V/STOL Propulsion Systems – Archived – 3/2009

Outlook

- First Pratt & Whitney F135-powered STOVL aircraft scheduled to fly in May 2008
- GE/Rolls F136 engine funding fully restored for 2008
- First complete F136 engine run scheduled for February 2008

Orientation

Description. Various programs and projects tasked with advancing the state of vertical/short takeoff and landing (V/STOL) and short takeoff and vertical landing (STOVL) aircraft engine technology.

Sponsor

United States. The U.S. government, through the National Aeronautics and Space Administration (NASA) – specifically, the NASA Ames and NASA Lewis Research Centers, Moffett Field, California, and Cleveland, Ohio, USA, respectively. Additional work is sponsored and funded by the Defense Advanced Research Projects Agency (DARPA) and the U.S. Department of Defense through the military services, primarily the Air Force and Navy.

United Kingdom. The U.K. government, through the Ministry of Defence, Air Staff and Navy Department. Other work done through the Royal Aircraft Establishment.

Power Class. Power output depends on the particular engine/propulsion system.

Status. The effort involves ongoing preliminary design, development, test, and evaluation of concepts as well as hardware.

Total Produced. Numerous V/STOL and STOVL propulsion systems have been built worldwide; the exact number is unknown.

Application. Military V/STOL aircraft.

Price Range. Owing to the diversity of propulsion systems and their levels of R&D, a price range cannot be assigned with any degree of reliability.

Competition. Major competitors among V/STOVL engine designers are Pratt & Whitney (USA), Rolls-Royce (including its Rolls-Royce North American Technologies for U.S. programs), and General Electric. Much work has also been done in the Russian Federation.

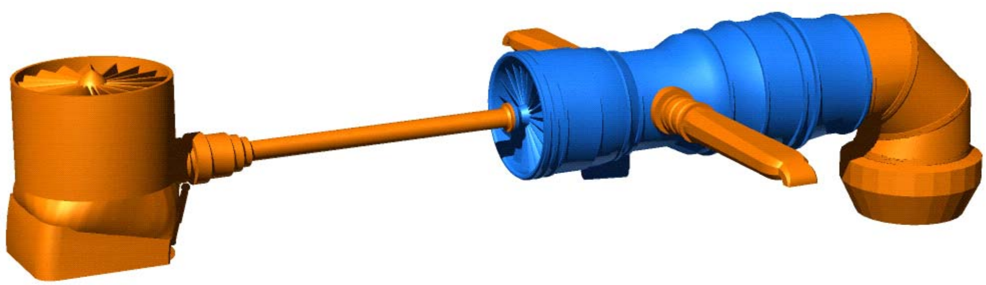
Contractors

Prime

Moscow Machine Building Enterprise, Federal Research & Production Center MMPP Salyut	http://www.salut.ru, 16 Budionny Ave, Moscow, 105118 Russian Federation, Tel: + 7 095 369 5555, Fax: + 7 095 365 4006, Prime (RDT&E)
Pratt & Whitney, Military Engines	http://www.pratt-whitney.com, PO Box 109600, West Palm Beach, FL 33410-9600 United States, Tel: + 1 (561) 796-2000, Fax: + 1 (561) 796-7258, Prime (RDT&E)
Rolls-Royce International Ltd	http://www.rolls-royce.com, 65 Buckingham Gate, London, SW1E 6AT United Kingdom, Tel: + 44 20 7222 9020, Fax: + 44 20 7227 9178, (RDT&E)

Technical Data

Many different V/STOL propulsion systems and technology concepts have emerged worldwide; see the **Program Review** section, below, for more information.



F135 STOVL Configuration, with Shaft-Coupled Rolls-Royce Lift Fan

Source: Pratt & Whitney

Variants/Upgrades

V/STOL propulsion systems have taken various forms, with varying degrees of complexity. See **Program Review** section below for a brief discussion of some of the major systems.

Program Review

Background. Outside the more conventional vertical air-lift technology of turboshaft engines for helicopters, there are many interesting and unique, and sometimes related, V/STOL propulsion concepts.

V/STOL Concepts

Tilt-Wing. In this configuration, the engines and wing translate from vertical to horizontal for both vertical and conventional flight modes. Technology in this area dates back to 1963, with the Vought XC-142.

Tiltrotor. The tiltrotor has undergone flight tests for many years in the form of the Bell XV-15. Bell and Boeing Helicopter have cooperated on the design and development of the V-22 Osprey, a tiltrotor design powered by twin Rolls-Royce T406-AD-400 turboshaft engines. Production of the V-22 for U.S. and international military services is now a virtual certainty.

In 1991, Sikorsky announced plans to conduct wind tunnel tests of a one-sixth-scale model of a 30-passenger tiltrotor design fitted with telescoping rotor blades. The semi-span model was equipped with a rotor that was 8.2 feet in diameter when fully extended, and approximately 5.5 feet in diameter when retracted. According to Sikorsky design engineers, a telescoping rotor would permit a tiltrotor to use larger blades in the helicopter hover mode to provide greater lift, and shortened blades for greater efficiency when in the aircraft cruising mode.

Vectored Thrust. The vectored-thrust system was pioneered by Bristol Engines, now a part of Rolls-Royce. The vectored-thrust Rolls-Royce/Bristol Pegasus (F402) powered Harrier, Sea Harrier, and Harrier II/ AV-8Bs are in service in the U.K., the U.S., Spain, Italy, and India.

Russia's Yakovlev OKB has evolved a follow-on to its Yak-36MP/Yak-38, designated the Yak-141. This twin-engine aircraft uses as the primary powerplant two Moscow Scientific Production Corp "Soyuz" Kobchyenko R-79 turbofans, each rated at 24,200 lbst (107.6 kN) dry, or 34,170 lbst (152.0 kN) with afterburning. The aircraft power is supplemented by two forward-located, vertically mounted RD-41 liftjets, each rated at approximately 9,040 lbst (40.2 kN). Each RD-41 weighs approximately 639 pounds (290 kg). The RD-41 is a product of the Rybinsk Engine-Building Design Office. The Yak-141 features a vectoring tailpipe and nozzle in which two tapering-wedge pipe sections rotate in opposite directions to vector from 0 degrees (forward flight) to 63 degrees (STO) and to 95 degrees (hovering and vertical landing).

Despite the apparent military effectiveness of the aircraft, the program was abruptly halted in 1994, due in large part to the halt of production in Russia of surface vessels from which the aircraft would be launched, as well as to worsening economic conditions and the loss of one of two prototypes.

Thrust Augmentor Wing/Ejector Lift. In this propulsion layout, high-energy air from either the engine fan section or an additional compressor is used to entrain (entrap) ambient air that is drawn through and mixed in the augmentor (ejector) to produce additional lift/thrust. In conventional flight, fan or compressor air is directed aft, and ejectors close or open depending upon the flap design.

A number of designs have been evaluated and proposed with such a system, including the Rockwell XVF-12, General Dynamics/de Havilland Canada E-7, and other aircraft by such firms as Lockheed.

Lift Plus Lift/Cruise. One of the original vertical-lift concepts, this method uses one engine (or lift jet) for vertical lift and one or more engines for forward cruise thrust and for vertical-lift augmentation with divergent exhaust nozzles. This approach was adopted by Yakovlev for its Yak-38 (NATO Forger) for carrier operations that began in the 1970s. The lift plus lift/cruise arrangement was also selected by McDonnell Douglas for its Joint Attack Strike Technology (JAST) development effort.

Lift Cruise Fan. This type uses ducted fans embedded in the wings and fuselage to provide vertical capability, and conventional turbojets for horizontal flight modes.

Tandem Fan. Rolls-Royce claims this design as its own, and it has been proposed for a number of U.S. aircraft, including the LTV/Vought Model TF-120 and Model 530 naval aircraft. The tandem fan is essentially a conventional turbofan engine with an additional fan section forward of the main gas turbine, connected by a common shaft from the power turbine. Separate inlets feed the two fans, and the forward one in the tandem arrangement provides air to be deflected downward for vertical flight, and aft for conventional flight. Another version, called "hybrid fan vectored thrust," combines the best of tandem fan and vectored thrust. In this mode, the forward fan feeds Pegasus-type translating nozzles, while the main gas turbine uses similar Pegasus nozzles for hot jet nozzle thrust.

X-Wing/RSRA. The NASA/ARPA (ARPA was then DARPA) project combined conventional helicopter rotor operation with high-speed fixed-wing designs. Sikorsky was the main contractor. The prototype X-Wing/RSRA used GE T58 turboshaft engines to drive the main rotor and provide blowing air for the leading and trailing edge slots of the rotor blades, for laminar flow control. The aircraft also used GE TF34s for forward propulsion. An ideal X-Wing would use a convertible fan/shaft engine that would eliminate one set of engines. NASA Lewis funded the development of a GE TF34 convertible fan/shaft engine.

In rotor-borne flight, the GE TF34 engines drive the rotors through a clutch/gearbox. During transition to forward flight, the clutch gradually disengages and the rotor locks, acting as the main wing, at which point the engines then provide all forward thrust.

Externally Blown Flaps. This type of powered lift system is more STOL than V/STOL. Aircraft having this design include the McDonnell Douglas YC-15 and Boeing C-17A. Engine exhaust is directed to slotted titanium flaps, enhancing lift while decreasing landing speed, landing distance, and takeoff distance.

STOL/Maneuver Technology Demonstrator. A McDonnell Douglas F-15 STOL/Maneuver Technology Demonstrator (SMTD) with definitive two-dimensional engine nozzles made its initial flight on May 10, 1989. The SMTD F-15 was extensively modified with 2-D nozzles for thrust vectoring and reversing (both in flight and on the ground), and with active foreplanes. The aircraft used a GE digital fly-by-wire system integrating

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flight, engine and nozzle control, plus steering and braking on the ground.

Upper Surface Blowing. Upper surface blowing (USB) is a prominent STOL concept that has been demonstrated and proven aboard the Boeing YC-14 AMST, the Antonov An-72/An-74, the Japanese Asuka aircraft, and the NASA Quiet Short-Haul Research Aircraft (QSRA) test aircraft. USB involves the use of engines mounted very high above the wing and exhausting over large aft flaps, exploiting the Coanda Effect and generating lift.

Shaft-Coupled Lift Fan. The shaft-coupled lift fan uses an augmented turbofan linked by a transmission shaft and clutch to one or two vertical lift fans. The transition from lift to cruise mode is automated, rather than manual as on the Harrier. While in the cruise mode, the vertical lift fan is decoupled. This approach was embraced by Lockheed Martin for its JAST demonstrator.

Lockheed Martin selected the shaft-coupled lift-fan (SCLF) propulsion system for three primary reasons: the STOVL lift-fan thrust can be decoupled from the cruise engine, thereby enabling the cruise engine to be appropriately sized for conventional flight; the significant amount of thrust augmentation obtained from the lift fan greatly exceeds the additional weight in-curred; and the lower exhaust jet temperature and pressures result in a more benign ground environment during hover than that produced by direct lift.

In the SCLF system, the fan (or fans) is a relatively simple design. It is lighter and more reliable than a lift jet and has a cooler exhaust – and energy can more efficiently be moved around the aircraft using a shaft than using ducted hot gas/air.

Lockheed Advanced Development Company (LADC), General Dynamics, GE, and the former McDonnell Douglas all actively explored SCLF technology. In March 1993, the Advanced Research Projects Agency (ARPA) funded the development and validation of lift-fan technologies by McDonnell Douglas and Lockheed under the Supersonic STOVL Strike Fighter program. Lockheed was selected to explore SCLF technologies under a $32 million ARPA contract. The company constructed a near full-scale aircraft model and wind tunnel test at its NASA Ames Research Center. This model was used in support of Joint Strike Fighter development (see Pratt & Whitney F135, below).

Gas-Coupled Fan Concept. This design is a modification of the lift-fan system. It was developed by GE in the early 1960s and tested in a Ryan XV-5A. The fans would be mounted in the wings and driven by tip-mounted turbine blades fed with hot air from the engine. GE studies indicate that a tip-driven fan with an inlet diameter of 47.24 inches (120 cm), approximately 11.81 inches (30 cm) deep, can provide approximately 10,117 lbst (45 kN) vertical thrust. Because of the thrust augmentation provided by its low jet velocity, however, it would “draw” only one-half the power from the engine.

In March 1993, ARPA provided funding to McDonnell Douglas and Lockheed for the development and validation of lift-fan technologies under the Supersonic STOVL Strike Fighter program. McDonnell Douglas was selected to explore gas-coupled lift-fan concepts under a $27 million ARPA contract. McDonnell Douglas was constructing and planning to test a nearly full-scale aircraft model equipped with a gas-driven fan and engine system. This approach was abandoned by McDonnell Douglas in June 1995 in favor of a lift plus lift/cruise configuration for its JAST development effort.

Vectored-Thrust PCB. The former McDonnell Douglas, in conjunction with British Aerospace, Rolls-Royce and P&W, was very active in the design and testing of scale models of two vectored-thrust plenum chamber burning (PCB) aircraft, the single-engine Model 279-3 and the twin-engine Model 279-4. Rolls-Royce has proposed versions of the Pegasus of up to 37,000 lbst (164.5 kN), while P&W is believed to have several advanced projects in the 35,000-lbst-range (155.6-kN) class, proposed for use in the Model 279-3.

As with the current Harrier I and II models, the aircraft would be powered by a single engine, located near the aircraft’s center of gravity.

Ejector Lift. The former General Dynamics, in joint development with de Havilland of Canada, explored a supersonic derivative of the F-16, designated E-7A. GD took the concept developed by de Havilland Aircraft (called ejector or augmentor jet lift) and applied it to the Fighting Falcon. Longitudinal ducts at the wing/ fuselage junction open and close, depending on flight mode. For takeoff and landing, the ducts are opened.

The E-7 was initially tested with a Rolls-Royce Spey powerplant, a subsonic inlet, and interchangeable, fixed central-core nozzles to simulate different vector angles.

Tandem Fan. The former Vought TF-120 and V-530 used this Rolls-Royce-patented concept, which employs twin tandem-mounted fans driven by turbines. Low-pressure compressor fan air can be deflected downward through vectoring nozzles, as in the Pegasus, or through doors. High-temperature exhaust effluent, meanwhile, is deflected downward for vertical operations. The doors or vectoring nozzles are closed and the exhaust nozzles are translated to the full aft position for horizontal flight. Augmentation can be used and is incorporated into the Rolls-Royce Hybrid Fan.

Remote Augmented Lift System (RALS). The RALS design is similar to that of the Hybrid Fan. In this system, IP compressor air is ducted rearward to mix with the hot exhaust gases for full forward flight. For vertical operations, low-pressure air is ducted forward to full-burning augmentor nozzles, as in the PCB Pegasus. Exhaust nozzles are deflected downward for vertical lift.

As with the Russian Yak-141 aircraft, aircraft effectiveness is penalized by the weight of the forward lift-generating engines.

Remote Unaugmented Lift System (RULS). The RULS is a version of the RALS without the remote burner for thrust augmentation – the aircraft thrust requirements are such that there is sufficient dry thrust available for powered lift operations. A logical arrangement for this concept is to duct the entire engine exhaust flow forward to one of two lift nozzles.

Reverse-Installation Vectored Engine Thrust (RIVET). RIVET offers mechanical simplicity, excellent transition, and good weapons integration. In the RIVET system, the reverse-facing engine is located at the rear of the aircraft, but the nozzles are located at the aircraft's center of gravity.

Rolls-Royce shifted its efforts from the PCB and tandem-fan solutions to the mixed-flow vectored thrust (MFVT) concept. The MFVT engine is a conventional augmented turbofan during cruise. During takeoff and landing, the fan stream is ducted forward to retractable vectoring exhaust nozzles, while the core flow exhausts through a rear vectoring nozzle. Rolls-Royce has begun studies of an RB571 MFVT engine incorporating a variable-flow fan that augments power during the powered-lift mode, and has proposed an RB578 demonstrator engine based on the Pegasus 11-61.

Pratt & Whitney F135. A derivative of P&W's F119 turbofan that powers the Lockheed Martin/Boeing F-22, the F135 will serve the U.S. Air Force, Navy, and Marines and the U.K. Royal Navy and Air Force on their fleets of F-35 Joint Strike Fighter (JSF) aircraft.

The F135 is, in its most interesting form for the F-35B STOVL fighter variant, a shaft-coupled lift-fan-configured turbofan engine (SCLF). The F135 SCLF propulsion system's main shaft is coupled to a Rolls-Royce counter-rotating lift fan that produces cool-air lifting force during STOVL operations. The front-mounted fan works in concert with a thrust-vectoring rear engine nozzle and under-wing lateral-control nozzles to generate nearly 40,000 pounds of lifting power. The lift fan alone produces about 18,000 pounds of thrust. Flight transition from lift to cruise mode is automated, rather than manual as on the Harrier. While in the cruise mode, the vertical lift fan is decoupled.

Rolls-Royce provides the unique shaft-driven lift fan, and the three-bearing swivel duct and roll control system that enables the F-35B to take off and land in locations with minimal or no runway space.

Lockheed Martin's F-35 SCLF design was chosen by the U.S. military in part because the lift fan provides enough thrust (close to 18,000 lb) to bring an aircraft back should the exhaust nozzle of the main engine be severely damaged.

The Lockheed Martin F-35B V/STOVL Joint Strike Fighter will be used by both the U.S. Marine Corps and the U.K. to replace their Harrier fighters. The U.S. Navy may also adopt the F-35B.

In September 2002, the British Ministry of Defence announced its selection of the version of the F-35 that will fill its Future Joint Combat Aircraft (FJCA) requirement. The FJCA will replace British Royal Navy Sea Harriers and British Royal Air Force Harrier GR7/9s. The MoD chose the F-35B STOVL version over the F-35C CV variant. Up to 150 F-35Bs will be acquired. Service entry is planned for 2014.

Also in 2002, the U.S. Navy proposed a reduction in the combined U.S. Navy/Marine Corps planned F-35B and F-35C buy from the current 1,089 aircraft to 680. The proposed reduction, however, awaits final approval by the Office of the Secretary of Defense. Deliveries of production aircraft should begin in 2008 or 2009.

In June 2004, P&W was awarded a $5.4 million cost-plus-fixed-fee task order against a previously issued Basic Ordering Agreement (N00019-02-G-3053) to perform F135 STOVL thrust optimization trade studies. Work under that contract will be done in East Hartford, Connecticut (76 percent); Indianapolis, Indiana (15 percent); and the U.K. (9 percent). We assume that the work done in the U.K. will be performed by Rolls-Royce.

Senate Demands STOVL Lift-Fan Study

The following was included in an item that appeared in the July 1, 2004 issue of *Defense Daily:*

> As concerns grow about the weight of the F-35 Joint Strike Fighter (JSF), the Senate is directing the Pentagon to look at options for increasing the thrust capabilities for the lift fan on the short takeoff vertical landing (STOVL) version of the aircraft.

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In the report accompanying the FY '05 defense spending bill, the Senate directed the Pentagon to use $15 million to fund a STOVL lift-fan study looking at ways to increase thrust capabilities. At issue is how best to get the STOVL aircraft – which the Marine Corps and Air Force both expect to buy – to meet its key performance parameters.

JSF prime contractor Lockheed Martin [LMT] is also working on a conventional takeoff and landing aircraft as well as a carrier variant, but the STOVL design is considered the biggest engineering challenge for the program.

Acting Pentagon acquisition chief Michael Wynne last week approved a much awaited "replan" of the multibillion JSF program, which includes delays to first flight and initial fielding. The new schedule was designed to allow additional time to trim the weight of STOVL aircraft.

That version is about 2,400 pounds overweight and, at current estimates, is in danger of not meeting several of its key requirements, including range.

Pentagon officials, however, have expressed optimism that the STOVL's weight can be reduced and the aircraft will be able to meet those requirements without adding additional engine capabilities.

"The engine companies have consistently shown an ability to increase power, and in some cases, have modest impacts on fuel consumption," John Young, the Navy's acquisition chief, told reporters following a hearing on Capitol Hill in June 2004.

But the goal right now is to maximize the thrust that is already installed; for example, by maximizing inlet flows, he said. "We would like to hold in reserve for future growth of this airplane – just as we've done with F-15, F-16, and F-18 – the potential to turn up engine performance."

Increasing engine performance to counteract the weight growth "is not the first solution we want," he said.

Funding

V/STOL funding is tightly integrated with several programs such as VAATE and cannot be singled out.

Contracts/Orders & Options

Contractor	Award ($ in billions)	Date/Description
GE/Rolls-Royce	2.46	Aug 2005 – Contract for work under the JSF F136 System Development and Demonstration (SDD) program.
P&W	5.5	Jun 2004 – Contract for conduct of STOVL thrust optimization trade studies.
P&W	1.0 (approximate)	Dec 2001 – Pratt & Whitney signed a 10-year contract with Rolls-Royce for development of the STOVL system for the F135 propulsion system. The contract covers the SDD phase of the program. The contract covers design and development work on the lift fan, the roll posts, and the three-bearing swivel duct and nozzle system that together provide the STOVL capability for the JSF. P&W is responsible for the development of the propulsion and lift system for the JSF under the terms of a $4.8 billion contract awarded by the U.S. Department of Defense. The total program will cover the design and manufacture of ground test engines, as well as subsequent production and support of flight test engines. The two companies also signed a teaming agreement for the F135 propulsion system, formalizing their relationship.

Timetable

V/STOL propulsion technology development began in the late 1950s, with early attention focused on tilt-wing designs.

Worldwide Distribution/Inventories

Numerous V/STOL and STOVL propulsion-type engines and systems have been fabricated worldwide, most notably in the **U.K.**, **Russia**, the **U.S.**, and **Ukraine** (when it was part of the USSR).

Forecast Rationale

The F-35B's development program continues with the recent delivery of the first complete F135 STOVL powerplant to Lockheed Martin in late November 2007. This comprises Pratt & Whitney's F135 engine and Rolls-Royce's lift fan, with first flight scheduled for May 2008. In November 2007, Pratt reported that its F135 STOVL system had accumulated over 1,700 STOVL hours and over 4,300 total running hours. SDD ground test hours had exceeded 8,500 at that time.

Earlier in the year, in June, Pratt completed the first propulsion system qualification test for the short takeoff/vertical landing (STOVL) F135 engine. This is the first time the full-scale STOVL F135 engine airflow was tested with the F-35 lift fan hardware in place.

GE/Rolls F136 Program Still Alive

The GE/Rolls F136 has survived another attempt by the Pentagon to cancel the program by eliminating its funding from the military budget. Congress has approved $480 million for continuing development, and the first full engine is scheduled to run in February 2007 at GE's facility in Ohio.

Ten-Year Outlook

No production forecast is included due to individual engines being covered in their own reports.

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