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Voyager circles the World

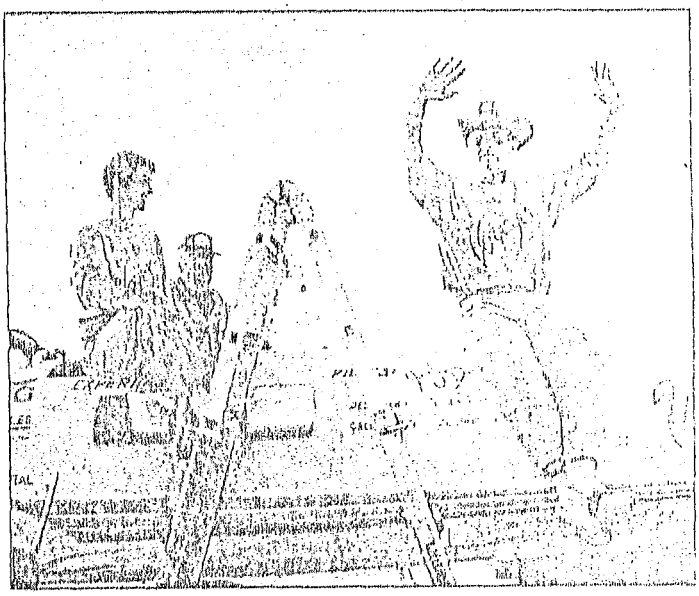
EDWARDS AFB

Not since Charles Lindbergh flew solo from New York to Paris has light aviation captured such world enthusiasm. Despite near disaster on take-off, ferocious weather, and fuel pump failure, Dick Rutan and Jeana Yeager have succeeded in their bid to be the first pilots to circle the world non-stop, unrefuelled. Despite the physical ordeal, the crew were reported to be in good shape on arrival, though suffering from temporary deafness owing to prolonged noise. Each had lost some 10lb in weight, having consumed only 10 per cent of their food supplies.

The Voyager landed at Edwards AFB, California, at 0805hr local time on December 23, nine days, 3min, 44sec after departing Edwards on December 13. The distance covered totalled 21,720 n.m. (25,012 miles), some 2,000 miles shorter than the route originally proposed. Owing to the sophisticated use of pressure pattern navigation, which optimised the use of favourable winds, Voyager averaged 100·56kt (115·8 m.p.h.), arriving a day earlier than expected.

Grossing at 9,750lb (including 1,000 US gal of fuel), Voyager came close to disaster on take off when the wingtips were damaged by ground contact during the 14,000ft ground roll. The right winglet broke free, and the left one was left dangling for the remainder of the flight.

The Pacific route passed close to Hawaii, Wake Island, and Guam, staying well north of Australia to take advantage of favourable winds. Skirting South-East Asia, Voyager took a westerly course over Sri Lanka and flew across Central Africa, passing close to Nairobi.



Jeana Yeager and Dick Rutan acknowledge the vast crowd at Edwards AFB

After leaving the West African coast, Voyager turned north-west, heading for the Caribbean, where a more southerly course than planned was necessary because of storms in the Gulf of Mexico.

Over the Atlantic the crew forgot their six-hourly oil level checks on the liquid-cooled rear engine on which they were relying (the front engine having been shut down early in the flight, as planned, to conserve fuel). A warning light indicated falling oil pressure and rising temperature. Pumping in additional oil and reducing power restored pressures and temperatures to normal.

Turbulence was a constant threat to Voyager, owing to the aircraft's light and ultra-flexible structure. The aircraft was twice thrown into a vertical bank as it passed South America.

Uncertainty over fuel quantity, caused by fuel flow measurement problems, caused further anxiety to the Voyager team.

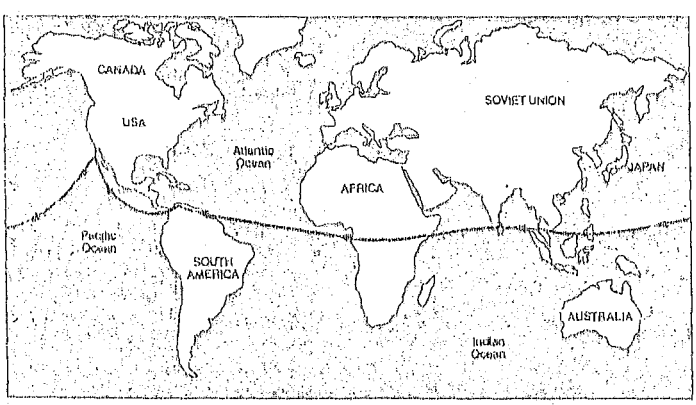
Because of adverse conditions in the Gulf of Mexico, Voyager crossed central America between Yucatan and Costa Rica before heading north off the Pacific coast of Mexico and southern California.

With just 450 miles to go, disaster was again narrowly avoided when a fuel pump malfunctioned and the rear engine cut out at 8,500ft. To save weight Voyager is not fitted with engine starters, and it took a 3,500ft dive to achieve a windmill start of the reluctant front engine.

Weather conditions at Edwards were perfect, allowing Rutan to make a leisurely flypast before his immaculate touchdown in front of a crowd of thousands.

Voyager was designed by Burt Rutan specifically for this flight, and will now be housed in the US National Air and Space Museum in Washington D.C..

Perhaps Yeager, who overcame so much physical discomfort and so often took a back seat, expressed it best to *Flight* some months ago: "We just want to do something that will go down in aviation history."



A girdle round about the Earth

It is gratifying to be able to start the year with good news. Even so, with the adulation pouring on to pilots Dick Rutan and Jeana Yeager it is worth assessing in balanced terms the significance of the Voyager flight.

First, the things it won't do. Voyager, for all its originality, will not transform the general-aviation scene. It is unlikely that tomorrow, or even the day after, we shall see low-cost H-shaped airframes with lightweight piston engines carrying high-powered yuppies to business appointments in cities 20,000 miles from their bases.

Nor is this version of the Rutan (Burt) dream likely to appeal to the wealthy young owner-pilot as a means of whisking his (or her) favourite companion off to an island or mountain hideaway.

The truth is, of course, that Voyager was designed not to meet an aviation market, but to realise an aviation dream. It attracted its sceptics, who thought the exercise singularly pointless, and were not a bit surprised when setbacks delayed the project. A departing blade nearly grounded it for good, and even in the last days before take-off unfavourable weather promised to postpone it well into 1987. Such a delay would have put intolerable pressures on the crew, who had already nearly impoverished themselves, and might well have disenchanted the many sponsors and industry contributors who were helping to keep the dream alive.

Even after the flight had started, the dream came close to turning into a brief nightmare, and any one of several incidents could have yielded disaster and an end in oblivion for the pilots and for the project. The wingtips scraped on take-off and were damaged to an extent that cast some doubt on the aircraft's capacity to fly, and must have affected its aerodynamics and handling. A forgotten oil change almost destroyed an engine. And the rear engine did fail over the Pacific Ocean, necessitating a 3,500ft descent to start the front engine by windmilling the propeller.

A measure of crew heart rates during those emergencies might have produced illuminating medical information. No such data are available, the events were overcome, and the aircraft landed as though an unrefuelled non-stop aerial circumnavigation were an everyday occurence. It isn't. And it won't become such, because flying round the world has no particular justification other than itself.

That is not to say that there are no benefits; there are, and they can be found not so much in the feat which Rutan, Rutan, and Yeager achieved, but in the means by which it was achieved. Voyager's technology, for a start, if not revolutionary in detail, was remarkably advanced in its combined application.

Carbon-epoxy composites with honeycomb interiors are well understood, and have already gained application in aviation from RPVs to business aircraft. The engines are derivatives of existing drone engine, with improvements in synthetic lubrication, and they clearly offer range improvements which could find application in the motorglider field. To put these elements together in a craft which could carry its own weight, two crewmembers, and enough fuel for nine days of flight, including some periods of material-cracking turbulence, was a technology achievement of a high order.

Behind the aircraft there existed also a matrix of less concrete achievements, many of them in the avionics and communications field. Voyager, carrying miniature King Radio avionics, was in touch constantly with the web of ground and satellite communications equipment which enabled it to take spectacular advantage of the weather. Aided by some fancy meteorological interpretation work by Leonard Snellman and his team, Rutan was able to slip into the outer edges of Typhoon Marge and gain speed.

If a satellite and ground network can achieve that degree of navigational control, and can maintain it for more than nine days, then acceptance of intensive long-range, long-endurance, low-cost, crewless stealthy military reconnaissance cannot be far away. The line from Raytheon to Beech to Rutan to Rutan is a pretty straight one.

But the greatest achievements are the human ones; of a pilot who had a vision and pursued it doggedly until he made it come true; of a copilot who not only supported her companion in his vision, but also shared the work and went along and helped fly the aircraft; of two people who put themselves into considerable danger, and inconceivably severe discomfort, inside a flying cigar box within a flying petrol bomb; of a designer who had refused throughout his career to accept conventional solutions; of dozens of people who gave money and backing to what, throughout, was a marginal endeavour; above all to the spirit of enterprise, eccentricity, and faith which the American, or at least the Californian, ethos allows.

The more one contemplates the Voyager achievement, the more it warrants praise and congratulation.

Rutan and Yeager may not, like Puck, have put a girdle round about the Earth in forty minutes. But they missed out only on the timing.

Encircling the Earth

Fighting sleep, fear, sickness, and weather, Rutan and Yeager made it around the world. After exclusive interviews, **Robin Blech** reports on their historic achievement.

Dick Rutan and Jeana Yeager have been acclaimed for their achievement in making the first non-stop unrefuelled flight around the world—25,012miles in 216hr in their Voyager aircraft made of highly flexible Hexcel Magnamite and glassfibre.

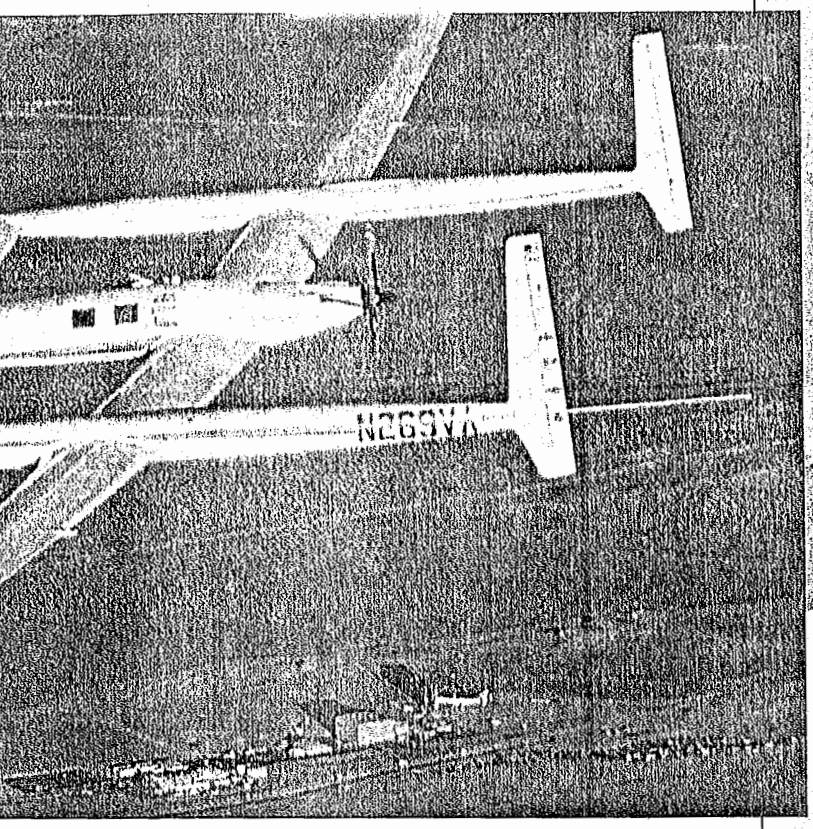
The numbers are already part of aviation history, but only subsequently have the full details of their human ordeal and achievement been revealed. So much happened during the nine-day flight that they are confused about the exact chronology of the drama that unfolded around them. Ask Jeana Yeager to highlight the worst moments, and her reply is simple: "There were no worst moments, it was all terrible".

Press reports that the flight was progressing smoothly, even that they were enjoying a scenic diversion over Sri Lanka, hid the truth. The mission continually looked as if it would fail through lack of fuel, owing to a baffling increase in specific fuel consumption. On top of severe tropical weather, discomfort, sickness, and Voyager's instability at high weights, there were many moments when Rutan and Yeager asked themselves "What the hell are we doing here?". At times they considered landing—Thailand, Sri Lanka, and Brazil all offered possible landing sites which would have enabled Voyager to be recovered for another attempt. But Yeager, who had always believed that the first attempt would succeed, "was very strong", says Rutan. They pressed on, hoping that fuel would last and that the aircraft would hold together.

The project had seemed doomed to failure so many times. Lack of money and suitable engines had dogged the six-year programme since Dick's brother Burt Rutan first designed the Voyager's layout on the back of a paper napkin in a Mojave restaurant. Low weight, flexibility, and strength were the key requisites which only composites could offer. Those very properties would also cause major handling problems, but the aircraft had only to be "mission adequate". The certification rulebook was irrelevant. Only the freedom of the USA could permit such a project, Rutan believes.

Voyager's airframe took 18 months and 22,000 man-hours to build, and this was achieved only with the help of Bruce Evans, who volunteered as crew chief, and test pilot Mike Melville (who reckons the true labour content for the programme to be nearer 167,000 man-hours). The finest expertise was sought. Veteran meteorologist Len Snellman came in to head the met, navigation, and flight-planning team at "mission control" in Mojave. "Without Snellman, the flight would not have been possible," says Peter Riva, who took over as public-relations manager, fund-raiser, and "all-round scrounger" when the programme ran out of financial steam.

Teledyne Continental was persuaded to donate engines, using Voyager as a flying test bed for the new liquid-cooled 110 h.p. IOL-200 engine, never tried before in the air. Only this engine, mounted in the rear, would give the fuel specifics needed to make the distance. Together with its Champion spark plugs, the engine would stand up to the test magnificently. The front engine, a standard air-cooled O-240, would be used at high weight, or when high altitude was required. It was re-started



Left *Oxygen was used to combat fatigue on the last day.* **Above** *Just 2 per cent of the fuel on board remained on landing.* **Right** *"We felt great—100 per cent"*

several times. An experimental long-lasting synthetic oil developed by Mobil, which also donated fuel, proved vital.

The complex fuel system had greater capacity than required because smaller engines were used than originally had been envisaged. Voyager held 1,200 US gal on take off—80 per cent of its total weight—but had capacity for "another ton" of fuel. "We took all we could safely carry for take off," says Rutan.

The aircraft had only been declared "mission ready" on December 12. Weeks of work, involving round-the-clock effort, had been required since the front propeller shed a blade during a test flight in October. It took two weeks to overhaul the front engine and to inspect all the avionics for vibration damage. The original electric MT propellers were dropped, and heavier hydraulic Hartzell units were supplied, thanks to a major propeller blade redesign effort by aerodynamicist John Roncz. Though 50lb heavier, the Hartzells gave a three-fold increase in range efficiency, says Rutan. "We should have chosen them all along."

By December, the weather picture in the tropics had radically changed, but by taking a more northerly equatorial route to avoid headwinds and bad weather over Australia, Snellman believed that a way through could be found. Although they were prepared to wait, the weather conditions on the California coastal belt, so critical to the grossly loaded craft, looked good for December 14.

At noon on December 13 the crew flew Voyager to Edwards AFB for departure the following day, merely filling the final 25 per cent of the required fuel load before departure. Rutan and Yeager, after months of non-stop work, managed to get one night's good sleep before leaving.

The near disastrous take-off caught world attention for the first time. In an attempt to prevent the sagging wing tips from bumping the ground during taxiing, Rutan had increased pressure in the undercarriage oleos and increased fuel in the forward-boom tanks. This increased the nose-down moment on take-off as speed increased. "The wings actually flew themselves [down] on to the runway at higher speeds due to negative angle of attack," he explains. While the ground team agonised, the crew were unaware of the problem until after lift-off. "The take-off seemed real smooth, though I could have done with a little more rearward stick pressure during the roll." Out on the Edwards AFB runway, Peter Riva saw it very differently: "I thought it was going to fireball".

Voyager needed 75kt for lift-off, and then had to accelerate to at least 100kt before being able to climb. With a maximum level speed of 115kt, initial performance was decidedly marginal.

Burt Rutan came alongside Voyager in a chase aircraft, and advised that the damaged tip sails, which were hanging loose, should be broken off by yawing the aircraft. Once he had proved that the aircraft would fly without tip sails, Dick Rutan decided "to go for it". The pressure for a world flight launch so late in the year was enormous.

The first day's running saw a forecast headwind change to a tailwind 200 n.m. from the Californian coast. "We then had tailwinds all the way until the final leg from Costa Rica," says Rutan.

Snellman was able to call on a continual stream of satellite pictures of the route,

Voyager's oxygen system

A Kevlar-wrapped aluminium bottle designed by Cryo Systems II and cleared for 1,850lb/in^2, was pressurised to 3,000lb/in^2 to give a three-day supply. Breathing was accomplished through cannula tubes fitted in the pilot's nose.

A stream of satellite data, coupled with local weather observation, allowed Len Snellman to navigate Voyager clear of most bad weather and optimise the use of pressure systems

and used complex calculation to achieve the ultimate in low-level pressure-pattern navigation. He was also able to call on local surface data at airports along the route *via* Lockheed's Jetplan service.

With every 5° of longitude travelled by Voyager, mission control passed a series of waypoint co-ordinates for the following three days' navigation, aimed at finding the best tailwinds and avoiding turbulence and tropical cloud buil-ups. This information would be updated every six hours in a routine broadcast to the crew, accompanied by weather information and suggested cruising altitude. The bulk of radio traffic was *via* HF, but UHF satellite-linked communication was also used.

Ideally, Voyager should cruise at 3,000-4,000ft, but it was frequently forced up to 10,000-12,000ft by weather. The first major weather hurdle to avoid was Typhoon Marge, which lay astride the south-west Pacific track. Snellman told Rutan to trust him, and took Voyager close to Marge's epicentre. Using satellite information, Snellman passed heading corrections every few minutes, avoiding the worst turbulence and improving ground speed. "It was like watching a brain surgeon at work," says Riva.

Leaving the weather system meant crossing the typhoon's outer feed bands. Snellman predicted severe turbulence. He was right. Bounced around, with Voyager's wing tips flexing through an estimated 40ft, with Rutan exhausted from non-stop piloting since take off, and with Yeager wedged into a corner of the rear cabin to prevent herself from being injured (there is no strap on the bed), the ride was unpleasant.

At one point Yeager had to slide under the instrument panel to swap wiring between two attitude indicators, one of which had toppled. "Her small size was really essential around the cockpit," says Rutan.

As they passed the Philippines, Rutan collapsed exhausted into the rear cabin while Yeager took control. To change seats earlier had been impossible, owing to the critical short-period longitudinal instability at high weights. "Without the autopilot engaged, the pitch oscillation doubles every 1½ cycles, due to an interaction between aerodynamic instability and the structure's aeroelastic properties," says Rutan, who had calculated that the aircraft would break up within 15sec. "It's a unique self-destruct mode, aimed at keeping the pilot awake."

Changing seats takes a full minute, and autopilot failure during the changover could have been fatal. "If we were doing it over again, we would have reclining side-by-side seating with dual controls, boom tanks further out for spanwise loading, and more stiffening material in the wings," he concedes. "Climbing over each other was a big problem. Without the autopilot, we would have been in a world of hurt."

Crossing the Pacific, the crew grew increasingly concerned at the apparent high specific fuel consumption recorded on Rutan's "howgozit" chart. More fuel per mile was being used than had been planned and, if it was correct, there might be insufficient for the world flight. The picture looked increasingly depressing, but exact fuel measuring relied on logging fuel transfer to the one 40 US gal feed tank in the cockpit.

Fuel in each tank was used selectively to maintain critical balance. Only the cockpit feed tank was gauged, being fitted with a plastic tube sight gauge. Alcor transducers measured transfer flow rate. Contents were calculated by zeroing the system, selecting tank required, and reading the feed tank sight gauge. Subtracting the result from the fuel log gave fuel remaining. "It was very complicated, with a lot of mathematics," says Rutan.

By the third day everyone was concerned that specific fuel consumption was greater than expected. Each time the front engine was shut down airspeed decayed, necessitating several restarts. Rutan wrongly attributed the poor performance to the wing tip damage (calculated by Burt Rutan to have cost them 4 per cent range).

Passing South East Asia, Yeager—piloting at last—was forced by weather to skirt Vietnam's forbidden coastal defence zone. Rutan had always feared being intercepted. Twenty years before he had been shot down over Vietnam and ejected into the South China Sea. He knew that the Vietnamese were well aware of the flight. "They were going to shoot us down. War's a bitch—you want to avoid it. I was glad to get out of there alive. I thought, hell, here I am again."

Having avoided airsickness in the back, Yeager was violently ill while flying. Rutan heard her retching, but was

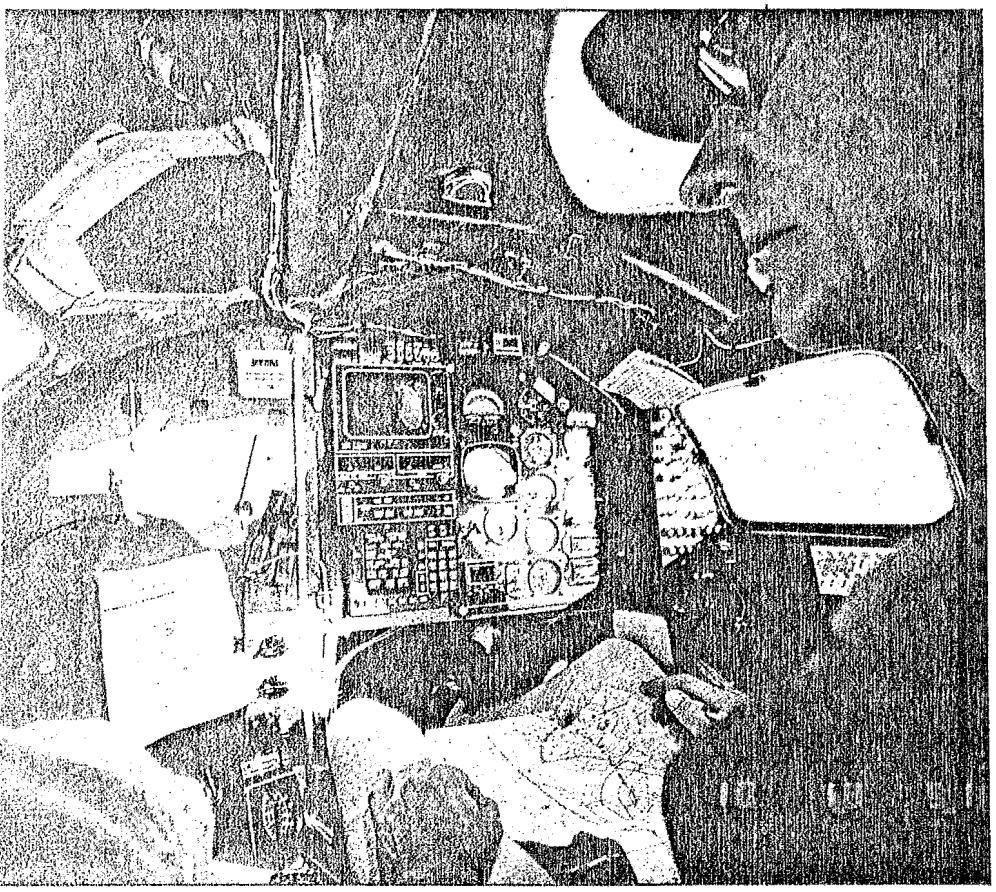
Navigation and communication

Primary navigation relied on a single King KNS660 depending on GPS/VLF/Omega signals. Its antenna was mounted in the roof of the rear cabin. Waypoints were passed by mission control at every 5° longtitude of travel for the following three days, updated every six hours.

The majority of radio traffic was via a King KHF990 HF radio. Its antenna trailed behind the left vertical stabiliser, radiating a north/south pattern. This proved less than ideal for an east/west flight. Various HF stations were used with ground-line relay to Mojave. "By the time we were halfway around the world, we had practically every HF station available to us. It was incredible."

Also carried was a lightweight LST-5 UHF satellite-link transceiver. Fitted with a portable antenna, its use was impossible when Rutan was in the rear cabin, owing to lack of available space with the antenna deployed.

Two UHF frequencies were allocated by the US Department of Defence, using Meteosat (Europe), GMS (Japan), and Goes (US) satellite systems. There were difficulties with both HF and UHF communications. "Twenty per cent of the time we were out of contact," says Rutan. Voyager also carried a standard KX-165 VHF for line-of-sight communication, together with VOR/ILS and Transponder. Bose noise cancelling headsets were praised by the crew.



Constant concern with transferring fuel and logging its consumption left no time to relax. "It was very complicated, with a lot of mathematics"

temporarily too exhausted to care. Yeager was much handicapped by being too short to see out of the bubble canopy. Avoiding cloud tops was a matter of pushing herself up with her hands to see out.

Passing Sri Lanka, the fuel situation appeared hopeless. "We had this terrible conversation, and wondered whether to land at an airport below us, but Jeana was all for continuing."

Voyager was now forced up to 20,000ft to avoid massive thunderstorms over Africa. A more northerly route in clear weather was prevented by refusal of overflight clearance by Ethiopia, Sudan, and Chad. Overflying Kenya, the crew rendezvoused with a Beech Baron which allowed measurement of speed, and both twin- and single-engined rate-of-climb performance. From that it was clear that Voyager must be much heavier than calculated, indicating a more optimistic fuel picture than painted by the log; by how much nobody knew. "Over Africa we discovered the problem, I actually saw fuel flowing backwards. It's impossible for fuel to flow uphill from the feed tank, but it was happening. I haven't yet had time to figure out how. When we made it I didn't care." Fuel had been flowing back from the feed tank into the main tanks. This "back flow" had been mistakenly logged as burn-off.

They decided to keep going and, if necessary, land on Ascension Island or in Recife (Brazil). "We discussed mission failure and what secondary achievements we could be proud of. I don't know when I have felt worse".

At 20,000ft over Africa Rutan found that Yeager had lost consciousness owing to anoxia. Having set off with a cold, she was unable to absorb enough oxygen despite using the mask [illegible]ygen system. Rutan had the option of risking her dying at 20,000ft or descending into fatally severe turbulence. He stayed above the weather until it cleared, but the choice was agonising.

Throughout the Atlantic portion of the flight, fuel shortage haunted them. They filled the feed tank to ensure reaching Ascension Island, then topped up with enough to go on to Recife or to back-track to Ascension. Rutan became an expert at engine mixture leaning. "The idea that leaning wrecks an engine is an old wives' tale,"—borne out by the IOL-200's subsequent clean bill of health. "You have to find the bottom of the bucket."

Because of fatigue the crew had failed to check the rear-engine oil level for 1½ days. The engine overheated while Yeager was flying, but by reducing power and pumping in a small amount of oil, normal temperatures and pressures were restored.

Following the north coast of Brazil and Venezuela, Rutan hugged the coast, encouraged by Snellman to choose a route two miles offshore, midway between the coastal updraughts and the tropical build-ups out to sea. Despite this, severe turbulence almost brought disaster once more, with Voyager flung about severely.

Off the west coast of Mexico the right-hand transfer pump failed. It doubled as a boost pump for the rear engine, which kept running on its own pump while Rutan replumbed the system by swapping over left and right transfer pumps. "Pump failure was in no way due to a faulty unit," says Rutan, who admits that pump cavitation had frequently been necessary while running various tanks dry. "A pump is not designed to run on air." With the rear engine drawing fuel from the canard, engine-pump pressure was sufficient for level flight only. Descending over the Pacific the engine cut out, spurring Rutan to restart a reluctant front engine. Once rear-engine power had been restored, both were kept running for the remainder of the flight.

"Mission Control calculated that we needed 28gal to get home. According to the sight gauge in the cockpit we had only 15gal left, so I went gleaning. In transferring fuel from the outboard tip tank to the intermediate wing tank we discovered that 15gal had leaked out through the tank cap. That hurt."

Despite this, Rutan managed to find sufficient fuel. "It was a happy moment. We had 'get home' fuel, and could relax for the first time." Voyager landed with around 7gal in the feed tank and 18.3gal throughout the system, "enough to reach Seattle at our final 2 gal/hr consumption."

Team manager Peter Riva had kept the pressure of world publicity from the Voyager's crew. "Coming up the coast of California, I was worried that we would arrive early in the morning, when Edwards AFB always has heavy test flying traffic. When they told me that they had closed down for Voyager's arrival, I thought that was real nice. I had been worrying about having left my car at Mojave and getting a ride home."

A crowd of 50,000 people was awaiting their arrival. "Being an old airshow pilot, I made a few fly-bys to show them how Voyager looked with the gear up and to make it a nine-day flight."

Despite having had an average of 2¼hr sleep per day, Rutan and Yeager found that the sheer volume of work kept up their performance. Oxygen was used continually for the last couple of days to combat fatigue and depression. Anxiety over fuel and exhilaration during the final few hours kept them alert despite unremitting noise (110dB) and vibration. "Adrenalin was certainly flowing. We felt great—one hundred per cent—for the last 36 hours."

Rutan is convinced that the success of the Voyager underlines the start of a new era of composite construction. Voyager's success "will make it easier to walk up to all these old aluminium people and say 'something has got to be made of compos[illegible]'"

The materials used

Hercules Magnamite graphite was used for spars and load-bearing members, (Hexcel HRH10 paper honeycomb bonded with FM73 American Cynamid adhesive). Secondary load-bearing components were of Apco E-glass and S-glass, the latter for toughness and electronics transparency for antennae. Carbon was used for the main gear struts. Because it was fitted with a wheel brake, the nose gear was made of steel.