Spacecraft or aircraft?

He became the first Scotsman in space when piloting SpaceShipOne in 2004. Now David Mackay is the chief pilot of Virgin Galactic, and as the spacecraft enters the next phase of testing, *Aerospace Testing International* gets an exclusive insight into the progress made so far

BY CHRISTOPHER HOUNSFIELD

It takes considerable skill to handle and fly the oldest, original flying aircraft (and engine) in existence on the planet. It dates back more than 100 years and is the 1909 Bleriot. It was made from ash wood, in a 'tractor' box configuration, with wire bracings and steel tubes, and 'pulled' through the air by a tiny 50hp engine.

What makes the expert pilot who flies this craft all the more different is that over and above having the flying skills to display the Bleriot XI around the world, test pilot Dave Mackay is also the chief pilot for Virgin Galactic, arguably the most advanced and unique air/spacecraft of modern times. His aim? To be the first commercial astronaut/pilot in the world. In 2004, he became the first Scot in space, when he piloted SpaceShipOne on October 4.

LOOKING BACK DOWN

It was back in 2004 that the 'Ansari X Prize' called for private sector innovation that would look into the field of manned space exploration. Participants were asked to design and manufacture a privately funded vehicle that could deliver the weight of three people (including one real person) to suborbital space (100km above Earth). The vehicle had to be 80% reusable and fly twice within a two-week period. Indeed, to cut a long story short, Mojave Aerospace Ventures and Burt Rutan's Scaled Composites pursued the X Prize with Rutan's SpaceShipOne, sponsored by Virgin, with an air-launched, all-composite rocket ship.

Virgin Galactic was born and development was put in place for two vehicles, the carrier, and then the actual spaceplane. Mackay has been involved in the development of both these craft.

SpaceShipTwo (SS2) is a reusable spaceplane designed to carry six passengers and two pilots into space. It uses much of the same technology, construction techniques, and basic design of the earlier SpaceShipOne, but is twice the size. It was unveiled in December 2009, and test flights began in March 2010. The first rocket-powered supersonic flight of SS2 took place on April 29, 2013.

WhiteKnightTwo (WK2) is the carrier aircraft for both SpaceShipTwo and LauncherOne. It is the largest 100% carbon composite carrier craft ever built. It made its first flight in December 2008.

Mackay says, "I have flown both – WhiteKnight, a lot, and SpaceShip, a little. Although outwardly the vehicles are very different, there are many similarities internally. Also, WhiteKnightTwo has the ability to act as an inflight trainer for SpaceShipTwo; with its gear down and its powerful speedbrakes deployed, it can replicate SpaceShipTwo's approach path angle."

LATEST DEVELOPMENT

On September 5, 2013, SS2 successfully completed the second rocket-powered, supersonic flight. In addition to achieving the highest altitude and greatest speed to date, the test flight demonstrated the vehicle's technical mission profile in a single flight for the first time, including a high-altitude deployment of the unique wing 'feathering' re-entry mechanism.

Chief pilot Dave Mackay was at the WK2 controls. SS2 pilots Mark Stucky and Clint Nichols, both of Scaled, ignited the rocket motor for the 20-second burn, propelling the spaceship vertically to 69,000ft. During this time, SS2 achieved a maximum speed of Mach 1.43. According to Virgin Galactic, the flight was flawless.

Mackay has flown many types of aircraft, from the oldest to the latest, and cut his teeth in the Royal Air Force flying Harriers, and later as a test pilot on exchange with the French test pilot school, EPNER (École du personnel navigant d'essais et de réception), through an exchange with the RAF's Empire Test Pilots' School. He became Commanding Officer of the RAF's Fast Jet Test Flight in 1992 at RAF Boscombe Down. Life's a bit different now! And it was in 1995 that it all changed.

"THERE IS NO FLY-BY-WIRE SYSTEM – THE FLIGHT CONTROLS ARE SIMPLE CABLES, AND PUSH-RODS; THERE IS NO AUTOPILOT OR AUTOTHRUST"

Talking exclusively to *Aerospace Testing* just a few days before the latest flight, Mackay describes the lead-up to the trial, and explains that although both vehicles have such different roles, there is still a conformity of design that is incredible.

"Both vehicles [SS2 & WK2] were deliberately designed to be as simple as possible," he says. "The rationale is that a simple system is less likely to fail and therefore is inherently safer. Because of this, there are very few pilot aids that are common in the majority of modern aircraft. There is no fly-by-wire system – the flight controls are simple cables, and push-rods; there is no autopilot, autothrust or artificial feel system. In other words, the pilots really do have to fly the vehicles and, of course, that's what pilots enjoy doing most of all! As a result, the crew feels the real vehicle directly, not through some artificial feedback system."

The result, says Mackay, is that WK2 feels like you might expect a large aircraft to feel: "It's a little slow and heavy in roll and it has quite a lot of inertia," he says, "Other than that, it flies surprisingly well given its very unusual configuration. Its most unusual aspect is probably the twin fuselage, which is flown from the right-hand-side. On the ground, pilots have to be careful when positioning it, especially on narrow taxiways. But in the air, it feels just like any other aircraft and it's easy to forget there is another fuselage out there on the left-hand side."

Mackay says WK2's performance is very impressive, capable as it is of carrying a large and very heavy external payload up to 50,000ft in around 45 minutes. But what of SS2?

"SS2 follows the same simple design philosophy," he responds. "For a vehicle designed for very high Mach numbers and for the critical re-entry from space, you might perhaps expect its low speed handling characteristics to be poor. In fact, it flies really nicely on the approach and landing. It has a very good field of view and is quite agile; if a rapid maneuver is required, it is capable of responding quickly. The feather configuration is highly stable and the beauty of it is that no matter what angle the vehicle meets the atmosphere at on re-entry, it will automatically orientate itself in the optimum position, requiring no pilot input. In the feather, the crew is able to point the vehicle in whichever direction they desire – as there is a small forward velocity in feather, this is a useful capability," says Mackay.

ABOVE: SS2 flies supersonic for the first time – piloted by Scaled's test pilots Mark Stucky and Mile Alsbury

INSET: Sir Richard Branson and Mark Stucky congratulate each other after the first rocket-powered flight of SS2 in April

RIGHT: Boom camera shot of SpaceShipTwo breaking the sound barrier

DOUBLE TROUBLE

It is sometimes easy to forget that Scaled Composites has built and developed the two vehicles in parallel – a big undertaking, especially since both are unusual designs and have demanding roles. To help it better understand their projected performance, Scaled performed a great deal of CFD analysis prior to beginning flight testing.

Clearly, coupling one air vehicle to another can drastically impact handling. This was certainly the case back in the 1970s when a Boeing 747 was used to give piggy-back rides to the Space Shuttle. The 747 had to be stripped out completely to make it lighter, but the combined weight and dynamics made drag and vibration a huge factor. When you consider it took the entire craft to somewhat less than 1% below absolute maximum take-off weight, it was amazing it ever got off the ground.

However, when you provide bespoke vehicles, the situation changes, as Mackay is keen to point out: "When attached to WK2, riding in SS2 is a very comfortable experience. If there is any turbulence in the air, it tends to have a greater effect on the extremities of a wing, so as SS2 is mounted in the center of WK2's wing, it is remote from, and well isolated from, the greatest movements."

Surprisingly, Mackay says having SS2 attached to WK2 does not make a great deal of difference to the way WhiteKnight handles. "However a fully-laden SS2 is a significant part of the all-up vehicle weight and so it's performance is not quite as sparkling as when it's on its own," he admits.

Another benefit of Scaled's bespoke approach is evident in the cockpits of both vehicles: "The displays in the vehicles were designed and built by Scaled," he says. "In principal, they are very similar to those found in the majority of modern aircraft. Both vehicles have three multifunction displays – one in front of each pilot, normally set up as a primary flight display, and one in the center of the instrument panel.

"The primary flight displays are quite conventional flight instruments and navigation information. In WK2, the center display normally shows the engine parameters and top-level systems information. In SS2, the center display shows vehicle energy, which is very useful for the approach and landing. Most pilots would quickly be able to identify all the normal parameters they require to fly the vehicles. However, the advantage of having the avionics system designed and built in-house is that, particularly in SS2, there are many bespoke features that make it much easier to fly the vehicle in the atmosphere and in space.

650 The number of individuals so far who have signed up to become a Virgin Galactic astronaut – Katy Perry, Ashton Kutcher, Justin Bieber and Leonardo DiCaprio are just a few of the stars on board

70 secs How long SS2's rocket engine fires for to boost it to its maximum altitude of 361,000ft (110km)

US$250,000 The current cost to sign up as a Virgin Galactic astronaut!

90in SS2 cabin diameter, which is similar in size to a Falcon 900 executive jet – but without the floor, to allow passengers to experience floating in zero gravity

ABOVE: A view of a SpaceShipTwo hybrid rocket engine test firing by SpaceShipTwo builder Scaled Composites

SIMULATION AND MODELS

A flight simulator has been developed in parallel for both vehicles and has now reached the stage where it is a prime test device. According to Mackay, it accurately simulates vehicle performance, the influences of various atmospheric conditions, and almost any system failure. It also feeds information to Scaled's telemetry system in its mission control, enabling effective training for the entire test team. Mackay adds, "It was initially designed to be an SS2 simulator, but as the cabins of both vehicles are built from the same molds, and the flight controls and the avionics are very similar, it can also be used with a WK2 aero model as an effective simulator for that vehicle too. It is hard to imagine carrying out a flight test program on a vehicle such as SS2 without such a capable simulator."

ENGINE TESTING

The September 5, flight tests opened up the flight envelope following the second successful rocket-powered test over Mojave. The vehicle's Sierra Nevada RM2 solid rocket motor was tested for a longer duration than previous tests at more than 20 seconds, ignited just four seconds after release, which pulled it straight into a vertical climb.

As Mackay states, "The rocket testing is a huge part of the development program and there have been a very large number of test firings, to optimize the fuel, as well as the general performance of the motor itself. Most of the ground tests have been conducted by SNC at its Powey facility. But several have also been carried out at Mojave. Motor testing continues in parallel with flight testing.

"With a rocket motor, which accelerates the vehicle very rapidly, the challenge becomes much more difficult. So the first powered flight expanded the flight envelope significantly and very quickly, also passing through the transonic region [there have been flutter and oscillation concerns that Virgin explained were entirely predicted and expected]. This was one reason we were so pleased with the highly successful outcome.

"The path forward now is to incrementally increase the rocket motor burn-duration to expand the flight envelope and eventually achieve our goal of space flight. We will then start flight testing the customer equipment, to optimize the experience for all those hundreds of people patiently waiting for their ride into space," says Mackay.

So what has been the experience that has stood out the most? Mackay shows his sense of humour: "For me personally, it was my first feather flight in SS2. I was so impressed by the fact that you could fold this vehicle in half and yet it still flew really well. I also recall us all talking after my first flight experience in SS2 in June 2011. As a UK citizen I am classified, under the TSA rules, as an alien, so the Scaled test pilots were delighted to be able to honestly say they had seen an alien fly a spaceship."

WHAT NEXT?

Further flights will continue to expand the supersonic aerodynamic flight envelope, launch weight and structural loads. Testing is expected to end with a maximum apogee demonstration flight to 361,000ft (110km), after which SS2 developer Scaled Composites will turn the vehicle over to Virgin Galactic.

The company says it is adamant the first commercial sub-orbital flights will commence next year from New Mexico, with more tests this year.

As Mackay reflects, "Some of this may sound rather far-fetched, but if you look back at the way technology has evolved over the past 100 years, it would be a brave man that would say this cannot happen." Indeed, as Mackay next climbs into the Belriot XI, the original French aviator Louis Belriot could not have dreamed of the revolution he was pioneering as he crossed the English Channel a little over a 100 years ago. ▮

RECENT TESTING MILESTONES

Second rocket-powered flight of SpaceShipTwo
Date: September 5, 2013
WhiteKnightTwo took off carrying SS2 to an altitude of 46,000ft. Virgin Galactic chief pilot Dave Mackay was at the WK2 controls, assisted by Scaled Composites' co-pilot Mike Alsbury and flight test engineer Scott Glaser. Upon release from WK2, SS2 pilots Mark Stucky and Clint Nichols, both of Scaled, ignited the rocket motor for the planned 20-second burn, propelling the spaceship to 69,000ft. During this time, SS2 achieved a maximum speed of Mach 1.43. SS2 landed in Mojave at 9:25am.

First rocket-powered flight of SpaceShipTwo
Date: April 29, 2013
The test began at 7:02am local time when SpaceShipTwo took off from Mojave Air and Space Port mated to WhiteKnightTwo. In control of SpaceShipTwo were Mark Stucky, pilot, and Mike Alsbury, co-pilot. At the WK2 controls were Virgin Galactic's chief pilot Dave Mackay, assisted by Clint Nichols and Brian Maisler, co-pilot and flight test engineer, respectively, for Scaled. Upon reaching 47,000ft altitude and approximately 45 minutes into the flight, SS2 was released from WK2. After cross-checking data and verifying stable control, the pilots triggered ignition of the rocket motor, causing the main oxidizer valve to open and igniters to fire within the fuel case. At this point, SS2 was propelled forward and upward to a maximum altitude of 55,000ft. The entire engine burn lasted 16 seconds, as planned. During this time, SS2 went supersonic, achieving Mach 1.2.

The rocket-powered flight test lasted just over 10 minutes, culminating in a smooth landing for SS2 in Mojave at approximately 8:00am local time.

"The rocket motor ignition went as planned, with the expected burn duration, good engine performance and solid vehicle handling qualities throughout," said Virgin Galactic president and CEO George Whitesides. "The successful outcome of this test marks a pivotal point for our program. We will now embark on a handful of similar powered flight tests, and then make our first test flight to space."

SS2's control and handling was very positive during its first supersonic, rocket-powered flight. The motor operated as designed, and provided a strong, yet surprisingly smooth, acceleration through the sound barrier. The boost was terminated at the intended shutdown duration of 16 seconds. Trajectory was nominal, with Mike and Mark topping out at 1.3 Mach and 56,200ft. Post shutdown glide was nominal. The vehicle and the team performed excellently according to the company.

SpaceShipTwo 'Cold Flow' test
Date: April 4, 2013
Preparing for SpaceShipTwo's first powered flight, test teams from Scaled Composites and Virgin Galactic completed the profile of the upcoming milestone flight – apart from actually igniting the rocket. Importantly, and for the first time in the air, oxidizer was flowed through the propulsion system and out through the nozzle at the rear of the vehicle – thus successfully accomplishing the 'Cold Flow' procedure.

As well as providing further qualifying evidence that the rocket system is flight-ready, the test also provided a stunning spectacle due to the oxidizer contrail, and, for the first time, gave a taste of what SpaceShipTwo will look like as it powers to space.

Feather flight and nitrous vent test
Date: April 9, 2013
On a beautiful calm Mojave morning, SS2 completed her 24th glide flight and the sixth inflight test of her patented feathered re-entry system. The flight test team also successfully verified SS2's nitrous loading and venting system, another key milestone on the way to its first powered flight. Galactic's chief pilot David Mackay was at the controls of WhiteKnightTwo, and Scaled's pilot Mark Stucky was in command of the spaceship.

First glide in powered flight configuration
Date: December 19, 2012
SpaceShipTwo undertook its 23rd glide flight in the pre-powered portion of its incremental test flight program. This was a significant flight as it was the first with rocket motor components installed, including tanks. It was also the first flight with thermal protection applied to the spaceship's leading edges. It followed an equally successful test flight the week before that saw SS2 fly in this configuration, but remain mated to WhiteKnightTwo. All objectives of both flights were successfully met.