

Hybrid Helicopters: Compounding the Quest for Speed



By Raymond L. Robb

Less than two dozen years after the Wright Brothers attained powered, heavier-than-air, fixed-wing flight in the United States, Germany astounded the world in 1936 with demonstrations of the vertical flight capabilities of the side-by-side rotor Focke Fw 61, which eclipsed all previous attempts at controlled vertical flight. However, even its overall performance was modest, particularly with regards to forward speed. Even after Igor Sikorsky perfected the now-classic configuration of a large single main rotor and a smaller anti-torque tail rotor a few years later, speed was still limited in comparison to that of the helicopter's fixed-wing brethren. Although Sikorsky's basic design withstood the test of time and became the dominant helicopter configuration worldwide (approximately 95% today), all helicopters currently in service suffer from one primary limitation: the inability to achieve forward speeds much greater than 200 kt (230 mph). Despite the tremendous impact of the helicopter, Sikorsky realized the inherent speed limitations even at the outset, and predicted that the speed of the helicopter would never match that of the airplane. For the most part, he was

absolutely right in terms of a so-called "pure" helicopter. However, the quest for speed in rotary-wing flight drove designers to consider another option: the compound helicopter.

The definition of a "compound helicopter" is open to debate (see sidebar). Although many contend that augmented forward propulsion is all that is necessary to place a helicopter in the "compound" category, others insist that it need only possess some form of augmented lift, or that it must have both. Focusing on what could be called "propulsive compounds," the following pages provide a broad overview of the different helicopters that have been flown over the years with some sort of auxiliary propulsion unit: one or more propellers or jet engines. This survey also gives a brief look at the ways in which different manufacturers have chosen to approach the problem of increased forward speed while retaining the helicopter's unparalleled advantages in vertical flight.

While the last 70 years has seen more than two dozen different combinations of rotors with propellers or jets, the compound is by no means ancient history. Today

we see numerous new concepts for compound helicopters, capable of both hover and high-speed forward flight. Within the next few years, we should see the propeller-augmented Sikorsky X2, the ducted propeller Piasecki X-49A, and the jet-powered Groen Brothers/Adam Aircraft Heliplane all begin flight tests. In addition, Bell completed successful ground tests of its Propulsive Anti-Torque System (PATS), planned for the now-cancelled Unmanned Combat Armed Rotorcraft (UCAR), and is considering it for other applications. Additionally, compounds continually emerge from high-speed rotorcraft studies, whether sponsored by the Army, NASA or internally funded. Naturally, there are weight, drag and fuel consumption penalties from adding wings, propellers or jets, so designers must carefully consider the mission requirements to determine the optimal solution for a design. While no compound helicopter has ever reached production, the future has never looked brighter.

The Hybrids Emerge

Man's quest to fly has resulted in a multitude of aircraft configurations over the years, each of which has had its own advantages and disadvantages when compared with other designs in the methods by which it defeats the pull of gravity and overcomes the forces of aerodynamics. This menagerie of aircraft sometimes makes it difficult to place them in a specific category. A good example of this is the tiltrotor, which has obvious features of both a conventional fixed-wing airplane and a helicopter. The inability to easily categorize aircraft as either an "airplane" or a "helicopter" will likely become increasingly prominent as new technologies emerge and aircraft continue to evolve. As indicated in the sidebar, a compound helicopter may or may not include some form of augmented lift, such as a fixed wing, depending on what the designer hopes to achieve. When fitted, a wing is designed to offload much, if not all, of the rotor's lifting duties at high speed. Likewise, forms of augmented propulsion serve to relieve the main rotor of the majority, if not all, of its duties in propelling the aircraft forward. Whether or not it includes a wing, the compound helicopter is designed for one primary purpose: to permit forward speeds higher than those that are possible with conventional rotorcraft.

In a pure helicopter, two specific factors limit forward speed. One is retreating blade stall and the other is advancing blade compressibility. A compound helicopter is able to reduce or delay the onset of the negative factors associated with both of these problems by limiting or even reducing the speed of rotation in the main rotor as the aircraft gains forward speed by way of its auxiliary propulsion. This is achieved by reducing the power supplied to the main rotor, the degree to which is determined by the amount of forward thrust produced by the auxiliary propulsion. At the same time,

What is a Compound?

Mike Hirschberg, Managing Editor

Prof. Barnes McCormick tells the story that when he first published his *Aerodynamics of V/STOL Aircraft* (Academic Press, 1967), he printed an artist's concept of a tandem rotor aircraft with stub wings on both the fore and aft rotor pylons as an example of a compound. Frank Piasecki called him up and said the example given was *not* a compound because it didn't have any auxiliary propulsion. He sent McCormick a photo of the Piasecki Pathfinder, which is what is found in the later editions.

This vignette highlights a lack of agreement within the rotorcraft community that continues to this day on exactly what defines a compound helicopter. Does a rotorcraft need wings, an auxiliary propeller or jet, or both to be classified as a compound? Two excerpts from rotorcraft design books show the nuances in attempts to develop a cohesive definition:

- *The Art of the Helicopter* by John Watkinson (Elsevier Butterworth-Heinemann, 2004) offers: "The compound helicopter...is one in which the rotor does not produce any forward thrust in cruise. Instead the thrust is provided by other means."
- Ray Prouty, in *Military Helicopter Design Technology* (Krieger, 1989) states: "These aircraft may be considered to be aeroplanes which have an effective low-speed lifting device. They use a wing and some form of auxiliary propulsion such as propellers, ducted fans, or jet engines to relieve the rotor of all, or nearly all, or its lifting and propulsive duties at high speeds."

Other references are more generic in stating that a compound is a helicopter that has a wing or an auxiliary propulsor or both. Perhaps the best way to understand what people mean when they say "compound" would be to differentiate between the two types. According to *Principles of Helicopter Aerodynamics* by Prof. J. Gordon Leishman (Cambridge University Press, 2003):

A compound helicopter involves a lifting wing in addition to the main rotor (lift compounding) or the addition of a separate source of thrust for propulsion (thrust compounding)... The idea is to enhance the basic performance metrics of the helicopter, such as lift-to-drag ratio, propulsive efficiency, and maneuverability. The general benefit can be an expansion of the flight envelope compared to a conventional helicopter.

In other words, a "compound" may involve both lifting and/or propulsive compounding. The goal is to "off-load" the rotor from its normal lifting and propulsive duties. This can be done by using a wing and/or auxiliary propulsion.

Thus, the compounds described in this article would best be described as "thrust compounding" rotorcraft. Although adding a wing may allow higher speeds, the real "quest for speed" has required an auxiliary propulsion device to accelerate the rotorcraft beyond conventional helicopter capabilities. As can be seen in the article, unloading the rotor to the maximum amount possible, such that the rotor autorotates, allows an autogyro-like maximum speed while still preserving a hover and vertical flight capability. In fact, one could argue that there are only shades of gray – or maybe only semantics – between a "compound helicopter" and an autogyro that is powered for hover, take-off and landing. Vehicles like the XV-1 and Rotodyne spent (figuratively) 95% of their mission flying as an autogyro and only 5% as a helicopter. All other concepts discussed in this article approached this extreme in varying degrees by unloading the rotor in flight.

vertical flight capabilities are retained by diverting power back to the main rotor as the aircraft slows down or enters a hover. While allowing increased forward speeds, inherent design features generally make a winged compound helicopter less efficient in both flight regimes when compared to its respective fixed-wing and rotary-wing counterparts.

Despite the penalties inherent in the compound helicopter, such as increased weight and complexity, designers have returned to this hybrid configuration numerous times in attempts to meet the demanding requirements for speed. While some instances were for the sake of general experimentation, most of these efforts were in direct response to a military requirement. Others were directed toward creating an efficient means of high-speed intercity transport.

The majority of compound helicopters that have flown originated in the United States, but others have also been tested in France, Germany, Russia, and the United Kingdom. The first compound was built in Austria (then part of Germany). Immediately following World War II, German aeronautical engineers and scientists were eager to share their knowledge, expertise, and experience with others around the world. As a result, immediately following the War, compound helicopter efforts were taken up in each of the three leading Allied countries. Although many designs were conceived on paper, only a comparatively small number ever made it from the drawing board to the flightline. We will briefly discuss each of them here, arranged by their country of origin.

GERMANY

Flettner

In the late 1930s, the world as a whole was fascinated with aviation and many countries were involved in efforts to devise new and innovative aircraft. Germany was no exception. One designer in particular, Anton Flettner, had turned his efforts from ship-building to aviation with an emphasis on rotary-wing flight. Since 1927, his company, Flettner GmbH, had become involved in developing no less than four aircraft, with designs drawn up for two more. Of the different rotary-wing aircraft tested by Flettner, one of them could be considered an early ver-



The Flettner Fl 185 used two propellers mounted on outriggers. They were used for anti-torque and for forward thrust.

sion of a compound helicopter. This aircraft, known as the Fl 185, took to the air for its maiden flight in 1936. (A preceding design, the Fl 184 may also qualify as a compound, but it is unclear if it was capable of hovering or was merely a powered autogyro, as limited information on it has survived.)

Unlike contemporary autogyro designs equipped with propellers, this was a true helicopter, capable of vertical takeoff, landing, and hovering. The most unusual feature of the Fl 185 was the method by which torque from the 39.3 ft three-bladed rotor was countered. Instead of using a tail rotor, the aircraft was equipped with a lateral outrigger on each side, fitted with a variable-pitch propeller. The one on the port side faced aft and the one of the starboard side faced forward, acting in unison to counter torque and provide directional control. The propellers also provided a degree of forward propulsion in concert with the rotor during cruising flight. The fuselage resembled that of an autogyro, with a frontal cooling fan for a single 140 hp Bramo Sh-14A radial piston engine. This engine was used to power the rotor and both propellers through a series of four transmissions, clutches, and driveshafts.

The Fl 185 was supported on the ground by a set of tricycle wheeled landing gear and a tail bumper. Limited flight testing took place during which the aircraft flew very well at low speeds, but a resonance occurred when the aircraft exceeded 40 mph. In any case, the Fl 185 was reported to be very stable and easy to fly. One reason for this was due to a newly-developed yaw dampening gyro, which provided automatic adjustment of the propeller blade pitch depending on the torque of the rotor. This effectively allowed the correct amount of thrust to be applied to counter torque in all flight regimes without any input from the pilot. The exceptional in-flight stability of the Fl 185 allowed it to remain largely unaffected by wind gusts. Despite the positive attributes of the Fl 185, Flettner abandoned the

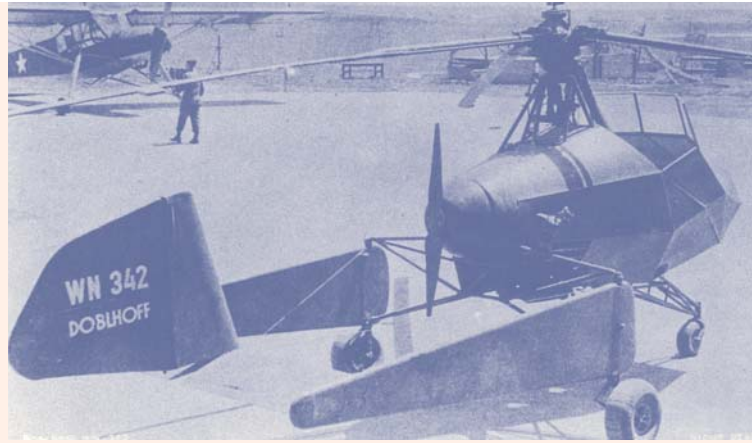
design in 1938 in favor of using twin intermeshing rotors for future aircraft development, which eliminated counter torque rotors altogether. Although the loss of some German aviation records during World War II limits the amount of data available on Flettner's designs, particularly with respect to their actual flight performance, the information we do have indicates that the Fl 185 was arguably the first compound helicopter in the world to fly.

Weiner Neustadt Flugzeugwerke (WNF)

Once World War II began, Germany used every ounce of its industrial might and engineering excellence to devise high-performance weapons, particularly aircraft, spawning some of the most innovative designs the world had ever seen. The Wiener Neustadt Flugzeugwerke (WNF) Wn 342, was designed to fulfill a requirement for an aerial observation platform capable of operating from German Navy U-Boats and surface ships. Although simple in its basic configuration, the aircraft made use of a novel rotor drive in which the three rotor blades were each equipped with small jets at their ends. These so-called "tip-jets" operated by way of an Argus As 411 centrifugal supercharger that pumped a fuel-air mixture through the hollow rotor blades, which was ignited at the tips, causing the rotor to spin as the hot air was expelled. In effect, this made the Wn 342 the first helicopter in the world to make use of jet propulsion, an achievement for which the principal designer, Friedrich von Doblhoff, is generally credited. Another unique feature was that high-pressure air from the compressor was also used to control collective blade pitch. When pressure was not applied, the rotor blades remained at autorotative angles.

Prior to construction of any prototype aircraft, a test rig was built to prove the concept. After many successful tests, four prototypes were built. The Wn 342 V1 ("V" denoted *Versuchsflugzeug* for "test aircraft") flew for the first time in Vienna during October 1942. As demonstrated by the V1 and the second prototype, V2, fuel consumption of the tip-jets was extremely high. This discovery resulted in a change such that the V3 restricted its use of the tip-jets to takeoff, hovering, and landing only. After takeoff, the Wn 342 V3 achieved forward propulsion by way of a two-bladed pusher propeller powered by a 140 hp Bramo Sh-14A radial piston engine installed behind the pilot. After the pilot diverted engine power to the propeller via a selective clutch, the fuel flow was stopped and the rotor began to autorotate. During testing, the V3 developed severe vibrations, eventually resulting in a crash. The damaged aircraft was then rebuilt as the V4 with a reconfigured tail section. The aircraft's proposed role aboard ships at sea dictated that it be simple in design and relatively lightweight, resulting in a fabric-covered tubular framework structure with twin tailbooms supported by a set of fixed tricycle landing gear. The lack of a tail rotor or a transmission helped keep the weight down. One inherent disadvantage was the noise generated by the tip-jets, a trait which may have compromised its role as an observation platform, had it entered service.

In all, the four versions of the Wn 342 completed a total of 25 flight test hours during their development. However, none of them were flown in excess of 25-30 mph in forward flight before development ceased. As World War II drew to a close, American military forces captured the Wn 342 V4 and transferred it to the United



The rotor tip-jet technology used in the WNF Wn 342 V4 was very advanced for its time. It was thoroughly tested in the US after World War II.

States, where it was extensively tested at Wright Field, Ohio. Testing revealed that the maximum endurance of the aircraft was only 15 minutes due to the high rate of fuel consumption of the tip-jets, which proved to be approximately nine times that of conventionally-powered helicopters in hover. It was at Wright Field that the last recorded flight of the aircraft took place in June 1946. It was then converted to a test stand at General Electric, after which it is believed to have been scrapped.

The three main designers of the Wiener Neustadt Flugzeugwerke WNF 342 each took up residence in other nations after the war. Von Doblhoff, the principal designer of the WNF 342, immigrated to the United States and found work with the McDonnell Aircraft Corporation. Another member of the team, August Stepan, relocated to the United Kingdom where he worked for Fairey Aviation. The third member of the team, Theodor Laufer, moved to France and found employment with Sud-Ouest. Within a few years, each of these companies was working on a more advanced version of tip-jet propulsion combined with a propeller.

Vereinigte Flugtechnische Werke (VFW)

More than two decades after the appearance of the Wn 342, Germany again experimented with compound helicopter designs, this time primarily for the civilian and commercial market. A merger of Focke-Wulf, Weser and Heinkel in 1963/64 resulted in the Vereinigte Flugtechnische Werke (VFW). The company conducted research into a variety of rotorcraft, including compound helicopters, building on work that had begun in early 1963. Their first experimental design was the VFW H2. Looking more like a typical autogyro, the H2 was actually a helicopter since it was able to takeoff and land vertically, as well as hold a hover. This single-seat aircraft was designed strictly to test the two-bladed rotor and propulsion system components. Rotor propulsion was primarily generated by way of a Borsig air compressor which routed compressed (cold) air through the



Although it resembled a typical autogyro, the VFW H2 was able to takeoff and land vertically, as well as hover.

blades and out the tips, forcing the blades to spin. However, the rotor was also equipped with combustion-type tip-jets (similar to those used on the Wn 342) that could be used for extra rotor power in hover and for a vertical takeoff. A pusher propeller fitted behind the pilot was powered by a 72 hp McCulloch four-cylinder, horizontally-opposed two-stroke engine. This engine also drove the air compressor, thereby powering the rotor.

Prior to actual flight tests of the H2, the rotor and control system was extensively evaluated on a test stand beginning in March 1964. After a mere 20 hours of testing, it was discovered that blade vibrations occurring at high rotational speeds necessitated the addition of stiffeners, along with other modifications. Testing concluded in early 1965 with 110 run hours. On April 30 that year, the H2 took to the air for the first time. The combustion tip-jets were not used for the first flight, so a takeoff roll was necessary for the H2 to become airborne, which was accomplished at a speed of 22 mph. Tests were conducted with the tip-jets ignited; however, the hot tip-jets were found to produce excessive noise, so their use was discontinued, especially since the rotor proved to be fairly loud even when only using the jets cold. After 36 flight hours, the test program was completed in September 1966.

Using the wealth of data obtained in their research with the H2, the company began development of the VFW H3 in 1966. Unlike the H2, the H3 was designed to be a production compound helicopter primarily for use as an executive transport with an enclosed cockpit. The cabin seated the single pilot and two passengers. The first flight was planned to occur in 1968, but development reached a virtual halt until that year when VFW received funding from the German Ministry of Defense for a possible successor to the Aérospatiale Alouette utility helicopter. The following year, VFW merged with the

Dutch company Fokker. Along with its role as an executive transport, the VFW-Fokker H3 was envisioned to fulfill several other roles such as that of an agricultural aircraft or as a two-seat dual-control trainer with provisions for armament. Another potential role for the H3 was as an ambulance or Search and Rescue (SAR) helicopter, being fitted with an enlarged cabin to carry a medical crew and the necessary equipment, along with a rescue winch.

As with the H2, the rotor for the VFW-Fokker H3 was powered by an air compressor which routed compressed air through the blades and out the tips, forcing the blades to spin. There were no



The VFW H3 was to have used a set of ducted propellers for high-speed flight. Its jump takeoff performance earned it the nickname "Sprinter."

combustion-type tip-jets on the H3; only cold air was generated by the compressor. After a vertical takeoff, the H3 attained forward flight by way of two seven-bladed ducted propellers, one mounted on each side of the rear fuselage. Power for these propellers was provided by the air compressor, which progressively diverted air from the rotor to the propellers as forward speed increased, leaving the rotor to autorotate in forward flight. The entire system was designed for ease of piloting, low maintenance, cost-effectiveness, and reduced noise. The absence of a transmission, driveshaft, hydraulics, clutch, or tail rotor was expected to make the aircraft simpler and less expensive when compared with conventional helicopters in the same class.

Two prototypes of the H3 were built, with a third one started. Each of them had a 370 hp Allison C250-C18 engine installed. The initial flight of the first prototype, the H3 E1 ("E" denoted *Entwicklungs-Modell* for "development (or research) model") took place on May 5, 1970 at the VFW factory in Bremen, Germany. The first flight of the second prototype, known as the H3 E2, occurred eight months later, with an engine uprated to 470 hp. This aircraft was also used for static vibration testing.

By spinning the rotor up at a very low pitch to the maximum rotor speed, a large amount of rotational energy could be stored in the spinning blades. The pilot

could then make a very dynamic takeoff by gradually increasing blade pitch, at which time the entire amount of stored energy in the rotor could be used to provide a maximum rate of climb in excess of 1,600 ft per minute. Although the stored energy would actually be expended at an altitude of 280 ft, the initial rate of climb from takeoff was very impressive. This ability to leave the ground so quickly earned the H3 the nickname "Sprinter."

Between the two flying prototypes, a total of 75 flight hours was recorded. Technically speaking, the H3 was never actually flown as a compound helicopter, as the ducted propellers were never installed prior to cancellation of the program. They had, however, been thoroughly tested on a ground test stand. Results of these tests gave the Sprinter a projected maximum speed of about 186 mph. Design studies for larger and more capable versions of the Sprinter continued until the mutually-agreed split between VFW and Fokker in 1980 and the subsequent absorption of VFW into Messerschmitt-Bölkow-Blohm (MBB) the following year.

UNITED KINGDOM

Fairey

Efforts in the United Kingdom to develop a compound helicopter actually began prior to the advent of the Wn 342, but the country was forced to delay the project until after World War II. Dr. James A. J. Bennett, then at the Cierva Autogiro Company, conceived of a compound helicopter to meet a Royal Navy requirement for a rotary-wing aircraft capable of operating from the deck of a ship. After the war, Bennett was hired to lead rotorcraft work at Fairey Aviation Company Limited, and full-scale development of this concept, which he called a Gyrodyne, began in 1946. Two prototypes were constructed, the first of which was completed in September 1947, and first flight occurred three months later. This flight, which took place on December 7, 1947, made the Gyrodyne the first compound helicopter in Britain to take to the air.

Designed as a hybrid flying machine with features of both a helicopter and an airplane, the Gyrodyne had a very unique appearance. The fuselage had a generous amount of Plexiglas covering the nose, affording excellent visibility for the crew of two seated side-by-side, while the rear cabin could comfortably accommodate 2-3 passengers on bench-type seating. The aft end of the fuselage tapered to a point with a horizontal tailplane mounted at the end. On both sides of the tailplane were vertical fins affixed as endplates. Most unusual for a helicopter, particularly for the time period, was a set of wings protruding mid-level from the fuselage, spanning 17 ft. Mount-

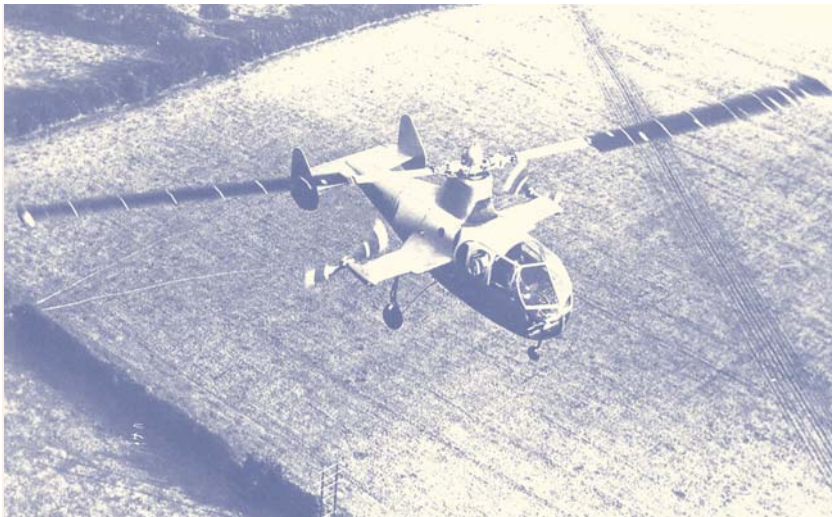
ed at the end of the right wing was a single two-bladed propeller with variable-pitch designed to counter torque and provide additional thrust for forward flight. The weight of the propeller on the right wing was countered by a teardrop-shaped fuel tank mounted on the left wingtip. The three-bladed rotor, with a diameter of 51.7 ft, was mounted atop a streamlined pylon and powered by a single 525 hp Alvis Leonides nine-cylinder radial piston engine. This engine also provided power to the propeller on the right wing by way of a horizontal driveshaft. A set of non-retractable wheeled tricycle landing gear allowed easy ground handling.

By the summer of 1948, the Gyrodyne was involved in a very successful flight test program, demonstrating speeds significantly greater than other helicopters of the period. It attained the International Helicopter Class G Speed Record for outright speed in a straight line on June 28, 1948 with the average speed for two opposing runs measured at 124.3 mph; this was Britain's first rotorcraft record ever. Inspired by their success, the flight test team decided to make an attempt at the closed-circuit speed record the following year. However, this attempt was to end in tragedy. After completing 16 months of trouble-free flight tests, the first prototype suffered an in-flight mechanical failure prior to the record attempt and crashed on April 17, 1949, killing both crew members. As a result, the second prototype was precluded from entering flight status pending completion of the investigation and thorough fatigue testing. The investigation eventually concluded that the crash resulted from fatigue in the rotor head.



The Fairey Gyrodyne - with a three-bladed rotor and a tractor propeller - was the first compound helicopter to take flight in the United Kingdom.

After an extensive rebuild, the surviving Gyrodyne prototype was rolled out as the Jet Gyrodyne. In January 1954, tethered flight tests of this new machine commenced and the first free-flight was accomplished later that month. Although it retained the basic configuration of the original aircraft, the Jet Gyrodyne incorporated a number of modifications, including the addition of rotor tip-jets on a larger 59 ft two-bladed rotor. The



The Fairey Jet Gyrodyne was an improved version of the original Gyrodyne, fitted with two pusher propellers and a large diameter two-bladed tip-jet rotor for increased forward speed.

larger diameter rotor provided a useful 25% reduction in disc loading. The tip-jets were fed by fuel and compressed air, which was forced through tubes in the hollow rotor blades, as with the Wn 342; the Jet Gyrodyne was intended as a tip-jet testbed for a larger, operational transport then being designed. The engine was uprated to 550 hp and a Rolls-Royce centrifugal compressor provided power for the rotor tip-jet system. In addition to a new rotor, the Jet Gyrodyne was fitted with two variable-pitch two-bladed pusher propellers, one on each wingtip, replacing the single propeller and the fuel tank on the wingtips. Directional control was achieved by applying differential pitch on each propeller.

Although these modifications were intended to permit higher levels of performance, the transformation to the Jet Gyrodyne imposed weight and power penalties. This fact became obvious in March 1955 when transitions to autorotational forward flight, although successful, revealed the inability to maintain level flight in this mode due to the aircraft being underpowered. In addition, transitioning from horizontal flight to a vertical descent proved particularly dangerous since engine power had to be diverted to the compressor before the tip-jets could be engaged. Disengaging power from the propellers forced the aircraft into unpowered autorotation during the transition until the tip-jets could be activated. At this point, if the tip-jets failed to engage, the pilot would simply continue in autorotation and find a safe place to land.

By late 1956, the Jet Gyrodyne had completed numerous flights with approximately two hundred transitions to autorotational forward flight. However, the difficulties encountered in achieving flight in this

mode and the inability to maintain it made further development very difficult. In addition, Great Britain's economic climate and unfavorable government policies at that time greatly contributed to the demise of the concept. Fortunately, this one-of-a-kind aircraft survives today, standing proudly on display at the Aerospace Museum near RAF Cosford, England.

Disregarding the economic and political difficulties which ended further development of the Gyrodyne and Jet Gyrodyne, Fairey Aviation continued unabated in its quest to succeed. Making use of the large amount of data gleaned from its previous two efforts, Fairey developed the Rotodyne, the largest com-



The Fairey Rotodyne held great promise in revolutionizing high-speed inter-city transport. Its cancellation was a huge disappointment to the British aerospace industry.

pound helicopter, and indeed the largest rotorcraft, built up to that time, in an attempt to fully exploit the technology. The Rotodyne was designed from the outset to fulfill specific operational requirements, rather than to serve strictly as an experimental aircraft. The ability of the Rotodyne to carry up to 40 passengers (not demonstrated) or approximately 11,000 lb of cargo was very impressive for the time. Production versions were projected to carry even more, possibly as much as 18,000 lb or 70 passengers. Loading of cargo was facilitated by a pair of clamshell doors at the rear end of the fuselage, permitting a direct drive-on capability for vehicles to be loaded.

Although primarily intended to serve as a commercial transport, the potential versatility of the Rotodyne did not go unnoticed by the British military, which was involved from the very beginning. The Rotodyne's ancestry was clearly marked by features similar to those found on the Gyrodyne, but on a significantly larger scale. The generous amount of cockpit glazing was retained, providing the two-man crew with excellent visibility. The 58.6 ft fuselage boasted an internal cabin space of 46 ft in length, 8 ft in width, and 6 ft in height, providing a good indication of the Rotodyne's considerable cargo capacity. To provide a means of partially sup-

porting the aircraft and its payload during high-speed cruising flight, a set of wings spanning 46.5 ft was mounted high on the fuselage midway down its length. Mounted on each of these wings was a Napier Eland N.El.3 four-bladed turboprop engine, rated at 3,000 hp and each fitted with a 13 ft diameter four-bladed propeller. Each engine was fitted with an auxiliary compressor, which supplied air to a rotor-tip-mounted pressure jet system through compressed air ducts inside the 90 ft diameter four-bladed rotor mounted high on a streamlined fairing above the mid-fuselage. The aircraft's empennage consisted of a horizontal tailplane with large rectangular endplates. The top halves of these endplates were movable, hinging downward automatically upon landing to provide adequate clearance for the drooping rotor blades when moving at slow rotational speeds or at rest. These endplates were also fitted with rudders on their lower halves. A set of fully-retractable wheeled tricycle landing gear supported the Rotodyne on the ground, the nose gear retracting into an area beneath the cockpit and the main gear retracting into the lower half of the engine nacelles.

Prior to construction of the prototype, very extensive wind tunnel testing of the basic design was conducted using 1/6 and 1/15 scale models. Use of such models was deemed necessary due to the sheer size and mechanical complexity of the full-size design. After completion of the prototype, flight testing began on November 6, 1957, when the Rotodyne made its first flight at White Waltham airfield. Three days later, the aircraft was flying at forward speeds of 46 mph in winds of 23 mph and gusting up to 40 mph.

The Rotodyne's unique design allowed it to fly in helicopter or autogyro mode, depending on the horizontal or vertical speed. As with similar designs using a tip-jet system, the rotor was powered strictly by the tip-jets, allowing vertical takeoffs like a conventional helicopter. Once sufficient forward speed was reached and the wings were able to generate lift, the tip-jets were extinguished and the aircraft continued to fly as an autogyro. Prior to deceleration, the tip-jets were re-ignited and the rotor was reengaged, permitting hover and vertical landing capability. The first full transition from helicopter mode to autogyro mode took place on April 10, 1958. The Rotodyne established a world speed record for rotorcraft of 191 mph in the 62 mile closed-circuit category on January 5, 1959. As testing continued, the Rotodyne demonstrated a cruising speed of 185 mph. Range was approximately 450 miles depending on the payload. The maximum weight at which the aircraft attained flight during testing was 32,998 lb, although a much higher weight of 60,053 lb was projected for the military configuration when fully loaded. All of these performance figures, along with even higher passenger capacity, were slated to see a significant increase in the larger production aircraft.

The Rotodyne was conceived to fulfill a requirement for a large transport capable of vertical takeoff and land-

ing, with many roles envisioned. In the civilian world, it was to be used as a passenger or freight-carrying aircraft, making use of direct routes between major cities in Western Europe up to 250 miles away or within the United Kingdom itself. In addition, interest in the Rotodyne as an intercity transport was expressed by Kaman Aircraft Corporation in America, which negotiated with Fairey to become a North American partner. As a military aircraft, it could be used to rapidly transport troops or equipment, or a mixture of both, across the battlefield at unprecedented speeds. Flight tests were increasingly favorable and the British government appeared ready at one point to place an order for 18 aircraft – 12 for the Royal Air Force and 6 for civilian operations. In any of the roles for which the Rotodyne was designed, it held a lot of potential for mission expansion.

However, these concepts never reached fruition. The loud noise of the Rotodyne tip jets necessitated a change to a low pressure design, which in turn necessitated a much larger rotor for a production aircraft. The much higher payload requirements being demanded by both potential commercial and military customers precipitated a similar growth in engine capability, fuselage size and wing area. The resulting production design would have been essentially an all-new design, and would have required a new engine development program. The lack of adequate government or industry resources to develop a new aircraft and a new engine resulted in a discontinuation of official funding for the project in February 1962.

The simultaneous "rationalization" of the British aviation industry by the government that began in 1959 eventually resulted in the consolidation of more than 20 British aircraft firms into three remaining companies: British Aircraft Corporation and Hawker Siddeley for fixed-wing aircraft and Westland – combining its activities with that of Fairey and two other companies – for rotorcraft. This forced consolidation was certainly a disruption to the management of the program. Lacking the once-promising government sponsorship, Westland cancelled the Rotodyne project. Sadly, the single prototype that was built was subsequently disassembled and mostly sold for scrap. The few components which survived – a single Napier Eland engine, a rotor blade, the rotor mast, a small fuselage section, and several tip-jets – are on display at The Helicopter Museum in Weston-Super-Mare, England.

FRANCE

Sud-Ouest

While Fairey was immersed in testing of the Gyrodyne and Jet Gyrodyne, engineers across the English Channel were conducting their own research into compound helicopters. In the early 1950s, France's Societe' Nationale de Constructions Aeronautiques du Sud-Ouest, otherwise known as

SNCASO (and later Sud-Ouest), was engaged in testing its own tip-jet compounds. The Sud-Ouest S.O. 1100 Ariel was a compact egg-shaped helicopter with a ducted propeller at the rear of the fuselage. Initial testing in 1948, with the pusher propeller removed, found a number of problems – including an unacceptably high fuel consumption – and the design was abandoned. Prototypes of the S.O. 1110 Ariel II and S.O. 1120 Ariel III also used tip-jets, but there was no auxiliary propulsion system for forward flight.

The S.O. 1310 Farfadet again used the tip-jet concept, but with a tractor propeller mounted in front. Conceived primarily as a technology demonstrator, a contract was awarded in December 1951 for two prototypes. First flight of the Farfadet, which lasted about 20 minutes, occurred on April 29, 1953, but only as a pure helicopter. By year's end, the Farfadet made a successful transition and flew for the first time as a compound helicopter on December 2, 1953.

In many respects, the Farfadet closely resembled a conventional fixed-wing aircraft, but with a helicopter rotor mounted on top. Its streamlined fuselage had a two-bladed 6.2 ft diameter variable-pitch propeller on the nose powered by a 275 hp Turbomeca Artouste II gas turbine engine. The cockpit provided good visibility for the two-man crew seated side-by-side and a compartment behind the pilots' seats could be configured to carry cargo or accommodate up to three passengers. Immediately above and behind the canopy glazing was a pylon mounting a 36.7 ft three-bladed helicopter rotor. Rather than develop a totally new rotor system, SNCASO chose to use the same rotor as that in the earlier S.O. 1120 Ariel III helicopter, albeit with a different powerplant. The tip-jet system was supplied with air by a 275 hp Turbomeca Arrius I gas turbine compressor. Not surprisingly, fuel consumption of the tip-jets was found to be extremely high, so their use was restricted to takeoff, hovering, and landing only. A set of unswept wings extended from the lower fuselage, spanning 20.7 ft. Under these wings and the nose was

mounted a set of non-retractable wheeled landing gear in a tricycle configuration. The rear fuselage tapered to a conventional fixed-wing-type tail section with a single vertical fin and a low-mounted horizontal stabilizer. At the very end of the tailboom, just below the stabilizer, were exhaust outlets on either side. These outlets were used to control yaw at low speeds by ejecting high-pressure exhaust gases from the engine compressor. At higher speeds, the airplane-type rudder was used for yaw control.

Flight testing of the Farfadet confirmed the aircraft to be stable, controllable, and pleasant to fly. In forward flight, the wings provided much of the lift, offloading the rotor by approximately two-thirds. The maximum speed demonstrated by the Farfadet was 165 mph. However, testing at this speed resulted in a catastrophic failure of the turboprop and turbocompressor engines, forcing the pilot to make an emergency autorotational landing. As a result of the total destruction of the engines, the first prototype was grounded. The second prototype was completed with a 360 hp Turbomeca Arrius II gas turbine compressor installed for improved hover performance. During ground testing, the rear fuselage of this aircraft was completely destroyed when the new engine failed as a result of

a surge. Testing and development throughout the program was hampered by difficulties with the gas turbines which, being prototypes, required constant adjustments. The Ariel III had been the world's first helicopter with a turbine engine, and reliability of early turbines was rather poor compared to piston engines.

To further complicate matters, when the original funding for the program was exhausted, additional funds were not granted and were instead diverted to operational helicopter programs, specifically the S.O. 1221 Djinn light utility/observation helicopter (which used cold-cycle tip-jets without combusting fuel). The ongoing war in Algeria required the full attention of the French defense industry, relegating many experimental



The original Sud-Ouest Ariel was intended to use tip-jets for vertical and hover flight and a pusher propeller for high-speed forward flight. Unfortunately, it never progressed beyond limited hover flights.



Using high-pressure exhaust outlets and a rudder to control yaw, the Sud-Ouest Farfadet was a very stable and controllable aircraft to fly.

programs to a lower priority. As a result, further research was terminated and the Farfadet program was cancelled. The significant amount of damage incurred during testing on both prototype airframes did not make it practical to restore and preserve either of them. Research and studies continued at SNCASO on other compound helicopter designs, but none of them ever reached fruition.

SOVIET UNION

Kamov

Since the invention of the helicopter, Russia has historically been a solid believer in the value of vertical lift. The sheer size of the country – even larger when it was the backbone of the Soviet Union – has presented unique challenges in finding an efficient means of transporting people and materials across the vast Russian frontier. Igor Sikorsky stated many times in his life that Russia was “made for the helicopter,” referring to the successful impact the helicopter had in “shrinking” the country. As in many nations, requirements for a vertical heavy-lift capability in the Soviet Union originated with the military, rapidly expanding into the civilian world. A need to provide the Soviet military with such a capability was identified in the early 1950s, when leaders in the armed forces sought a way to supplement the fixed-wing transport aircraft then in service with an aircraft that was not dependent on runways. In 1951, the Kamov Experimental Design Bureau (*Optyuno-Konstruktorskoe Byuro or OKB*) embarked on a program to fulfill the requirement using a Lisunov Li-2 (NATO codename ‘Cab’) fixed-wing transport (a Soviet version of the American-made Douglas DC-3) as the basis for conversion into a compound helicopter using co-axial rotors. However, the impending end of Li-2 production made it pointless to proceed and development was discontinued.

To take its place, Kamov decided to create a totally new aircraft based on the idea of a “Vintokryl,” or screwing aircraft. Their concept was presented for review to the Soviet Air Force and the Central Aero-Hydrodynamics Institute, known as the *Tsentralniy Aerogidrodinamicheskii Institut*, or TsAGI, in 1953. On June 11, 1954, development of the aircraft, designated the Ka-22, was sanctioned by the Soviet military and Kamov proceeded in its efforts. Three prototypes were to be constructed. The Ka-22 was unlike any other aircraft built in the Soviet Union or in the world. It had a fuselage, wings and empennage like that of a conventional fixed-wing aircraft. In a sharp departure from the norm, it was equipped with a large, four-bladed rotor, 73.8 ft in diameter, mounted atop engine pods at the tip of each wing. These pods each housed a 5,900 hp Soloviev TV-2VK turboprop engine driving the rotors as well as a set of four-bladed propellers. For loading and unloading cargo, a large portion of the nose section under the cockpit was hinged on the right, permitting the nose to



The Kamov Ka-22 Vintokryl was unlike anything the world had ever seen in terms of size, speed, and sheer vertical lifting capability.

be swung open for unhindered access to the large cargo hold.

The first Ka-22 test article was evaluated in the TsAGI wind tunnel during the Fall of 1954. Four years later, tests were completed on the rotor system using a modified Mil Mi-4 helicopter. In late-1958, the first Ka-22 prototype was delivered to the OKB flight development department. By March the following year, engine tests, aircraft vibration assessment, fuel and oil system calibration, control system changes, and adjustments of the rotors and propellers were completed. On June 17, 1959, the Ka-22 attained its first tethered hover, during which the aircraft experienced serious vibrations. As a result, several modifications and adjustments were carried out which included changing the rotor blades, adjusting the cyclic pitch control unit and associated linkages, altering the load balance, and changing the rotor trim tabs and angles of attack. The Ka-22 then made its first untethered hover on August 15, 1959. Recurring instability and control problems necessitated the construction of a flight simulator in which subsequent hover flights indicated a need to reverse the rotation of the rotors.

As the flight envelope was gradually expanded, the propellers were engaged and forward flights were made at slowly-increased speeds. On October 11, 1959, the Ka-22 was demonstrated to the Soviet Air Force Commander and the Minister for the Soviet Ministry of Aviation Industry. It then underwent a number of modifications over the next six months. The first flight after these modifications in April 1960 again revealed serious vibrations, the origins of which were immediately traced to the skin having been peeled away from one of the starboard rotor blades. This was, in turn, traced to the development of span-wise cracks in the rotor blades, leading to tests of several types of blades constructed with many different materials and airflow sections. The rotor hubs were also modified.

The Ka-22 made its public debut at the Tushino Air Display on July 9, 1961, impressing those who attended with its sheer size and speed. Given the NATO code-name ‘Hoop,’ it was the largest rotorcraft in the world at the time. Three months after its appearance at Tushino,

the Ka-22 established eight international aviation records, which included a speed of 356 km/hr (221 mph) over a 15-25 km course. The enormous lifting capability of the Hoop was also impressive, demonstrating the ability to carry a 16,485 kg (36,343 lb) payload to an altitude of 2,588 m (8,491 ft). Due to poor gas-dynamic stability of the original engines, they were replaced with 5,500 hp D-25VK turboprop engines, a derivative of those being fitted to the then-new Mil Mi-6 heavy-lift helicopter. This change resulted in the Hoop being redesignated as the Ka-22M, which was intended to be the future production standard. On September 23, 1961, the Ka-22M was flown for the first time, reaching an altitude of 3,280 ft and a speed of 124 mph.

In February 1962, a joint flight evaluation program was initiated for both the Soviet Air Force and the civilian airline Aeroflot. That summer, it was decided to ferry two of the Ka-22M aircraft to Moscow for further testing. During this ferry flight on the morning of August 28, 1962, one of the aircraft entered a steep spiral dive and crashed, killing its crew of seven. Subsequent investigation attributed the crash to mechanical failure in the starboard rotor, resulting in a loss of control by the flight crew. Afterwards, installation of ejection seats in the aircraft was considered, but this was never implemented. The accident resulted in a two-year setback for the program while modifications were made to the aircraft, three of which were then in various stages of construction.

In 1964, the Ka-22M completed its preliminary flight development program in preparation for the planned military/civilian evaluation. However, disaster struck again when a second Ka-22M suffered a fatal crash on July 16, 1964 after the starboard engine nacelle broke away as a result of violent maneuvers by the crew in an attempt to recover from an involuntary dive. The ensuing investigation concluded that this accident was caused by similar factors encountered in the first crash two years before. With no aircraft in flyable condition, and facing a considerable amount of modifications for the remaining airframes, the State Committee for Aviation Technology elected to terminate development of the Ka-22M, citing the great complexity of the aircraft, particularly in the use of the engines to power both the rotors and the propellers. It was suggested that the lessons learned be applied in future heavy-lift helicopter programs. None of the surviving aircraft hardware was preserved.

Despite the many problems encountered in its development, the Ka-22 was able to demonstrate impressive flight performance, even by today's standards, having achieved a forward speed higher than many of its contemporary helicopters, along with a very large payload capacity. The lasting influence of the Hoop was obvious in later Soviet designs, both built and unbuilt. The Mil Mi-12 (NATO codename 'Homer'), which appeared in the late-1960s and remains as the largest rotorcraft ever built, adopted a rotor configuration similar to the Ka-22,

but dispensed with auxiliary forward propulsion units, relying solely on the rotors for propulsion and lift.

UNITED STATES

Gyrodyne Company of America

The Gyrodyne Company of America (GCA) was formed after World War II with the intent of producing a helicopter with better performance than any in existence at the time. Specifically, GCA was looking at ways to increase maximum speed, and tested several novel rotor control concepts, including a rotor-tip brake control system for directional flight.

Their first design, designated the GCA-2A, used a coaxial Bendix Model J helicopter, with the rotor system modified and a propeller added on each side of the fuse-



The Gyrodyne GCA-2A was the first compound to fly in the US. It added two propellers on the side of a standard Bendix Model J helicopter.

lage. The propellers were each powered by a 100 hp Continental engine, mounted with it on an outrigger. The propellers could be operated independently for yaw control. The 48 ft rotors were powered by a 450 hp Pratt & Whitney R-985 engine. In cruise flight, the cyclic pitch of the blades was significantly less than that required without the auxiliary propulsors. First flight was conducted at the end of November 1949.

GCA continued various design studies and experiments with rotor control schemes, but did not build another compound demonstrator. One concept that they did study was a tail rotor that could pivot from providing anti-torque at hover and low speed to providing thrust at high speed. Known as the GCA-5, the project involved a three-seat helicopter with a four-bladed rigid main rotor and a two-bladed tail rotor. As forward speed increased, more than 80% of the engine power would be diverted to the tail rotor as it was swung to face the rear, serving as a pusher propeller. The GCA-5 had a projected speed of 155 mph and a range of 264 miles, but

it never went beyond the conceptual stage. GCA is best known for its portable XRON Rotorcycle and QH-50 Drone Anti-Submarine Helicopter (DASH), which continues to be used by the military today.

McDonnell Aircraft Corporation



The McDonnell XV-1 Convertiplane inherited many of the same features of the Wn 342, both having been designed by Austrian engineer Friedrich von Doblhoff.

The first compound helicopter to fly extensively in the United States was the McDonnell XV-1 Convertiplane. Developed jointly by McDonnell Aircraft Corporation, the U.S. Army Transportation Corps, and the U.S. Air Force Wright Development Center, the XV-1 was built as an experimental aircraft that combined the vertical takeoff and low-speed handling characteristics of the helicopter with the higher speed and range of a fixed-wing aircraft. Initially given the designation L-25 to denote a liaison role, the aircraft was then briefly assigned the H-35 designation as a helicopter. However, this was subsequently changed in 1952 to XV-1, making it the first of the 'V' series aircraft.

The first of two prototypes was completed in early 1954. Like many compound helicopters that have flown, the XV-1 was designed as an entirely new aircraft, rather than as a modification of an existing design. Therefore, by its very nature, the XV-1 had a decidedly unorthodox appearance. Approximately two-thirds of the cylindrical fuselage was formed of Plexiglas, providing almost unlimited visibility for the two-man crew seated in tandem. Alternatively, the cockpit and cabin could accommodate one pilot with three passengers seated behind him. A set of straight wings with a 26 ft span were mounted high on the fuselage, supporting twin tailbooms to the rear, each with a vertical fin connected in the middle by a movable horizontal tailplane. Mounted in the rear fuselage and nestled between these tailbooms was a two-bladed 6 ft diameter pusher propeller powered by a 550 hp Continental R-

975-19 seven-cylinder radial piston engine. The 31 ft three-bladed rotor was mounted high on a faired pylon, although it was later lowered – to just above the arc of the pusher propeller – as flight testing progressed. A set of sturdy non-retractable metal skids supported the aircraft on the ground. In order to reduce weight and enhance performance, a large portion of the XV-1 was constructed of aluminum.

Tethered hover tests of the XV-1 began on February 11, 1954, but developmental difficulties with the tip-jet rotor propulsion system delayed free-flight until July 14. Designers added a number of minor improvements to the second prototype based on data from flight tests performed with the first aircraft. These improvements were later fitted to the first prototype as well. The most prominent change was the addition of small rotors at the ends of the twin tailbooms to improve directional control (since the tip-jets resulted in a reaction rotor, there was no torque to counteract, and thus no anti-torque rotor to also provide yaw control). Like previous tip-jet compounds, the XV-1 was capable of operating in helicopter or autogyro modes, depending on the horizontal or vertical speed. However, this was not automatic, so it was up to the pilot to adjust the pitch of the rotor blades accordingly as the airspeed increased or decreased. The single engine in the XV-1 powered not only the pusher propeller, but also the two compressors for the tip-jet rotor propulsion system. They fed a fairly complex system of piping to direct the high-pressure air through the hollow rotor blades to the combustion chambers on each rotor tip. Once there, the air was mixed with fuel and ignited with a burner to produce jet thrust, thereby spinning the rotor in a counter-clockwise direction. The decision to use two compressors was made to avoid the unacceptable penalties in weight that would have resulted from using two transmissions. In helicopter mode, engine power was directed to the compressors to power the tip-jet rotor system. When transitioning to autogyro mode, engine power was diverted to the pusher propeller and the rotor simply entered autorotation.

After more than nine months of flight testing in rotary-wing mode, the Convertiplane lived up to its name by completing its first successful transition from helicopter mode to autogyro mode and back on April 29, 1955. On October 10, 1956, the second XV-1 prototype made history when it became the first rotary-wing aircraft in the world to achieve a speed of 200 mph, which gained the immediate attention of the aerospace community across the globe. This level of performance was significant because it meant that the XV-1 had flown 44 mph faster than the conventional helicopter speed record at the time, and about twice as fast as most contemporary helicopters of the period. At cruise speeds greater than 138 mph, the wings provided as much as 85% of the total lift, while the remaining 15% was provided by the rotor blades in autorotation. Even when flying at top speed, the wings did not possess enough

area to generate all the lift necessary to keep the XV-1 in the air, so the rotation of the rotor was necessary to sustain a level altitude. The range of the Convertiplane was about 593 miles and service ceiling was 19,800 ft. With a cruising speed of 138 mph and a top speed of 203 mph, the XV-1 demonstrated a remarkable leap in rotorcraft performance over its contemporaries...but not for long.

Despite the speed advantage demonstrated by the Convertiplane, the aircraft's relative complexity, particularly in the tip-jet rotor propulsion system, negated its initial advantage over mechanically powered helicopters. In addition, the bright flash and loud noise generated by the tip-jets were unacceptable in view of the military liaison role that the aircraft was intended to fulfill. As a result, the XV-1 program was cancelled in 1957 and the two prototypes never flew again. Today, they reside in the collections of two of the most prominent museums in the United States: one at the Army Aviation Museum, at Ft. Rucker, Alabama and the other at the National Air & Space Museum's Paul E. Garber Preservation, Restoration, and Storage Facility in Suitland, Maryland.

Piasecki Aircraft Corporation

McDonnell was not the only aircraft company in the U.S. with an interest in high-speed rotary-wing flight. Recognizing the potential of such an aircraft, particularly in the area of short-haul air operations, Piasecki Aircraft Corporation in Philadelphia, Pennsylvania began work on a high-speed helicopter as a privately-funded venture. The result, known as the 16H-1 Pathfinder, was a five-seat compound helicopter fitted with a fully-articulated three-bladed main rotor 41 ft in diameter and a unique 5.5 ft diameter three-bladed ducted propeller forming what was called a "Ring-Tail." The Ring-Tail provided directional and anti-torque control by means of four vertical vanes in the duct. The aircraft could lift-off vertically or conduct a rolling takeoff like a fixed-wing aircraft as a means to increase operational gross weight in its useful payload. As the aircraft transitioned into forward flight, the pilot would apply increased power to the ducted propeller for forward propulsion. Power for both the main rotor and the Ring-Tail was provided by one 550 shp United Aircraft of Canada PT6B-2 shaft-turbine engine. The aircraft had a set of 20 ft span fixed wings mounted to the lower sides of the streamlined fuselage, each fitted with a set of ailerons and flaps for increased maneuverability. The wheeled landing gear was in a "taildragger" configuration, with the main gear retracting into the underside of the fuselage and the fully-steerable tailwheel remaining fixed.

The Pathfinder achieved first flight on February 21, 1962. This flight, along with the first few subsequent flights, was made with the cockpit and cabin unenclosed, the wings unfitted, and the landing gear in the down position. By early fall of the same year, flight tests



Piasecki pioneered the Ring-Tail on its 16H-1 Pathfinder as a means of auxiliary propulsion and anti-torque control.



Extensive modifications to the original Piasecki Pathfinder resulted in the 16H-1A Pathfinder II, a faster, more refined aircraft.

had progressed enough to allow the cabin enclosure and wings to be fitted for testing at higher speeds. During testing, the Pathfinder attained a total of 185 flight hours and a top speed of 170 mph. The success in flight testing attracted the interests of the military, giving rise to a joint Army/Navy program to jointly fund flight demonstrations of a modified 16H-1 as part of an ongoing study of advanced high-speed rotorcraft technology. The jointly-funded program began in May 1964 with the goal of gathering information on the characteristics of a compound helicopter flying at speeds greater than 225 mph. In order to achieve this, Piasecki funded several modifications to the Pathfinder. The engine was replaced with the much more powerful 1,250 shp General Electric T58-GE-8 shaft-turbine engine, a new drive system and propeller were installed to absorb the increased power, and a larger 44 ft diameter main rotor was fitted, the same as that used on the Vertol H-21 Shawnee/Workhorse helicopter. In addition, the fuselage was lengthened, allowing accommodation for eight people. These extensive modifications warranted a new designation and a new name, resulting in the 16H-1A Pathfinder II.

Army/Navy-funded ground tests of the Pathfinder II began in early May 1965 and the first tethered hover took place on November 13 that year. Two days later, the first free-flight occurred on November 15, 1965. By April 1966, the Pathfinder II had logged more than 40 flight hours under the Army/Navy contract and attained speeds up to 225 mph while demonstrating a high degree of maneuverability. Backwards and sideways flight had also been explored with speeds as high as 32 and 35 mph respectively. As the Pathfinder II entered the final stages of its flight test program in the Summer of 1966, new air intake ducts were fitted for improved efficiency and the powerplant was replaced with a still larger 1,500 shp General Electric T58-GE-5 turboshaft engine. Although the aircraft retained the name Pathfinder II, the company changed the aircraft designation to 16H-1C.

At the conclusion of the program later that same year, the Army and Navy had collected a vast amount of research data in the field of compound helicopters, much of which was used in the development and testing of other research aircraft and remains as a useful resource for future efforts. A more advanced commercial variant of the aircraft, tentatively called the Pathfinder III, was planned, but emerging interests within the military took precedence over further commercial development. Today, the Pathfinder II remains in storage with Piasecki for future use in high-speed compound helicopter research, which continues as an active program to this day.

Bell Helicopter Company

Bell Helicopter Company in Fort Worth, TX, began research into increased speed performance for rotary-wing aircraft as early as with the "Wing-Ding," a Model 47 with a wing. Much more extensive work followed under a contract with the U.S. Army, initiated on



The Bell Model 533 reached an incredible 316 mph in 1969. It was tested with various combinations of rotors, wings and jets, including a winged 2-bladed version (right) and a 4-bladed version with the engines mounted on stub wings (above).

August 7, 1961. Funded under a U.S. Army Transportation Research Command (TRECOC) contract for a high-performance research helicopter, Bell modified a YH-40 helicopter with UH-1B dynamic components. The company designation was Model 533. The primary objective of the project was to evaluate various rotor systems and methods of drag reduction. Initial modifications included the addition of fiberglass honeycomb aerodynamic fairings on the rear fuselage, streamlined fairings for the landing skids, a cambered vertical fin on the tailboom to unload the tail rotor, and an in-flight tiltable rotor mast protruding from a large, neatly-faired structure above the cabin. Shortly after the aircraft achieved its first flight on August 10, 1962 with the standard UH-1B 44 ft two-bladed rotor, another rotor system was tested on the Model 533: a gimbal-mounted 42 ft diameter, three-bladed rotor, which could be mounted to the mast either rigidly or through a gimbal. The control system was modified to accommodate the tilting pylon system and to be adaptable to both the 2-bladed and 3-bladed rotor system. True level flight airspeeds of 150 knots (173 mph) were achieved with the standard 2-bladed rotor.

Having established the basic benefits of drag reduction, the U.S. Army funded a second phase with the main purpose of investigating the effects of auxiliary thrust. Bell used two 920 lb thrust Continental J69-T-9 turbojet engines in pods attached closely to each side of the fuselage for this purpose. The 2-bladed rotor was chosen for this program and the standard UH-1B blades were replaced with an experimental set. A pair of swept-back wings spanning 26.8 ft was fitted to the lower fuselage. These wings had ground adjustable sweep and could be tilted in flight. The tilt mechanism was later coupled to the collective control to avoid excessive wing lift and attendant rotor rpm control problems during autorotation.

After exploratory testing in pure helicopter configuration, the wings were removed and the turbojet engines were fitted. Flight tests in this configuration began on 21 October 1963. An additional elevator was soon installed on the vertical fin, opposite the tail rotor, since the standard elevators were now located in an area of turbulent airflow from the jet engines. The full-up configuration, with wing and auxiliary jets installed was first flown on 2 March 1964. A level flight true airspeed of 214 mph was achieved using maximum auxiliary thrust. Contracted testing was completed in April of 1964. Immediately following the contracted tests, the 2-bladed rotor was fitted with special tapered tip blades under a Bell Helicopter independent research program. A level flight true airspeed of 222 mph was attained using maximum auxiliary thrust.



To provide even more thrust, the J69 turbojets were removed and the Model 533 was refitted with more powerful 1,700 lb static thrust J69-T-29 turbojet engines, the same as those used in the Ryan BQM-34A Firebee target drone. The significantly increased thrust allowed the aircraft to reach higher speeds, becoming the first rotorcraft in history to exceed a speed of 200 kt (230 mph), reaching 236 mph on October 15, 1964. Six months later, it became the first to reach 250 mph in level flight on April 6, 1965. Along with the higher speeds, test pilots demonstrated impressive maneuverability with the Model 533, routinely performing 2G turns at 60 degrees of bank.

Early in 1968, the U.S. Army awarded Bell a follow-on contract with the aim to expand the envelope even further and replace the J69 turbojets with much more powerful 3,300 lb thrust Pratt & Whitney JT12A-3 turbojets. The wings that had previously been fitted were removed and replaced by a new unswept pair upon which the new engines were wingtip-mounted. Additionally, the shape of the main rotor fairing was altered. The longitudinal control system was totally changed, allowing a changeover from standard helicopter cyclic controls to pure fixed wing elevator type controls. On 15 April 1969, the 533 attained the incredible speed of 316 mph (274.6 knots) in this configuration. The final test phase of the program involved replacing the two-bladed main rotor with a four-bladed flex-beam rotor system.

At the completion of testing, the Model 533 was permanently retired, having collected an enormous amount of data for possible use in future compound helicopter projects. Today, the sole example of the Model 533 is displayed outside the main building of the U.S. Army's Aviation Applied Technology Directorate (AATD) at Ft. Eustis, Virginia.

Kaman Aircraft Corporation

Kaman Aircraft Corporation, based in Bloomfield, Connecticut, explored the potential of high-speed helicopters when it was awarded a contract by TRECOM on June 27, 1963. The company elected to carry out trials using a modified UH-2A Seasprite, a single-engine (at the time) utility helicopter that had just entered service a few years earlier with the U.S. Navy. To augment its existing shaft-turbine engine, the Compound Seasprite was fitted with a single 2,500 lb static thrust General Electric YJ85 turbojet engine mounted on a stubby pylon attached to the starboard side of the cabin. Externally, the only other configuration and/or performance-related modification made to the Seasprite in this phase of the program was an increase in the incidence of the horizontal stabilizer to a 3 degree nose-up angle. The standard four-bladed main rotor of the UH-

2A was retained.

Following the conclusion of ground testing, the flight test program began on November 26, 1963. While flying at progressively increased forward speeds, the Compound Seasprite attained 216 mph. The retractable wheeled landing gear, which was standard to the UH-2A, proved beneficial in drag reduction. Even before the conclusion of flight testing with the auxiliary turbojet, plans were made to add a pair of fixed wings to the aircraft to offload the main rotor and increase the aircraft's maneuverability. This phase of the program, announced in June 1964, would investigate roll control using ailerons to supplement rotor control and evaluate the use of a collective bob-weight to adjust rotor/wing load sharing during maneuvers. Upon completion of the envelope expansion and definition phase with the auxiliary turbojet in September 1964, flight tests were suspended for modification of the aircraft to the winged configuration.

Over the next five months, modifications were made to graft a pair of wings from a Beech Queen Air light executive transport aircraft onto the sides of the lower fuselage, giving the aircraft a wingspan of 35.25 ft. In order to install the wing, the structural tie-in within the fuselage necessitated removal of the aft fuel cells, which normally had a capacity of 176 gallons. Although some fuel capacity was recovered using the fuel tanks in the wings, the total internal fuel capacity was 80 gallons less than that during testing with the auxiliary turbojet only. Nevertheless, there was sufficient fuel for the purposes of flight testing.

Along with adding the wings, the horizontal stabilizer, which had remained fixed in previous tests, was modified to allow in-flight changes of incidence from 12 degrees trailing edge-up to 16 degrees trailing edge-down. This allowed the pilot to trim the aircraft to various angles of attack, thus obtaining a wide range of



Along with an auxiliary turbojet, Kaman's UH-2 Compound Seasprite flew with the wings of a Beech Queen Air to offload the main rotor in high-speed flight.

wing/rotor lift ratios at given airspeeds. The aircraft was flown in this configuration for the first time in February 1965, thereby initiating the lift augmentation phase of the program. At high speed, the wings effectively offloaded the main rotor by approximately 50%. The wings retained full use of their ailerons, which were initially used as spoilers to induce drag and facilitate entry into autorotation. However, this was found to be unnecessary, as pilots reported that the wings did not hinder autorotation. The flaps were also usable, but were found to produce substantial drag. The wings, which were fully instrumented to measure lift directly, were designed to be ground-adjusted from 0 degrees to 5 degrees leading edge-up to provide a nose-up aircraft attitude and determine the optimum flight angle. Ultimately, the Compound Seasprite reached 225 mph in the winged configuration and maneuverability was significantly increased. This phase of the program was formally completed on April 28, 1965 after a total of 70 flights and 39.6 hours of flight time. Later that same day, qualitative flight evaluations were conducted by pilots from the U.S. Army Aviation Materiel Laboratories (USAAVLABS), as well as by Naval Air Test Center (NATC) personnel on May 21, 1965.

Intrigued by the high degree of speed and maneuverability attained in flight tests, the Army considered funding the addition of a second turbojet to the Compound Seasprite to exploit the full speed potential of the aircraft, but this never occurred. Such modifications would have required additional fuselage structure and a high degree of strengthening on the port side due to the existing opening for the cargo door. Furthermore, it was determined that additional speed was unwarranted, as the single turbojet was sufficient to meet the stated goals of the program. The Compound Seasprite was intended strictly as a research aircraft and was never intended for production. The entire test program was exceptionally smooth, with very few difficulties encountered. As such, it was tremendously successful in gathering a wealth of data on the capabilities and limitations of compound helicopters with thrust augmentation only and with lift augmentation. In the end, Kaman concluded that aircraft control in a compound helicopter strictly through use of the main rotor was not optimal. Instead, the addition of a fixed wing using multiple control surfaces in conjunction with the rotor greatly enhanced maneuverability. At the conclusion of the test program, the Compound Seasprite was de-modified to its standard configuration and returned to Navy service.

Lockheed Aircraft Corporation

Traditionally a leader in fixed-wing aircraft design, Lockheed-California Company in Burbank, California, a subdivision of Lockheed Aircraft Corporation, became interested in advanced helicopter development in the late 1950s. Having already been awarded a contract

under a joint Army/Navy research program to further develop their design for a rigid rotor system, Lockheed accepted another contract from TRECOM in 1963 to modify one of their demonstrators, the XH-51A, into a compound helicopter. The XH-51A was itself a variant of the company's CL-595/Model 286, an experimental helicopter designed to exploit the advantages of the rigid rotor. Key features of the rigid rotor system were its sheer simplicity in design, construction, and functionality. The relatively small number of moving parts was a positive attribute from a maintenance perspective. Simply put, the system eliminated the familiar flapping and lead-lag hinges found in most conventional rotors by attaching the blades directly to the rotor hub, taking full advantage of the gyroscopic effect of the spinning hub and therefore balancing the system. A gyro ring was attached underneath the rotor hub, fastened directly to the swashplate. The pilot's controls were connected to a set of springs which acted directly upon the swashplate and hence the gyro, forcing the rotor to react instantaneously to pilot inputs.

The basic design of the aircraft itself provided a good foundation on which to build a compound helicopter, as it was very streamlined. The tadpole-shaped fuselage was flush-riveted and the landing skids retracted nearly flush into the underside of the aircraft. To create the XH-51A Compound, a set of wings spanning 16.9 ft in was fitted to the aircraft, along with a 2,500 lb static thrust Pratt & Whitney J60-P-2 turbojet on the port side of the fuselage. A pod containing batteries and test instrumentation was mounted to the tip of the starboard wing to counter the weight of the turbojet. The wings were each equipped with spoilers to assist entry into autorotation at high speed in an emergency. In addition, the horizontal and vertical tail surfaces were enlarged. As with the standard XH-51A, the aircraft had a four-bladed 35 ft diameter rigid main rotor and a two-bladed 6 ft diameter tail rotor, both powered by a single turboshaft engine.



The diminutive Lockheed XH-51A Compound used small wings and a J60 turbojet to attain an unofficial rotary-wing speed record of 302.6 mph in 1967.

The XH-51A Compound first flew, without the use of the turbojet, on September 21, 1964. It continued to be flown as a winged helicopter over the next several months to evaluate the handling characteristics associated with the unusual modifications. On April 10, 1965, the turbojet was ignited for the first time and in May, the aircraft achieved a speed of 272 mph, the fastest of any rotorcraft up to that time. From a hover, it was capable of reaching 230 mph in 45 seconds. The auxiliary turbojet and stub wings partially unloaded the main rotor in forward flight, reducing the critical blade tip speed and blade angle, allowing the aircraft to fly much faster than it ever could as a pure helicopter. As flight testing progressed, it was found that the high forward speeds necessitated additional bracing to the windshield to resist the intense aerodynamic pressures encountered. On June 19, 1967, the XH-51A Compound set another (unofficial) record for rotorcraft by attaining a speed of 302.6 mph. High-speed flight tests were conducted at a variety of altitudes, ranging from several thousand feet to extreme low-level, terrain-following flights. The auxiliary turbojet and the stub wings gave the XH-51A Compound flight characteristics very similar to that of a fixed-wing aircraft. However, due to the rapid rate at which the turbojet consumed fuel, the aircraft was only able to sustain its maximum speed for approximately 20 minutes before the tanks ran dry.

The wealth of data obtained by the XH-51A Compound was applied directly toward Lockheed's ongoing development of an advanced military compound helicopter using its innovative rigid rotor system – the AH-56A Cheyenne. The Cheyenne was conceived under the Army's Advanced Aerial Fire Support System (AAFSS) program for use in Vietnam as an advanced high-speed escort for troop-carrying helicopters and as a direct fire support aircraft for troops on the battlefield. Lockheed was selected as one of two finalists (the other being Sikorsky) in September 1965 to compete for the AAFSS contract. Lockheed's submission, known as the CL-840, was declared the winner two months later. On March 23, 1966, Lockheed was granted a contract for ten engineering development airframes, assigned the designation AH-56A by the Army.

Rolled-out on May 3, 1967, the AH-56A was christened as the Cheyenne. On September 21 that year, the second prototype achieved the type's first (non-public) flight and on December 12, a 13 minute flight demonstration was held for the public at the Van Nuys Airport in California. To achieve high forward speeds, the AH-56A was equipped with a Hamilton Standard variable-pitch 10 ft diameter three-bladed pusher propeller that,

along with the main and tail rotors, was driven by a single 3,435 shp General Electric T64-GE-16 shaft-turbine engine. As development progressed, engine power was upgraded along the way, eventually reaching 4,275 shp. Along with increased speed, the propeller provided unique hovering options to the pilot. By applying counteracting positive or negative thrust, he could hold the Cheyenne in a 10 degree nose-up or nose-down attitude while hovering, allowing the two-man crew to fire the wing-mounted ordnance down into a valley or up a hill. The propeller also allowed the aircraft to accelerate or decelerate very quickly in level flight, eliminating the need to pitch the nose up or down. As with several other compound helicopters of the period, the main rotor was partially offloaded during cruising flight by a set of wings, these spanning 26.75 ft, which also served to carry a large variety of ordnance. There were no airplane-type control surfaces fitted, as all maneuvering inputs were accomplished through the main rotor. The



The formidable Lockheed AH-56A Cheyenne attack helicopter came closer to production than any other compound helicopter to date.

four-bladed 50.5 ft diameter main rigid rotor was based closely on that of the XH-51A Compound, albeit larger and more robust. The idea of a rigid rotor appealed greatly to the Army, which felt a significant degree of stability was necessary for this revolutionary new weapons platform.

Lockheed built ten developmental prototypes with which to complete an extensive ground and flight test program. Flight and envelope expansion tests went well, with the aircraft routinely demonstrating speeds approximately 100 mph faster than conventional helicopters then in service.

Having full confidence in the performance and advanced weapons capabilities of the Cheyenne, the Army placed an initial production order for 375 aircraft in January 1968. Early in the flight test program, pilots encountered instability when flying close to the ground, but these problems were eventually corrected. By March 1968, the Cheyenne had demonstrated a forward speed of 195 mph, sideways flight at 27.5 mph, and rearward flight at 23 mph. During high-speed flight, with the wings partially offloading the main rotor, approximately all but 300 hp of the total engine output was diverted to the pusher propeller, allowing it to provide the majority of forward thrust.

As testing progressed, a lack of stability while flying at speeds in excess of 200 mph was discovered, leading to tests with a number of different rigid main rotor designs and configurations to try and eliminate the problem. Unfortunately, these problems proved difficult to correct. The most troubling technical challenge throughout most of the program involved a phenomenon known as the "1/2 P hop." This problem consisted of

a sub-harmonic vibration that occurred every two rotations of the main rotor, resulting in severe aerodynamic stresses on the blades. If unrecognized and improperly handled by the pilot, this condition could cause serious and possibly fatal rotor oscillations. During one high-speed flight test off the coast of California on March 12, 1969, the $\frac{1}{2}$ P hop caused the main rotor to strike the aircraft, slicing it in half and killing the pilot. All Cheyennes were temporarily grounded pending a full investigation.

This accident, along with a number of financial and political factors, led the Army to cancel the production portion of the contract on May 19, 1969, only six months before the scheduled delivery of the first production model. Six months after the crash, the $\frac{1}{2}$ P hop was encountered during wind tunnel tests at the NASA Ames Research Center and the tenth prototype was completely destroyed. Despite these setbacks, the Army encouraged Lockheed to continue development of the AH-56A in order to fulfill the requirement for an advanced gunship.

In the end, the Cheyenne was not to be. Politics, changing Army doctrine, and mounting pressure from the other military branches combined to doom the Cheyenne. Lockheed finally terminated the program in its entirety on August 9, 1972. Ironically, virtually all the problems with the rotor system were either solved or well on their way to resolution when the program was cancelled. The top speed achieved by the AH-56A was no less than 253 mph (220 kt) – very impressive even by today's standards. Despite being viewed by some as a failure, the Cheyenne actually succeeded in many ways, contributing much of the lessons learned and advanced technology used to develop today's breed of attack helicopters. With the construction of ten prototypes and a production order having been placed, the Cheyenne came closer to mass production than any other compound helicopter thus far. Not to be forgotten, the amount of valuable data gathered on compound helicopters through Lockheed's efforts continues to prove useful in such research to this day.

Recognizing the potentially lucrative market for a high-speed helicopter in both civil and military roles, Lockheed had also explored a number of possible designs for civilian compound helicopters. Concepts for such aircraft carrying between 30 and 90 passengers at high-speed at ranges up to 250 miles were envisioned. However, none of these designs were ever to leave the drawing board. The unfortunate demise of the Cheyenne resulted in the end of Lockheed's involvement in rotary-wing aircraft design. Today, two remaining examples of the AH-56A can be found at the Army Aviation Museum at Ft. Rucker, Alabama, while one each can be found at Ft. Campbell, Kentucky and Ft. Polk, Louisiana. Also resting in the collection at Ft. Rucker awaiting restoration is the sole XH-51A Compound and one example of the XH-51A.

Sikorsky Aircraft



Sikorsky's heavily-modified Sea King, the S-61F, possessed a number of drag-reduction features designed to permit higher speeds.

While Lockheed was flight testing the XH-51A Compound, Sikorsky Aircraft in Stratford, Connecticut began testing its own compound rotorcraft, the S-61F. Partially funded by Sikorsky and built under a joint Army/Navy research contract awarded in 1964 to attempt speeds as high as 230 mph, the S-61F was a highly-modified SH-3A Sea King anti-submarine helicopter optimized for research into high-speed flight through extensive drag reduction features. The boat hull fuselage was faired over to form a rounded nose and streamlined underbelly, while the stabilizing floats on either side of the cabin were completely removed. The retractable wheeled main landing gear was repositioned inside a streamlined structure on either side of the lower fuselage which supported two 3,000 lb static thrust Pratt & Whitney J60-P-2 turbojet engines. The tailboom was redesigned to form a more tapered shape and a larger vertical tail fin was fitted, which included an airplane-type rudder. In addition, a large horizontal stabilizer (using components from a Cessna T-37 jet trainer) equipped with elevators was fitted midway across the vertical fin. Large 170 square foot wings spanning 32 ft with full-span flaps were fitted high on the fuselage. A new six-bladed rotor head was built, fitted with new low-twist blades.

The helicopter was designed to fly in various configurations for research purposes: with or without wings; with or without turbojets; with a five or six-bladed main rotor; and with high or low-twist blades. The S-61F received the military designation NH-3A and was flown for the first time on May 21, 1965 with the turbojets and the five-bladed main rotor equipped with low-twist blades. In July, it attained a speed of 187 mph. As flight testing progressed, turbulence generated by the rotor head was found to cause tail shake, necessitating the addition of an aerodynamic fairing, or "beanie," on top of the rotor head. The next phase of the program involved the addition of the wings in order to partially

offload the main rotor and attempt even higher speeds. Although the standard five-bladed main rotor was retained in initial flight tests, the six-bladed rotor with standard and reduced-twist blades was also tested. The S-61F did not have integrated flight controls. The full-span flaps could be moved up or down with a beeper switch. Beeper controls were also used for elevator and rudder control. Stabilizer incidence was ground-adjustable only.

Flight tests of the S-61F were highly successful with a total of 113 flights made and 88.2 hours of flight time accumulated at the time of flight test completion on May 8, 1967. The maximum speed achieved was 255 mph. In the final report produced on March 20, 1969, Sikorsky recommended continuation of the project with further aircraft modifications to increase its speed capability. However, this option was not exercised by the military and the program was terminated shortly thereafter. Although the S-61F significantly increased the information available on the characteristics of compound helicopters, the limitations imposed by using off-the-shelf components and having non-integrated flight controls were a hindrance to achieving the full capability of the helicopter. After completion of the program, the S-61F made one final contribution to high-speed helicopter research when the forward fuselage was converted for use as a rocket sled test vehicle to evaluate the crew extraction system for the later Sikorsky S-72 (detailed below).

During the same time period as the S-61F was being flight tested, Sikorsky briefly ran another program in support of their competing design against Lockheed to

win the AAFSS contract with the Army. Their proposal, known as the S-66, never went beyond the design stage as a whole. However, one key element of the S-66 did reach flight test status. The concept, known as the Rotoprop, involved a tail rotor that could be swung 90 degrees to the rear to function as a pusher propeller and provide additional forward thrust (similar to that proposed for the GCA-5, 15 years before).

To test the concept, a standard SH-3A was modified in 1965 with a new tail section that included a large vertical fin equipped with an airplane-type rudder for yaw control. The Rotoprop, which was a standard SH-3A tail rotor configured to swivel, was mounted at the extreme end of the tail. When the helicopter reached a speed of approximately 80 mph, the pilot would initiate the transition with a pushbutton control. At that point, directional control was provided solely by the rudder. When airspeed decreased below 80 mph, the pilot would revert the device back to tail rotor configuration. Although the test article was manually controlled, production models would have operated automatically as forward speeds increased or decreased. The system worked well, proving the concept. However, having lost the contract to Lockheed, Sikorsky discontinued development of the S-66 and the Rotoprop concept was abandoned.

In the early 1970s, engineers continued to seek ways to increase the forward speed of helicopters. By then, several designs by many different manufacturers had been test flown, all of which met with varying degrees of success. In February 1972, Sikorsky announced that it was working on a research aircraft to test the Advancing

Blade Concept (ABC), one in which the rotor system is made up of two co-axial contra-rotating rotors that take advantage of the aerodynamic lift potential of the advancing blades. Although very similar in appearance to the designs favored by the Soviet manufacturer Kamov, Sikorsky's design was different in that the blades were rigidly fixed to the rotor mast. In the ABC rotor system, the retreating blades are unloaded during high-speed flight and the majority of the load is carried on the advancing sides of both rotors, thus eliminating the usual penalties associated with retreating blade stall. As with all co-axial designs, the ABC also negated the need for a tail rotor as the contra-rotating three-bladed rotors cancel out any torque. Sikorsky's efforts were carried out under a contract awarded by the U.S. Army Air Mobility Research and Development Laboratory at Ft. Eustis, Virginia.

Called the S-69 by Sikorsky, the Army applied the designation XH-59A to the



Sikorsky's innovative Rotoprop, tested on the S-61F, swiveled to function as both a pusher propeller (above) and a conventional tail rotor (inset). It was intended for use on their proposed S-66 attack helicopter.

two demonstrators that were built. The primary purpose of the program was to test and evaluate the flight performance of the ABC system. Prior to actual flight tests, a 40 ft diameter rotor system was successfully tested in a wind tunnel at the NASA Ames Research Center, although both demonstrators were actually fitted with 36 ft diameter rotors. The first XH-59A was flown on July 26, 1973. However, a flight accident occurred the following month, severely damaging the aircraft and necessitating a number of design changes, including a modified control system. The damaged aircraft was subsequently repaired for wind tunnel tests. Resumption of the flight test program occurred on July 21, 1975 when the second aircraft flew for the first time. This aircraft continued to fly successfully in helicopter configuration for nearly two years, demonstrating impressive performance and speeds up to 184 mph in level flight and 224 mph in a shallow dive. The sleek airframe of the XH-59A, which looked more like a conventional airplane than a helicopter, contributed to its high-speed abilities, having few drag-inducing protrusions and being equipped with fully-retractable tricycle landing gear. The empennage consisted of a horizontal tailplane with twin endplate fins and rudders. In addition to enhancing forward speed, the ABC rotor system was found to be more efficient in the hover and a good deal quieter than conventional rotor systems.

At the conclusion of flight testing in pure helicopter configuration in March 1977, Sikorsky readied the aircraft for testing in the compound configuration under a program jointly funded by the Army, Navy, Air Force, and NASA. This was done with the addition of two 3,000 lb static thrust Pratt & Whitney J60-P-3A turbojet engines, one on either side of the fuselage. Since the ABC rotor system already provided a great deal of maneuverability, the addition of fixed wings was not considered necessary. The auxiliary turbojets were installed in 1978 and low-speed flight tests were completed later that year. High-speed tests were initiated early the following year at United Technologies Division's Development Flight Test Center located near West Palm Beach, Florida. Testing went well, and the XH-59A attained a speed of 235 mph in level flight on April 12, 1979. Twelve months later, the aircraft flew at 274 mph on April 21, 1980. By May, the high-speed and load factor test programs were completed, but testing continued under a new Army/Navy contract effective on June 1, 1980 to evaluate aircraft performance under expanded altitude and center-of-gravity flight envelopes. Actual flight tests under this new contract commenced in August 1980. Ultimately, the XH-59A achieved an incredible 303 mph, the first rotorcraft up to that time to attain such speeds without the addition of wings.



The Sikorsky S-69 exploited the inherent advantages of the Advancing Blade Concept (ABC) by eliminating retreating blade stall.

Despite the impressive accomplishments of the XH-59A, the demonstrator suffered from vibration problems, as well as unfavorable weight and drag. In particular, the high weight of the coaxial transmission and the drag of the rotor hub were deemed excessive. The ABC also suffered from an image problem, as the demonstrator used four engines, adding to the perception of being overly complicated.

Under a contract with NASA, the first XH-59A was rebuilt and modified as a full-scale wind tunnel test article for evaluation in the 40 ft by 80 ft wind tunnel at Ames. Plans were also made in 1982 to develop a new design configuration for the ABC demonstrator, known as the XH-59B. This variant was to incorporate an advanced bearingless 36 ft diameter ABC rotor system with composite blades, a new main gearbox, and new rotor controls, while retaining the basic airframe, landing gear, and fuel system of the 'A' model. Power was to be provided by two General Electric T700 turboshaft engines. Most prominent of all was to be a completely redesigned tail section with a 6.6 ft diameter ducted pusher propeller. This design was created in response to the Army's desire to evaluate an integrated propulsion system, rather than the turboshaft-plus-turbojet research configuration. A proposal for the development and flight test of the XH-59B was submitted to the Army, but Sikorsky's refusal to share costs (in part due to the resource strains on the company that resulted from the simultaneous development of the UH-60 Black Hawk, SH-60 Seahawk, CH-53E Super Stallion, and civil S-76) resulted in the Army not awarding a contract. As a result, the XH-59B was never built.

The series of successful flight evaluations of the XH-59A that had been made by the U.S. Army Aviation Development Test Activity at Ft. Rucker, Alabama renewed interest in the ABC rotor system by Army leaders for potential application in the Light Helicopter Experimental (LHX) program, then in its very early stages of program definition and development. Howev-

er, the very stringent constraints on empty weight of the LHX led the Boeing-Sikorsky team to err on the side of caution and familiarity, selecting a more conventional helicopter configuration for development as the RAH-66 Comanche that eventually won the LHX competition. Ironically, that design was itself cancelled after nearly two decades of research and development. However, the ABC concept is now preparing to experience a rebirth in a current Sikorsky project known as the X2 (detailed below).

Since completion of the wind tunnel tests, the first XH-59A has been languishing in storage at NASA Ames. The second aircraft was moved back to Sikorsky's main plant in Stratford and eventually transferred to the Army Aviation Museum at Fort Rucker, where it remains today.

Not all compound helicopters have been designed with speed as their primary goal. When NASA and the U.S. Army identified the need for a high-speed research aircraft to test a wide variety of rotor systems and integrated propulsion systems, Bell Helicopter and Sikorsky entered the design competition for a Rotor Systems Research Aircraft (RSRA). Having won the competition, Sikorsky was awarded a contract in January 1974 for the construction of two prototypes. Since the aircraft would potentially be testing rotor systems that might be too small to support it, a compound helicopter was the preferred solution to ensure the safety of the pilot and crew.

Sikorsky's winning design for the RSRA received the company designation S-72, the first of which was rolled out on June 7, 1976. This example was configured as a conventional helicopter only, with the second example being in compound configuration. Five-bladed main and tail rotors from an S-61 were fitted. The basic airframe of both versions was identical, having a sleek fuselage with retractable wheeled landing gear arranged in a "taildragger" configuration. For the helicopter version, a 35 square foot "T-tail" was used. As a pure helicopter, the S-72 first flew on October 12, 1976. After 21 flights, it completed its initial flight test phase in February 1977 and was flown to NASA's Wallops Island Flight Center, Virginia in July. After additional flight tests, it was subsequently flown to the NASA Ames Research Center at Moffett Field, California on February 11, 1979.

The compound version of the S-72 was fitted with a pair of full-size wings spanning 45 ft with an area of 370 square foot. Each wing was equipped with full-span conventional ailerons and flaps. The wings had in-flight

adjustable incidence from -9 degrees to +15 degrees. A large, low-set 88 square foot stabilizer with a geared elevator was fitted on the tailboom and the large helicopter "T-tail" was replaced with a smaller 17 square foot surface. Auxiliary propulsion was provided by a pair of 9,275 lb thrust General Electric TF34-GE-400A turbofan engines, as used on the Lockheed S-3 Viking anti-submarine aircraft, mounted on either side of the fuselage. It achieved its first flight on April 10, 1978. As with the first aircraft, the compound S-72 was tested at Wallops Island and then flown to Moffett Field to join its counterpart.

Able to fly as a pure helicopter, a compound helicopter, or as a fixed-wing aircraft, the S-72 provided unique opportunities to perform tests which could not be carried out by existing aircraft in actual flight or in a wind tunnel. The variety of rotor systems considered for the RSRA to evaluate included composite bearingless, variable-geometry, gimbaled, articulated, hingeless, circulation control, reverse velocity, and jet flap systems. The main transmission was mounted on a specially designed balance so that lift and torque of the rotor system being tested could be measured directly. Speed brakes were fitted to the wings to allow very precise control of airspeed. The flight control system



The Sikorsky S-72 Rotor Systems Research Aircraft (RSRA) had the unique ability to fly as a pure helicopter, a compound helicopter, or as a fixed-wing aircraft.



The Sikorsky S-72X, seen here in fixed-wing configuration, was intended to test the innovative X-Wing, but was never utilized for this purpose.

was very sophisticated and provided stability augmentation and trim in all axes. The proportioning of the pilot's control inputs sent to the rotor controls and to the fixed-wing controls was fully variable in flight using mechanical control phasing units.

In the event that an emergency arose during rotor system testing, the crew could jettison the main rotor

blades at their mounting points with explosive charges and continue to fly the S-72 safely as a fixed-wing aircraft. As an added margin of safety, each crewmember was provided with a Stanley Aviation Yankee Extraction System, the same type installed in some versions of the Douglas A-1 Skyraider attack aircraft. This was the first ejection-type system ever installed in an operational test helicopter. When the ejection sequence was initiated, the rotor blades were immediately severed with the aforementioned explosive charges. A catapult rocket system was then fired upward which yanked the seats out of the aircraft by way of a pair of rope-like straps fastened to each crewmember's harness, hence the term "Yankee." Prior to installation in the S-72, this system was successfully tested in the S-61F rocket sled mentioned above.

Both NASA and the Army conducted tests with the RSRA until 1980, at which time NASA assumed "ownership" of both aircraft. Four years later, Sikorsky was awarded a contract by NASA and the Defense Advanced Research Projects Agency (DARPA) to convert the helicopter version of the S-72 into a demonstrator for the company's innovative X-Wing system. The X-Wing was conceived as a "stopped rotor" system where the four-bladed main rotor could be used for vertical flight like a conventional helicopter and then stopped in mid-air to serve as an X-shaped fixed-wing once adequate forward velocity was attained. What's more, the X-wing used a circulation control rotor (CCR). With the CCR, the lift of the rotor blade was controlled by blowing compressed air through the leading edge or also the trailing edge of the rotor blade. The very stiff rotor, which had an elliptical airfoil, was conventionally driven but used circulation control to vary its lift so that all four wing segments of the "X" could generate lift, whether rotating or stopped.

The aircraft, redesignated as the S-72X, flew for the first time as a pure fixed-wing aircraft on December 2, 1987 to assess flight characteristics without a rotor. In this form, it eventually achieved a speed of 301 mph in level flight. The estimated speed at which the X-Wing, when fitted in future tests, could be stopped was 196 mph, and the projected top speed of the aircraft with the rotor stopped was 518 mph. This project was pursued in earnest from 1984 to 1988 when, despite the enormous potential behind the concept, development was discontinued and the project was eventually cancelled due to lack of funding needed to overcome some of the technological barriers encountered.

The RSRA offered the rotary-wing community a great opportunity for high-speed research that was never fulfilled. Despite the sophistication of the design, the extensive on-board instrumentation, and the sophisticated flight control system, no significant research programs with either of the aircraft were ever conducted. In fact, Sikorsky accumulated more flight hours on the air-



Although the X-Wing's circulation control rotor system was ground tested extensively, it was quite a challenging concept. Sikorsky's S-72X is shown here with a flightworthy and operating X-Wing rotor, but it never left the ground.

craft in determining airworthiness and flight envelopes than NASA did in rotary-wing research. The two S-72 aircraft are currently in storage at the NASA Dryden Flight Test Center and there are no plans to fly them again.

The Need for Speed Continues...

Given the obvious advantages in speed and performance, one will inevitably ask why the compound helicopter has never made it into full-scale production. Although some experts continue to debate the advantages and disadvantages of adding a fixed-wing, most agree on the speed advantage offered by the addition of some form of thrust augmentation. In fact, many companies around the world continue to study the benefits of the compound configuration, with and without wings, for future applications.

Bell Helicopter is continuing to study an innovative concept known as the Propulsive Anti-Torque System (PATS), originally developed for the now-cancelled UCAR program. PATS consists of a high-bypass propulsion system contained within a helicopter's tailcone that provides an anti-torque capability comparable to modern helicopter designs, along with forward propulsive thrust. Combined with advanced main rotor technology, PATS is designed to eliminate the need for a tail rotor and provide the benefits of compounding without the weight penalties normally associated with compound helicopters. The system is fed with cold bypass air ingested through an inlet by a low-pressure, high-volume fan in front of the engine. The fan doubles as a supercharger to increase the pressure boost to the compressor inlet, improving overall engine efficiency. As the air flows across the engine, it is then mixed with the hot engine exhaust. Eliminating the tail rotor not only pro-



The PATS compound system that was ground tested under the cancelled UCAR program may yet find an application.



Piasecki has updated their Ring-Tail concept as the Vectored Thrust Ducted Propeller (VTDP), being fitted to a YSH-60F Seahawk, dubbed the X-49.

vides a higher degree of safety for ground crews, but the reduction in noise will be conducive to operations in an urban environment. In addition, the resulting reduction in radar and infrared signatures will mean increased survivability in military applications of PATS.

Making use of its extensive research with the Pathfinder series, Piasecki has developed a newer version of the Ring-Tail called the Vectored Thrust Ducted Propeller (VTDP). The VTDP differs from the original Ring-Tail by incorporating significant improvements in aerodynamics and thrust vectoring control. Under an Army contract, Piasecki built a 5.5 ft diameter model of the VTDP and thoroughly tested it in a wind tunnel, demonstrating a 46% improvement in hover efficiency over the original Ring-Tail. Results were then incorporated into real-time computer simulation models of VTDP compound helicopter versions of the AH-1 Cobra and AH-64 Apache attack helicopters, during which pilots recognized significant improvements in handling qualities and attained an 80%-plus increase in mission success rate. These successful tests led to a follow-on Army contract to build a full-scale VTDP for ground test-

ing, completed in October 2000. The Navy awarded Piasecki a contract for design, fabrication and flight test of the VTDP on a YSH-60F Seahawk helicopter, which received the official designation X-49A and is unofficially referred to as the Speedhawk. In 2004, the Army joined the program and assumed lead oversight. The overall objective of the flight demonstration program is to validate potential improvements in speed, range, altitude, survivability, and life cycle costs using VTDP technology. Using the VTDP in conjunction with a set of fixed wings to partially offload the main rotor, the aircraft is projected to attain speeds as high as 230 mph. As of this writing, the X-49A has completed all required qualification tests and is in the process of final assembly for ground and flight tests. First flight is expected early in 2007.

At the AHS Forum 61, on June 1, 2005, Sikorsky announced initiation of a program referred to simply as the X2. At this time, a technology demonstrator is under development for a possible first flight of a technology demonstrator in late 2006. Taking advantage of the experience gained with the S-69/XH-59A, Sikorsky will emphasize high-speed and high-maneuverability with the X2, which will entail a co-axial ABC rotor system and a pusher propeller. Speeds as high as 250 kt (288 mph) are anticipated, while retaining the positive



At the 2005 AHS Forum, Sikorsky unveiled its plans for a new compound demonstrator, the X2, which is expected to fly before the end of 2006.



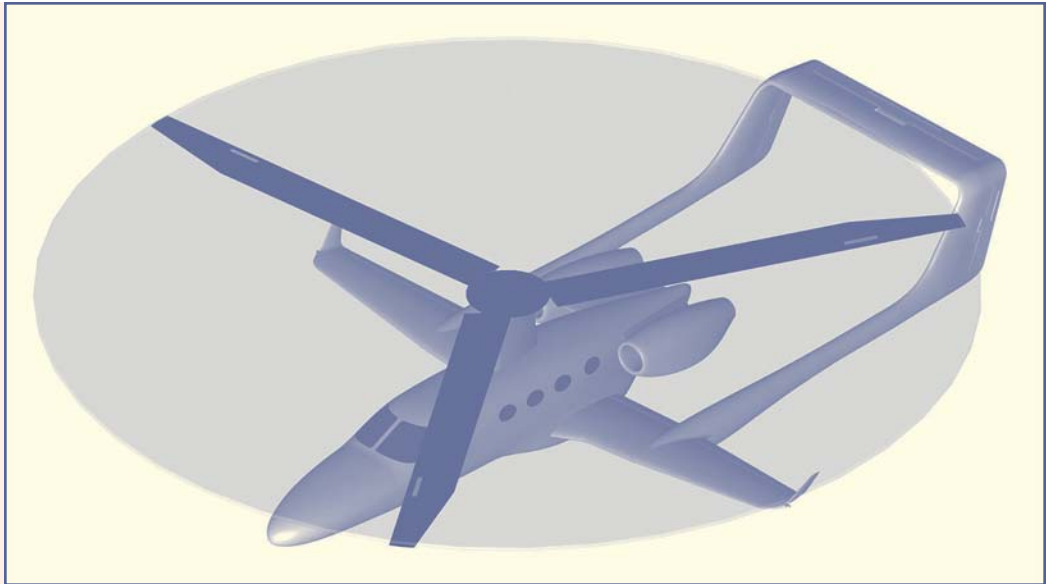
Sikorsky's X2 rotor technology could be applied to a wide range of future platforms, such as the high-speed heavy lifter being studied for the Army.

attributes of vertical flight capability. With no fixed wing to degrade hover capability, the X2 is expected to perform well in all flight regimes. The X2 will employ a number of cutting-edge technologies, including active vibration control, advanced flight controls, and new rotor blade designs. Drawing on its experience from the RAH-66 Comanche program, composite rotor and advanced transmission designs will also be incorporated. Several designs using X2 technology in various weight classes and configurations are envisioned in order to fulfill both civil and military roles and missions. First flight of the planned X2

fly-by-wire system took place using a Schweizer 333 as a surrogate helicopter in November 2005, a key milestone in progression toward a flying demonstrator. The final system configuration will integrate the main rotor, pusher propeller, and engine to meet commands from the cockpit.

Two of today's top companies in autogyro research and development are also pursuing concepts for advanced compound helicopters. Carter Aviation Technologies (CAT) and Groen Brothers Aviation, Incorporated (GBA) are very active in their quests to expand the performance of their autogyros beyond the current level of performance. In addition to the work they performed with their slowed-rotor CarterCopter Technology Demonstrator (CCTD) autogyro under a contract with the U.S. Army, CAT developed a number of self-funded designs for future development of a so-called "Heliplane," which is reminiscent of the Rotodyne in its general layout. Unlike the Rotodyne though, the main rotor on these designs would be fully-powered for take-off, hover, and landing, rather than using tip-jets. In cruising flight, the rotor would be significantly slowed to reduce power consumption and minimize drag, while the majority of the lift would be provided by the fixed wings. Forward propulsion would be provided by pusher propellers.

In the meantime, GBA – known for their advanced Hawk 4 autogyro – in November 2005 was awarded the first phase of a \$40M contract by DARPA to develop a high-speed, long-range proof-of-concept vertical takeoff and landing aircraft, also dubbed the Heliplane. This aircraft aims to offer speed and range improvements of more than a factor of two over conventional helicopters. The GBA Heliplane will essentially revive the same operating concept as that of the Rotodyne, using tip-jets to drive the rotor during takeoff, hover, and landing.



Groen Brothers Aviation is working on a vertical take-off and landing Heliplane that will be capable of a 400 mph cruise speed.

During high-speed forward flight, the rotor will autorotate and lift will be transferred to a set of fixed-wings while power will be provided by two turbofan engines. The first two phases of the program will involve system design and wind tunnel tests. At this time, the GBA team – which includes Adam Aircraft, Williams International and Georgia Tech – plans to modify and test fly an Adam Aircraft A700 business jet as a demonstrator by the end of the 40 month contract.

In addition to the wide variety of compound helicopters that have actually flown over the years, countless other designs have been, and continue to be, explored on the drawing board as designers seek ways to increase the speed of the helicopter. It is important to note that very few of the compound helicopters that actually flew were built from the outset with a final production model in mind. The majority of them were built strictly as testbeds and research aircraft to collect data for potential use in future production aircraft. Today, the immense computing power available to designers and engineers for modeling and simulation has drastically reduced the dependence on prototypes. Nevertheless, the only way to prove certain concepts and technologies is through actual flight tests of the hardware itself. There will always be advantages and disadvantages to the compound helicopter compared with the pure helicopter. Therefore, the secret lies in finding just the right combination of features, balanced with the required role and mission of each aircraft. Whatever the answer, prototypes of various shapes and sizes will continue to fly and serve as an inspiration to those who witness them in our never-ending quest for high-speed rotary-wing flight.

Further Reading

- Boyne, Walter J. and Donald S. Lopez, *Vertical Flight: The Age of the Helicopter*, Smithsonian Institution, Washington, D.C., 1984.
- Coates, Stephen, *Helicopters of the Third Reich*, Ian Allen, Publishing, Hersham, Surrey, England, 2002.
- Hirschberg, Michael J., Thomas Müller and Michael J. Pryce, "British V/STOL Rotorcraft Concepts In The 20th Century," American Helicopter Society Forum 61, June 1-3, 2005.
- Hirschberg, Michael J., Thomas Müller and Alexis Rocher, "French Low-Speed V/STOL Concepts Of The Twentieth Century," American Helicopter Society Forum 58, June 11-13, 2002.
- Hirschberg, Michael J. and Thomas Müller, "German V/STOL Rotorcraft and Propellercraft In The Twentieth Century," American Helicopter Society Forum 57, 9-11 May 2001.
- Kuznyetsov, G.I., *Kamov OKB: 50 Years*, Aviation and Cosmonautics Center, Moscow, Russia, 1999.
- Landis, Tony and Dennis R. Jenkins, *Warbird Tech Volume 27: Lockheed AH-56A Cheyenne*, Specialty Press Publishers and Wholesalers, North Branch, MN, 2000.
- Polmar, Norman and Floyd D. Kennedy, Jr., *Military Helicopters of the World: Military Rotary-Wing Aircraft*

Since 1917, Arms and Armour Press, London, England, 1981.

- Rogers, Mike J., *VTOL Military Research Aircraft*, Haynes Publishing Group, Sparkford, Nr. Yeovil, England, 1989.

Acknowledgements

The author wishes to personally acknowledge and thank the following individuals who generously provided detailed information and photos in preparation of this article: Mike Hirschberg, American Helicopter Society; Jerry Irvine, Aviation Applied Technology Directorate; Erin Dick and Walter Sonneborn, Bell Helicopter Textron; Anthony Rita, Kaman Aerospace Corporation; Tom Lawrence and John Daniell, Sikorsky Aircraft Corporation; John Piasecki and John Romanski, Piasecki Aircraft Corporation; and Roger Connor, Smithsonian Institution.

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THE NAVAL TEST PILOT SCHOOL VARIABLE-STABILITY HELICOPTER

By Scott Bruce

The U.S. Naval Test Pilot School, located at Patuxent River Naval Air Station, trains students in the finer points of aircraft flying qualities using two NSH-60B Seahawk helicopters fitted with variable stability systems (VSS). What makes the VSS aircraft unique is that instructor pilots can change the stability characteristics of the helicopters in real time using special software programs designed into the aircraft. Over the years, VSS demonstration flights have become one of the most important elements of the school's rotary wing curriculum for student test pilots, which include members of all four services and the U.S. Coast Guard, as well as foreign military pilots.

The VSS aircraft incorporate a three-axis, limited-authority, analog, variable-stability system to program inputs into the flight control system. Designed by Calspan Corporation, the VSS allows instructor pilots to demonstrate the effects on low-speed handling qualities of up to 64 cockpit-selectable feedback and forward path gains. The system uses the production aircraft stability augmentation system actuators to alter flying qualities. The VSS demonstrations are typically conducted using digitally pre-stored configurations (up to 256 are avail-



able) but independent gain variation is also possible.

The rotary wing test pilot curriculum at the school incorporates academic theory, flight test planning and execution, and report writing. Instructors cover a range of disciplines, including performance, systems, structures, and stability and control. After training in helicopter stability theory, students are given the opportunity to experience laboratory simulations, followed by a series of actual VSS helicopter flight exercises.

Recently, AHS Executive Director Rhett Flater - a former U.S. Marine Corps aviator and instructor pilot with more than 3,000 flight hours - flew the VSS Demo as the guest of Lieutenant Colonel Steve Kihara, USA, the Naval Test Pilot School's commanding officer. CW4 Rob Pupalaikas of the U.S. Army, the unflappable senior rotary wing instructor at the test pilot school, agreed to serve as Flater's instructor pilot for purposes of the demonstration. Flater received a classroom brief, followed by Seahawk familiarization. His flight concentrated on low-speed flying qualities and lasted one and one-half hours. (There were no incidents or mishaps.) Flater gave the VSS an unqualified endorsement, saying "I had no idea that this capability existed and how effective a teaching tool this aircraft can be." 