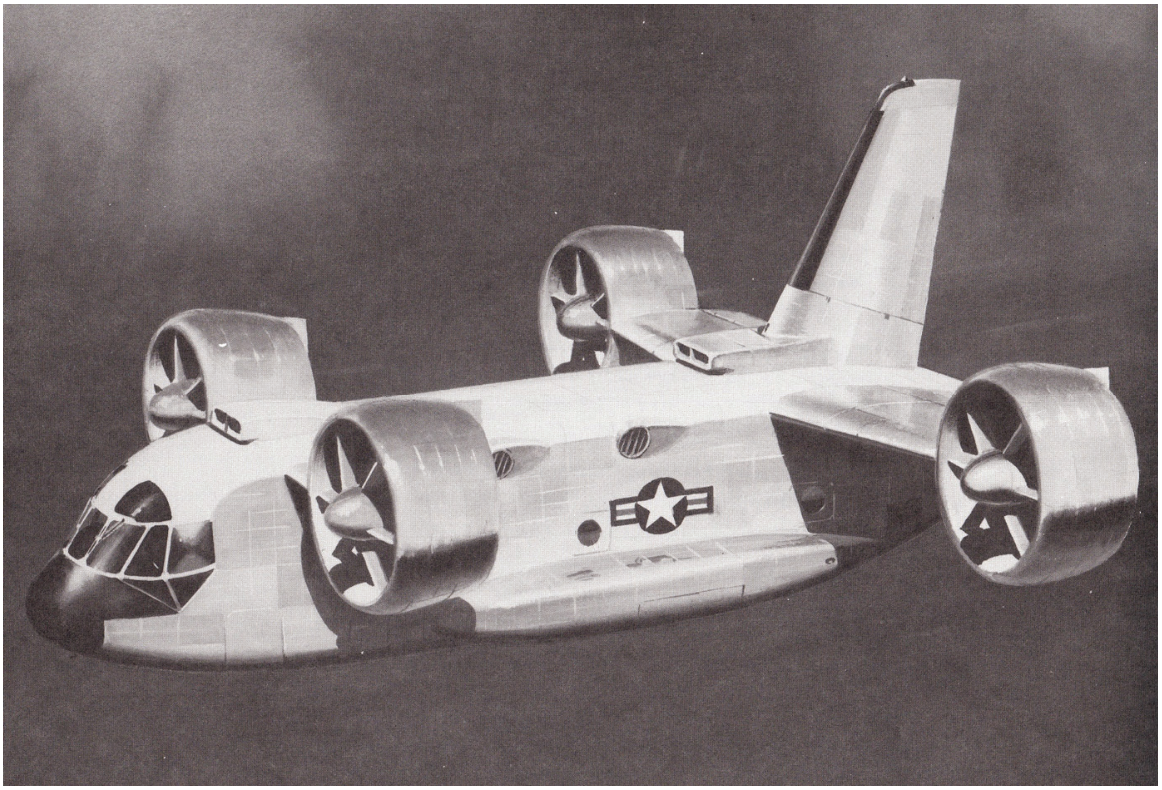

Figure 63. Douglas Model D-828 (Douglas drawing).

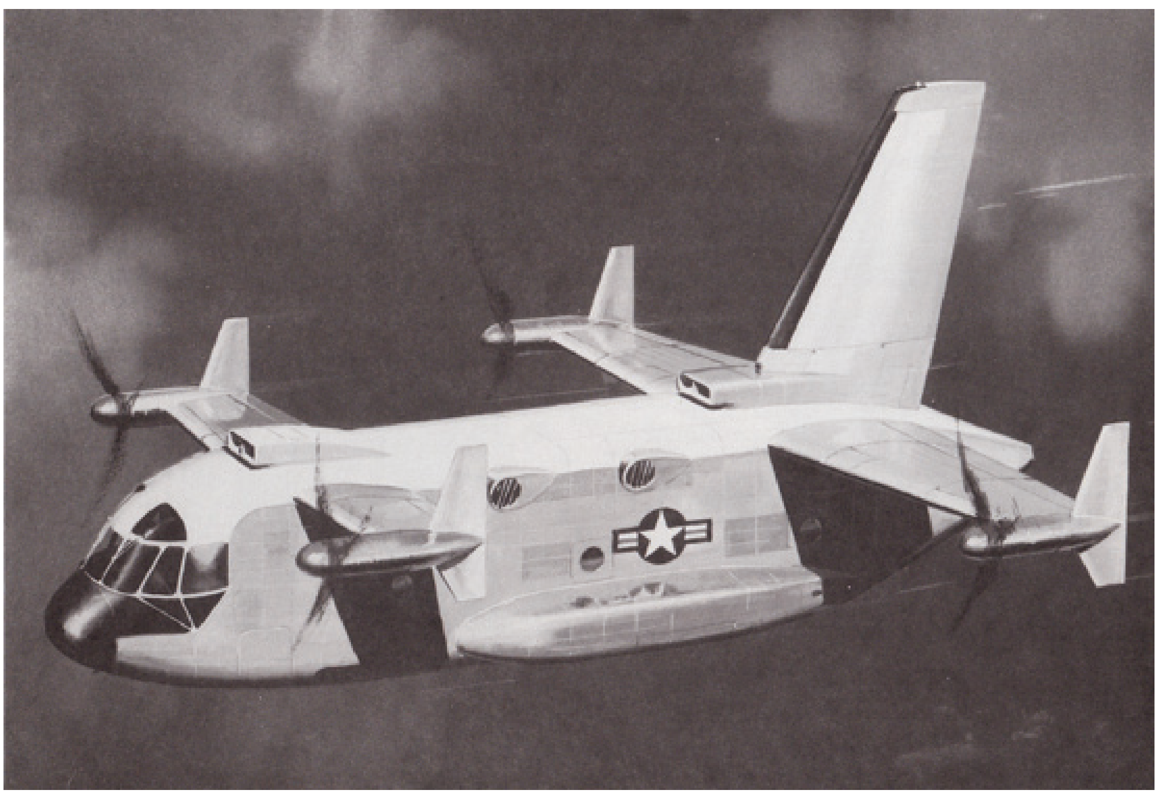

Figure 64. Douglas Model D-829 (Douglas drawing).

These two VTOL transport designs had many identical components, including the fuselage and vertical fin. The cockpit design and layouts were the same (fig. 65), and both throttles and collective controls were used for thrust control. Four T-64 engines drove the four ducted fans, and the aircraft was predicted to fly at 250 knots.

The ungainly Bell/Lockheed D2064 (fig. 66) entry was similar in appearance to the Douglas Model D-828 depicted in figure 63. Four tilting ducts were driven by four T-64 engines. and the four-blade ducted propellers were 8.6 feet in diameter.

A maximum speed of 385 knots True Airspeed (TAS) was estimated at approximately 15,000 feet with an 8000-pound payload. Thrust control was managed by four throttles that could be ganged together for ease of operation (fig. 67).

North American Aviation (NAA) submitted a design for a tiltwing transport (fig. 68). A unique aspect of this entry was the implementation of thrust control through the throttles. Two handles in the throttles for engines no. 1 and 4 (outboard) could be raised to form a single throttle to permit a simultaneous application of thrust **(**fig. 69). For airplane mode flight, they were to be used conventionally. In the VTOL modes, however, the inboard throttles were preset forward while the outboard throttles were moved forward to apply collective pitch to the propeller blades.

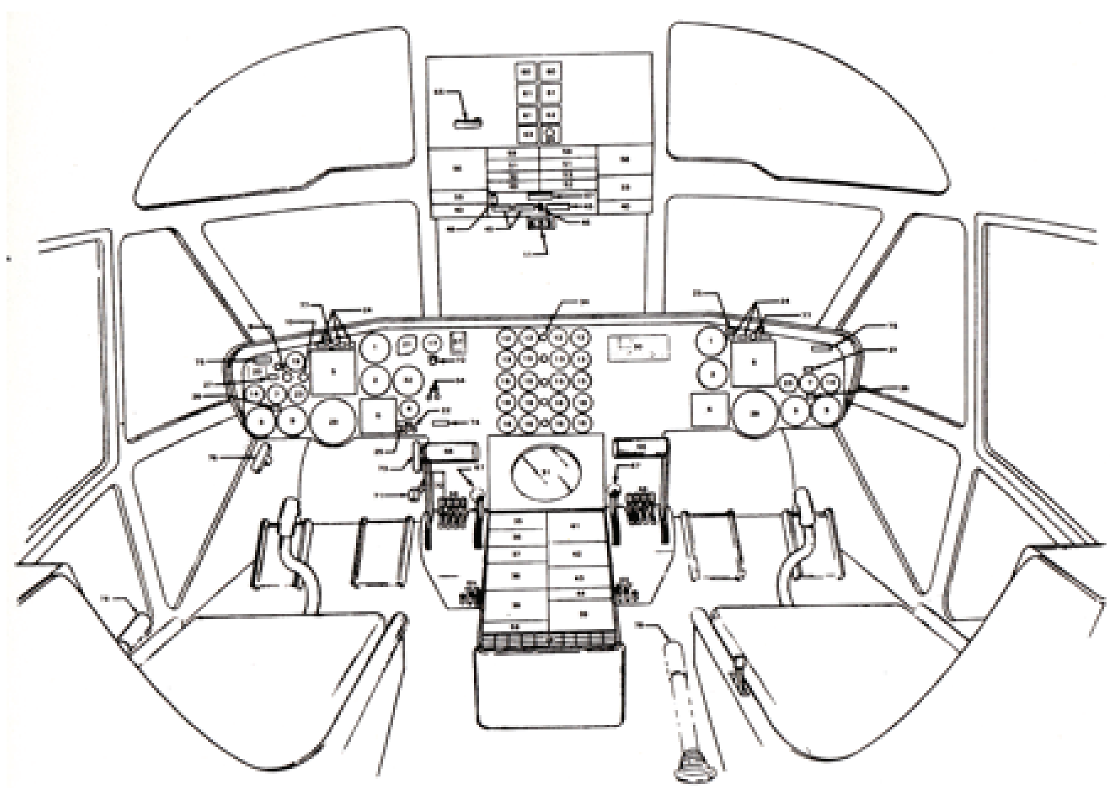

Figure 65. Douglas Models D-828/829 cockpit (Douglas drawing).

Figure 66. Bell/Lockheed Model D2064 (Bell drawing).

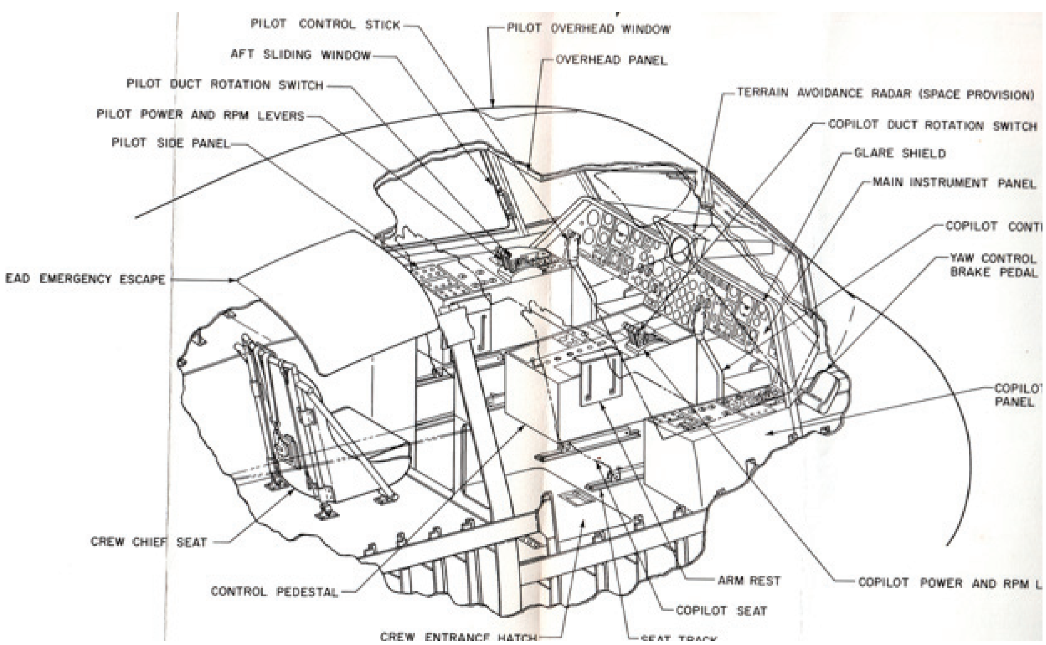

Figure 67. Bell/Lockheed Model D2064 cockpit (Bell drawing).

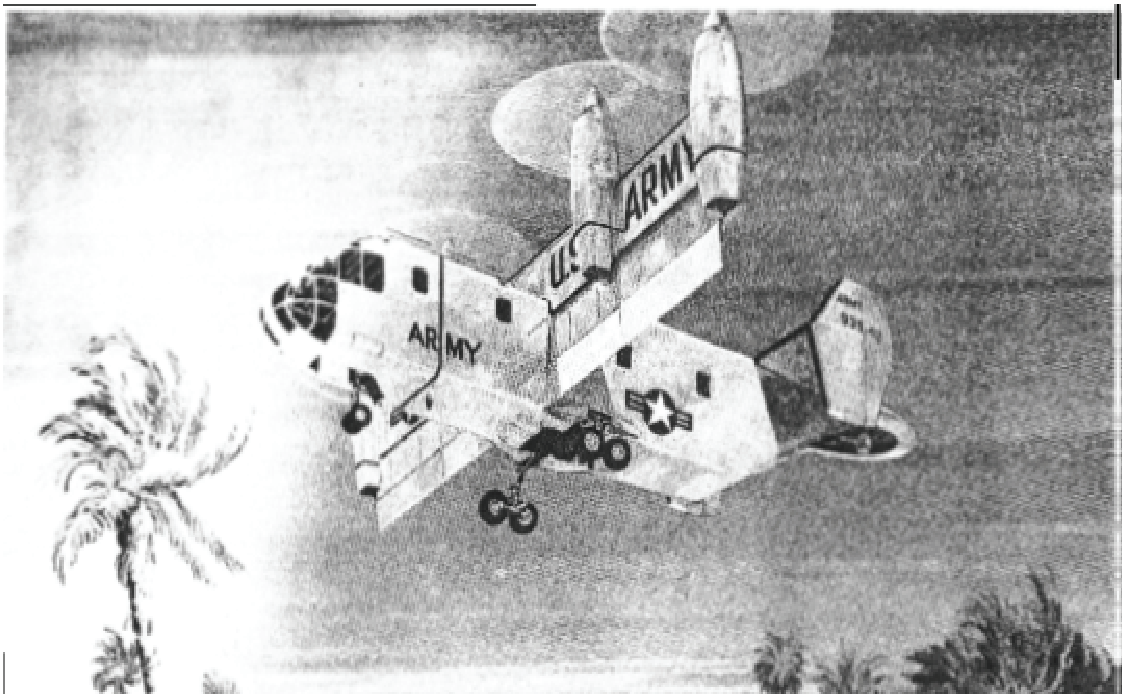

Figure 68. North American Tiltwing (NAA drawing).

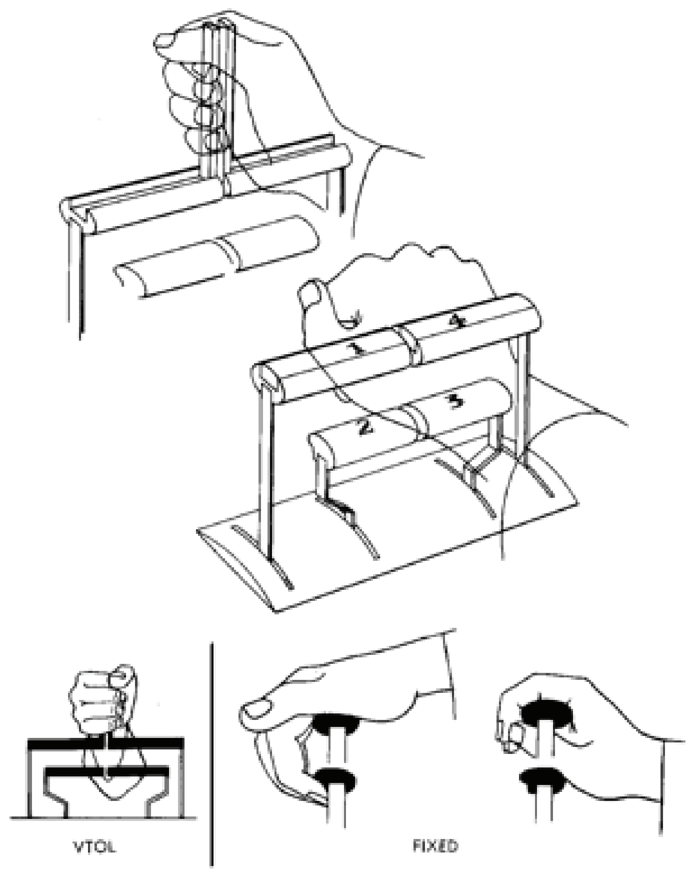

Figure 69. North American throttle design (NAA drawing).

The Sikorsky entry was a tiltwing design (fig. 70). It was designed to cruise at 233 knots at sea level at a mission GW of 35,000 pounds. At lighter gross weights, maximum speed was estimated to be approximately 350 knots. It used a throttle-type control for thrust in the vertical mode. Differential cyclic control provided yaw control in the vertical mode of flight while cyclic control of the propellers provided pitch control. An artist's depiction of the aircraft cockpit is shown in figure 71.

It had a unique "height control lever" that controlled propeller pitch in its forward range in the helicopter mode of flight. It was oriented vertically like a throttle. Separate engine control levers placed the engines in the governing range for airplane mode flight.

The Compound Model 177 (fig. 72) was McDonnell's entry and the only compound (both a rotor system and a propulsive system for wing-borne flight) submitted in the competition. It was powered by two T-64 engines also used in many of the entries. For airplane mode flight, there were two 11-foot-diameter, fixed-pitch propellers to provide sufficient thrust for the Model 177 to reach a maximum speed of 237 knots. The main rotor system had three blades and a rotor diameter of 65 feet. The blades were driven by tip jets that eliminated the need for any anti-torque control. A collective was used for thrust control in this design.

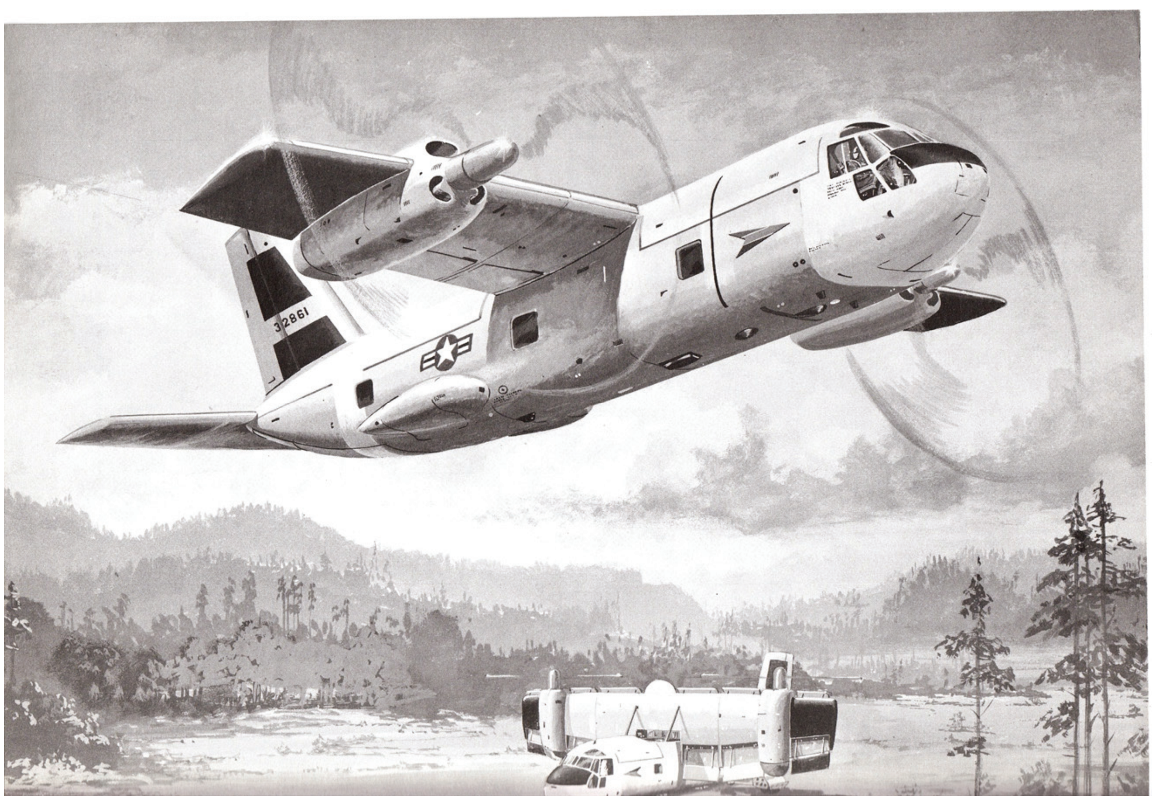

Figure 70. Sikorsky Tiltwing entry (Sikorsky drawing).

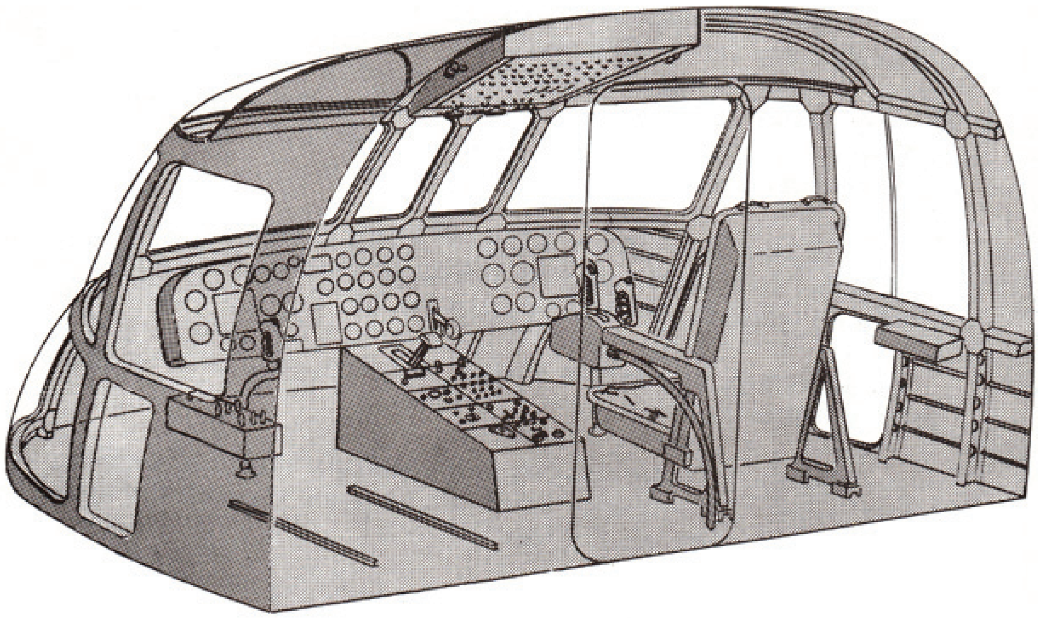

Figure 71. Sikorsky cockpit design (Sikorsky drawing).

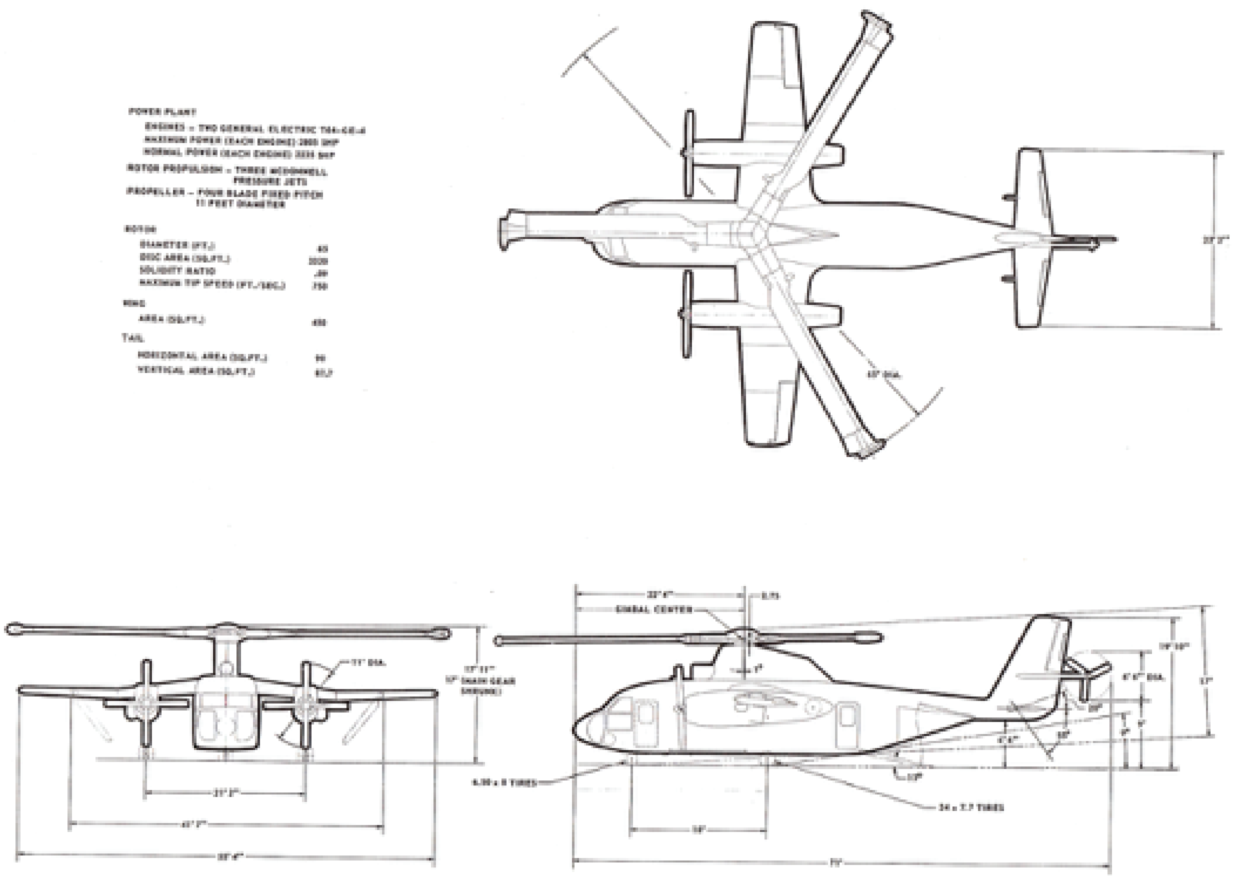

Figure 72. McDonnell Model 177 (McDonnell drawing).

McDonnell also proposed a tiltwing Model 175 in the competition (fig. 73). It had large, four-blade, wide-chord propellers with a diameter of 21 feet. They were constructed of fiberglass. Two vertical tails were designed to provide adequate directional control and reduce the size of a single tail configuration. A 9-foot horizontal tail rotor was located behind the empennage for pitch control.

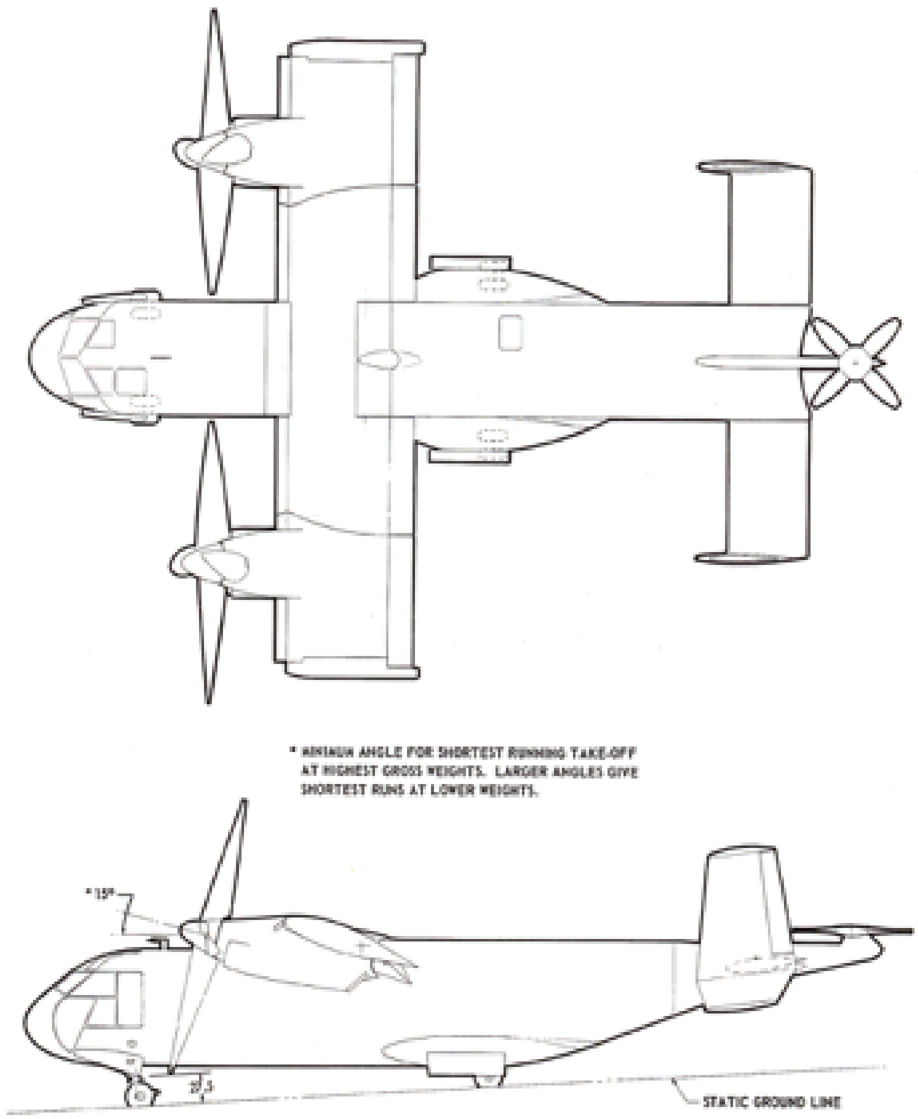

Figure 73. The McDonnell Model 175 (McDonnell drawing).

A collective "stick" was used in this design with throttles for airplane mode flight (fig. 74).

The Boeing-Vertol Model 137 Tiltwing (fig. 75) was designed to build on the experience and data derived from the Boeing-Vertol VZ-2, and was entered into the Tri-Service competition for a 35,000-pound VTOL transport with a 4-ton payload. It had four T-64 engines podded in pairs below the wing. Two three-blade propellers were interconnected with a cross shaft for engine-out safety. The wings incorporated leading edge slats and double slotted flaps for lift augmentation during conversion and steep descents. Pitch control in hover was provided by longitudinal cyclic control of the propellers. This negated the need for a propeller or other thrusting mechanism in the tail for pitch control. A collective pitch controller was used for thrust control in the hover and conversion modes of flight, while throttles were used conventionally in the airplane mode.

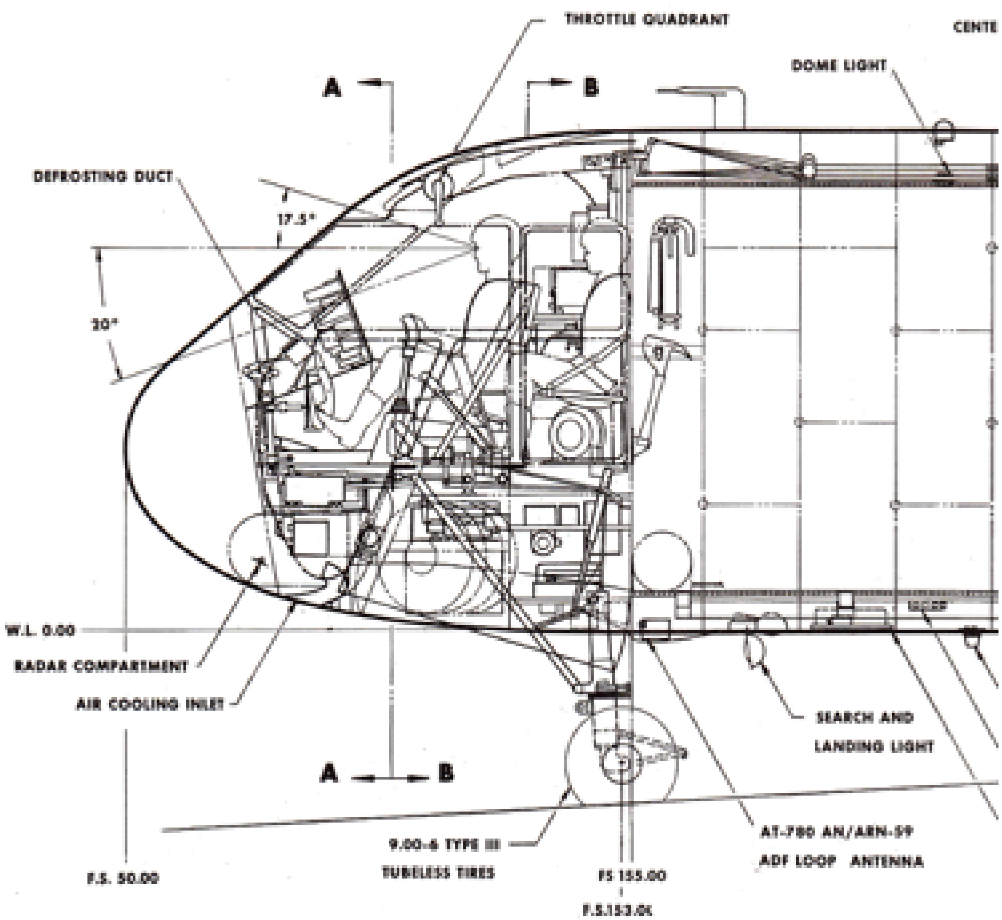

Figure 74. The McDonnell Model 175 cockpit (McDonnell drawing).

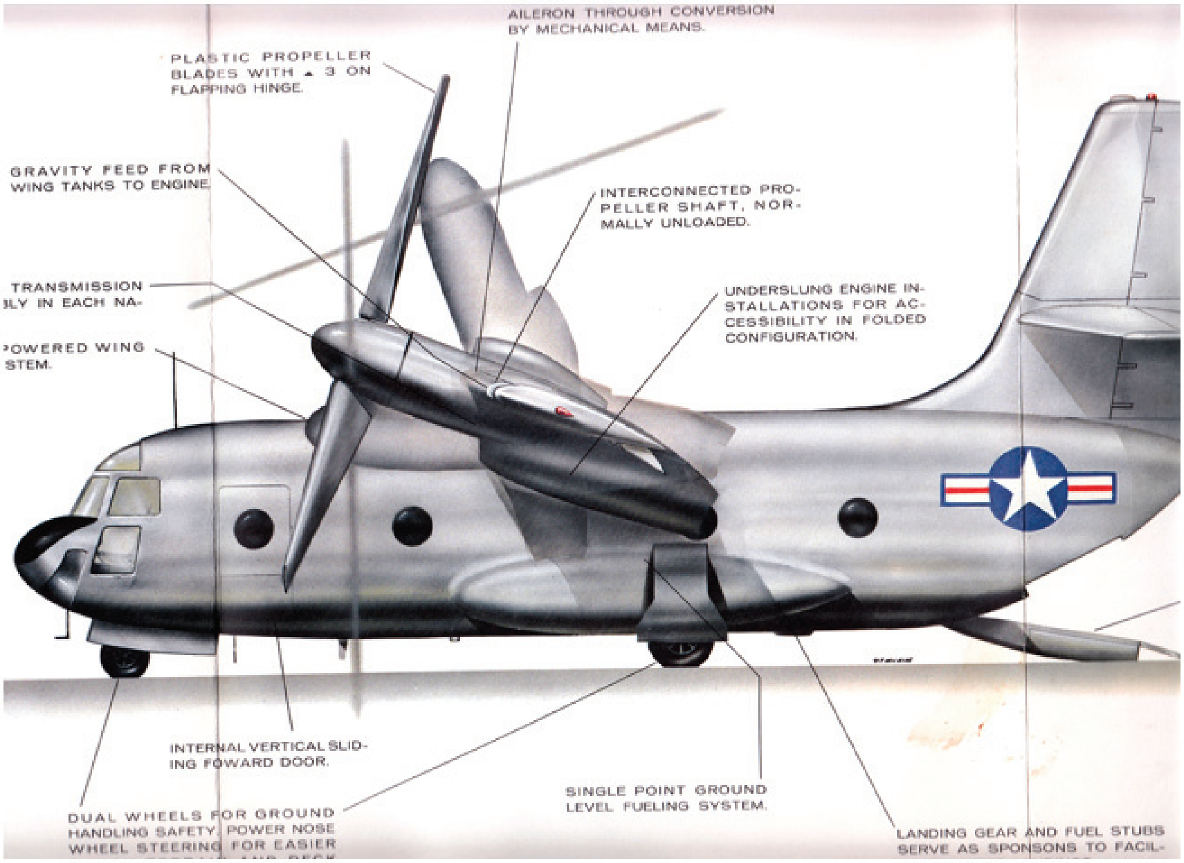

Figure 75. The Boeing-Vertol Model 137 Tiltwing (Boeing-Vertol drawing).

Cockpit controls were comprised of a longitudinal-lateral stick, directional pedals, and a collective pitch lever of unique design allowing unrestricted entry into the cockpit (fig. 76). These units are similar in design and location to those found in the UH-l helicopter except that the pilot's controls for the Model 137 were located on the left side of the cockpit (fig. 76). The cockpit controls and necessary under-floor bell cranks were to be mounted in a preassembled unit removable from a well in the cockpit floor.

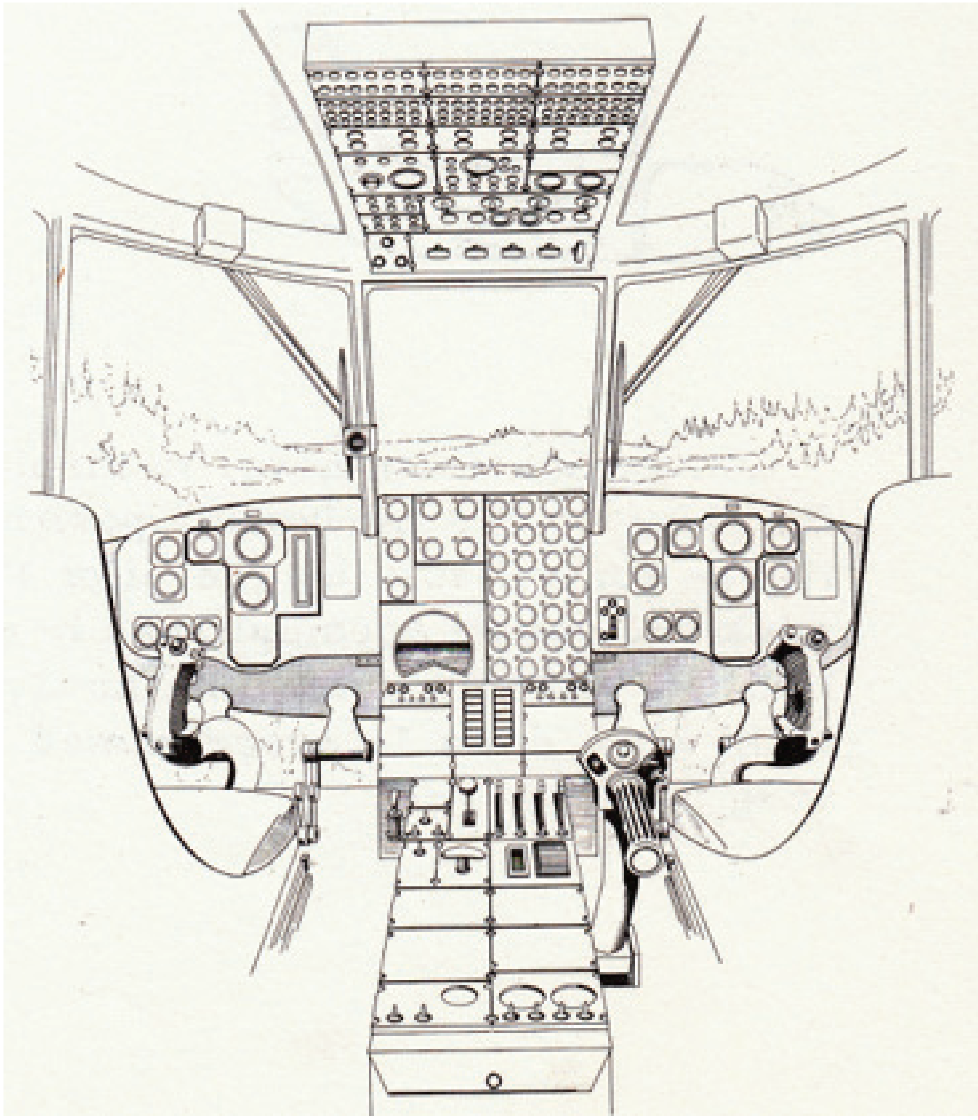

Figure 76. The Boeing-Vertol Model 137 cockpit (Boeing-Vertol drawing).

The Boeing-Wichita Model 900 was a unique entry in the competition in that it featured 12 LE 4000 lift engines imbedded in streamlined nacelles along each side of the fuselage, and two GE CF700 turbofan cruise engines for airplane mode flight (fig. 77).

Prominent canards were designed to reduce the size of the aft wing and eliminate the need for a horizontal tail. Powered by turbofan engines, the Model 900 had an estimated speed of 360 knots at sea level at its DGW of 35,000 pounds. The ferry range was predicted to be 2200 nautical miles, and it could still hover at an overload GW of 43,600 pounds on a sea level standard day.

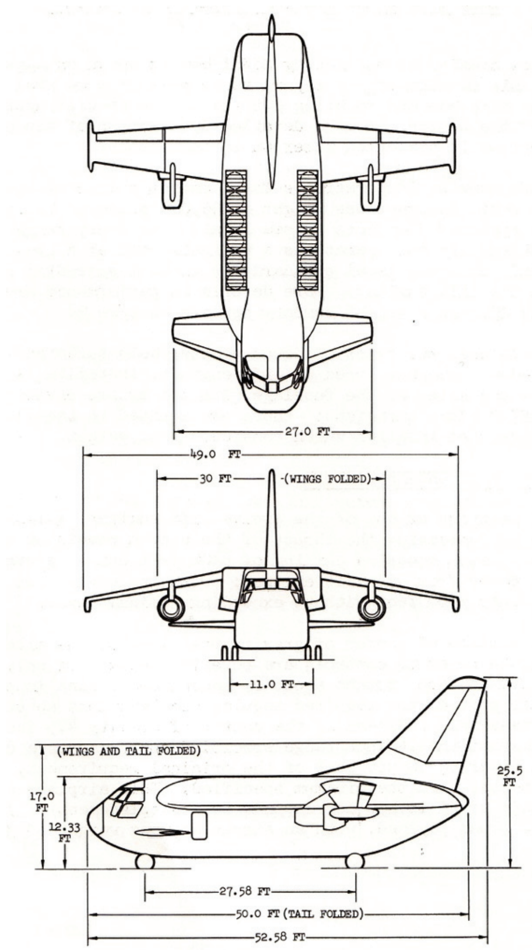

Figure 77. The Boeing-Wichita Model 900 (Boeing-Wichita drawing).

The numbers were impressive, but in the author's opinion, overly optimistic. The Model 900 used a collective-type thrust control referred to as a "height control lever." The lever also served to provide thrust control of the cruise engines in airplane mode flight. However, an aircraft with 14 engines was not seen as a practical design.

The Vanguard Model 30 Lift Fan was a four-engine, fan-in-wing configuration powered by Allison 501-H2 engines (fig. 78). The fans were 8 feet in diameter, and the two propellers were 14 feet 6 inches in diameter. Two fans were imbedded in each wing (one pair inboard of each engine pod and one pair outboard), and a pitch fan was located in the nose of the aircraft. This entry was not as polished as those of other competitors, but the essentials were included. Throtttles were used for thrust control in all modes of flight as shown in the obstructed cockpit view (fig. 79).

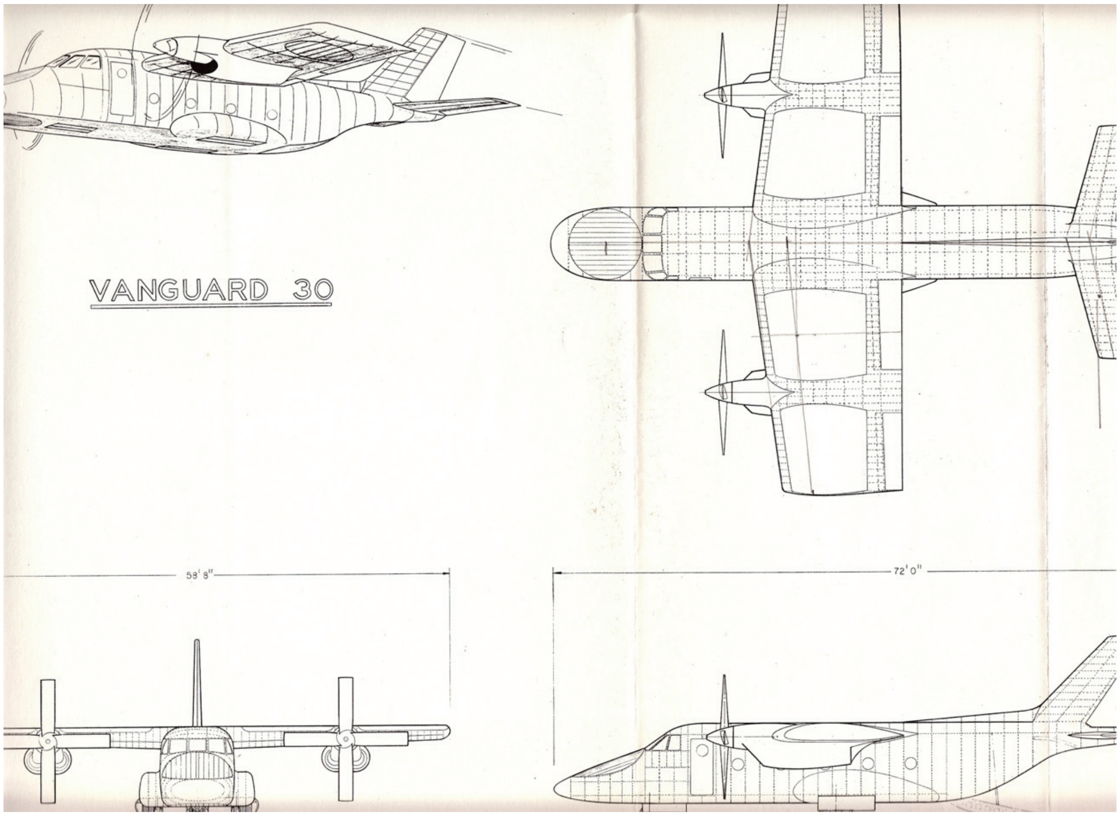

Figure 78. The Vanguard Lift Fan (Vanguard drawing).

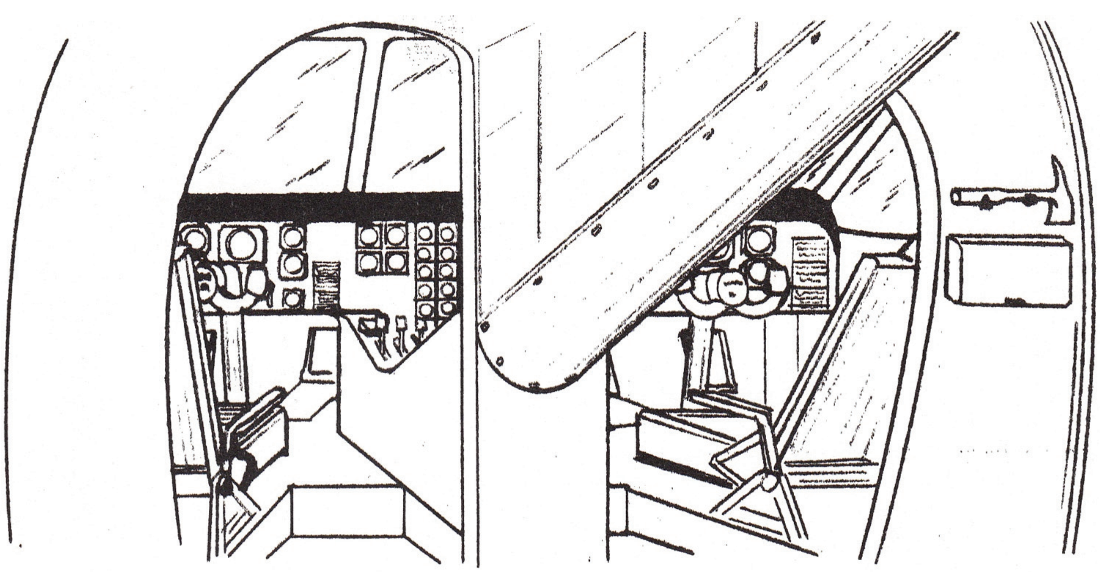

Figure 79. The Vanguard Lift Fan cockpit (Vanguard drawing).

The last entry reviewed in the I961 VTOL Transport Request for Proposals (RFP) was submitted by an individual from Burlingame, California. His proposal was to convert the existing Bréguet 941 Short Takeoff and Landing (STOL) transport into a VTOL transport (fig. 80). The proposal had insufficient content to determine the method designed to be used for thrust control, but it is the author's speculation that the aircraft's power levers would remain as installed and it appears that there is also a type of collective controller in the cockpit (fig. 81).

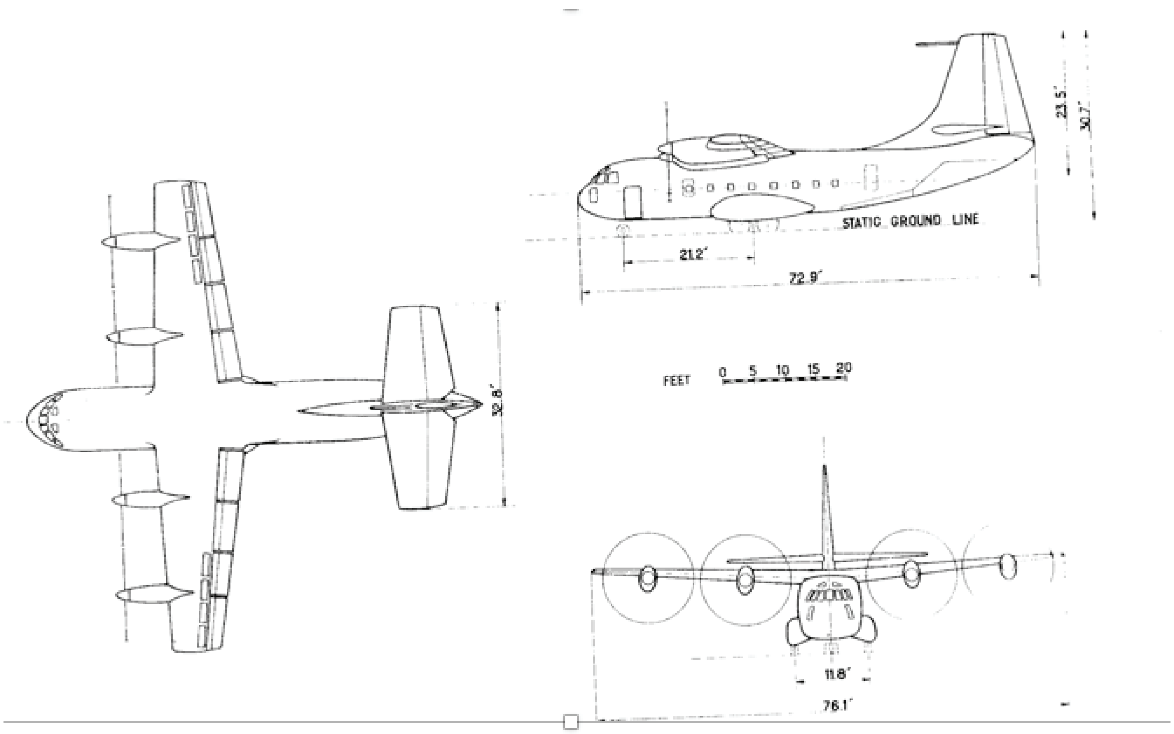

Figure 80. The Bréguet 941 (Bréguet drawing).

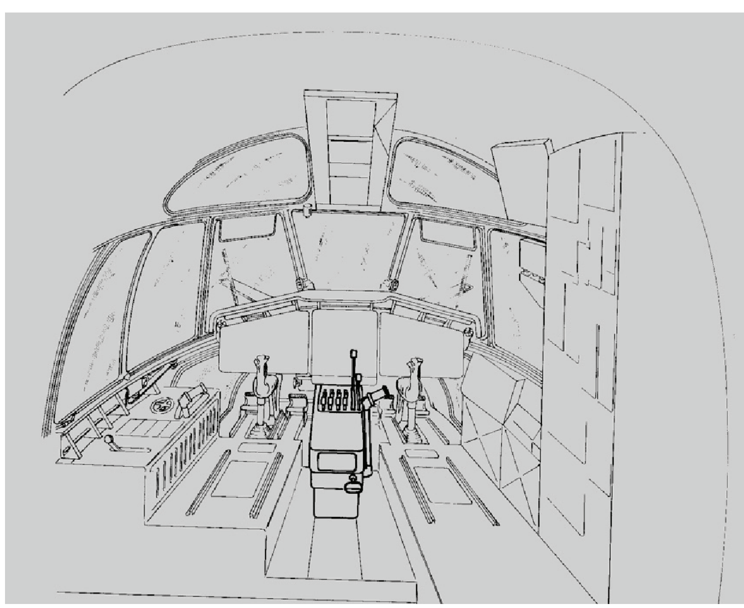

Figure 81. The Bréguet 941 cockpit (Bréguet drawing).

CONCLUDING REMARKS

It is important to document the 1961 Tri-Service Transport Competition designs, and other designs for thrust control, to preserve a part of this country's aviation heritage. Perhaps control design teams in the future may benefit from reviewing the various designs that succeeded and those that failed, and those that were never built. It also seems apparent that as engine technology progressed, new aircraft designs were generated. The lighter, higher thrust and shaft horsepower turbines such as the J-85, and the T-53 and T-64 series, permitted many designs that otherwise would not have been possible.

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