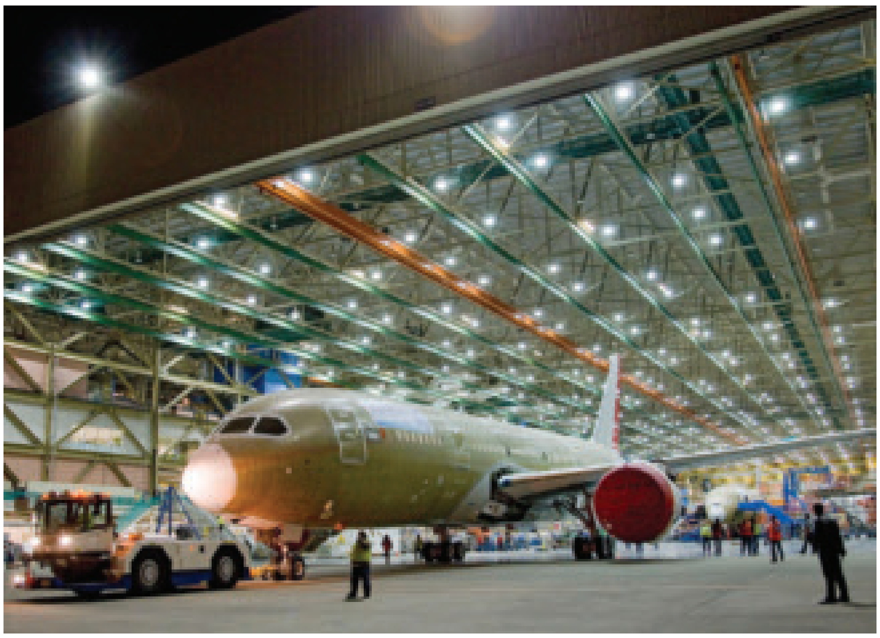
Boeing's 787: trials, tribulations, and restoring the dream

As we anticipate the long-awaited first flight of Boeing's 787 Dreamliner, George Marsh reviews the history of this high-profile composites project.

Four years ago, Boeing promised a dream of an airliner; in fact it named its new B7E7 (subsequently redesignated B787) mid-size, wide-body passenger twin-jet, the Dreamliner. Among its claims was that this aircraft, super-light by virtue of its unprecedented 50% (by weight) composites content, would be 17% more fuel efficient than the metal B767 it was intended to replace, as well as more comfortable for passengers.

Unhappily the dream has soured somewhat, the project having become mired in serial snags and delays. Boeing has experienced a veritable nightmare with its 'plastic fantastic' and has struggled to put the project back on track.



ZA004, the fourth flight-test 787, being moved from the final assembly bay to a temporary facility at Aviation Technical Services (ATS), south of Paine Field in Everett, Washington. Boeing has leased hangar space from ATS to perform the side-of-body modifications. (Picture © Boeing.)

Over confident?

In reality, the planemaker's original vision should ultimately be realised. To aircraft operators prepared to invest in even a 1-2% improvement in fuel efficiency, a 17% hike does appear to be the stuff of dreams.

A large part of this improvement is due to the low airframe weight realised by making it half composite. Boeing took a real flyer (sic) in adopting carbon/epoxy for the fuselage, as well as the more usual wings, empennage, fin and nacelles. This trumped anything Airbus, a previous leader in exploiting composites for civil airliners, was then doing. The US planemaker went further out on a limb by deciding to wind its fuselage, using fibre placement, in barrel sections that would then be joined. Only Raytheon Aircraft (subsequently Hawker Beechcraft Inc) had done anything like it before, with its much smaller Premier and Hawker 4000 business jets.

As if this level of risk were not enough, Boeing elected, at the same time, to adopt a new manufacturing model. Its vision was to have the airframe produced in several large sections, each of which would be farmed out to a major cost and revenue-sharing partner which would be fully responsible for detail design and production. Finished sections, complete with all their systems and internals, would then be brought together at Boeing's aircraft factory at Everett, Washington, USA, for final assembly, inspection and flight preparation.

Did the world's joint leading airframer over-reach itself? Troubles that have subsequently ensued might suggest as much and a lot depends on how well, or otherwise, the project is now recovered.

Certainly the company appears to have been guilty of over-confidence. On the adoption of composites, for instance, John Leahy, chief commercial officer at Airbus, referred to Boeing's approach as 'rushed and ridiculous.' More surprisingly, a former senior Boeing engineer, Vince Weldon, reportedly warned that the risks of attempting a composite fuselage had been under-estimated. Others suggested that issues associated with using carbon for the critical pressure vessel that is an airliner cabin – lightning strike, the fact that damage can be hidden within the laminate, repairability, long-term fatigue behaviour, crash behaviour etc – would consume more time and resources than had been allowed for.

Composite airframe

But the thought of a super-light, largely monocoque plastic fuselage that would require 50 000 fewer fasteners than a metal equivalent, and could boost passenger comfort by being pressurised to a 5000 ft service altitude rather than the industry-standard 6000 ft, was highly alluring. Boeing had already built and tested its first composite fuselage section when working on its Sonic Cruiser project almost five years previously and executives were convinced that the advantages justified the risks.

Sonic Cruiser, an intended advanced Mach 0.98-capable airliner, had been conceived at a time when speed still held sway as a leading design driver. The re-ordered priorities of a post-'9/11' world led to the project's demise, but Boeing, determined to salvage as much as possible from this debacle, was keen to migrate the concept of an extensively composite airframe to a more conventional airliner that would nevertheless deliver 'dream' qualities. Executives argued that years of experience in exploiting composites for nacelles, empennages and control surfaces had made these materials a known quantity and said that special defect detection and repair procedures being developed by the company would address concerns being expressed by some potential customers. For instance, Boeing stated that the new airliner would meet lightning requirements, especially in view of a mooted easement of these by the FAA (Federal Aviation Administration).

Nose section fabrication at Spirit Aerosystems facility in Wichita, Kansas. (Picture courtesy of Spirit Aerosystems.)

After assessing market reaction to its concept and carrying out an information campaign to dispel lingering customer doubts about composites, Boeing launched the B7E7 in early 2003. The B787 designation was adopted the following year and the 'Dreamliner' name was added after a public naming competition.

Early success

There were early signs of success. The market reacted enthusiastically to the idea of a low weight, low maintenance B767 replacement that would consume almost a fifth less fuel per passenger mile than its predecessor, and orders poured in. First to sign up was Japan's All Nippon Airways (ANA) with a requirement for 50 aircraft. These included 30 of the 290-330 seat B787-3 variant and 20 of the 210-250 seat B787-8 version for long-haul routes. Orders and commitments for 237 aircraft were achieved during the first year of sales and, by July 2007, firm orders received for 677 aircraft made the 787 the world's fastest selling widebody airliner ever before entry into service.

Boeing had also seemingly assembled a formidable supply chain and was leaning its aircraft manufacturing operation at Everett accordingly, encouraged by a similar system that seemed to be working for its earlier metal B737 narrowbody jet. Suppliers signed up initially included Alenia Aeronautica of Italy, Vought Aircraft Industries in the USA and Japanese suppliers Fuji, Kawasaki and Mitsubishi Heavy Industries. Also on board were two engine manufacturers; customers could choose

The first 787 nose section, a single composite part. (Picture © Boeing.)

between the Rolls-Royce Trent 1000 and the General Electric GEnx. Toray Industries was to expand its carbon fibre manufacturing capacity by almost 40%, including a new prepreg factory in Japan, so that it could provide up to an estimated $6 billion worth of carbon, most of it for the 787. This reflected Japan's position as the leading national partner, its project share of some 35% equalling that of Boeing itself.

Today the wings and central wing box are produced in Japan. Italy's Alenia makes the horizontal stabiliser while Boeing produces the tail fin in the USA. Boeing Australia manufactures ailerons and flaps, while Boeing Canada Technology fabricates fairings. Boeing's Charleston, South Carolina, facility along with Spirit AeroSystems (Kansas), Japan's Kawasaki and Vought (USA) produce the major fuselage sections. Global Aeronautica, a joint venture between Boeing and Alenia, integrates the major central part of the fuselage in the United States. France's Latecoere and Saab (Sweden) between them make the aircraft's doors. India's Tata Group produces floor beams and Nordam fabricates carbon fibre window frames.

Altogether, Boeing has contracts with over 50 suppliers, some 28 of them outside the USA.

The first composite fuselage section was rolled out in January 2005. By January 2007, a big year for the programme, Dreamlifter aircraft (three bulbous, heavily modified B747s) were transporting major sub-assemblies from Japan and elsewhere to the final assembly line at Everett.

Roll-outs that year included:

- the first production vertical tail fin (from Boeing's Composite Manufacturing Centre in Frederickson, Washington, in March);
- the first complete nose and cockpit section (Spirit AeroSystems, Wichita, Kansas, in April);
- Alenia's first horizontal stabiliser (April);
- the first carbon wings from Mitsubishi (May); and
- rear fuselage sections from Vought.

By May, Boeing was starting to assemble the first Dreamliner. The lead engine, the Trent 1000, was certificated on time in August. A significant milestone was the roll-out on 8th July (in US parlance the seventh month's eighth day in year '08 - ie 787), with all due fanfare and attendance by the world's press, of Dreamliner One.

Beset

But, despite these high-profile achievements, all was not well with Boeing's flagship programme, which was becoming beset with problems. The public could not know that the July roll-out had been of an aircraft which, behind a gleaming exterior, was little more than an unfinished shell. Reasons for this sham were rooted in earlier stages of the project.

The second Boeing 787 Dreamliner, painted in the livery of launch customer ANA (All Nippon Airways), during taxi tests in August 2009. The test took place at Paine Field airport in Everett, Washington. (Picture © Boeing.)

Alenia Aeronautica completes ultimate load tests on a B787 horizontal stabiliser. (Picture courtesy of Alenia Aeronautica.)

The first major snag causing the programme to stutter had been the fastener issue. While the adoption of a half plastic airframe greatly reduces the need, compared with metal, to fasten a multitude of structural items together, thousands of fasteners are still needed to join the fewer, more integrated components and sub assemblies. Here, a weak point in the supply chain became apparent. A shortage of the specified and qualified aluminium-based fasteners (akin to rivets) had arisen, partly because the selected sole supplier had shed much of its workforce during the post-'9/11' aviation slump. As a result, Boeing's manufacturing partners were delivering fabricated items held together with temporary fasteners obtained from everyday sources – even, it is said, hardware stores. Some were incorrectly sized, all were unqualified.

Although these fasteners had been painted red so that they could be identified, the task of locating and replacing several thousand of them challenged the capabilities of a leaned-down Everett. Fasteners have to be replaced very carefully since composites are more sensitive to clamping pressure and installation force than metal. This point struck home forcefully when, as well as having had to change many fasteners on partners' sub-assemblies after their arrival at Everett, technicians there found themselves having to re-install thousands more on flight test and static (ground) test aircraft that everyone thought had already been re-fastened. This happened because of damage suffered when some temporary fasteners had been removed to make way for correct replacements. Inspectors found that metal swarf produced at metal-to-composite joins when drilling oversize holes was preventing fasteners from

Three B787 composite fuselage sections arriving in Everett. The all-composite forward section known as section 41 (wrapped in white), manufactured by Spirit AeroSystems in Wichita, is 21 ft in diameter and 42 ft long. Sections 47 and 48 (wrapped in black) are the two aft composite sections of fuselage. They were manufactured by Vought Aircraft Industries in Charleston. Section 47 is 23 ft long and 19 ft in diameter. Section 48 is 15 ft long and 14 ft in diameter. (Picture © Boeing.)

sitting flush to the fastened surfaces, prejudicing structural integrity.

Machinists had to be trained in correct installation procedures. Then, to fix Dreamliner One, technicians had to remove cabin linings, insulation blankets, overhead bins and other interior items fitted prior to the show roll-out in July, in order to gain access to the aircraft skin. For a period last year, the fastener issue practically stalled production.

The schedule was further hit by a strike conducted by members of the machinists' union at the Everett plant. This was perhaps symptomatic of pressure felt by the machinists who were in the front line of the re-fastening purge. It was 57 days before negotiations finally led to a resumption of work.

To add to Boeing's woes, its vaunted new supply chain model was not working. By January 2007, the airframer had exercised four out of eight contingency plans designed to help suppliers having difficulty in meeting production schedules. These plans involved sending personnel, from shop floor technicians to senior programme managers, to partners' facilities in Europe and Japan to 'blitz' the problem. More firefighting was needed as sub-contractors, keen to be seen to meet their commitments, were sending each other incomplete parts and assemblies, leaving the recipients to complete the work. The effects reverberated up the supply chain such that major assemblies airlifted into Everett by Dreamlifter were arriving with substantial work still to be done. Completing this unexpected 'travelled' work strained Everett's slimmed-down resources, introducing further programme delays. James McNerney, chief executive of Boeing Commercial Airplanes, appealed to partners to 'over-resource' the situation and to cooperate with each other in addressing it.

Assailed by delays and engineering difficulties, supply chain partners were showing signs of strain. Vought, in particular, experienced cash flow problems as part of Global Aeronautica, its 50/50 joint venture with Alenia. This prompted a request to Boeing to negotiate new contract terms. However, the airframer implemented its own solution and bought out, for a reported $1 billion, Vought's share of the venture, thereby increasing its control over the process of integrating a large part of the 787's fuselage.

This move reflected a growing disenchantment within the Boeing hierarchy with the way the supply chain was performing and a conviction that its manufacturing model, though satisfyingly logical, had perhaps taken out-sourcing too far. Diverse autonomous partners, many of them geographically distant are, it has transpired, harder to coordinate and control than conventional build-to-print sub-contractors. While Scott Carson, then Boeing Commercial Airplanes' chief executive, declared that the Vought move was intended to 'strengthen the 787 programme by enabling us to accelerate productivity and efficiency improvements as we move to ramp up production,' commentators like Richard Aboulafia of the Teal Group consultancy suggest that it was more about damage control.

Another setback arose when tests in May this year on the static airframe revealed a structural flaw in the join between the centre fuselage and each wing. As a result, an already substantially delayed maiden flight planned for Dreamliner One in June was again postponed.

The area of concern centres on 17 points on each side of the aircraft where stringers in the centre wing box (Fuji) are bonded

Flight test aircraft two through five for the Boeing 787 Dreamliner in the final assembly facility in Everett, Washington. (Picture © Boeing.)

to partner stringers in the wing box (Mitsubishi). During wing flexing tests, stringer caps suffered damage including, according to reports, some laminate disbonding. Boeing had no choice but to revisit the detail design and develop a fix. Repairing and fortifying the structure on aircraft already built involves technicians accessing a very tight repair space to install titanium reinforcements, a process expected to take about three months. The fortified structure will then have to be re-tested before the six flight test aircraft can fly. A definitive structural modification is being developed for production aircraft.

Discontent

Repeated delays to the maiden flight, the flight test programme and to delivery and service entry dates were trying customers' patience. The first flight has now been delayed for more than two years and, though Dreamliner One could yet fly by the end of this year according to Boeing, an early 2010 flight would not be surprising, which means first deliveries could not take place before the end of 2010 – and that assumes a relatively trouble-free flight test programme. As well as the problems so far mentioned, delays can also be attributed to issues of electrical wiring, software and design changes.

Furthermore, the early aircraft are worryingly over-weight – by about two tons each for the flight test fleet of six. Because of this, by early 2009 Boeing had reduced its estimate for the 787's range by some 500 km, according to insiders. It seems likely that the weight originally advertised will not be achieved until at least the 20th production aircraft.

Customers have openly expressed their discontent about the delays and the performance shortfall, and a number are thought to be discussing compensation terms with Boeing. Among these is launch customer ANA, which is unlikely to receive any Dreamliners before late 2010 at the earliest. That means that European launch customer LOT Polish Airlines would not get its first aircraft until at least May 2011. LOT has warned that its may switch its order for fourteen 787s, placed in 2005, to Airbus types.

It is believed that Delta Airlines may have delayed deliveries of its early 787s so that it can have later aircraft with nearer the promised weight and performance. In March, Shanghai Airlines said it too wanted to delay or cancel its initial order. In fact, five Chinese carriers have deferred their orders. Aircraft leasing organisation ILFC, largest 787 customer with 74 on order, has expressed its concern about both delay and performance issues.

Akba Al Baker, chief executive of another key customer, Qatar Airways, reportedly cautioned at the Paris Air Show: "Boeing doesn't realise how much its hurting its customers' plans. They're mistaken if they think we are going to give them much more time."

As an outcome from the problems, Boeing expects to have to write off up to $2.5 billion, much of it in compensation, as well as suffering a serious blow to its credibility.

Supply partners can hardly wait for the programme to get into its stride. Jeff Turner, chief executive of Spirit AeroSystems, voices a common sentiment when he says that his organisation badly needs momentum so that it can incorporate new ideas and improvements, while enhancing productivity (not to mention revenue!).

For Boeing itself, turbulence surrounding the programme meant that heads had to roll. Many of the names most closely associated with the B787 have gone in successive management shake-ups. Programme manager Mike Bair went in late 2007, while Boeing veteran Scott Carson is retiring as head of Boeing Commercial Aircraft at the end of this year. Carson, a businessman, is being replaced by an engineer, Jim Albaugh, who previously headed Boeing's Integrated Defense Systems. Scott Faucher has come in as the top 787 manager, replacing previous vice president and general manager Pat Shanahan, who has moved elsewhere within the company. Ray Conner, formerly vice president of sales, now heads a new supply chain management and operations organisation.

Back on track?

Despite the avalanche of troubles, there are signs that Boeing is restoring its more customary authority over the programme and making better progress. By now, it has substantially completed six flight test aircraft as well as two non-flying airframes, one for static tests and the other for fatigue testing. The production system appears to be stabilising. Flow times at Global Aeronautica, for instance, have improved, helped by seven improvement plans, and should no longer be a roadblock item. Even so, Boeing may look to rebalance supplier workscopes, placing work where it can be carried out with greatest efficiency, and will actively help the supply chain succeed. Over the last year, a new Product Integration Centre, essentially a command centre for global production, has been providing early warning of supply chain problems and resolving production issues.

At Everett, Boeing had virtually completed assembly of Dreamliner One by mid 2007. The Rolls-Royce Trent 1000, the lead engine, achieved certification, on time, in March this year. In June, Dreamliner One achieved its first 'Power On', a significant event in which the aircraft's controls along with electrical and other major systems were exercised. By July, ZA001 (the first Dreamliner) was moving around under its own power in low-speed taxi trials. Engine run-ups and high-speed taxi trials have followed. The fuselage has been tested at almost 15 psi, some 150% of the maximum pressure likely to be experienced in commercial service (at maximum cruising altitude). Were it not for the fuselage-wing join pitfall revealed on the static test airframe, a B787 maiden flight would have taken place by now.

Just the start

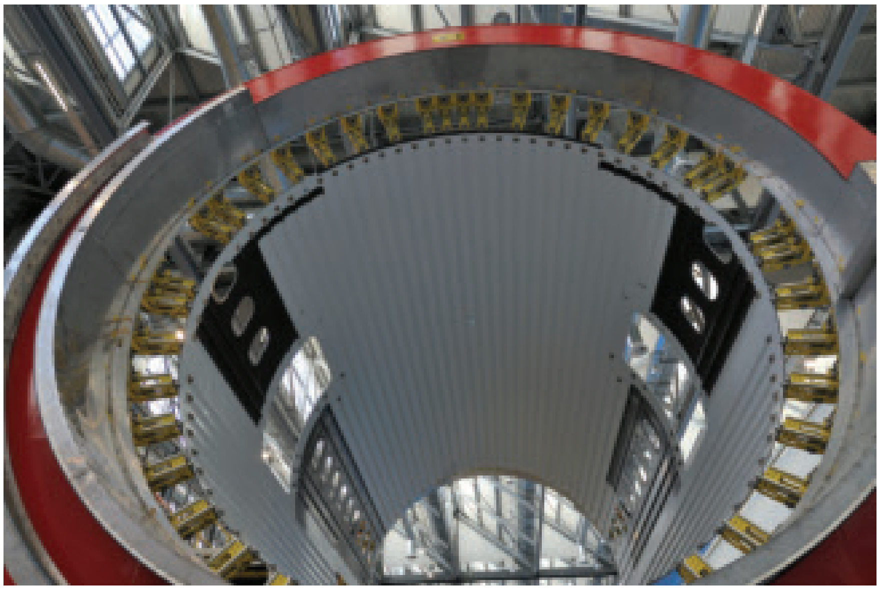
In one sense, however, achieving first flight is just the start and the challenge that follows, the accelerated flight test and pre-certification phase, is equally severe. As one insider dryly put it: "once the first aircraft has flown, the hard work really begins!"

Boeing's decision to field six flight test aircraft rather than the four first intended was taken so that 120 flight test hours could be flown per month, rather than the 70-80 hours accomplished for previous aircraft. This will involve an intense 24/7 operation, with continuous three-shift working, in which long daytime hours of testing will be followed by data analysis in the evenings and aircraft maintenance by night. In this way, the company hopes to achieve FAA, EASA and JCAB (the US, European and Japanese airworthiness authorities) certification within nine months.

This target assumes that flight test will be relatively trouble-free, unearthing only the usual issues associated with any new aircraft and no 'show stoppers.' Given the 787's structural novelty and advanced systems, this might by a forlorn hope and one hopes that the airframer is not, once again, being over-sanguine. The company claims, however, that it has allowed a 15-20% margin to allow for unforeseen contingencies.

Even as the flight test and certification phase proceeds, the 787 team will be pushing to ramp up production. Boeing is aiming for a rate of 10 aircraft per month, at least until 2013 when a further acceleration might be undertaken. Starting late 2010 or early 2011, it will also be making the first customer deliveries and seeing the first few aircraft safely into service. In doing so, it will attend to all the teething troubles that invariably crop up at this stage. Route proving trials will precede full revenue service.

On-going will be the effort to refine the design, including material combinations and specifications, so as to progressively reduce aircraft weight and restore the 'lost' performance. Reports suggest that full-scale structure tests have revealed instances of structural over-engineering, enabling potential weight savings to be identified. Significant design revisions, many of them involving first-tier suppliers, will be incorporated in aircraft number seven and onwards.



B787 fusleage panels under construction at Alenia Aeronautica's Grottaglie facility. (Picture courtesy of Alenia Aeronautica.)

Dream restored

If Boeing can overcome the effects of a shaky start to its 787 project and restore its own credibility during the next phase, it should still have a glittering success on its hands. So far, orders have largely held up, due to airlines – hard pressed by present dire financial conditions –- desperately needing aircraft that will consume much less fuel and require lower maintenance than present-generation types. By July this year, some 850 B757s were on order for 56 customers and, although this is down on the peak of 910 orders reached last year, due to a few cancellations, new orders have largely compensated.

The airframer could be looking at a three decade long programme to build and deliver several thousand of its super-composite B787s, in the various planned models, to replace a multitude of Boeing 757, 767 and 777 aircraft as well as competing Airbus types, in service today. When, any time now, ZA001 first takes off and flies out over Puget Sound, it could mark the start of something more akin to a dream than a nightmare. ■

Further information

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