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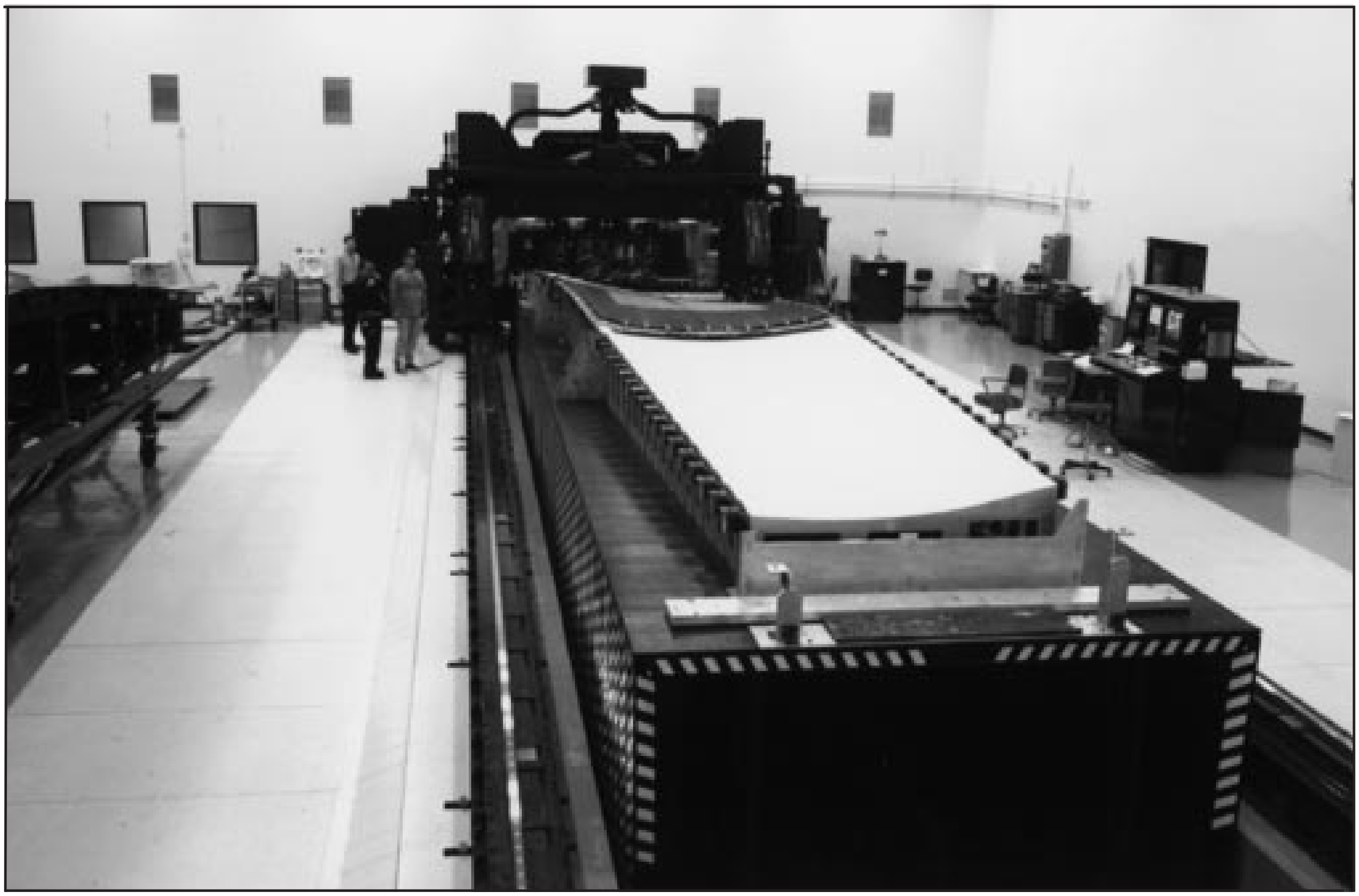
The Advanced Stitching Machine:

Making Composite Wing Structures Of The Future



NASA's Advanced Stitching Machine is located at the Marvin B. Dow Stitched Composites Development Center--a new Boeing facility that will produce low-cost composite wing structures.

From the World War II image of "Rosie the Riveter" bolting together war planes to the jets flying overhead today, Americans have always associated metal airplanes with strength. However, aircraft designers today are turning to composite materials to meet the growing challenge of maintaining safety and economy for commercial air travelers. Anticipating this challenge, NASA and Boeing have joined forces under the NASA Advanced Composites Technology (ACT) program to make large composite airplane structures a reality.

Here, the full span of the stitched/RFI wings is shown. Composites will make up all but the leading and trailing edges of the wing. The largest portion of the wing, called the wing stub-box (shown bottom right), was tested at NASA Langley in July, 1995.

The ACT Program

The NASA ACT program was set up in 1989 to improve the efficiency of composite structures and to reduce their manufacturing costs. The program aims to reduce air travel costs through the use of composite materials on commercial aircraft.

The Advanced Stitching Machine (ASM) was designed and built under the ACT program to aid in making large structures out of composites. The goals of the ACT initiative are to make composite wing structures 25 percent lighter, to reduce production costs by 20 percent and to reduce operating costs to airlines. The ACT program will develop the scientific basis required for FAA certification of composite wings. The program will also help accomplish one of NASA's new technology goals for aeronautics--to reduce the cost of air travel by 25 percent within 10 years, and by 50 percent within 20 years.

Background

NASA's early composites research provided the aircraft builders with important technology but the industry lacked the confidence to use laminated composites to manufacture wing and fuselage structures. The barrier issues were high cost and low damage tolerance. Industry wanted composite structures that cost less than aluminum and that were robust enough to withstand the rigors of airline services. However, low damage tolerance remained an issue despite major efforts to develop new tough epoxy resins.

In the 1980s researchers looked to textile composites as breakthrough technology. Supporters argued for new concepts which would use knitting, weaving, braiding and through-the-thickness stitching for reinforcement and use existing U.S. textiles manufacturing technology for cost efficiency.

Under the ACT program, various types of textile composites were thoroughly tested but it was stitching combined with resin film infusion that showed the greatest potential for overcoming the cost and damage tolerance barriers to wing structures. Assembling carbon fabric preforms, (pre-cut pieces of material), with closely spaced through-the-thickness stitching provided essential reinforcement for damage tolerance. Also, stitching made it possible to incorporate the various elements--wing skin, stiffeners, ribs and spars--into an integral structure that would eliminate thousands of mechanical fasteners. Although studies showed that stitching had the potential for cost-effective manufacturing, the critical need was for machines capable of stitching large wing preforms at higher speeds.

Evolution of Textile Technology

A primitive single-needle stitching machine, resembling a scaled-up version of a household sewing machine, was the first prototype used to determine the benefits of stitched composites. This initial research identified that stitched composites offered better levels of damage tolerance than conventional laminated composites.

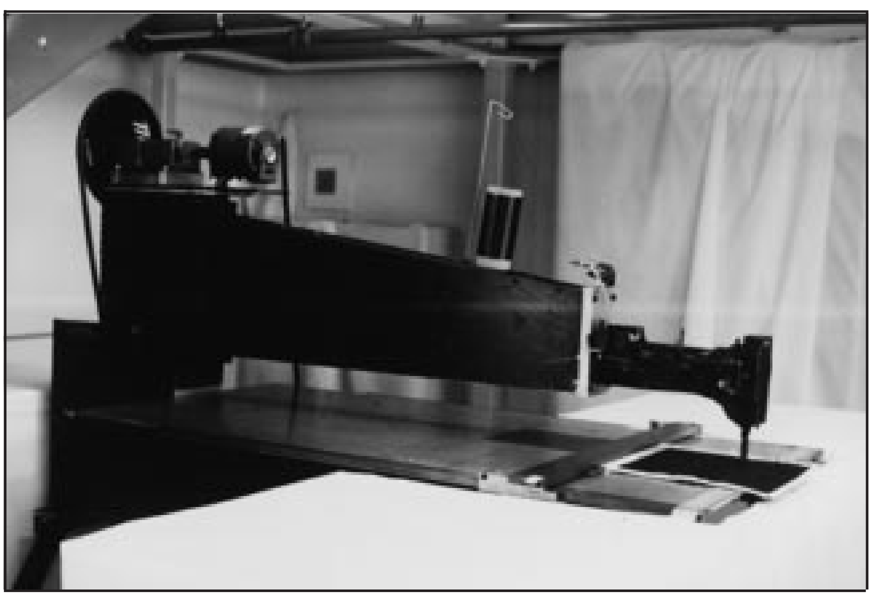
Under a six-year NASA ACT contract, Boeing chose the stitching of dry textile fabrics, in conjunction with the resin film infusion (RFI) process to develop cost-effective wing structures. For stitching the skins of large test panels, a multi-needle quilting machine was obtained and modified to demonstrate a manufacturing approach to stitching layers of carbon fabric. Although the multi-needle machine served important needs in the wing development, it was relatively slow and unable to stitch thick layers of fabric.

The next step in the development was a computer-controlled single-needle gantry machine that could stitch through the thick carbon fabrics. Both the multi-needle and single-needle gantry stitching machines had unique features and capabilities; however, neither were designed with the capability to quickly stitch large, complex contoured wing structures.

NASA awarded Boeing a contract to develop a larger machine capable of stitching entire wing covers for commercial transport aircraft. This high-speed, multi-needle machine, known as the Advanced Stitching Machine (ASM), was designed and built under the NASA ACT wing program. Under subcontract to Boeing, Ingersoll Milling Machine Company, Rockford, IL, was selected to design and build the ASM. The ASM's advanced stitching heads were designed and built by Pathe Technologies, Inc., Irvington, NJ.

Concurrent with the development of the large stitching machine, NASA and Boeing proceeded with a building block approach to demonstrate the design and manufacture of stitched/RFI wing structures.

The largest of the demonstration sections was a 12-ft. long wing stub box which was fabricated at Long Beach, CA, and tested at NASA Langley Research Center in July 1995. The wing stub box manufacture demonstrated that the stitching/RFI concept could be used to make the thick composite structures needed for heavily loaded wings. The successful test of the stub box proved the structure and damage tolerance of a stitched wing.



This single-needle sewing machine was used in exploratory research on stitched composites.

New Composites Manufacturing Process

The stitched/RFI composite wing manufacturing approach uses three textile processes--knitting, braiding and stitching.

Knitting

The basic "skin" of the composite wing upper and lower covers is made using knitted carbon-tow fabrics. A commercial supplier delivers multiaxial warp knit fabrics stacked as specified by Boeing. Next, the stacks are cut into the pieces that form the shape of the wing (preforms). The knitted preforms are stacked with as few as two stacks in low-stress areas and up to twenty stacks in high-stress areas. When the fabric pieces are arranged in the proper position, the ASM stitches the stacks to make a solid wing preform.

Braiding

The stiffeners and rib clips for wing covers are made using a braiding process which makes it easier for them to conform to the contours of the wing. Braided tubes are collapsed and stitched to make blade-shape stiffeners and rib clips.

Stitching

In a final step, the ASM stitches the stiffening elements to the skin preform. The result is an integral wing cover preform, shaped to the wing contours, ready for the RFI process.

The Role of the ASM

The ASM is an integral part of the stitched/RFI composites manufacturing process. With through-the-thickness technology, the ASM's stitching heads can penetrate through textile preforms 1.5" thick. This type of stitching increases damage tolerance and load capability especially when assembling and binding secondary materials--stiffeners, spar caps and intercostal clips--onto the skin.

Stitching materials together is also faster than drilling holes and assembling the 80,000 metal fasteners found on an aluminum wing. Removal of this excess metal decreases the weight of the wing and eliminates the problems of fatigue or corrosion of the metal fasteners.

The RFI Process

When the stitching is complete, the still flexible wing skin panel is put into an outer mold line (OML) tool that is the shape of the outside surface of the wing. A film of resin is laid on the OML form, followed by the composite skin panel and the tools that will define the inner mold line.

These elements are put into a plastic bag from which the air is drawn out, creating a vacuum.

The materials are then placed in an autoclave, where heat and pressure are applied to let the resin spread throughout the carbon fiber material. After heating to 350 degrees for two hours, the wing skin panel takes on its final hardened shape.

The stitched/RFI method differs from conventional composite methods in which the composite material with the resin already impregnated (pre-preg) is laid down on a tool before being put into the autoclave. The new RFI process eliminates the cost of conventional pre-pregging and its time-critical setup.

Analytical models are used to predict several factors in the RFI process to reduce the risk of failure. Engineers have to factor in the viscosity of resin, compaction and permeability of the fabric materials, and length of processing time before the resin sets.

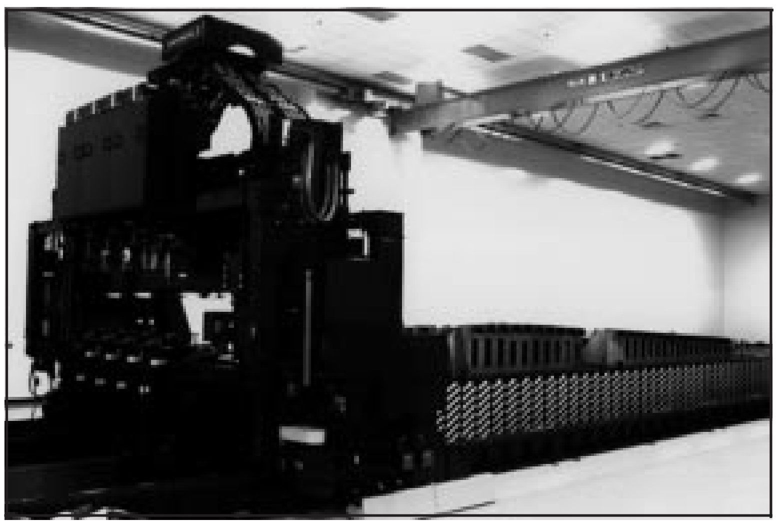
The Future of The ACT Program

The panels currently being stitched on the ASM will eventually be used as test articles in a full-scale ground test of a composite wing for an airliner. A test of this forty-foot semi-span wing will take place at NASA Langley's Structures and Materials Laboratory in 1999. The tests will simulate various levels of damage to ensure that the composite wing meets FAA standards. The ACT program will be completed in the year 2001.

Advanced Stitching Machine

In this cost-sharing effort, NASA has spent $10 million on the development of the ASM and Boeing has paid for the renovations at the Marvin B. Dow Stitched Composites Center at Huntington Beach, CA, where the ASM will be housed. (The building had to be modified for the huge machinery of the ASM, with the inclusion of specialized equipment.)

The ASM features high speed stitching capability with advanced automation allowing it to stitch large, thick, complex wing structures without manual intervention.



The ASM's 50 lift tables can be seen outstretched behind the stitching heads in front.

Equipped with four stitching heads, this massive machine is able to stitch one-piece aircraft wing cover panels 40-feet long, 8-feet wide and 1.5-inches thick at a rate of 3,200 stitches per minute. The stitching heads also offer machine tool precision, stitching at 8 stitches per inch with a row spacing of .2 inches.

However, to achieve this rate, a pivoting or walking needle mechanism and needle cooling system had to be developed. These improvements prevented excessive needle bending and associated temperature build-up in the needle. In addition, to maintain desired stitching speeds, an automated thread gripper and cutting mechanism was developed.

A technological marvel, the ASM has computers controlling 38 axes of motion. The computers are also used to simulate and confirm the stitching pattern on the 50-foot bed of the ASM.

A laser projection system is used to precisely locate the wing skin on the lift table surface before stitching begins. This same aerospace precision is used to locate secondary materials, like the stiffeners, for stitching.

The movements of the stitching heads are synchronized with each of the fifty lift tables it takes to control stitching over the contoured shapes of the wing panels. The lift tables are used to support the dry fabric preforms as they are stitched.

Live-feed cameras are mounted to let operators monitor stitch formation for real-time quality assurance. The machine gantry operates on precisely aligned rails that are 75 feet long. In total, the machine measures 75 feet long, with specialized machinery stretching 20 feet below ground and 20 feet above ground.

The ASM is capable of stitching wing cover panels in one, two-shift operation saving days over conventional composite manufacturing processes. Cost analyses indicate that a reduction of 20 percent in cost can be achieved over equivalent wings built from aluminum.

This, together with the reduction in weight, translates to a much improved competitive position for airlines in the global market and ultimately a reduction in future air travel costs.

Marvin B. Dow Stitched Composite Development Center

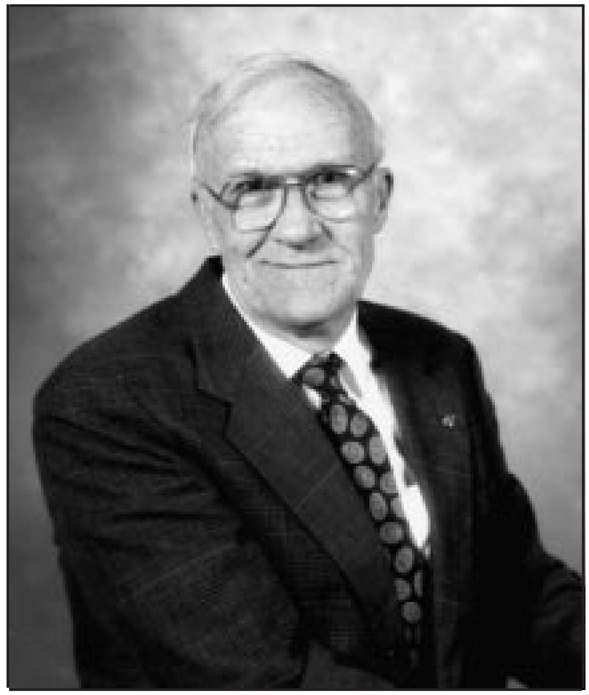
Boeing named its new Stitched Composite Development Center after NASA Langley researcher Marvin B. Dow in honor of his contributions to stitched composites research and, specifically, to the Advanced Stitching Machine (ASM). Dow spent the last 25 years of his 40-year NACA/NASA career in pursuit of the application of advanced composite materials on commercial transport aircraft. He is the first NASA employee honored in the naming of a corporate facility.

Dow's composites research began in the 1970s. His work on composites led to the flight testing of graphite/epoxy rudders on the McDonnell Douglas DC-10 commercial transport aircraft.

During the next 10 years as a key technical leader in the NASA AirCraft Energy Efficiency (ACEE) Program, he was instrumental in developing composites technology for application to structures on DC-10, B-737 and C-130 aircraft.

In the late 1980s, Dow conducted pioneering research on innovative reinforcement concepts that would lead to improved damage tolerance and reduced cost compared to state-of-the-art composite manufacturing methods. This research focused on textile reinforcement concepts such as weaving, braiding, knitting, stitching and resin transfer processes. In 1989, Dow became the technical manager of the NASA ACT Wing Program. Dow worked with Boeing, (then McDonnell Douglas), to develop the ASM and the stitched/resin film infusion process. His vision of large-scale automated stitching technology finally came to fruition with the success of the ASM. The ASM--made possible by Dow's long-term dedication--is expected to revolutionize the way aircraft wing structures are fabricated.

Dow retired from NASA Langley in September 1996 and currently serves the Center as a Distinguished Research Associate. His latest project is a technical summary and bibliography titled, "The Development of Stitched, Braided and Woven Composite Aircraft Structures in the U.S. (1985 to 1997)."



Marvin Dow, Distinguished Research Associate with NASA Langley, spearheaded the development of the ASM.

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