Starship History

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A five and a half year development program has resulted in an FAA certified aircraft -- the world's first pressurized all-composite business turboprop. The program cost more than $300 million and millions of man hours. The task was larger than simply developing an all-new aircraft. Beech Aircraft had to master a new technology, build a new manufacturing facility and train a workforce. Much of this effort was concentrated on areas the industry had not addressed before.

Beech had to work hand-in-hand with the FAA to develop the standards for the construction of composite aircraft, because none existed. The company also had to comply with a series of special conditions set by the FAA to certify the unusual configuration. The way in which Beech accomplished those things will have a profound effect on future designs.

In 1979 Beech decided to begin to work on a new twin-engine turboprop aircraft. The King Air was about 15 years old and with its six models had about a 50 per cent market share. The remainder of the business turboprop market was divided among Cessna, Piper, Mitsubishi, Swearingen and Rockwell. A new company, Learfan, had announced an unusual-looking aircraft made out of composites which was scheduled to reach the market in the early 1980s.

What's new and works

Beech began by studying a number of potential designs, some radical, some quite conventional, including a tractor/ pusher and a twin-pusher version. Beech's merger with Raytheon caused a temporary hiatus in development activity, but by 1982 work was underway again.

The design goals became the configuration driver, and soon one design emerged from the pack. It had its engines mounted in the rear to reduce cabin noise levels. It had an aft positioned main wing to mount the engines and balance the lifting forces. A conventional rudder would have made a huge sounding board for the propellers, so, instead, control of the yaw axis and vertical stabilizer function was assigned to tip-sails on each wingtip.

The King Air's large cabin had always been a major selling point, and the new Beech design had an even larger one, approaching the size of a medium jet's. Increased size brings increased weight, and the decision was made early on to build using composites for its favorable strength-to-weight ratio.

The world's acknowledged expert in tandem wing, all-composite pusher aircraft at that time was Burt Rutan. In 1982 Beech approached him and his company, Scaled Composites in Mojave, California, to participate in the final configuration study.

The result was the design for Starship, with its variable sweep forward wing, all composite construction and rear-mounted Pratt & Whitney turboprops. While Beech began preliminary design of the full-size prototypes, Scaled Composites was engaged to build an 85 per cent scale proof of-concept prototype to flight test the configuration.

The proof-of-concept vehicle was completed in record time, and made its first flight in late August of 1983. A little over a month later the new aircraft, now called Starship, was introduced at the National Business Aircraft Association Convention in Dallas, Texas.

When the Proof of Concept Starship made its first appearance in late 1983, it seemed to most people like a very real aircraft. It was as large as a 90-series King Air, it looked good in the air and clearly performed well. To the uneducated observer it appeared you could put an interior in it, tweak the design here and there and begin a certification program. Sadly, this was not the case.

The Proof of Concept had no certifiable systems and no pressurization. It did not have any of the airframe structure that would be built into Starship, and it was not even built out of the same materials. It was, quite simply, a very large flying wind tunnel model, designed for a program of 100 test flight hours or less -- although it flew five times that long.

Not only was the development not very far along, but Beech Aircraft had virtually no experience with the materials or the manufacturing techniques required to build it. We had never built anything out of composites, and we did not have any data on the properties of resins, fibers, adhesives, composite honeycombs or sealants necessary to design it.

But the Proof of Concept Starship's appearance at Dallas gave the impression we were much further along and much more knowledgeable than we actually were, and that gave some credence to the extremely optimistic schedule that we initially announced for certification -- the end of 1985.

The company had a plan to meet that schedule, by having the majority of the three prototypes built in subassemblies by outside contractors, with final assembly to take place at Beech.

Development frontiers

In theory this might have been a workable plan, but in practice it definitely was not. By early 1984 it was clear the subcontractors could not come close to delivering on time, and some may not have been able to deliver at all. If there was going to be a Starship, Beech Aircraft would have to develop the technical skill to build it by itself.

Clearly this would require more time, so we set a new target date: certification by the end of 1986. It was particularly unfortunate for the image of the Starship program that the 1985 certification target date was ever announced. Less than five months after the program was introduced, it had been branded as delayed. That impression has remained ever since.

In fact, from the time the program was put on a realistic schedule in early 1984 it has experienced only two delays: the first was announced in mid-1986 when we chose to redesign the aircraft to take advantage of the new FAA regulations to certify at 14000 pounds. The second came at the beginning of 1988, and was necessary to correct a pitch damping problem and to develop a stall warning system that would adequately define a stall on an aircraft inherently designed not to stall. This was the only unplanned delay necessary to resolve technical problems in the program's five year history.

All to production standard

The new schedule called for six prototypes, including three flight test articles and the equivalent of three more for static, environmental and damage tolerance testing. As work got under way it began to divide itself into three broad categories: development, certification and production.

In a more conventional program, production would have taken a back seat to development and certification, but the nature of composite construction -- making parts in moulds -- virtually dictated that Beech build the Starship prototypes with production tooling, and that gave production an equal priority. To accommodate production we added 242,000 sq ft of manufacturing space.

Having been active in metal bonding technology for nearly 30 years, the company had seven operating autoclaves, the largest of which was 12ft in diameter by 30ft long. This was not large enough to support Starship production activity, but with minor design compromises would work to build the prototypes.

To support full-scale Starship production and to handle the composite subcontract work that was hoped would follow, a huge new autoclave, 60x25ft was installed. When completed, it would be the second largest in North America.

Much of 1984 was taken up with building the tools and manufacturing facilities required, and by 1985 a start was made on building parts for Starship prototypes and assembling the aircraft.

Before tooling could begin, Beech had to accomplish the loads analysis and verification work required to validate the design of the structure, because of Starship's configuration, the FAA required the generation of substantially more aerodynamic loads data than would have been usual for a conventional design. It had to be proved that classical loads analysis techniques would conservatively apply to a tandem wing design.

Thorough wind tunnel testing established the pressure distributions, which were corroborated with computer-generated analysis. The computer's findings were confirmed with flight tests on the Proof of Concept using pressure taps.

With the loads confirmed, the complex and time-consuming process of developing a materials data base for composite structure began, because none existed. To arrive at this base, Beech installed a materials test laboratory and began experimenting with the lamina properties of the raw materials -- the tapes, fabrics and resins.

Starting with individual plies, we identified the properties of the various materials, established statistically reliable minimum values, and ultimately produced more than 8000 data points from which we could predict how an element made of a specific material would react to various loads and environments.

The next step was element testing, building small test panels that simulated the full range of structure. These were subjected to wide-ranging conditions of temperature, moisture, and static loads in shear, compression and tension. Then they were subjected to cyclic loading to demonstrate damage tolerance capability. Ultimately, an in-house software package was developed to prove we could successfully predict failure loads and modes.

Mistakes -- catch 'em young

The purpose of all the testing was to reduce the risk level of the overall program. If an article was inadequately designed, we wanted to know before we reached the full-scale test stage. It is much less expensive to redesign early in a program. The goal was to make full-scale testing a validation program, proving what we already knew was going to work. We were very successful in this area, for the vast majority of static test articles performed flawlessly. In the few instances where problems were experienced, minor redesign was sufficient to correct the situation.

More than 128 static load conditions were tested on the various Starship static test certification articles, both at room temperature and at elevated temperatures with moisture conditions to simulate more extreme environmental conditions than the aircraft could ever be expected to encounter.

In a conventional metal airplane the next step would have been fatigue testing. Composites do not fatigue in the way metal does, so cycling composite structure does not cause it to lose strength or crack. It was necessary, however, to prove that Starship's structure could carry design loads even with inflicted damage. To do this we applied more than 1.6 million test cycles to various critical assemblies.

The FAA did not have established design-life criteria for composite structures, and it was through the materials data base developed in the test program that the standard for future designs was developed, a cycle test structure for one lifetime (20000 hours), inspecting for damage every 5000 hours; inflict damage, and cycle test it through a second lifetime. If it will carry limit load at the end of the test, the structure is approved.

Not all structures can be made as a single piece, some must be attached together, and this is typically done with either film or thicker paste adhesives; the work accomplished in certifying Starship has become the basis for industry standards on adhesively-bonded structures.

Multiple redundancy

Large primary structural assemblies must be designed so that in the event of any one bonded joint failing, the remaining structure will still be able to carry the design limit load and retain sufficient stiffness to resist flutter with a safe margin above maximum operating speed.

Beech uses ultrasonic testing to ensure the quality of every structural part that goes into a Starship. Sound waves, passed through water, measure density and detect flaws or voids.

Crashworthiness and occupant safety has also been an important consideration in the design, so fuselage drop tests at increasing energies were made until visible damage, then a second article was dropped at the required energy level to see what effect it would have on the occupants. The goal was to contain maximum lumbar loads below 1500 pounds, the level at which crippling spinal injuries are likely to occur; we hoped to stay below this level with a 10 ft/s drop.

In the final test a fuselage section dropped at 17 ft/s incurred no damage, and the anthropomorphic dummies inside sustained a spinal load of only 1000 pounds.

Sled testing, to 269 for crew seats and 219 for passenger seats, has been done in keeping with the recently-established standards of the General Aviation Safety Panel.

One of the greatest challenges to building and certifying an all-composite airframe is lightning protection. Unprotected composite material can be blown apart by a lightning strike. This occurs because graphite epoxy is 1000 times more resistant to current flow than aluminum, and the high resistance converts the current flow to heat.

Lightning protection was the subject of intensive study and testing; for instance a fuselage section absorbing a 200 000 amp simulated lightning strike generated in our test facility. Only 1 in 200 lightning strikes is likely to contain that much current. By comparison, normal US house current is only 20 amps.

We had to be able to demonstrate compliance with the Federal Aviation regulations concerning protection of structure and fuel systems, as do all metal aircraft, but we also had to show that Starship could sustain a lightning strike without damage to avionics or other electrical components.

This was accomplished by using a combination of fine wires in the first layer of composite skin and a ground-plane system to shield the electronics, allowing the lightning current to flow through and out, leaving only minor surface and cosmetic damage at the strike point.

There is an old saying that lightning will never strike the same place twice, but the FAA does not believe it for they were concerned about the ability to repair lightning strike damage in a way that would continue to offer lightning protection. To prove this, wires or thin aluminum sheets were added at the time of repair.

Struck lucky

During the course of final certification testing the number two prototype, NC-2, sustained lightning strike. The lightning attached itself to a test pod mounted on the aircraft, one being recorded on videotape at the time. In a remarkable piece of footage the strike was filmed from inside the aircraft, showing the lightning striking the front of the pod and exiting from the Starship's tip-sail and rudder. The aircraft was unscathed.

The avionics system was developed specifically by Rockwell Collins Avionics, and consists of a 16 tube EFIS panel (Electronic Flight Information System). Basically, these are TV tubes that display information on the lines of a conventional T; the method is also known as the glass cockpit.

The primary flight display shows aircraft attitude, as well as the flight director commands, lateral deviation, glide slope, radio altitude and marker beacon. The pilot can select display of flight guidance modes, autopilot status, airspeed deviation, decision height alert, altitude alert, ILS deviation alert and minimum descent altitude alert as desired. Our philosophy is to provide the pilot with as much or as little information as desired to accomplish the job.

The airspeed indicator provides the classical dial readout, as well as outside air temperature and true air speed; it also has a trend feature which will predict the aircraft's speed in ten seconds at the current rate of acceleration or deceleration.

Over on the right of the T we have a unique instrument that combines the altimeter and vertical speed indicator functions, as well as an altitude alert. It displays barometric altitude, pre-selected altitude, barometric setting, and a flight-level one-eight-zero alert.

During an instrument approach, either crew member can set radio altitude decision height on their respective altitude awareness panels and the readout will appear on the primary flight display. Decision height and radio altitude display appear automatically on the screen when the radio altitude passes through 2500 ft descending.

Another key element of the T-display is navigation information, where the display shows the aircraft's horizontal navigation situation in a familiar manner, with heading, selected heading, selected navigation source, selected course and lateral deviation.

The primary navigation function can be displayed in any of three modes -- the Horizontal Situation Indicator (HSI) mode shows the full compass rose traditionally displayed on conventional EFIS and electromechanical displays; the are mode displays a 70" section of the compass, for a closer look at a developing situation; and the map mode adds a graphic representation of waypoints to the are display.

Starship's radar display can be superimposed on the are or map modes to assist in circumventing weather or turbulence. The radar itself is a Collins TWR-850 unit which uses Doppler technology to help predict where turbulence might exist.

Avionics enhance safety

Flight experience in the Starship prototypes has shown that the unit is capable of accurately detecting and displaying turbulence, sometimes in areas where conventional radar sets showed only light rain. The avionics display offers a conventional presentation, but one that is also enhanced with capabilities not previously available to the general aviation pilot. The design driver is function, with developed features that reduce workload and provide real-world information to increase the ease and safety of flight.

Engine instrumentation is also generated on video tubes, in a display called EICAS (Engine Indication and Crew Alerting System). The engine instruments are presented in a traditional turbine display, but the pointers on Starship's EICAS change color from green to yellow or red to alert the crew to any abnormal condition.

Generally the philosophy in EICAS has been that simpler is better, and the system is designed to produce minimal or, in many cases, no display when the aircraft is operating normally. When an abnormal condition begins to occur, one of eighty color-coded caution, status and advisory annunciations light to alert the pilot. The system also records and stores the data, including the time and date it occurred.

This gives maintenance personnel an unprecedented record of aircraft operation, and should contribute to reduced engine operating costs.

Even as the materials testing and verification was taking place, Beech was building Starship prototypes to be used in static and flight testing. The computer has been a significant tool in this effort. Beech made extensive use of computer-assisted design in development work, and this allowed the analysis of the aircraft as no Beech had ever been before.

Prior to today's computer technology we would design a wing and do a number of theoretical load equations in various flight regimes. The computer allows us to look at thousands of cases, where once it was practical to only investigate a few dozen at best.

But the computer played a much larger role in development and manufacture than simply predicting loads, for a major portion of the work was done on a system called CATIA, which provides a three-dimensional design environment and interfaces with tooling; an interesting result of this system's use is that our drawings do not have dimensions-on them.

Computers will continue to play a major role in Starship production for many years, because Beech is converting to a paperless factory. When that is accomplished there will be personal computers throughout the shop floor, and when someone needs to build a part the instructions will be called up on the computer screen.

Parts orders will come through the computer system, completed parts will be inventoried, and management will be able to generate real-time parts inventories at any time. A bar code system, such as used at supermarket checkouts, will be used for quality control and to ensure that only approved employees have access to tooling and information.

Every operation of the factory will be instituted and monitored to completion on computers. Portions of this system are on line now, and more are being added monthly. Complete conversion will take about four years.

More than any aircraft ever built in general aviation, Starship is a child of the computer age; its design, development, manufacturing, operation and maintenance all benefit heavily from computer input.

The first full size Starship made its maiden flight on 15 February 1986. The second joined the test flight program in June 1986, and the third was ready for flight in the early spring of 1987.

In the course of a two-year flight test program they have flown almost 2000 hours in pursuit of certification for the most ambitious new development project in the history of general aviation, and on 14 June it received FAA certification. The first production Starship, NC-4, went on flight test late 1988.

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