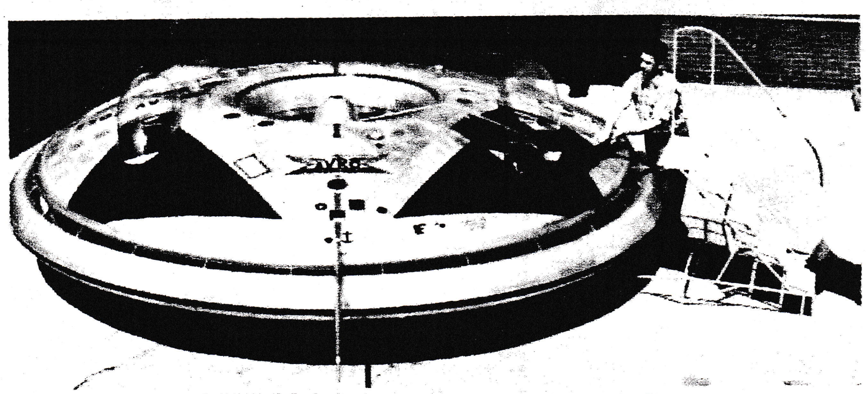
THE VZ-9 "AVROCAR"

By Bernard Lindenbaum and William Blake



One of the most unusual V/STOL aircraft programs that was ever conducted was the Avro VZ-9 "Avrocar". Designed to be a true flying saucer, the Avrocar was one of the few V/STOL aircraft to be developed in complete secrecy. Despite significant design changes during flight test, the Avrocar was unable to achieve its objectives and the program was ultimately canceled after the expenditure of more than $10 million (1954-61). This article will discuss the origins, technical problems, and demise of the Avrocar program.

In 1952, a design team headed by J.C.M. "Jack" Frost, of Avro Aircraft, Canada, began design work on a supersonic VTOL aircraft with a circular wing. The Canadian Defense Research Board funded the effort with a $400,000 contract. VTOL capability was to be achieved by ducting fan air and engine exhaust to the periphery of the planform and deflecting the air flow downwards. Close to the ground, this provides a cushion effect where the lift exceeds the thrust due to increased pressure on the underside of the aircraft. This phenomenon was confirmed in a wind tunnel test. For transition to forward flight, the air flow would be gradually redistributed backwards. Frost was convinced that a thin, circular planform wing, or flying saucer, was the ideal shape to take advantage of both the ground cushion effect (for STOL overload capability) and supersonic flight.

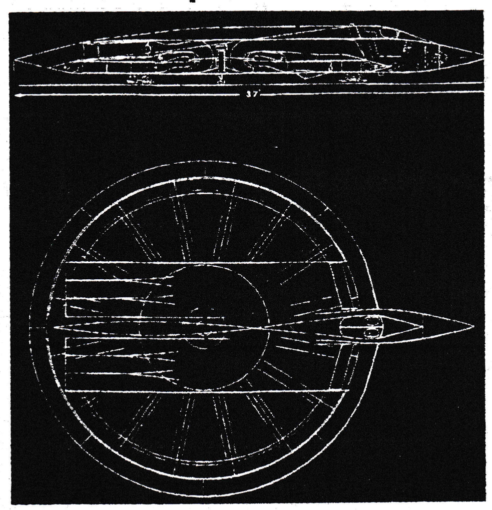


Figure 1. Weapon System 606A.

In 1954, the Canadian government abandoned the project as too costly, but enough progress had been made to interest the US Air Force. Concern with the vulnerability of forward placed bases in Europe heightened Air Force interest in VTOL aircraft. A three-quarter million dollar contract was awarded by the Air Force in 1955 for further study. By 1956, Avro was sufficiently satisfied with the results to commit $2.5 million to build a prototype research aircraft. In March 1957, the Air Force added additional funding, and the aircraft became "Weapons System 606A". These efforts remained highly classified until July 1960. One of the most promising 606A concepts (Figure 1) had a thin circular wing, 35 feet in diameter, a maximum weight of 27,000 lb. and a design speed of over March 1.4. A large fan was driven by the exhaust from six Armstrong Siddeley Viper 8 engines whose air was ducted radially outward to the wing periphery. Numerous wind tunnel tests, both at Avro and Wright Field, Ohio, were conducted and a full scale test bed of the propulsion system was built.

In 1958, Avro made a series of presentation to the US Air Force and Army, after which Avro began design of an aircraft for the US Army which was given the designation VZ-9 and named Avrocar (Figure 2). The Avrocar was to be a subsonic flying

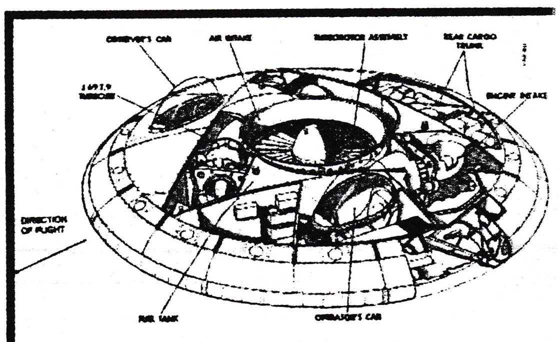


Figure 2. Avrocar cutaway view.

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wing of circular planform with VTOL capability. The Army was interested in improved battlefield survivability of its air vehicles and was studying alternatives to its existing light aircraft and helicopters. The Air Force supported the Avrocar program because it would demonstrate many of the design features of the 606A in a shorter time at much lower cost. A $2 million contract to be managed by the Air Force was awarded to Avro to build and test one Avrocar. Additional Air Force funding of approximately $700,000 (unexpended from the 606A program) was applied to the effort.

Initial performance requirements for the Avrocar were a ten minute hover capability in ground effect and 25 mile range with a 1000 lb payload. A representative Army mission is shown in Figure 3. Work began in earnest and a $1.77 million contract was awarded for a second Avrocar in March 1959. The first Avrocar rolled out of the factory in May 1959. At roll out, projected performance was far in excess of the requirement, with a 225 Kt maximum speed, 10,000 ft ceiling, 130 mile range with 1,000 lb payload, and hover out of ground effect was calculated to be 5,650 lb, maximum weight with a transition in ground effect (GETOL) was 6,970 lb.

The Avrocar was 18 feet in diameter, 3 feet thick, and had two cockpits. The pilot's cab was located on the forward left side of the vehicle with the crew cab on the right. A third compartment in the rear was provided for cargo storage. The Avrocar was lifted by the efflux from a five foot diameter central fan, called a turborotor. Exhaust from three Continental J-69 turbojet engines (920 lb thrust ea) was ducted to the outer rim of the turborotor which had 124 small turbine blades. Driven in this fashion, the turborotor took in and propelled ambient air from a central opening on top of the vehicle. This air, mixed with the turbine exhaust, was ducted to the periphery of the vehicle provided air for the engine inlets through a four inch high annular nozzle. Separate flush openings on the top of the vehicle provided air for the

Figure 3. Representative Army Mission.

engine inlets through a short pipe with a 90 degree turn. Each engine was connected to its own fuel and oil tank. The fuel tanks were not interconnected, although this was planned in a later version.

Pilot control consisted of a side-stick that provided pitch and roll control through conventional fore-aft and side-to-side motions. Twisting of the stick was used for yaw control. The stick was not connected to any mechanical linkages. Control was provided by high pressure air that was piped to both the control stick and control actuators at the base of the turborotor. Pressure differences caused by movement of the stick resulted in actuation of the proper control cables at the turborotor.

In forward flight, the Avrocar was satirically unstable in pitch, with an aerodynamic center well forward of the center of gravity. An automatic stabilization system was employed which used the gyroscopic action of the turborotor. The turborotor was not rigidly fixed to the vehicle; it was mounted on a bearing system which allowed limited motion. Any disturbance to the vehicle in pitch or roll would cause movement of the turborotor relative to the aircraft. This would result in movement of the control cables located at the base of the turborotor shaft, which were phased to give the correct balancing control moment in pitch or roll.

Army interest in the Avrocar program was very high. One of the authors (Lindenbaum) recalls a trip to Washington in the late 1950's to request additional funding for a study on helicopter drag reduction. Although the funding was approved, he overheard an Army General remark that the Huey was to be the last helicopter the Army would buy since the helicopter would be replaced by the Avrocar!

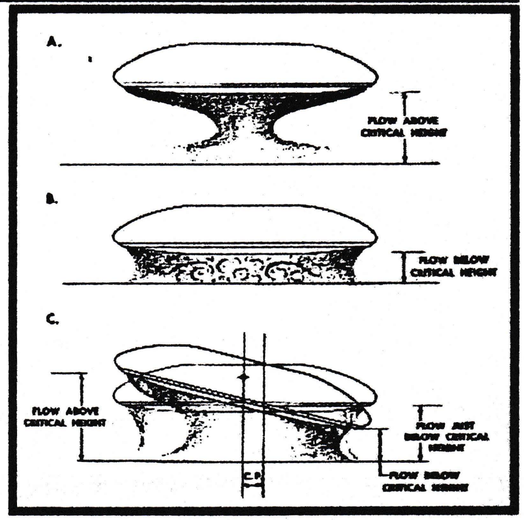
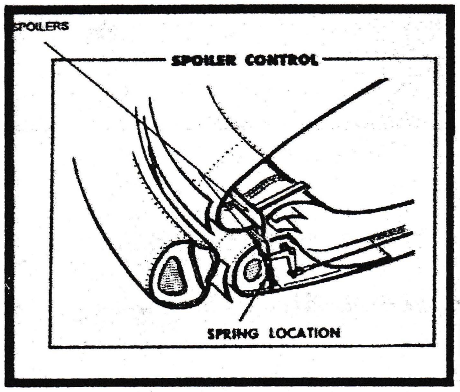


Figure 4. Hubcapping Effect.

From June to October 1959, the first Avrocar was tested in a static hover rig. Hot gas recalculation reduced turborotor RPM and thrust. Excessive losses in the ducting systems also became apparent; these were never cured despite extensive design changes. Maximum lift attained out of ground effect was 3,150 lbs. With a zero fuel weight of 4,285 lb, the Avrocar was thus incapable of hover out of ground effect. Following these tests, the vehicle was sent to NASA Ames for a wind tunnel evaluation.

The second Avrocar rolled out of the factory in August 1959. On September 29, the first attempt to hover was made with the Avrocar tethered to the ground. After the vehicle became airborne, an uncontrollable oscillation occurred with each wheel alternately bouncing on the ground. The pilot immediately shut down all engines. Subsequently, a variety of alternate tethering schemes were tried and numerous changes were made to the springs at the spoilers and the base of the rotor shaft. These early tethered flights unearthed a new problem, termed "hubcapping", that was never fully solved. Hubcapping was a rapid, unpredictable oscillation in pitch and roll. It resulted from an unstable ground cushion if the vehicle exceeded a critical height (Figure 4). The critical height was found to be about two feet from the ground. Control inputs were ineffective in damping the oscillation. Fifty two holes were drilled in the bottom of the vehicle, located radially three feet from the center. These were holes to provide a central jet to stabilize the ground cushion.

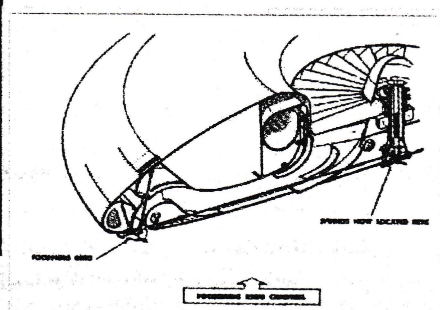
The first complete free flight occurred on November 12, 1959, and the nozzle spoiled control system proved unac-



ceptable. The system used two continuos rings of spoilers located at the annular nozzle, which was open to both the upper and lower surface of the aircraft (Figure 5). The spoilers were intended to control the direction of the jet flow. In hover, the air would be directed through the lower surface. In forward flight, the air would be directed through both the upper and lower surfaces at the rear of the aircraft. Pitching and rolling moments were produced by reducing lift on one side of the vehicle. Unfortunately, more lift was not created on the opposite side, resulting in a loss of height with control input. After five flights, testing was temporarily, halted on December 5, 1959, by which time the Avrocar had logged 18.5 hours of test time in both tethered and free flight.

A new focussing ring control system was installed later in December (Figure 6). The nozzle opening to the upper surface was covered, and the spoilers were replaced with a flat ring on the bottom of the vehicle. Lateral changes in the position of the ring would increase the lift on one side of the vehicle while decreasing lift on the opposite side. Flight test resumed in January 1960 with this system. A USAF flight evaluation was conducted at the contractor facility on April 4, 1960, with Major Walter Hodgson at the controls. Maximum airspeed achieved was 30 Kts, above this speed, an uncontrollable oscillation in pitch was encountered. The cockpit was cramped, noisy and became excessively hot during a 15 minute flight. Later that month, a test was conducted in the NASA Ames 40x80 ft full scale wind tunnel. This

Figure 5 (left). Spoiler Control.
Figure 6 (below). Focussing Ring Control.



test found that the focussing ring control system provided insufficient thrust for forward flight out of ground effect, and large angles of attack were required to generate aerodynamic lift. This was because the flow on the underside of the vehicle diminished the wing circulation, reducing lift. At the end of April, the initial Avrocar program came to and end. Shortly thereafter, the program was declassified by HQ USAF.

Avro was convinced that tl concept was still workabl and proposed a new progra for major rework of tl propulsion and control system (Figu 7). A new USAF contract for the peri July 1960 to July 1961 was awarded f modification and testing of both veh cles. A new nozzle was installed on tl rear half of the vehicle. Transitic doors were provided to eliminate tl flow from the lower surface of the pı mary annular nozzle. Vanes we added in the exit of the new nozzle deflect the thrust for pitch and rc control. To accommodate the changes, the yaw control vanes we moved forward.

A second wind tunnel test wi the new configuration wa conducted at NASA Ames i April 1961. It was found th sufficient control was available to trai sition to a speed of about 100 Kts, ar trimmed flight (thrust=drag, zero n moment) was possible at this spee However, the vehicle was still unstab in pitch. It was hoped that the chang

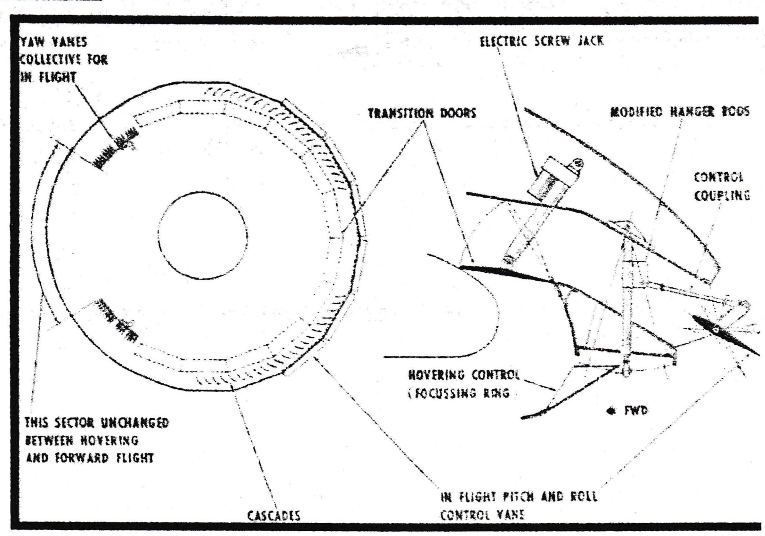


Figure 7. High Speed Control System.

in flow over the aft portion of the veh cle would increase lift due to a jet fla effect and decrease the nose-u moment, reducing the instabilit Unfortunately, this was not found to b the case. A vertical tail and horizont "T" tail were added (Figure 8). The were totally ineffective. NASA sur

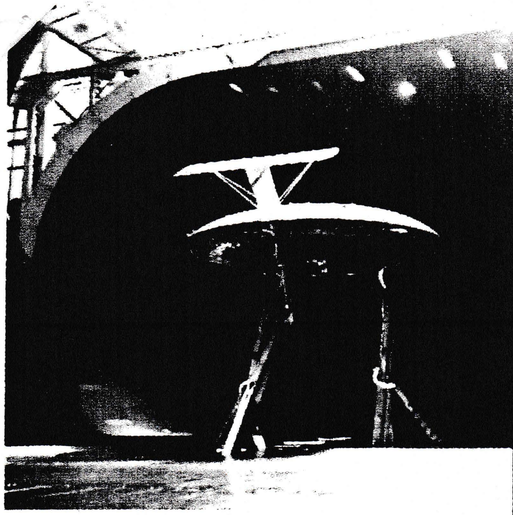


Figure 8. Avrocar (with tail) in NASA Ames Wind Tunnel.

mised that this resulted from the tail being in a region of very high downwash caused by the propulsion system. In any event, it became clear that the Avrocar as configured, could not sustain high speed flight.

On June 9, 1961, the second and final USAF flight evaluation of the Avrocar was conducted at the Avro facility. During these test, the vehicle reached a maximum speed of 20 Kts and showed the ability to traverse a ditch six feet across and 18 inches deep. Flight above the critical height was impossible. The flight test report summarized a litany of control problems. For example, a large asymmetry in directional control was present. Five seconds were required to turn the aircraft 90 degrees to the left, while eleven seconds were required for a 90 degree right turn. Avro proposed radical modifications to the vehicle to address the major problems. Frost's team developed two new designs, one with a large vertical tail and one with a wing with tip mounted verticals (Figure 9). Both designs used two 2,700 lb thrust GE J-85 turbojets in lieu of the three 920 lb thrust J-69's and increased the turborotor diameter from five to six feet. The proposals were rejected, and the program was terminated in December 1961. The second Avrocar had logged a total of about 75 flight hours.

The concept of ground effect takeoff and landing did not die with the Avrocar. In 1963, Bell Aerospace began studies of an Air Cushion Landing System (ACLS) which was later patented. These studies were headed by T. Desmon Earl, formerly Chief Aerodynamicist for the Avrocar. An ACLS replaces conventional landing gear with a large rubber inner tube-like structure which surrounds a region of increased pressure air. In August 1967, the concept was proven by Bell with successful tests on a 2,400 lb Lake LA-4 amphibian aircraft. Further development was funded by the Air Force Flight Dynamics Laboratory, and a much larger system was designed for testing on a Fairchild C-119 (64,000 lb weight). The Canadian government joined the program and a DeHavilland CC-115 (41,000 lb weight) was selected for further tests. Given the US designation XC-8A, this aircraft flew with the ACLS in March 1975. ACLS was considered, but rejected, as an option for the Advanced Medium STOL Transport program that produced the Boeing YC-14 and McDonnell Douglas YC-15 prototypes, the latter evolved into the Boeing C-17 transport.

The concept of a lift fan driven by a turbojet engine did not die either, and lives on today as a key component of the Lockheed X-35 Joint Strike Fighter contender. While the Avrocar was under development, Peter Kappus of General Electric independently developed a lift fan propulsion system which evolved into the GE/Ryan VZ-11 (later XV-5) "Vertifan". This vehicle, discussed in two earlier Vertiflite issues (March/April 1990, March April 1996), paved the way for further lift fan studies. Supersonic fighter studies sponsored by DARPA included both gas driven (McDonnell Douglas) and shaft driven (Lockheed) lift fans.

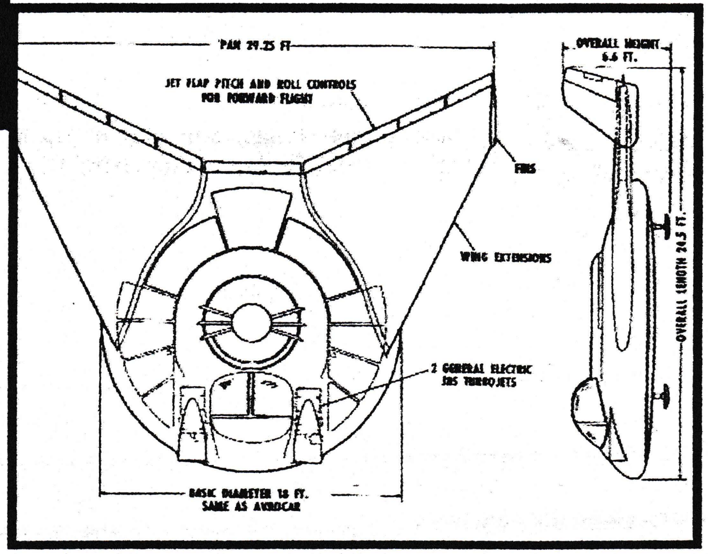


Figure 9. Proposed Avrocar with Wings and Tail.

Why did the Avrocar program fail? The opinion of the authors, shared by LtCol (ret) Dan Murray, USAF program manager for the Avrocar, is that too many "novel" ideas were tried simultaneously in what was a radical aircraft concept. These included the turborotor stabilization system, The pneumatically powered control system, the jet exhaust/turborotor ducting system and three-axis sidestick control. Two other innovations (GETOL, lift fan) were later demonstrated separately with "conventional" aircraft. How should radical new concepts be approached today? Probably not with a full-scale manned vehicle. Subscale, remotely piloted vehicles can be used to explore new ideas with less risk at far less cost.

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William Blake is an aerospace Engineer at the Air Force Research Laboratory, Wright Patterson AFB, OH, and is currently a Director-at-Large of the AHS. Bernard Lindenbaum retired from the Air Force in 1974 following a distinguished career and is currently President of Aerial Mobility, Inc. He participated in the Avrocar program during the latter stages of its development, witnessing several of its flights. He is an Honorary Fellow of AHS and a Dr. Alexander Klemin Award recipient.