Testimony

Anthony A. duPont
President, duPont aerospace Company, Inc.

<u>Program</u> The purpose of the DP-2 program is to introduce Vertical and Short Take Off and Landing (VSTOL) capability into high performance turbofan powered aircraft using vectored thrust. The program was moved forward entirely with company funds and outside investment until 1995. At that point previously appropriated funds were released by the Defense Advanced Research Projects Agency (DARPA) to fund a full scale test of the thrust vectoring system. The purpose of the government investment in the program is to make a sufficient demonstration of the technology that the military services would be able to make an informed decision to use it.

The DP-2 achieves vertical and short field operation by incorporating larger engines and vectored thrust into an otherwise conventional turbofan powered transport aircraft. The X-14, first flown in the 1950's, demonstrated the idea of fixed turbojet engines with a movable cascade system to achieve vertical take off and landing. One way to view the DP-2 program is to think of it as using the cumulative advances in aeronautical technology since the 1950's to provide an operational capability similar to conventional airline and military aircraft in a vertically rising aircraft similar to the X-14.

In terms of currently operating aircraft the DP-2 carries a larger payload about twice as fast and twice as far as the V-22, and is considerably less expensive to procure.

<u>History</u> The origins of the DP-2 go back to the late 1960's when I was working for the Garrett Corporation and developing the Hypersonic Research Engine (HRE) for the X-15 and the ATF-3 turbofan designed to replace turbojets then in service on business aircraft. The HRE was managed by the National Aeronautics and Space Administration (NASA) Langley Research Center, and I spent a lot of time at that facility. NASA Langley was also testing two P-1127, early versions of the Harrier VSTOL fighter aircraft. I had ample opportunity to study this aircraft because both airplanes were often disassembled for maintenance and spread all over the hangar floor. My interest was in the potential market for the three spool high bypass turbofan technology embodied in the ATF-3. The high bypass and high overall pressure ratio promised a large increase in combat radius, and the mixed exhaust promised a huge reduction infrared signature as well as greatly reduced ground erosion. I talked with Jack Reeder, the chief test pilot, about flying the aircraft. He said that it was flyable without any stability augmentation. In fact most pilots preferred to turn off the stability augmentation system. However, he said he would like some artificial stability in height. It was easy to get pre-occupied and pick up a rate of descent in hover that was hard to stop with the thrust margin available. He also wanted altitude stability like a trimmed aircraft has in forward flight.

In the fall of 1968 Garrett was about to sign production contracts for the ATF-3 with North American Aviation and Dassault, but was unwilling or unable to buy the machine tools on which the cost and schedule were predicated. Not being willing to make promises I knew the company could not keep, I resigned from the Garrett Corporation. In the spring of 1969, I laid out an 8 place business jet with VSTOL capability.

The only small turbofan engines then available were the General Electric CF-700, an aft fan version of the well proven J-85 turbojet. This engine was in service on the Dassault Falcon 20 and was destined to eventually be replaced by the ATF-3. The reliability of turbofans was expected to be quiet high. The odds of losing an engine on take off eventually passed a million to one making the odds of losing both engines on a twin engine airplane a trillion to one. Therefore, a twin engine VSTOL aircraft would be reliable enough to make commercial sense.

A number of locations for engine placement were studied, and side by side in the nose very quickly emerged as the only practical possibility. The engines had to be ahead of the airplane's center of gravity to permit vectoring the thrust downward for liftoff, and they had to be as close to the centerline as possible to enable the roll control system to maintain a level atitude if one engine fails.

The initial control system design was a bleed air "puffer jet" system like the Harrier. This proved to be unsatisfactory because not enough control moment could be generated with the available bleed air, and use of bleed air reduced the thrust lift available. A transport airplane has much higher inertia than a fighter and requires more moment to get the same angular acceleration response. A vane control system in the engine exhaust was designed to replace the bleed air system and remove these deficiencies.

While we were trying to arrange financing for this airplane, then called the DP-1, the bottom dropped out of the business aircraft market in the early 1970's. We had a larger airplane called the DP-2 using the General Electric TF-34, then in development by the Navy for the S-3A, on the drawing board when the Navy issued a request for proposal for VSTOL A, a utility airplane for the Sea Control Ship. No VSTOL A was procured, but the DP-2 got a little exposure. When the Navy issued a Request for Proposals (RFP) to replace the Grumman C-2A with an aircraft that could also be a 30 seat airliner, we were encouraged to respond.

Although the C-2A many years later was replaced by more C-2A's, the exposure to the Navy and the airlines generated enough interest to keep us working on the DP-2. A wind tunnel model with operating engines and a fixed thrust vectoring cascade that was removable for normal flight was tested in the 8 foot tunnel at Cal Tech in 1978. In 1982 the same model with a retractable cascade and vector control system was tested for a month in the 7 X 10 foot tunnel at NASA Ames. In the 1980's requirements in all the services as well as the Coast Guard and Customs Service were identified, but the numbers were too small to generate a Department of Defense (DOD) development program. In the late 1980's the Special Operations Forces became the most persistent advocate. Their interest was in an aircraft to meet their long range exfiltration requirement, notionally a thousand miles in and a thousand miles out at 200 feet above the ground with a vertical landing at the mid point. To make a vertical landing instead of a short landing larger engines were required.

The first engine that truly offered vertical capability was the Pratt and Whitney JT8D-219, which was rated at 21,700 pounds thrust. With this engine the DP-2 could insert and extract a twelve man team weighting approximately 3,600 pounds. Later when funds appropriated for the DP-2 were finally released by DARPA in 1995, the International Aero Engines V2500 was selected in order to raise the payload capability to 10,500 pounds. This engine was used in a successful test of the DP-2 thrust vectoring system at Pratt and Whitney in 1996.

Following this successful test, which demonstrated a 5% thrust loss compared to the 25% estimated by a 1986 Navy evaluation sponsored by the Special Forces, the balance of the $15 million appropriation was transferred to the Office of Naval Research (ONR) by DARPA, who wanted one of the services to continue the program.

The ONR program manager, Dr. Tom Taylor, wanted to build and fly a smaller airplane because there were no 30,000 pound thrust turbofans available from the military, and no follow on appropriation large enough to purchase them was on the horizon. A 53% DP-2 size was selected to use available Pratt and Whitney Canada experimental 530A turbofans and capitalize on some fuselage tooling available at Mississippi State University. Thus the current DP-1 program was born.

In addition to the initial engine test vehicle, which had a steel wing, three versions of the DP-1 have been built. The DP-1A used leased PWC 530A engines rated at 2,887 pounds of thrust. The first lift off was achieved on January 16, 2002 with these engines, but in spite of many inlet refinements no additional installed thrust was obtainable. On October 9, 2002 two Pratt and Whitney Canada (PWC) 535A engines with considerably more thrust, over 4,000 pounds, were purchased under a NASA grant. The airplane, modified to install these engines, is called the DP-1B. The first lift off of the DP-1B was on January 22, 2003. Many other successful lift offs were accomplished in early 2003. In these flights the controls were locked. They were adjusted until the aircraft lifted off vertically. On May 10, 1999 Dr. Tom Taylor had sent a letter from ONR saying all hover testing would have to be accomplished autonomously without a pilot in the cockpit. This decision greatly increased the cost of the program and the time to complete. A rough estimate is a factor of at least three times the original manned flight approach. In the fall of 2003 this aircraft was flown several times under autonomous autopilot control. Testing was terminated after a dual autopilot failure on November 2, 2003 caused the airplane to hit the tethers at an excessive rate of climb. The subsequent gear impact, at a very high roll rate, pulled the main landing gears out of the wing.

The airplane was repaired with stronger landing gear attachments. Testing was resumed on April 14, 2004. During a control characterization test the nozzle box failed on November 16, 2004. The cause of the failure was testing a new NASA cascade vane design in the old nozzle box. The cascade pressed on the bottom of the nozzle box, breaking the tension link supports and eventually causing the cascade actuator to break loose allowing the cascades to rotate aft.

Rather then repair the DP-1B, a new fuselage was built with many other new parts to eliminate the control mounting flexibility that had emerged in the DP-1B as a result of the modifications to accept the 535A engines. New electrical wiring was installed to improve reliability, and a new, lighter tail built. The only major components retained from the DP-1B were the wing, the PWC 535A engines and the nozzle box. The floor of the nozzle box was modified to conform to the NASA cascade design and eliminate the cause of the November 2004 failure. This aircraft was renamed the DP-1C.

Testing of the DP-1C started on February 8, 2006. A nozzle box delamination failure released the cascade actuator on April 25, 2006. Rather than repair the nozzle box, the floors and tops were salvaged and incorporated into the new coreless configuration. In this nozzle box, the cascade actuator support is secured by a one inch diameter steel bolt precluding the previous failures.

Tests resumed on June 9, 2006. The airplane trim tests were completed and the first tethered hover attempt was on July 19th. 49 flights were completed by October 5th, and by Navy direction operations were terminated on October 6th.

A greatly scaled down level of activity was resumed on December 13, 2006, again per Navy direction. Some testing in ground effect was accomplished in March of 2007. The test results indicated vortices shed by the nose wheel cause engine stall before the engines reach full thrust. Either engine could be run up to full thrust, but not both simultaneously. NASA laser sheet instrumentation was used during these tests, and the results indicate vortex ingestion as opposed to hot gas ingestion. NASA is supplying fast response pressure instrumentation to further investigate this phenomenon.

Extensive analysis was conducted to validate the analytical model of the aircraft and the control system. The aircraft was trimmed and ready for renewed hover attempts on June 1, 2007 and is waiting for permission from the program manager to do hover tests. The throttle servos have been moved down to the engines to eliminate the cable stiction, defined as static friction force to be overcome before the control moves, which is the reason the airplane could not acquire and hold altitude for extended hover during the 2006 tests.

<u>DP-2 Program Viability</u> The DP-2 addresses the need for vertical operating aircraft with more speed and range than are available from rotary wing technology. A successful direct lift aircraft, the AV-8B Harrier, is in the Marine Corp inventory, and the F-35B, a successor to the Harrier, is in development. The DP-2 applies direct lift with a different type of control system to combine vertical and short field operation with the payload range capability of conventional airliners and combat transports.

Extensive use of composite structures and smaller wings and tails can provide an empty weight fraction similar to current turbofan aircraft even with larger engines. The DP-2 is compared to two similar sized conventional aircraft in the figure below.

COMMERCIAL COMPARISON

	DP-2	Gulfstream G550	Bombardier CRJ200 LR
Length	79 ft 8 in	96 ft 5 in	87 ft 10 in
Wingspan	58 ft 1 in	93 ft 6 in	69 ft 7 in
Height	27 ft 9 in	25 ft 10 in	20 ft 5 in
Weight (Empty)	30,037 lbs	48,300 lbs	30,900 lbs
Weight (Max Takeoff Gross)	53,000 lbs	91,000 lbs	53,000 lbs
Powerplant	2 x IAE V2500 Turbofans	2 x Rolls-Royce Tay BR710 Turbofans	2 x GE CF34-3B1 Turbofans
Thrust per Engine	33,000 lbs	15,385 lbs	8,729 lbs
Max Speed	.95 Mach	.89 Mach	.81 Mach
Best Fuel Economy Speed	.88 Mach		.74 Mach
Max Range with Full Payload	2,500 nm		1,700 nm
Max Range as Executive Jet	4,000 nm	6,750 nm	
Service Ceiling	45,000 ft	51,000 ft	41,000 ft
Field Length	3,000 ft T/O and Landing 500 ft VTOL	T/O 5,910 ft Landing 2,770 ft	T/O 6,290 ft Landing 4,850 ft
Crew	3	4	3
Commercial Passengers/Cargo	50 Pax or 10,500 lbs		50 Pax or 13,100 lbs
Executive Jet Passengers	12 Pax	14-18 Pax	
Sales Price	$25M	$46M	$35M

One of these aircraft is a top of the line business aircraft and the other a widely used 50 seat airliner. Because its block speed is higher and its hourly cost is similar, the DP-2 offers 20% or more reduction in direct operating cost. Block speed advantage is not only cruising speed, Mach 0.88 versus 0.74, but also reduced time to climb and less time on the ground due to being able to use shorter runaways. Use of engines in widespread airline service provides similar hourly costs to the smaller engines installed in other aircraft, in spite of the larger engine size.

The military has two notional transportation requirements illustrated below. One is Ship To Objective Maneuver, STOM, which is to supply a beachhead 140 n. mi. inland from a ship 100 n. mi. offshore. How the acquisition cost of DP-2s to accomplish this mission compares to existing alternative aircraft is shown in the first figure.

SHIP TO OBJECTIVE MANUEVER (STOM)

Aircraft Type	CH47E	CH-53	V-22	DP-2	DP-3
Cruise Speed	143k	150k	240k	505k	505k
Time R/T 480 NM (Hours)	4.09	3.86	2.67	1.62	1.62
Payload (Tons)	4	5	2	9	36
R/T Per Day Capable	5.87	6.22	8.98	14.8	14.8
Aircraft Req. for 1,500 tons/day	64	48	84	11	3

Acquistion Cost $ 1.7B $ 1.6B $ 5.8B $ 0.44B $0.42B

The other scenario is to deliver 2,000 tons per day from 2,000 n. mi. distance. The comparison of acquisition cost is shown in the table below. In both cases a larger aircraft, the DP-3 using GE-90 engines, is slightly more economical than the DP-2.

2000 TONS per DAY DELIVERED over 2,000 nautical miles

	DP-2	C-130J	DP-3	C-17A+
Cruise Speed	505k	340k	505k	442k
Time R/T (Hours)	7.3	11.9	7.3	9.6
Payload (Tons)	5.25	7.5	20.0	65
R/T Per Day Capable	3.3	2.0	3.3	2.5
Aircraft Req. for 2,000 tons/day	116	134	31	13

Acquistion Cost $ 4.7B $ 11.4B $ 4.4B $4.9B

* C-130J payload reduced to make radius

** Current C-17A uses 3,000 ft field, C-17A+ estimated cost of $378M per plane with 2,000 ft field length, cost does not include larger GFE engines

The DP-3 is the largest airplane that can be envisioned using DP-2 technology. It is capable of carrying a Stryker vehicle. The limit is the engine thrust, and the GE-90 is currently the highest thrust engine available. Both the DP-3 and DP-2 have nearly identical performance in terms of speed and range.

Runway independence is the critical need for future transport aircraft. A 3,000 foot takeoff and landing distance effectively gives runway independence. With 3,000 feet almost all the smaller airports are available as well as the unused portions of the inactive runways at the major airports. The DP-2 helps relieve airport congestion both by handling traffic from smaller airports that will no longer need to use the nearest major airport and by using the unused portions of runways at the major airports.

A 3,000 feet field length can be achieved by vectored thrust in a conventional take off and landing mode. Enough thrust is available to achieve a 3,000 feet FAA take off distance without vectoring the thrust. If the landing approach is made with vectored thrust and 50% maximum thrust setting, the Federal Aviation Administration (FAA) landing distance is less than 3,000 feet. In the event of an engine failure on landing approach the good engine can be run up to 100% and the landing completed in the same distance as with both engines operating. This method of operation does not require the same precision control system needed for hover.

Critical Technical Reviews. At least four critical technical reviews have been conducted during the life of the DP-2 program. The first one was a Navy review funded by the Special Operations Forces in 1986. The basic numbers on aerodynamics and weights were in reasonable agreement with duPont's estimates, but a 25% thrust loss was estimated for the thrust vectoring system which affected the aircraft performance accordingly. This estimate was used in spite of data from NASA Ames testing showing a 4% loss. The full scale thrust vectoring test in 1996, funded by DARPA, at Pratt and Whitney's Florida facility showed 5% loss. As a result of this test DARPA released the balance of funds appropriated in 1991 and re-appropriated in 1993 to ONR to test an airplane using this thrust vectoring approach. Other concerns expressed about the thrust vectoring system have been resolved by the contracted DP-1 development work.

The second critical review was conducted by a blue ribbon panel of experts convened by DARPA in March of 1990. The information used by the reviewers was the 1986 Navy review, additional information on the review prepared by duPont subsequent to the 1986 review and submitted to the Navy and a briefing by duPont. The report included a roughly two page summary from each participant. All four of the findings were negative, supporting DARPA's decision not to spend the original $3 million DP-2 appropriation. The first was concern about exhaust erosion of unprepared surfaces. The second was control problems following an engine failure during vertical take off or landing. The third was critical of shutting down one engine to increase the range, and the fourth cited the difficulty of re-doing the aircraft to make it into a low radar cross section configuration. Most of the experts cited the difficulties to be overcome in a potential DOD development program. Almost all of these concerns have been overtaken by events as the full scale thrust vectoring test and the DP-1 testing has moved forward. Scott Crossfield, then on the Science Committee staff, was one of the reviewers and was very supportive of moving ahead. Three Special Forces officers in attendance, who were strongly supportive of the DP-2 and the need for it, were ignored both at the meeting and in the written summaries.

The third critical review was a systems study by Dr. Mark Moore from NASA Langley in 2002 when NASA started funding the DP-2. His work, although generally sound, contained two errors which made the DP-2 have an excessive gross weight. The first was a very high fuel fraction for a 2,500 nautical mile stage length. He may have inadvertently used the fraction for 5,000 nautical miles. With the correct fuel fraction the DP-2 looks O.K. The second error was using vertical take off for a 5,000 nautical mile stage length. For 5,000 nautical miles the DP-2 uses a short conventional take off.

The fourth critical review was by the Naval Air Systems Command (NAVAIR) funded by John Kinzer, the ONR program manager for the DP-2. This report together with areas where duPont differs from NAVAIR's numbers is included in the final contract report for the contract terminated in 2006. Two copies of this report have been provided to the committee staff. To summarize the major points of contention: NAVAIR assessed a 4% bleed penalty at takeoff even though the airplane has no systems that use bleed air at takeoff, and some of NAVAIR's subsystem weights were very high compared to actual aircraft or weight trends. NAVAIR will not accept honeycomb core structure, but duPont has developed structure that does the same job without honeycomb. An example is the coreless nozzle box panels currently installed in the DP-1C airplane.

<u>Testing Mishaps.</u> Mishap is a word that implies something far more serious than the incidents that have occurred during DP-1 testing. In government terminology these are characterized as equipment failures.

The first incident occurred on November 2, 2003. The autopilot commanded full thrust and the aircraft hit the tethers at a high upward velocity. The right wing tether came taut before the left causing a high rolling velocity, over 100 degrees per second. The right gear hit the deck first and then the left at a high velocity breaking the main gears out of the wing. The airplane came to rest on its belly damaging the nozzle box and thrust vectoring system. The airplane was repaired and was ready for test on April 14, 2004. A double failure in the autopilot system caused the maximum thrust command. The Differential Global Positioning System (DGPS) went into a less accurate measurement mode and said the aircraft was a foot below the starting position throughout the flight, and the rate feedback which would have caused a pull back in response to the high velocity was not working due to a hardware failure. Automatic shut downs were incorporated to prevent these and other failures from damaging the airplane in subsequent tests. When the gears were reinstalled they were strengthened as much as possible and the carbon composite blocks that support the gear trunnion bearings were redesigned to be more than twice as strong.

The second incident occurred on November 16, 2004. In this case the lower door was jammed against the nozzle box bottom breaking the upper tension link mounts, which in turn broke the keel allowing the titanium part which supports the cascade actuator and its carbon composite supports to rotate up into the floor and allow the cascades to move aft. The nozzle box was damaged beyond repair, and a second nozzle box was modified for future testing. The major modification was installation of new contoured nozzle box bottoms which allow the NASA designed cascade to move freely. The incident investigation was very prolonged and involved the same people who were designing a new coreless nozzle box that inherently precludes this type of failure. The new nozzle box design work had to be put off until the investigation was complete. This was the reason for re-working the second nozzle box instead of using the new design.

The third incident on April 25, 2006 involved a delamination of the solid carbon block that retained the titanium actuator support allowing the support to rotate upward and the cascade to move aft. The failure was a straightforward delamination that may have been caused by the jackhammer effect of rapid sinusoidal lateral control inputs used for control characterization testing, but the cause is not certain. The coreless nozzle box was far enough along that coreless sides and keel were mated to tops and bottoms salvaged from the damaged nozzle box. Testing was resumed on June 9, 2006.

The fourth incident was a test on August 8, 2006 in which the test was automatically aborted for exceeding the 3 feet altitude limit with an excessive rate of climb, in excess of 2 feet per second. The aircraft hit the left front tether first causing the airplane to land left wing down with a large left wing down rolling rate and side velocity component. The left gear impact caused a crack in a portion of the lower wing skin. The wing was repaired and the aircraft was back on test on August 21, 2006. The cause of the incident was the installation of a loaner Inertial Navigation System (INS) unit that had a negative vertical velocity bias over 0.6 feet per second causing the autopilot to command more thrust than was required. To help preclude this type of failure the rate of climb limit for an automatic abort was reduced from 2 feet per second to 1 foot per second, and the INS biases were automatically measured just before lift off and the appropriate corrections inserted in the flight control computer.

<u>Funding</u> Until 1995 the DP-2 program was funded entirely by the company's earnings and about $400,000 of outside investment. Since the DP-2 development became government funded all but about $40,000 of all fees earned has been re-invested in the project. This investment totals about $5 million.

In addition to the $63.9 million appropriated for the DP-2 by the Congress, of which we received $47,991,844, NASA has awarded grants to duPont Aerospace in the amount of $7,500,000 to further support the DP-2 project. duPont has received $7,326,547 of this grant money and has applied it to the purchase of two Pratt and Whitney 535 engines, development of the NASA designed cascade vane and additional research as mutually deemed beneficial by NASA and duPont Aerospace.

Progress to date At the present time the DP-1 research and demonstration aircraft has been developed to the point where it has almost airline type reliability for hover testing. The DP-1 can be flown repeatedly every hour including being weighed and refueled between flights.

The DP-1C has a slightly lower structural weight fraction, defined as wings, fuselage, tail and landing gear divided by gross weight, than the KC-135 which has the smallest fraction of any transport aircraft, civil or military.

The surface controls that move the elevators, ailerons and rudder have not yet been installed and connected to the stick and rudder pedals. The parts have been made, and a duplicate set has been installed on the iron bird, a test framework, for check out prior to installation in the aircraft. This work is proceeding, but at a slower pace because, by Navy direction, it has a lower priority than tethered hover or in ground effect testing.

The iron bird also is used as a flight simulator, and both the DP-1 and DP-2 can be flown throughout the flight envelope. In 2006 a series of tests were flown to see if further wind tunnel testing was required for flight safety. The results showed that any stability derivative could be varied plus or minus 50%, and the aircraft could still be flown safely. The expected error in any of these derivatives is much less than 50%.

The analytical model of the aircraft, vector control system and autopilot servos has been exhaustively reviewed by the NASA Airworthiness Review Panel (ARP). The model agrees closely with the flight data obtained to date. With the recently measured reduced stiction in the throttle system this model predicts hovering flights of indefinite duration within the box defined by the tether system, six feet wide, six feet long and three feet high. With the stiction measured in 2006, the model predicts a tendency to climb out of the box as observed in all but one of the 2006 tests that got more than a few inches off the deck. To put the tethered hover task in perspective, the specification ADS-33E for the most maneuverable classes of helicopters is to hover in a six foot wide, six foot long and four foot high box for 30 seconds starting from a trimmed hover. The DP-1 has to acquire the desired altitude and trim itself with a foot less altitude to maneuver in.