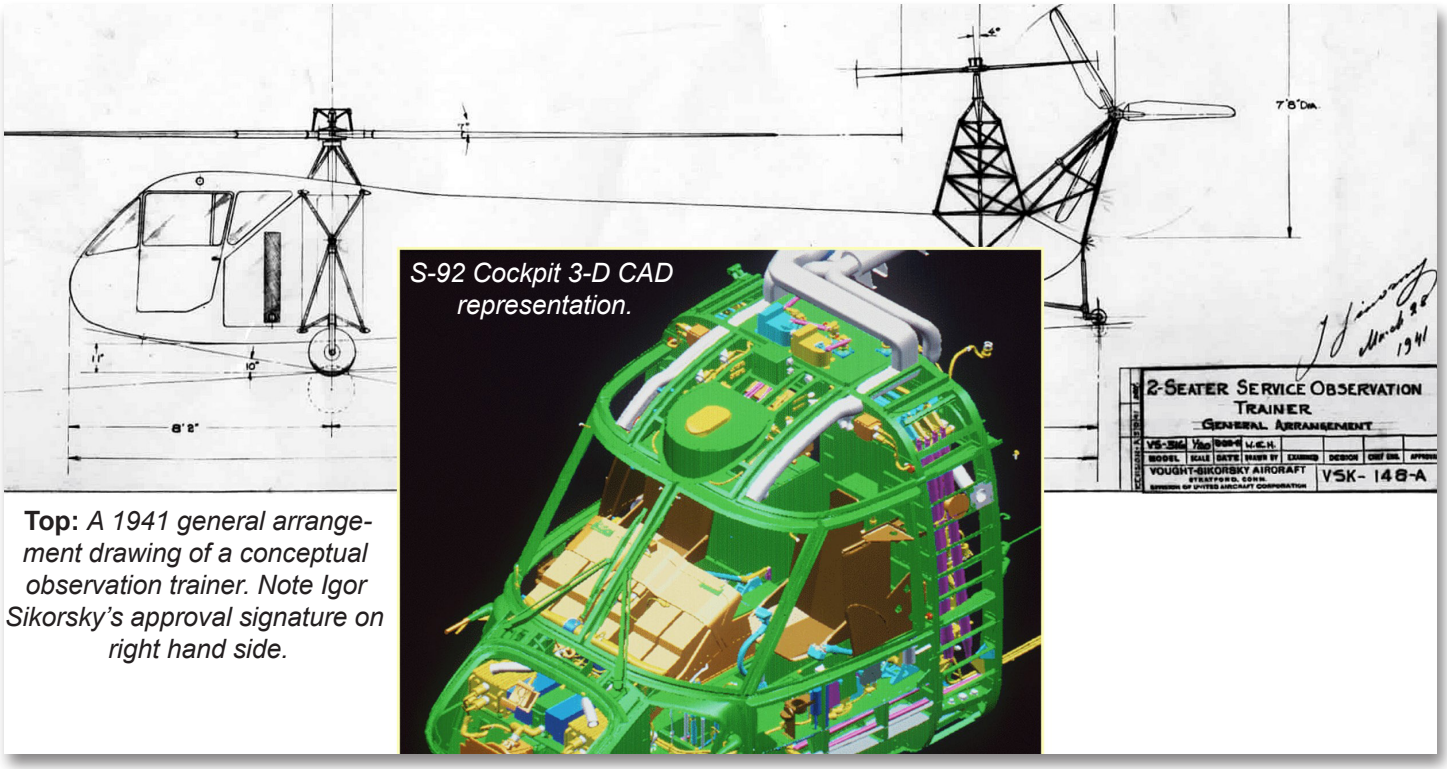
IGOR I SIKORSKY HISTORICAL ARCHIVES

Sikorsky Archives News

October 2022

Published by the Igor I. Sikorsky Historical Archives, Inc. M/S S578A, 6900 Main St., Stratford CT 06615

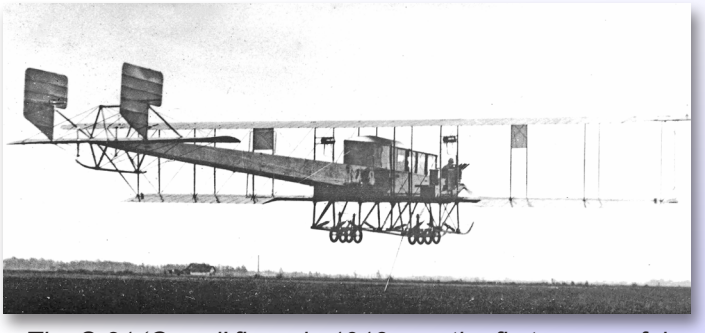
Sikorsky's Engineering Evolution



Top: *A 1941 general arrangement drawing of a conceptual observation trainer. Note Igor Sikorsky's approval signature on right hand side.*

Sikorsky engineering has evolved from paper drawings to digital models that reshape design, test, production, and support. (All images property of Sikorsky Archives.)

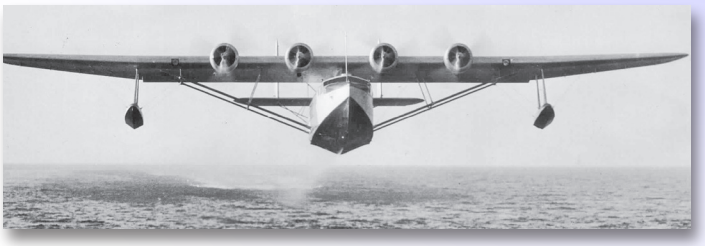
Sikorsky Aero Engineering Corp. was founded in 1923 by an intuitive engineer. Nearly a hundred years later, Sikorsky Aircraft, now a Lockheed Martin Company, has about 3,500 engineers using powerful computer tools to advance the helicopter. Of his father's engineering legacy, Sergei Sikorsky said, "At a minimum, you could say that Igor Sikorsky gave the world a number of interesting inventions. First of all, he pioneered the multi-engine aircraft, which many experts around 1910 said would never be done. Then, during the 1930s, my father gave the world some pretty high-performance flying boats and the Clipper amphibians. They allowed Pan American Airways almost single-handedly to establish long-range over-water flights with their Pacific and Atlantic passenger services." Soon after, Sikorsky engineering refined the helicopter. "In Dad's words, 'The jet may have made the world smaller. The helicopter made it bigger by allowing mankind to live and work in areas that would have been inaccessible by any other vehicle.'"



The S-21 'Grand' flown in 1913 was the first successful multi-engined airplane.

Igor Sikorsky took a hands-on approach to engineering. "During the period of his flying boats, if there was some sort of problem, Dad would come home, have supper, and then drive back to the factory. Sometimes, he would be alone except maybe for the night watchman -- in those days, single shifts were the rule rather than the exception. He'd come back into the factory, walk around, and mentally engineer whatever problem there was. And often in the middle of the night he would sketch it out, and bingo, he had the solution."

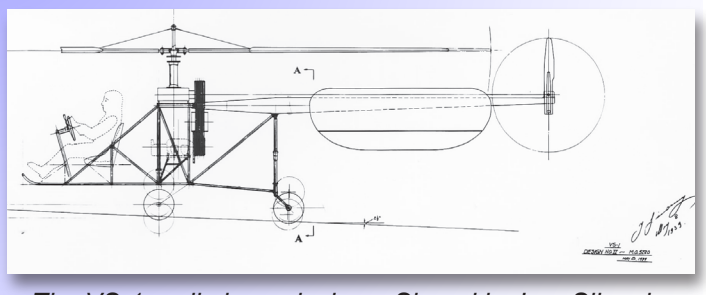
Igor Sikorsky's engineering genius saved the United Aircraft division that carried his name. "When he was finishing up the last of the big flying boats," Sergei recalled, "Dad was beginning to sense a crisis for the future of Sikorsky Aircraft. He would work on the flying boats during the day, but starting around 1936, he would come home, spend about an hour having a leisurely dinner, take a 15- to 20-minute hike around the back of our property, and then go upstairs into his own private little office and work there sometimes until midnight. It was there that I would see his first sketches of the first helicopters, and Dad was already zeroing in at that time on the configuration of a single main lifting rotor."



The S-42 Pan American Clipper flew in 1934 and opened long, over-water passenger routes.

Sketches took form in the experimental VS-300. Igor Sikorsky's cousin "Prof" Sikorsky, Alexander "Nick" Nikolsky, and brothers Serge and Michael Gluhareff made up the VS-300 senior engineering staff. Tethered flights in September 1939 began a cycle of helicopter discoveries and engineering changes. Sergei Sikorsky recalled, "I would say the high point, according to my father, was that very first lift-off and two or three weeks later in December 1939 as he realized he had a machine that could fly."

Excessive vibration and other flight test discoveries were addressed by trial-and-error. The VS-300 initially refused to fly forward. Sergei Sikorsky explained, "The problem was they, at that time, underestimated the power of the lead-lag phenomena when flying forward. They had very, very primitive rubber washer-snubbers to control the fore-and-aft movement of the rotor blades. It was shortly after that that they put the hydraulic dampers horizontally so they would dampen the forward and the rearward motion of the rotor blades as the helicopter flew forward. That was one of the major solutions tested on the VS-300."



The VS-1 preliminary design – Signed by Igor Sikorsky May 8, 1939, depicted the single main rotor helicopter concept.

With a fly-fix-fly approach, the helicopter became a useful platform. Sergei Sikorsky recalled, "Mechanically, technically, Dad was always impressed by three or four aircraft design factors. One was gross weight of an aircraft versus useful load. I remember several times when I had the privilege of escorting him at the Paris Airshow or at Farnborough. He would always look

up and kind of study an aircraft and make a couple of very incisive comments. For instance, he'd say, "This aircraft is going to be a bear to fly – too much of the airplane is forward and not enough in back." Another measure he would always make was the speed range of an aircraft – your stalling speed versus your cruising speed. It was the band between beginning to fly and the top speed could you stretch out of that aircraft with reasonable fuel consumption. If the aircraft could reach a three-to-one ratio, he'd say that was a well-designed, well-balanced aircraft."

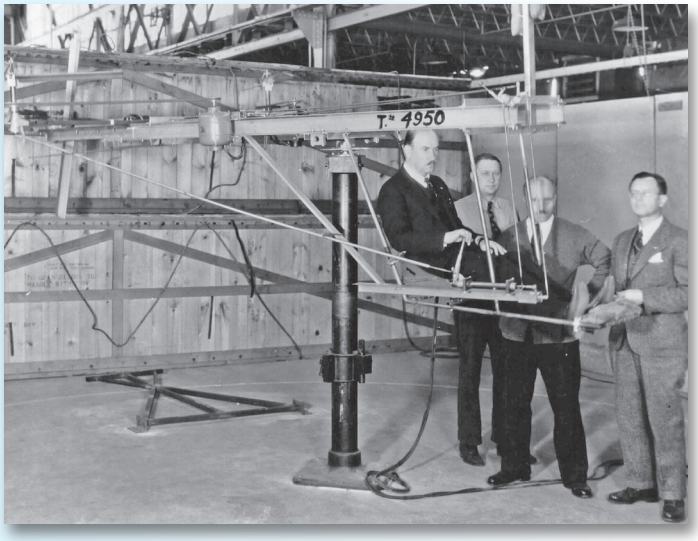
Sikorsky engineering overcame the unique challenges of the helicopter. "One of the times I saw my father truly relaxed and smiling was in Stratford, just after he'd established the world's endurance record for helicopters with the VS-300. There was a smattering of press people there and maybe 200 people from the factory who had come out in back of the old Sikorsky plant on the Housatonic River. I remember very clearly his flying or hovering the helicopter. When the sign was held up by one of the Sikorsky mechanics saying that Dad had just established a new record, you could see the smile on his face even though he was hovering maybe 50 feet away."

The VS-300 established a world endurance record of 1 hour 20 min in May 1941 and showed the Sikorsky helicopter was a viable product.

Hardened Helicopters

The VS-300 spawned production helicopters designed by a growing team of Sikorsky Aircraft engineers. In a September 2019 article for the Vertical Flight Society magazine Vertiflite, Ray Leoni recalled, "When I started work in June 1951 there were only 200 people in the engineering department. That number grew to 2,500 when I retired 41 years later. In 1951, the company was starting to rebuild its staff and production capacity as a result of the war in Korea and the military's need for more transport helicopters. For Sikorsky, that meant ramping up the S-55 and S-58 production lines eventually setting annual production records that peaked in 1957."

Leoni recalled, "About half of the engineering department consisted of Russian immigrants who left Russia at the time of the revolution. Many sought out Igor Sikorsky when he created his own company on Long Island. They were very motivated and dedicated people and very willing to help young guys who knew nothing about helicopters." Leoni continued, "There were no helicopter textbooks. There were no courses about helicopters in college and no company-sponsored educational opportunities at that time. To make learning even harder, there were no design manuals, no lessons-learned reports,



Igor Sikorsky, 'flies' the VS-300 simulator in 1938 surrounded by engineers Michael Buivid, Boris Labensky and Michael Gluhareff.

and in fact there were very few technical reports. The main source of technical information was in peoples' memories, so you needed to extract information from their heads.

"I recall being in Prof Sikorsky's office asking for help in calculating rotor performance. Professor Sikorsky, as he was called, was Igor Sikorsky's cousin who had become the company's chief aerodynamicist. When I sat down next to his desk, I noticed that his extra-long K&E slide rule was full of burn marks because he often rested his cigarette on the slide rule while doing something else. I asked Prof what he would do if the cursor ended up directly over a burn mark obscuring the answer to his string of calculations. Without hesitating, Prof replied, 'I make-ed verry good guess.'

Engineering at Sikorsky remained a hands-on activity. Leoni noted, "I remember starting my drafting career when everyone drew with pencil on paper. Some years later we changed from pencil on vellum to ink on Mylar and thought that was fantastic until you needed to make changes to the inked design. Much later, computer-aided design was invented which led not only to much greater engineering productivity but also to much better accuracy plus the ability to have remote design teams work together."

Increased helicopter production was matched by a growing engineering force at the Stratford North Main Street facility.

Leoni led design efforts on the Utility Tactical Transport Aircraft System (UTTAS) that would become the S-70 Black Hawk. "When Mr. Sikorsky was told about my design, he came over to my drawing board to see what it was all about. He said in such a nice way: 'Mr. Leoni, this is very ingenious but if we only modified this small part of your design, if we only changed this part, and perhaps this other part that would make it even better.' I ended up changing much of the design, but he made me feel like his changes were of my creation and not his. . . But he did ask me why the main rotor was so close to the top of the fuselage. I explained the need for a compact airframe to meet air transport requirements. Mr. Sikorsky understood the explanation, but he clearly felt uneasy about the main rotor location. He had at that moment pointed out what proved to be a major flaw in our initial UTTAS design that was later corrected by raising the rotor 15 inches. His intuition was right-on."

Bridgeport workers assembled Comanche No. 3 in November 2002 with graphic work instructions from CAD data.

Digital Tools, Digital Twins

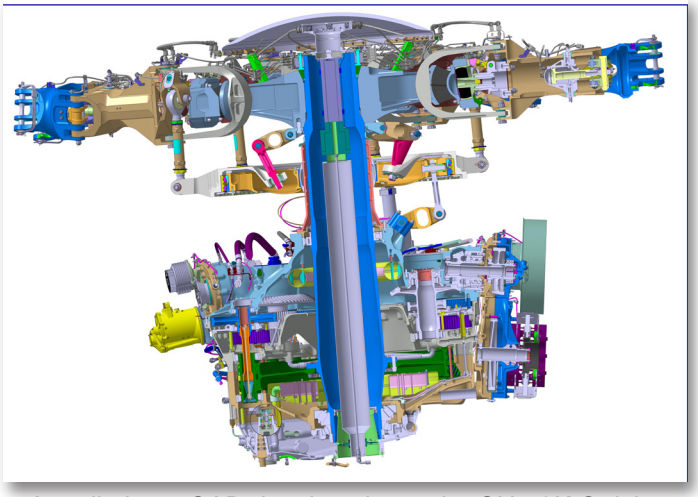
The UTTAS request for proposals was released in 1972, and the Sikorsky solution took shape in a two-dimensional design environment of paper and Mylar. When Sikorsky and Boeing formed

their LHX (Light Helicopter Experimental) First Team in 1988 to build the Army's next scout-at-tack helicopter, the RAH-66 Comanche, engineers adopted 3-D digital design and manufacturing plans. The Comanche database was stored in IGOR, the Stratford electronic drawing vault where it could be updated and shared by industry team members in different locations. Control points on the Comanche assembly line in Bridgeport had computer interfaces for assembly mechanics to call up graphic work instructions. The benefits of the use of digital technology soon became evident. The schedule for the initial assembly of the basic fuselage structure was one and a half weeks. The actual assembly took only a half day. The parts manufactured with digital design fit together so precisely no trim-and-fit was required.

The international S-92 team led by Sikorsky started preliminary design of the big, new transport helicopter in 1991 with two-dimensional CAD systems that replicated traditional drafting but stored drawings in electronic form. As collaborative design progressed, S-92 changes took form in a complete 3-D electronic mockup.

The S-92 had a 3-D electronic mockup shared with international partners.

When the Marine Corps CH-53K began system development and demonstration in 2005, design of the big heavy-lift helicopter relied totally on 3-D tools to create a digital twin of the real



A preliminary CAD drawing shows the CH-53K Quick Change Assembly.

aircraft. Digital twins – high fidelity virtual simulations of physical aircraft – promise to keep pace with changes throughout the real helicopter's life and may reveal component wear to manage maintenance and improvements. They are part of digital factory plans to optimize real-world manufacturing.

In July 2022, Lockheed Martin vice president of enterprise business transformation Mike Ambrose discussed Sikorsky's digital engineering and manufacturing transformation on the Made in America podcast. Ambrose served Sikorsky for 38 years in positions including chief engineer during the early stages of the fast, long-ranged Future Vertical Lift (FVL) initiative. "Now, the title is Enterprise Business Transformation," he explained. "People will often think of that as kind of like the interface between the design and manufacturing. It is a lot more than that. When I talk about supercomputers and high-performance computing, it starts with understanding how the helicopter's going to fly, even before you build it. There are all kinds of aerodynamic, acoustic, and vibration characteristics that we need to model at a conceptual level so we know what to design."

Sikorsky's proposed S-103 Raider-X Future Attack Reconnaissance Aircraft and SB>1 Defiant-X Future Long Range Assault Aircraft leverage

The Black Hawk engineering simulator tests cockpit changes in the UH-60M Systems Integration Lab.

the coaxial rigid rotor compound helicopter configuration demonstrated in the 1970s -- the S-69 Advancing Blade Concept. According to Ambrose, "What is different today is our ability to model how this advanced system works, and we've been able to do it with a really high level of accuracy that was unheard of, even maybe 10 years ago, 15 years ago. We do it with very little actual flight test data. If you go back to Igor Sikorsky, obviously, everything was trial-and-error and intuition. We didn't have computers. We didn't have anything to really base it on."

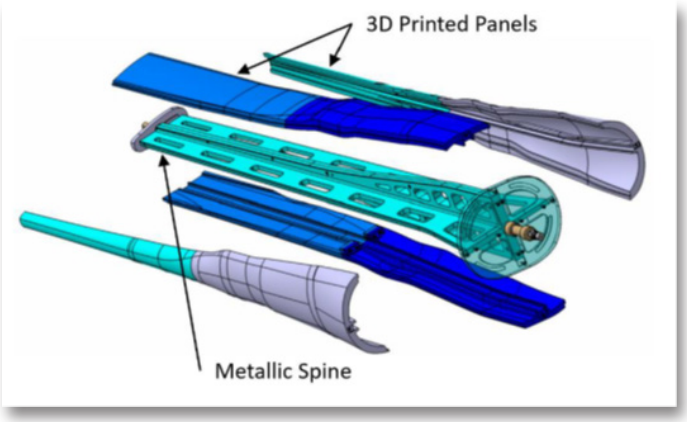
Model-based system engineering today provides a virtual foundation for physical flight test and can shorten historic fly-fix-fly development. "We're able to go and really maximize the data we have, and run through simulations, ultimately using artificial intelligence and machine learning to really predict how this revolutionary technology works. What we've been able to demonstrate over the last couple of years is that we were really good at it, to the point where we could fly the Defiant aircraft from West Palm Beach to Nashville, Tennessee, with a high level of confidence."

The Defiant Joint Multi-Role technology demonstrator was built to test FVL technology and design tools for the U.S. Army. The company funded-Raider modeled a notional armed scout. "We're able to fly what is basically a helicopter at almost 250 knots," noted Ambrose. "These flights are really validation of the tools and the processes that we had developed using computer simulations enabled by things like high-speed computing. We're able to really model and correlate what we saw in flight test to be able to ensure that the blade design and the shape of the blades and the way we tuned-out the airframe would provide us and the customer with the best vehicle possible."

A digital thread runs all through Defiant and Raider design, development, test, manufacture, and support. Ambrose explained, "The beautiful thing is because we talk about this digital thread, where there's a single source of data, everything's connected. We're simulating how the aircraft's going to perform. At the same time, we've got manufacturing engineers saying, 'Okay, [that's a] great blade shape, but I can't build that. Can you go and tweak this twist so at least I can build it for you?'. As you go through his iterations, we're simulating how we're going to go and fabricate and build it and how we're going to heat [cure] it in ovens."

The S-92 systems integration lab linked a cockpit simulator to actual flight control hardware to develop control laws and the pilot-vehicle interface.

Ambrose continued, "Once we get that done, we can go and build the tool that you're going to make that blade on. We can 3-D print it. . .[If] we need to go change a part of that -- the way it drops off, or the way it changes its taper. In the past, you would be looking at three to six months to go and make that change. We say, 'Give us a



Composite blades for the Raider X were made rapidly with 3-D printed tools.

couple of weeks and we're just going to go and additive-manufacture or modify this tool, and you'll have it in three weeks."

The digital thread also pays off in the digital factory where engineering data refines production processes. Ambrose noted, "One of the things that we're always looking at as we go and connect the digital thread. As we look to see how do we integrate processes, we also look at how do we integrate suppliers into that. By doing that, we're able to understand what are the processes that we need the supply base to focus on to be able to optimize our designs."

Computer-controlled torque wrenches on the CH-53K line ensure consistent assembly quality.

The digital factory already controls torque wrenches and other tools on Sikorsky's CH-53K production line to make assembly faster and quality more consistent. Mike Ambrose said, " Our workers embraced the transformation because it allows them to do their job easier, with better quality, less mistakes. The collaboration with our workforce on how we're able to go figure out these things together is an example of how, I like to think, engineers are pretty smart. We also have some really smart mechanics, who are there every day putting these things together, and they provide that feedback to our manufacturing engineers on how we can do it even better."

The Raider-X Future Attack Reconnaissance Aircraft leverages model-based systems engineering.

The Defiant Joint Multi-Role Technology Demonstrator proved digital design tools for Future Vertical Lift.

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Memberships and Donations enable us to continue the Archives mission of acquiring, managing, protecting and disseminating historical documentation associated with Igor Sikorsky and his legacy

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Thank You

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October 2nd Ribbon Cutting celebrating the opening of a Sikorsky exhibit at the Discovery Science Center and Planetarium (DSCP) in Bridgeport, Ct. The exhibit covered Igor Sikorsky - The Man and His Legacy. From L to R: John Petillo, Sacred Heart University (SHU) President, Paul Lemmo, President Sikorsky Aircraft, Sergei Sikorsky, Director Emeritus, Igor I. Sikorsky Historical Archives (IISHA), Dan Libertino, President, IISHA, Robert Panza, DSCP Board Chairman, John Bulakowski Vice President, IISHA, Mike Alfano SHU Vice Provost, Erika Eng, Executive Director, DSCP.

Prepared by Frank Colucci and John Bulakowski with graphic art and layout by Jodi Buckley.

"All the history of engineering and scientific development of the last century definitely indicates that the impossible of today becomes probable tomorrow and is being accomplished the day after tomorrow. Therefore, the development of this nature does not seem impossible even though at present we may not know how it can be done."

Igor Sikorsky — *The Story of the Winged-S*

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