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"A great 'might have been'"

Roland Beamont takes TSR2 XR219 into the air from Boscombe Down during the winter of 1964-65. Strictly speaking, there were no TSR2 prototypes and XR219 was the first of the development batch, XR219-227. KEY COLLECTION

Whatever the rights and wrongs of its cancellation, few would disagree with former BAC test pilot Don Knight's view of the TSR2. We gathered his recollections of the stillborn programme — and look back at the thoughts of his late colleague Jimmy Dell **WORDS:** DENIS J. CALVERT

As is often related, the British Aircraft Corporation TSR2 had but a short flying career. Only one aircraft, XR219, took to the air and made just 24 test flights between 27 September 1964 and 31 March 1965. Had XR219 flown earlier, and thus become more established in the test programme before Harold Wilson's government came to power in October 1964, had the second aircraft XR220 not had an unfortunate ground accident at Boscombe Down — one of the rare occasions where a Mach 2 bomber genuinely 'fell off the back of a lorry' — and had Australia put its faith in the type rather than in the General Dynamics F-111, things might well have turned out differently. As it was, an aircraft that promised so much including 'Mach 2 from a grass strip' and that was so central to the RAF's future long-term planning was cancelled on the grounds of necessary budgetary savings, the manufacturer BAC having been unable, perhaps wisely, to offer the government a fixed-price contract.

Only six people ever flew the TSR2. For the record, these were pilots Roland 'Bee' Beamont, Jimmy Dell and Don Knight and navigators Don Bowen, Peter Moneypenny and Brian McCann. By the time of cancellation on 6 April 1965 the programme had achieved momentum and was beginning to open out. XR220 was on the point of making its delayed first flight and several more development batch (DB) aircraft were identifiable on the line at Weybridge.

Roland Beamont made the early flights of XR219, some of which could fairly be described as eventful. This was the result of 'bell mode' engine vibration at certain power settings, and undercarriage problems which included an inability to retract on early flights and severe structural/undercarriage oscillations on landing. Jimmy Dell made XR219's sixth flight and then 11 more.

Don Knight, BAC's deputy chief test pilot at Warton, piloted XR219 on flight 12 from Boscombe Down and on flight 23 from Warton, which was intended to be the main base for the type's flight testing. Aeroplane had the privilege of meeting Don to discuss the TSR2 programme and his involvement with it. "'Bee' as the boss was definitely in line for the initial test flying", Knight recalls, "but would in time move on and Jimmy was to take over. In the end, Jimmy did more. It was the start of a handover."

Although his first TSR2 flight was on 10 February 1965, Don's involvement with the aircraft started at Buffalo, New York, in October-November 1962. "Much Lightning work was still going on at Warton, so someone had to stay behind and carry on with it! So, I wasn't really involved closely with TSR2 until quite late. Although that's not strictly true, because I had an involvement in 1962, two years before. A lot of simulation work was going on.

"There was some concern about TSR2's lateral stability, particularly in the landing configuration. BAC organised with Cornell Aeronautical Laboratory [CAL] in the United States involvement in a research programme using their highly-modified variable-stability T-33 [NT-33A 51-4120, fitted with an F-94A Starfire nose]. This was not a programme specifically orientated towards TSR2, but we did assessments of handling and stability over a range of configurations including those of interest for TSR2. I did the assessment flying from the T-33's front seat on this programme.

> **"Much Lightning work was still going on at Warton, so I wasn't really involved with the TSR2 until quite late"**

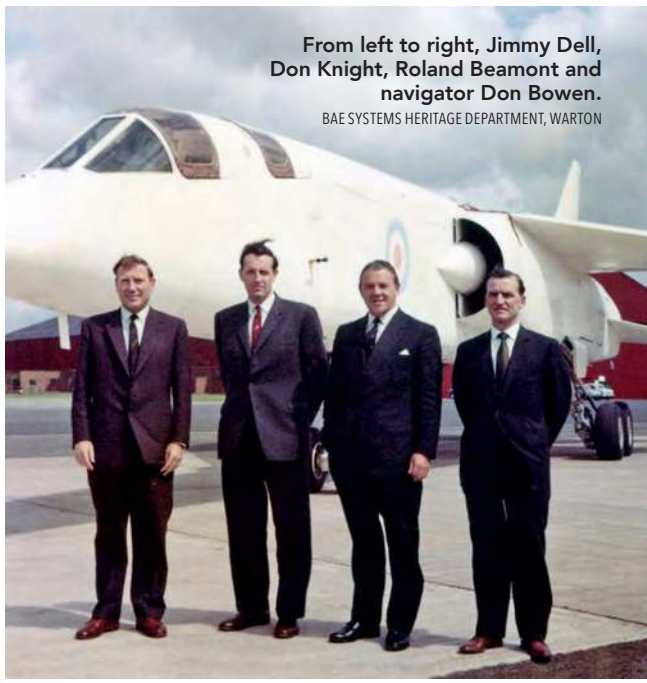
"The aircraft was much modified with front stick movements operating servos through a computer, whose numerous individual parameters could be set and adjusted in flight from the rear cockpit to vary control sensitivity and aircraft stability in roll, yaw and pitch. It had wingtip tanks modified to act as airbrakes which could be operated differentially to get the desired effects. The rear cockpit stick was linked normally to the control surfaces. Considering the range of configurations, some marginal, the aircraft was clearly restricted to very good weather conditions.

"I flew about 60-odd configurations, and to maintain impartiality wasn't allowed to know until the end what they represented. Each was given a number which I was asked to assess on a scale of one to 10. I was also divorced from any post-flight discussion — I would come into the room and they'd all stop talking! 'Your job is just to tell us what it's like, and to rate it'. This went on for about three weeks.

"The initial work done on simulators at Warton was led by a chap called Arthur Barnes. I

ABOVE: Test pilot Don Knight made two TSR2 flights before the programme's cancellation. Today he is the sole surviving TSR2 aircrew member. BAE SYSTEMS HERITAGE DEPARTMENT, WARTON

Don Knight in the front seat of the Cornell Aeronautical Laboratory's variable-stability NT-33A 51-4120, with Cornell's Ed Smith in the rear.
VIA DON KNIGHT



From left to right, Jimmy Dell, Don Knight, Roland Beamont and navigator Don Bowen.
BAE SYSTEMS HERITAGE DEPARTMENT, WARTON

ABOVE: Beamont and Moneypenny taxi in at Warton on 22 February 1965, XR219's 14th flight, and the TSR2's first supersonic and first cross-country sorties.
BAE SYSTEMS HERITAGE DEPARTMENT, FARNBOROUGH

ABOVE RIGHT: XR219 on flight seven, dated 22 January 1965, approaching with the port main undercarriage leg at less than the optimum angle. Roland Beamont was in command with Peter Moneypenny as navigator for the first time.
BAE SYSTEMS HERITAGE DEPARTMENT, WARTON

had worked a lot with him, as he developed simulator technology. It was all fairly crude by modern standards — none of your moving cockpits or anything like that. His initial approach was to obtain an acceptable match on the simulator with the Lightning, which was flying, with known characteristics. Once he managed to do that he could insert a range of the expected derivatives for TSR2 for pilots to assess as 'yes, that's acceptable' or 'no, that's not acceptable'. Particularly in more marginal cases, there was emphasis on the effects of the pilot in the loop and the consequent variation in response times [for example, the risk of pilot-induced oscillation]. I did a lot of work with Barnes on that, so I was the natural to go to Cornell when they had a real flying programme."

XR219's first flight was delayed by many factors. A crucial one was the decision to carry out TSR2 final assembly at the Brooklands plant in Weybridge but then partially to dismantle the aircraft, truck it to Boscombe Down and reassemble it for its first flight. This has always seemed a political decision and one that had a critically detrimental impact on the programme's progress. I asked Don how he saw it.

"Well, there's quite a story there, because years later I attended a 'TSR2 with Hindsight' symposium run by the RAF Historical Society. I was only a pilot at the time of TSR2, but a lot came out about the politics. It is generally accepted that the TSR2 project was used to further the government's aim for rationalisation of the aircraft industry. Although a massive programme, it seems the whole way of operating wasn't entirely sorted out and optimised either in industry or at the MoD. There were issues put down to the fact that the prime contractor was Vickers, but that all the expertise was with English Electric at Warton. In the case of the MoD, accusations include delays and cost effects due to changes and too many different departmental fingers in the pie.

"Regarding the first flight there was a suggestion at one stage that, as the VC10 was first flown out of Brooklands, we should do likewise with TSR2. Wisley, too, was considered but was a short strip. We always felt that, if common sense had prevailed, TSR2 would have been assembled at Warton — assembled, tested and flown all at one site. You could argue that, having ruled out Brooklands and Wisley, there was logic in choosing Boscombe Down for the first prototype with its extra-long runway and its proximity to Vickers as lead contractor."

As an aside, there was a precedent for the less-than-obvious choice of location for XR219's first flight. The English Electric P1A prototype,

WG760, had been taken to Boscombe Down in summer 1954 to make its first flight, this before the Warton runway was extended and the site developed into the major test centre it is today.

XR219 was dogged with restrictions on its Olympus 22R (Mk320) engines. The units fitted for the first flight, numbers 22218 and 22221, were signed off by Bristol Siddeley Engines Ltd (BSEL) on 27 September — a Sunday — for a single flight later that same day. It seems that the Olympus's vibration problem was understood but certainly not fully resolved either on XR219 or XR220 by the time of the programme's cancellation. Don recalls, "The engine was still restricted. We weren't taking off at 100 per cent power; 98 per cent, something like that."

Did the limitations affect use in afterburner only, or in cold power as well? "There were limitations too in cold power. I can say from memory that there were still engine vibration issues when XR219 flew, with special warning lights for the pilot to reduce power if certain levels were exceeded. 'Bee' was at the sharp end of those decisions. BSEL had an engine blow up on a Vulcan testbed [XA894 on 3 December 1962] at Filton. There was a lot of nervousness about the state of the engine."

One camp within the company and the ministry felt it prudent to take a more conservative approach and to wait until the problem was resolved before making the first flight, but such were the pressures — and the ever-present risk of cancellation — that the programme could not wait.

"Yes, it was under threat", says Knight. "I think you could sum it up by saying there were teething problems, with the undercarriage as well as with the engines. On landing there was a sudden vibration on touchdown. I seem to remember it was something like +/-2g lateral at the cockpit — disorientating but of fairly short duration."

Following XR219's first flight, which was of 14 minutes' duration and involved no more than a couple of circuits of Boscombe Down, the aircraft was laid up for more than three months before making its second flight on New Year's Eve. This time was used to give engineers the chance to address the most pressing issues and to replace both engines. BSEL and the National Gas Turbine Establishment had spent much time investigating the Olympus 22R shaft issues, which were having such an impact on flight-testing. The cause was an excitation of the low-pressure shaft giving rise to huge stresses and eventual failure — the so-called bell mode vibration. Although design and manufacturing changes to the shaft were implemented as a result, TSR2 engines had limitations imposed throughout the remainder of the type's test programme.

As Knight says, "There were quite a number of restrictions that were accepted for the first flight. Then they had to fix the problem with undercarriage retraction. The retraction sequence was very complicated: on take-off, the gear had to rotate to align with the leg and then move forward. There are pictures of 'Bee' with the gear only partly extended for a 'tippy-toe' landing, one wheel above the other."

> **"A windy day, and 'Bee' was sitting serenely in the TSR2 and Jimmy was having a nasty ride in the Lightning"**

Don's principal task on the programme was to be the avionic suite which had been installed in XR221 and was being ground-tested at Weybridge. "The way it worked was that, although everybody involved would participate in the overall programme, there was to be a lead pilot for each main task. For the handling and initial testing it was Beamont and became Jimmy Dell. My primary project was going to be XR221, the aircraft designated for initial avionics system clearance."

XR219 was very much an aerodynamic prototype, lacking the terrain-following radar (TFR), head-up sisplay (HUD) and other advanced avionics that would be fitted to later DB aircraft. As Don recalls, it had a 'Blue Circle' nose, named after a brand of concrete. Despite that, Jimmy Dell did some low-level flying with it, particularly on flight 16 on 26 February 1965, when he took the aircraft down to 200ft. But this was essentially flying by hand and eye, rather than with the benefit of TFR. "It was really all to assess the ride. It was a flight 'Bee' did at high speed over the Lake District and Jimmy was flying chase in the Lightning. A windy day, and 'Bee' was sitting serenely in the TSR2 enjoying a good ride and Jimmy was having rather a nasty ride in the Lightning.

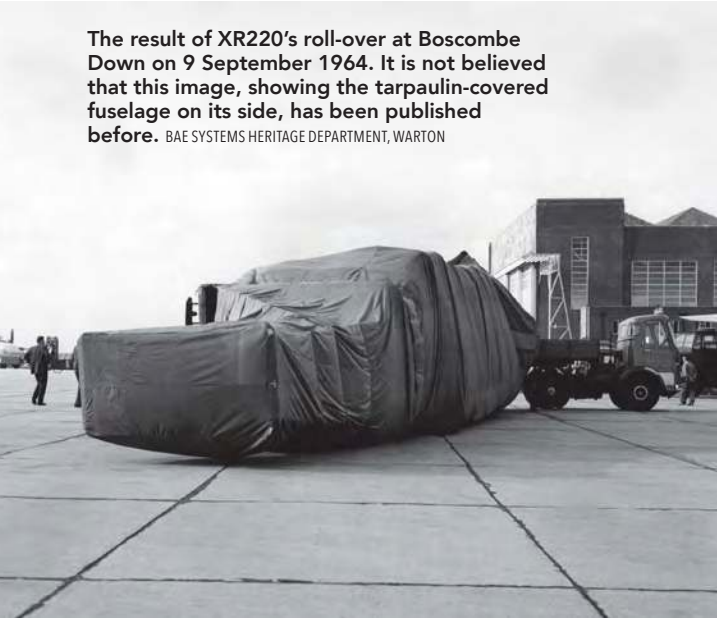
"A lot of effort went in to push the programme along, to ensure key requirements would be met — the gradual progression of air speed, flutter work was very much short-circuited, and they took the aircraft up to 600kt."

The supersonic corridor over the Irish Sea was conveniently close to Warton and Beamont took XR219 through Mach 1 on flight 14 on 22 February 1965. Using reheat on number one engine only — number two was in dry thrust — speed was increased to Mach 1.12 at 29,500ft before afterburner was cancelled. This also marked XR219's delivery to Warton, where flight-testing was to be based, and BAC workers turned out to greet 'their aircraft'.

"I came into the programme proper quite late", Knight continues. "I had these early involvements as we discussed, and then became

BELOW: Undercarriage problems bedevilled the TSR2's flight-testing, due not least to the complexity of the retraction sequence. This is almost certainly flight five on 14 January 1965, when the port main gear leg failed to retract and Beamont had to make a 'tippy-toe' landing back at Boscombe Down.

BAE SYSTEMS HERITAGE DEPARTMENT, WARTON



The result of XR220's roll-over at Boscombe Down on 9 September 1964. It is not believed that this image, showing the tarpaulin-covered fuselage on its side, has been published before. BAE SYSTEMS HERITAGE DEPARTMENT, WARTON

Even early on in testing, the TSR2 demonstrated the good low-level ride that would have been so valuable in its intended role. KEY COLLECTION

> "They were playing pool, the TV was on with the budget speech and they caught the announcement, as Jimmy Dell described it, of 'sixpence on fags, tuppence on beer and, by the way, we're cancelling TSR2'"

involved with the avionic systems in the simulator at Weybridge. XR220 and XR221 were still a few months away, so there was a lot of learning still to do."

Don's first flight in XR219 was on 10 February 1965. His second trip took place six weeks later, on 27 March, and would turn out to be XR219's penultimate flight. In each case his navigator was Peter Moneypenny, and he was briefed by Jimmy Dell. "Peter Moneypenny was the number two navigator. Don Bowen was the Vickers man and was 'Bee' Beamont's navigator. We started to spread the experience, first with Peter Moneypenny and then with Brian McCann."

Both flights were essentially for familiarisation purposes, although there were some test points involved. "I did two taxi runs, for familiarisation on the ground, before my first flight. My first flight was from Boscombe Down, the second from Warton."

The impressions of Don and other pilots who flew XR219 were that it handled much like 'a big Lightning', which is surely meant to be taken as a compliment. "A bit heavier than a Lightning, but the characteristics were very similar. I think people expected it might be slightly more of a handful because there was no autostabilisation at that stage, and yet it was good."

Don also flew Lightning or Canberra chase on XR219 for several of its test flights. Of his final Lightning chase sortie on 8 March 1965, a day when XR219 flew twice, he recalls, "I can't be certain which one I chased as I only have overall duration times in my logbook, not starts and finishes. It was my second flight that day in two-seat Lightning XM967 and I was accompanied on that occasion by a flight test department engineer."

Many, many years ago the author was given a black and white photo of a seemingly near-complete TSR2 airframe, lying on its side on the concrete with inflatable air bags under it and a large crane towering above. This could have been a shot of a part-completed airframe, taking during the mass scrapping that took place after cancellation at Warton and Samlesbury. Or was it of XR220, taken at Boscombe Down in the aftermath of its 9 September 1964 roll-over accident while being delivered from Weybridge in a semi-

BELOW: Some of BAC's finest: TSR2 XR219, Lightning F6 XR755 and Canberra B2 WD937 together at Warton. BAE SYSTEMS HERITAGE DEPARTMENT, WARTON

dismantled state by articulated truck? It turns out it was the latter, with the suggestion that the image had been taken by an insurance assessor as part of a (probably expensive) accident claim. Don Knight remembers it: "They had the drama with the second aircraft when it fell off the truck at Boscombe Down. Fortunately, it landed on the tailplane spigot that was the strongest part of the airframe. I understand it was on an articulated truck that just got too much angle on when reversing."

In the event, the damage incurred and the time taken to effect a repair meant that XR220 would never fly, becoming the victim of a cruel twist of fate. Jimmy Dell and Peter Moneypenny were to make its first flight from Boscombe Down on 6 April 1965. Don remembers, "They were there to fly the aeroplane, but it had a snag — a fuel pump required to be changed. They decided to go and get a bite of lunch while this was going on, so they went down to a local pub to get a sandwich, and while they were there they 'phoned Boscombe Down to see if the aeroplane was fixed and it wasn't. So, they were playing pool, the TV was on with the budget speech and they caught the announcement, as Jimmy described it, of 'sixpence on fags, tuppence on beer and, by the way, we're cancelling TSR2'! They thought, 'Let's get back and get this thing airborne', but when they arrived at Boscombe Down they were forbidden to do anything and that was the end. But what a way to hear."

Even now, opinion on the TSR2 remains divided. Those who flew it seem agreed that it showed every sign of being an excellent airframe with great handling and performance, but there's an equally strong point of view that, however good the airframe, the avionics would have been 10 years behind it in development. Don's thoughts: "A great 'might have been'. There were undoubtedly things to sort out on it, but there was nothing that looked fundamental to me from a flying point of view. Systems-wise, they had the undercarriage problems, but that was engineering. Personally, I always wondered a bit about the engine installation — a long tube with the engine going in from the back. I wondered if that might require a bit of attention when it came to operational usage. But I don't think there was anything that couldn't have been sorted out during development."

Jimmy Dell in the cockpit of XR219, in which he made a dozen flights.
BAE SYSTEMS HERITAGE DEPARTMENT, WARTON

"It was quite an exciting ride"

As chief test pilot at BAC Warton, Jimmy Dell flew TSR2 XR219 12 times, this representing exactly half the total of 24 flights achieved over the aircraft's short flying career. Sadly, Jimmy died on 25 March 2008, but *Aeroplane* was fortunate to have been able to interview him at IWM Duxford on 16 December 2005 on the occasion of the roll-out of restored TSR2 XR222, the fourth development batch aircraft.

Don Bowen was the navigator for Jimmy's first TSR2 flight on 15 January 1965, but for later flights he was accompanied by either Don Bowen or Peter Moneypenny. Dell took over the prime responsibility for handling trials from 'Bee' Beamont at a time in the programme when confidence was building, and sortie frequency and sortie lengths were increasing. I asked Jimmy how XR219 handled when taken down to low level, the environment for which it was designed. Could he compare the ride with that of any other front-line RAF aircraft?

"Well, I never flew a Buccaneer", he replied, "but I flew other aircraft at low level and this was superb because the design of the wing had a cushioning effect. We weren't supposed to go below 200ft, but I took it lower. It was quite an exciting ride because you sat there with your arms folded."

He really had that much confidence in it? "Yes, you had to have. You wouldn't do the test if you hadn't. But what amazed me was, initially of course, watching when everything is going alright, you didn't notice much outside your peripheral vision. But once you got used to it you found you could see a lot more because you weren't just concentrating on looking straight ahead. You could see a wider angle. And when we were going up through the Pennines about Mach 0.9, I'd set 250ft, so the autopilot was on, and it was amazing how much you could see. I remember seeing a van coming along the road which was crossing my path and I could even read the maker's name on the side, which amazed me because flying at that speed at that height it was only because you felt relaxed because the autopilot was doing all the work for you."

The comment has often been made that the TSR2 handled like a big Lightning. How much truth was there in that statement? "It was a much bigger aircraft, of course. But — well, you've seen the aircraft. When you're strapped in it's got such a long fuselage and you can't see anything of the aircraft. Even if you really screw yourself round, you can just about see a bit of it. There was no rearwards view, but we had rear view mirrors, so most of what you saw was out of the front. You had a super view because the nose slopes down very sharply, so it was great particularly for high-speed, low-level flying for which it was primarily designed. You really had a panoramic view."

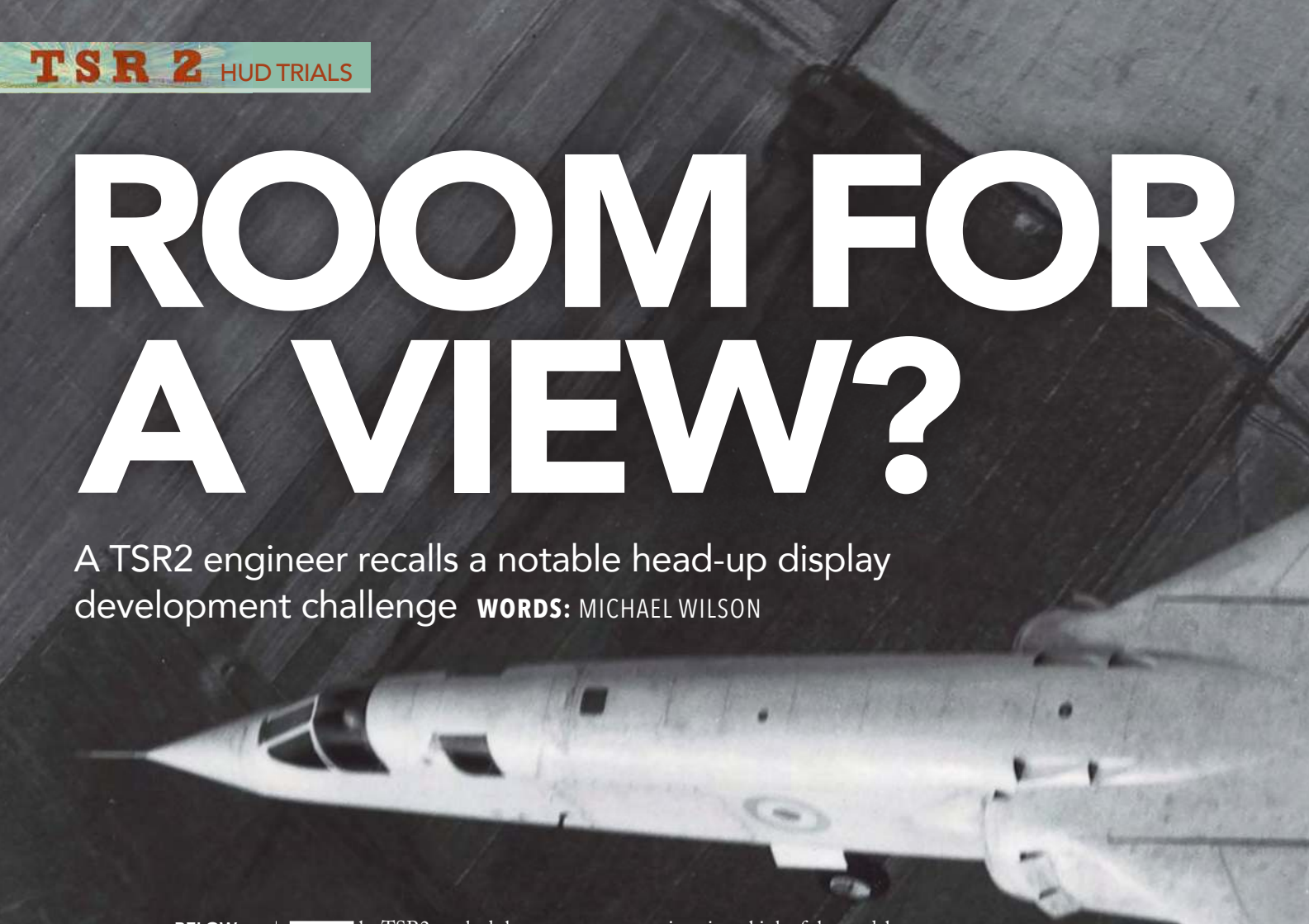
The TSR2 was always a political aircraft. It had its friends but also its enemies, ever ready to highlight any problems or delays and to underline cost over-runs. Cancellation came little more than six months after the first flight, but those closest to the programme remained enthusiastic and supportive, opining that the problems encountered were no more than might be expected at that early stage.

"They certainly weren't show-stoppers", said Dell. The bell-mode resonance was fairly easily sorted out. The undercarriage problems — it was a bogie undercarriage with two wheels either side. And when you lowered the undercarriage, it came down — the undercarriage is like this [he gesticulated to indicate the position of the undercarriage, which extended from bays in the fuselage] and as you touched down the rear wheels touched first. It was an alignment problem. The undercarriage was very flexible and of course you were in this long nose and you were going from one side to the other. Only for about three or four cycles, but initially when it happens you wonder what the hell is going to happen next, and whether the thing is going to disintegrate about your ears, but that was easily sorted out by fitting a jury strut, which stiffened up the undercarriage and stopped it happening."

And what about the likely date for entry into RAF service, had the project been allowed to continue. "Probably mid-seventies. It would have had to undergo so many tests to satisfy so many people. But I was anxious to try and get the Americans to have a trip in it, because they came across to look at it, but I think politics stepped in and they weren't allowed to fly it. I think they would have been very impressed with the performance at that stage."

ROOM FOR A VIEW?

A TSR2 engineer recalls a notable head-up display development challenge **WORDS:** MICHAEL WILSON



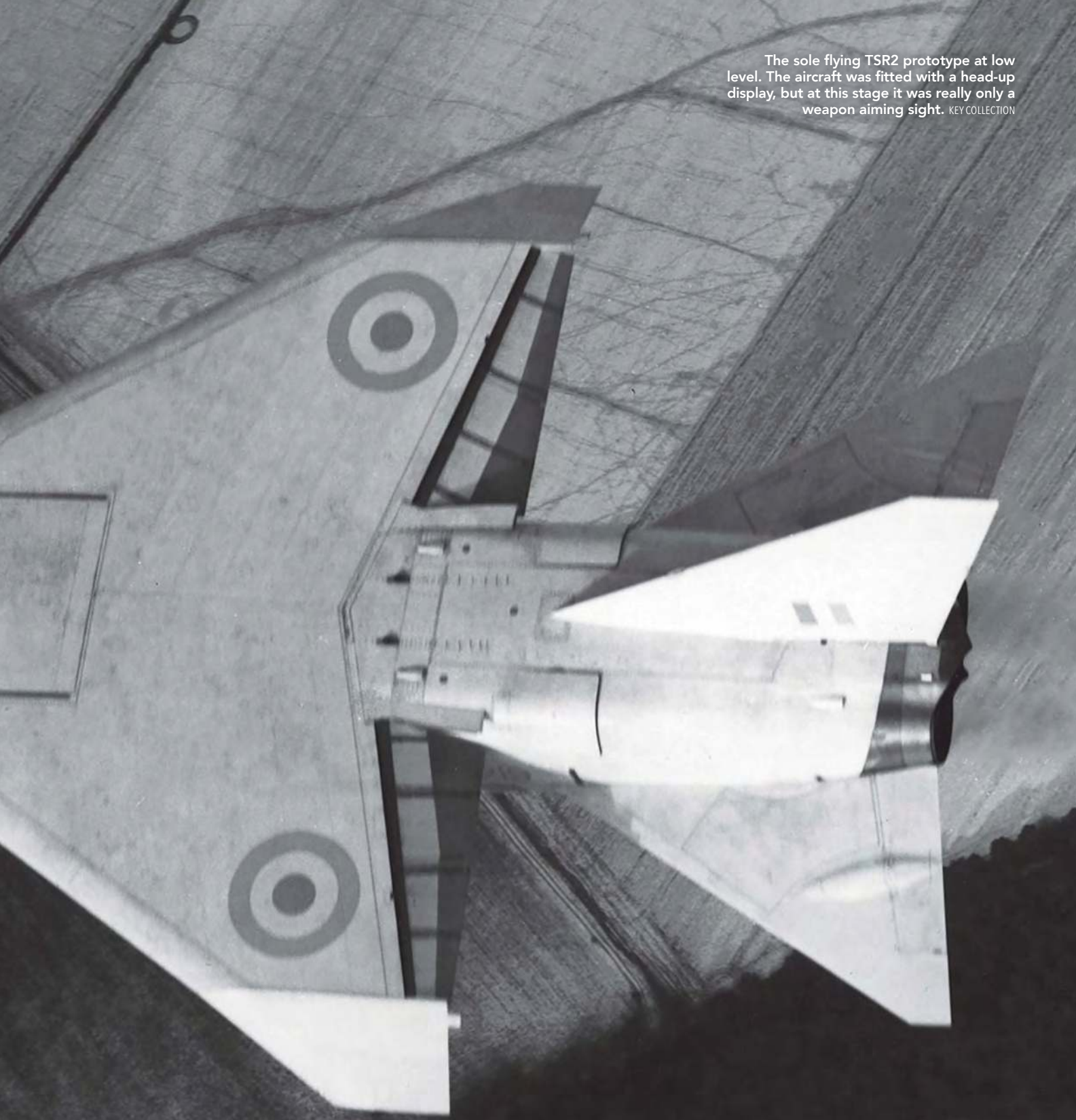
BELOW: A PDU (pilot's display unit) for the TSR2's HUD on test at Sydenham. It contained a 3in high-intensity cathode-ray tube. BAE SYSTEMS

The TSR2 marked the beginning of the global change from analogue to digital technology, freeing designers to explore new performance paths and levels. The problem with analogue devices is that any desired changes to their mode of operation can generally be accomplished only by time-consuming mechanical re-engineering: think of the models of the solar system on display in museums and the complexity of gearing needed to change the daily and yearly movement of the planets around the sun. Analogue equipment can also suffer from drift, where the design settings can change after a time due to wear and tear. Digital devices, on the other hand, are always either totally correct because each is designed with a built-in degree of accuracy by way of sequences of ones and zeros, or don't work at all because of a malfunction or design error. Yes, they can suffer interference, but we're talking theory here. A further complication is that operation in conjunction with analogue devices can be complicated, even impossible and rarely satisfactory.

The TSR2 was the world's second aeroplane to benefit from the new technology, the first being the North American A3J Vigilante carrier-borne bomber, cancelled in that role because of difficulties with stores ejection. But it was Europe's first digital aeroplane.

Nine two-seat development batch aircraft were ordered, the first being devoted to exploring the flight envelope and general handling, the second to validating the AFCS (auto-flight control system), and the third being the first fully equipped nav-attack example. The first, XR219, was flown successfully many times; XR220 was about to fly, while XR221 was some way down the line. My initial brief as a flight-test instrumentation engineer in BAC's electrical technical office in Weybridge was to join in planning the airborne instrumentation needed to check the performance of the navigation and weapon delivery systems in accordance with a schedule prepared by all parties. We were to do that in conjunction with English Electric at Warton, Lancashire, which was in my view really the senior technical partner in terms of military aircraft work.

In the operational system, digital signals from the various mission boxes were routed to the Verdan (versatile digital analyser) central computer, a US Autonetics system adopted by the UK's Elliott Brothers (later Elliott Automation) where they were processed as necessary before being routed to the two-man crew via navigation and weapon delivery screens. For flight-test purposes, signals of particular interest generated by the nav-attack equipment were



The sole flying TSR2 prototype at low level. The aircraft was fitted with a head-up display, but at this stage it was really only a weapon aiming sight. KEY COLLECTION

sampled at a general rate of two words a second by a specially built piece of flight-test instrumentation known as a buffer unit, in which signals could be slowed before being fed into a US-supplied Ampex industrial tape recorder.

In addition to assessing the reliability and accuracy of the airborne system for the flight test evaluation team, there was the need to check the electrical compatibility of the different systems boxes with one another. And there were a lot of them: AFCS, Doppler-monitored inertial navigation system, line-scan, sideways-looking radar, forward-looking radar, head-up display, moving map display, radar altimeter and central computer, not to mention the instrument landing system.

The HUD brought together for the pilot mission-critical data and guidance information from the totality of the nav-attack system. Thus it was vitally important that it be recorded for post-flight analysis by the assessment people who wanted to see exactly what the pilot saw: a real-time view of the outside world overlaid with all the symbology needed to accomplish the mission. Anomalies could then be investigated on the ground by checking individual boxes or in conjunction with the stage IV test rig, in which the boxes comprising the entire system were set up on benches and connected together in such a way that individual elements could be checked in a way not possible in the cramped conditions in the aeroplane's equipment bay.

ABOVE: NA39 Buccaneer development aircraft XK487 played its part, being flown during the TSR2 programme by Ferranti from Turnhouse. VIA GRAHAM PITCHFORK

The Cintel HUD, one of the many innovations on the new bomber, was a major development of the wartime gunsight/camera recorder. Cintel was a UK company, Cinema Television, formed by John Logie Baird of television fame, later absorbed into the Rank Organisation. The display was, I recall, recessed into the instrument panel coaming. Its symbology was to be projected onto the rear face of the pilot's windscreen and there aligned with the outside-world view. Duplicate information, though not the outside world, was provided for the rear-seat occupant.

In terrain-following mode the forward-scanning radar looked for obstructions along the line of travel — the flight-track vector. When obstructions were detected the radar computed a pull-up command at pre-determined distances and clearance heights, computed in conjunction with the forward-looking and altimeter radars. The climb and subsequent pushover manoeuvres could be set according to whether a 'hard' or 'soft' ride was chosen, dependent on aircraft speed and g-loads.

We had to meet a particular challenge in recording the HUD display: how to capture and record the outside-world scene without interfering with the pilot's view or causing injury during an ejection. A beam-splitting mirror in the line of sight could be used to divert outside-world/symbology data to a locally mounted video camera, but could it be done? At this point some remarks on the electronic world might be in order. As noted earlier, the 1950s marked the transition between analogue and digital; in engineering terms, between thermionic valves and solid-state devices known as transistors. Actually, the TSR2's designers had no choice but to embrace the new technology. Indeed, for an aeroplane with such an extensive electrical power demands just one item — cooling air for these heat-generating devices — would probably have ruled them out. As it is, one authority claimed that the new bomber would be unviable because MTBF (mean time between failures) of solid-state devices would be unacceptably short to complete any lengthy mission.

> **“It was claimed that the TSR2 would be unviable because of the mean time between failures of solid-state devices”**

To return to the HUD challenge, we were forced to consider a variation of the World War Two gun-camera as the only feasible option by which the imagery could be recorded. But this involved violating the sacred space reserved for the ejection envelope, an imaginary 'tube' which the seat and pilot occupied during ejection. It was a difficult decision, involving politics, policies, insurance and much else — all far above my level of seniority. I decided to sound out the individual whose views and decision would carry immense weight and could short-circuit the lengthy decision-making process.

David Morgan was the Vickers project pilot assigned to fly the nav-attack trials, and we agreed to meet informally at the aeroplane itself. We discussed the challenge at some length, him sitting in the cockpit and me standing on an access ladder and leaning over the fuselage side into the cockpit well. We manoeuvred a representative camera into all possible viewing regions and discussed methods by which it could be mounted. It was clear that, without the expense and time involved in designing a dedicated camera mounted in the equipment bay with split mirror in the cockpit, the outside-world view could be captured only by permitting a small breach of the ejection envelope.

Some tooth-sucking ensued, after which Dave expressed himself satisfied that there was no alternative and nodded the slight intrusion through — such is the stuff of which test-pilots are built. He felt that the camera could be dismounted at a moment's notice from a frangible mount in the event a rapid exit was called for. Presumably, with the possibility of personal injury and legal implications in mind,

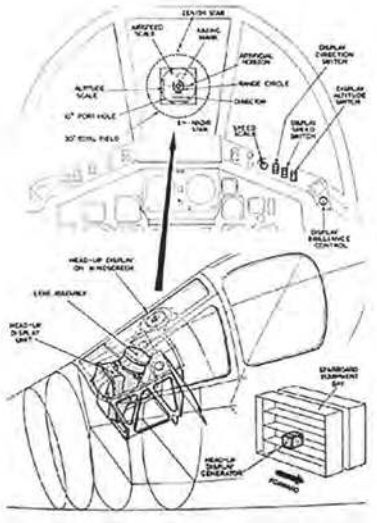
BELOW: Of 20 TSR2 PDUs built, just three survive, including this one in BAE Systems' Rochester collection. BAE SYSTEMS

he subsequently cleared the as-yet undesigned installation with peer opinions, because I had no comeback from higher-ups. In fact, the TSR2 was cancelled within a short time of our meeting. And now, for those still querying the title of this article, it comes from the effort involved in trying to find 'room' for something that needed 'a view'.

A number of trials aircraft were dedicated to supporting the TSR2 flight-test programme. One of them was a Comet 4 based at Boscombe Down in which a representative nav system and associated monitoring equipment had been set up on work-stations along the length of the fuselage, rather like those in larger ASW aircraft such as the Nimrod. The principal goal of the Comet trials was to check the accuracy of the Doppler-monitored inertial navigation system. Actual speed over ground and distance flown, calculated electronically from accelerometer signals in the INU (inertial navigation unit) is highly accurate in the short term but is subject to drift over long periods, while Doppler is less accurate over short periods but has better long-term performance and so can correct the inertial data.

To gain some familiarity with the complete system I took a flight in the Comet to see the different systems in action, supplementing the ground-based stage 4 rig. The trial involved cruising up north to a convenient navigation waypoint and back, twice, to check the long-term accuracy of the system.

Another trials aircraft was a Buccaneer in which a development forward-looking radar and HUD had been installed in a representative TSR2 radome, on loan to Ferranti. It was flown out of the company's flight-test centre at Edinburgh's Turnhouse airport during 1963 to get some experience in contour-following. The jet was big and tough and could carry the considerable weight and volume of development and recording equipment at representative speeds, heights and g-forces in advance of the TSR2 taking the air, providing valuable experience in automatically generating flight profiles at low level. It would be a good tool for crew physiological investigation as well. Flying was conducted over Schiehallion, a 3,500ft 'Munro' (with peaks more than 3,000ft high) in Scotland noted for its smooth shape which made for fewer 'jiggles' in the interrogating radar beam and thus in the command symbols that were presented to the pilot.



Since its design was based on analogue technology, incompatible with the TSR2's digital AFCS, signals from the two radars were fed directly to the HUD, bypassing the Buccaneer's own flight control system. Thus, in contour-following missions the pilot had to fly manually according to the HUD commands. It was tiring and demanding, and called for a level of trust in the system as the mountaintops could be obscured by mist or cloud.

I cannot let these recollections go by without recording an amusing and quite possibly apocryphal account of an incident involving the Buccaneer which was doing the rounds at the time. The story goes that, on one occasion following its arrival back late during the final flight of the day, the aircraft was landed back at Turnhouse and parked. The pilot clambered out, climbed aboard his car still clad in flight overalls and roared off home. Bodily seated in the car, he was mentally caught up with 450kt contour flying. Such a pity that the barrier came down at the level crossing just as his long-nose Bentley swept into view. With just seconds to spare he did the natural thing and hauled back on the steering wheel. Not responding to such commands, the car sped through the obstruction in a shower of broken wood.

Cancellation of the TSR2 programme was announced by the new Labour government in April 1965. Within a month or so I was invited to join *The Aeroplane*'s rival journal *Flight International* to replace respected aviation journalist and technical guru, the late Bill Gunston, who had left to join IPC's newly launched *Science Journal*. Early in 1966 I flew with a press party to join a presentation in Toulouse of Dassault's proposed TSR2 replacement, a Rolls-Royce Spey-engined version of France's Mirage IV nuclear bomber. It was the first of a long line of candidates put up to replace the TSR2.

From the published evidence, the TSR2 was outstanding in every way. Yes, it was expensive, partly because of the many support projects involved — the Buccaneer and Comet were not the only ones — and perhaps with the HS681 and HS1154 it was simply a bridge too far. But it had come to the notice of savvy Americans that the Brits could still do world-class engineering, something that was good for the future and for collaborative projects such as the McDonnell Douglas AV-8B Harrier II and Lockheed Martin F-35 Lightning II. More than that: UK leaders in the global technical, industrial, educational and other fields had begun to see what could be done with new technology.

ACKNOWLEDGEMENTS:
The editor thanks Chris Bartlett, curator of the BAE Systems Rochester Avionic Archives, for his help with photos for this article.

LEFT:
A diagram showing the positioning of the HUD installation, which was far from ideal. The Triplex glass used for the TSR2's cockpit glazing was very thick, hardened against high-speed birdstrikes and covered in a gold film to protect against nuclear flash — all of this caused multiple reflections off inner and outer surfaces and distortions at high speed. This required a complex optical system for the HUD, the positioning of which so far from the windshield rendered it large and heavy.
BAE SYSTEMS

BELOW:
The sole Hunter T12, XE531, saw much use on TSR2 HUD development work.
VIA TONY BUTTLER

STRIKING POWER

The range of weapons that would have been carried by the TSR2 proliferated during the early 1960s — some being practical propositions, others less so **WORDS:** CHRIS GIBSON

ABOVE: A rendering of a Strike Command TSR2 carrying the air-launched BAC Blue Water, one of many weapons that were proposed for the type in the strategic role. ADRIAN MANN

The TSR2's raison d'être was weapons delivery, specifically nuclear weapons, onto enemy targets, but as the geopolitical situation changed in the years following the Suez Crisis of 1956 its role, or rather proposed roles, changed. The weapons altered to reflect these and, of course, developments in weapons themselves. As the only game in town after the 1957 White Paper, the TSR2 and its weapons reflected the overall effort in weapons development.

During the lead-up to this period, the United Kingdom had a wide-ranging guided weapons industry, which from April 1957 felt the impact of four linked events. The first was that month's Defence White Paper which, despite the received wisdom that Duncan Sandys was pro-missile and anti-aircraft, saw guided weapons being cancelled. The second was 1961's move from the massive nuclear retaliation of the Trip Wire policy to one of flexible response. The third, also driven by the USA, was the cancellation of Skybolt in December 1962. Lastly came the 1968 decision to withdraw British forces from east of Suez. Throughout this period the tasks assigned to the RAF, and weapons requirements, changed. In the midst of this was the TSR2.

Developed to meet operational requirement OR1127, Red Beard was deployed in 1961. Like many British nuclear weapons it was euphemistically known as a target marker bomb, allowing it to be listed in ship stores without revealing its identity as a 15-kiloton (kT) weapon. Red Beard was to arm the Canberra, Scimitar and Buccaneer, none of which were supersonic. Only the Scimitar carried it externally. Early nuclear weapons were delicate and susceptible to changes in temperature and shock, so internal carriage in a temperature-regulated weapons bay was preferred. Another aspect of the early weapons was their size, which resulted in a draggy shape. Red Beard was 12ft long with a diameter of 2ft 4in and a rather bluff nose.

The TSR2 was designed for high-speed flight — Mach 1.7 — to its target, the last 200nm at low level. Flight at that speed would have caused external stores to heat up and therefore the delicate Red Beard required internal carriage, for which the TSR2's weapons bay was designed. Red Beard was intended for a loft delivery that required the aircraft to approach at low altitude, usually around 200ft, and at a predetermined range, pitch up into a 45° climb and release the weapon, maximising the distance from the detonation and allowing the aircraft to escape the effects of the explosion. That climb took the aircraft

up into the engagement envelope of enemy defences.

This was solved by way of a lay-down delivery whereby the aircraft released the parachute-retarded weapon as it passed over the target at high speed. There were down-sides to this: the aircraft might not escape the blast, Red Beard was not robust enough to survive the impact or the shock of retarder chutes opening, and it was not designed for external carriage in supersonic flight.

A new requirement, ASR1177, was drafted for an improved kiloton bomb. The Atomic Weapons Research Establishment took the US W59 warhead for Skybolt and substituted the US explosive for a more stable British one, less susceptible to shock. The resulting RE179 fission package, also known as Cleo, was much smaller than Red Beard's and formed the basis of the WE177 series, designed for the rigours of lay-down delivery.

Three variants, A, B and C, were developed, although the 10kT A version would principally be used by the Royal Navy as a nuclear depth bomb. The B, with a yield of 450kT, was the first to enter service with the RAF in 1966 as a strategic 'gap-filler' until the Polaris came into service, while the 190kT C was a tactical weapon. To accommodate the larger warhead, the WE177B and C were longer — 11ft 1in rather than the 9ft 4in WE177A — but maintained the same maximum diameter of 16in. The 10kT WE177A was originally intended for RAF service, its yield limited by Prime Minister Harold Macmillan who was concerned that in the new era of flexible response a higher yield would lead to escalation into full-scale nuclear war.

> "At least two WE177As, or even a stick of four, would be required to ensure destruction of vast or hardened targets"

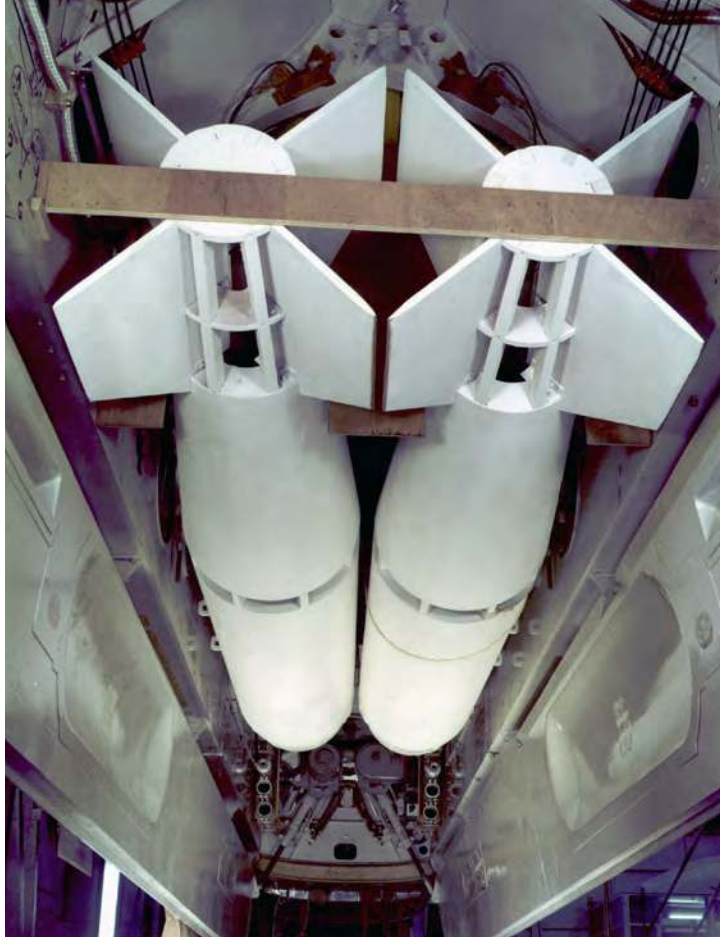
This brought a further complication. Some targets in eastern Europe, such as airfields and missile silos, were vast or hardened to the extent that nothing but a direct hit, even with a nuclear warhead, would be effective. At least two WE177As, or even a stick of four, would be required to ensure destruction of the target, delivered by the TSR2 using the lay-down or loft-bombing technique to minimise the aircraft's exposure to air defences.

The TSR2 could carry two WE177As in tandem or two longer Bs or Cs side-by-side in its weapons bay, thanks to the bay being sized for Red Beard. Another could go on each inboard wing pylon, although high-speed flight was time-limited to protect the WE177s from kinetic heating. In addition to British-designed nuclear bombs, the RAF had access to Project E weapons, whereby US weapons could be delivered by British aircraft in time of war. These included the B28 and B43 that could have been carried internally and externally, as per WE177.

The 1950s saw the rise of the guided weapon whose development went hand-in-hand with new strike aircraft such as the TSR2. Guided stand-off weapons allowed strike aircraft to avoid entering the enemy's air defence zone. The American AGM-112 Bullpup was intended for the TSR2 and would enter service with the Fleet Air Arm's Buccaneers, but the Air Staff was not particularly enamoured with it. Nor did the French AS30 appeal as its 7nm range and optical guidance would require the aircraft to enter the enemy's defended zone.

Meanwhile, at Vickers' plant in Weybridge, Barnes Wallis had been examining ways to provide stand-off. He came up with a weapon he called Apple Turnover, but which Vickers named the Momentum Bomb. Wallis' intention was to avoid the pitch-up required to deliver weapons by the loft technique. The Momentum Bomb was conceived to attack targets while the strike aircraft remained below the radar horizon. The unpowered weapon was fitted with small wings or long strakes with a symmetrical aerofoil section plus a basic tail unit. It did not require the attacking aircraft to climb before weapons release.

The TSR2 was to overfly the target at low level and release the Momentum Bomb at a pre-determined point down-range of the target. After release, the elevators commanded the bomb to enter a climb that became ever steeper and turned into a loop. At its apex, the elevators reversed and commanded the bomb into a gently sloping flight path to the target on the reciprocal bearing to the aircraft's flight path — that is, behind it. Being unpowered, the weapon relied on the momentum from its launch and low-drag shape to carry it to the target. For targets off the aircraft's ground track, Wallis suggested the aircraft



ABOVE: Two WE177 mock-ups, possibly the B or C variants, in the weapons bay of the TSR2 mock-up at Warton. The aircraft could carry two A variants in tandem or two B or C models side-by-side. BAE SYSTEMS VIA JOE CHERRIE

ABOVE: American weapons were available to the RAF under Project E. This photo shows a B43 'shape' on the starboard inboard pylon of the TSR2 mock-up. BAE SYSTEMS VIA JOE CHERRIE

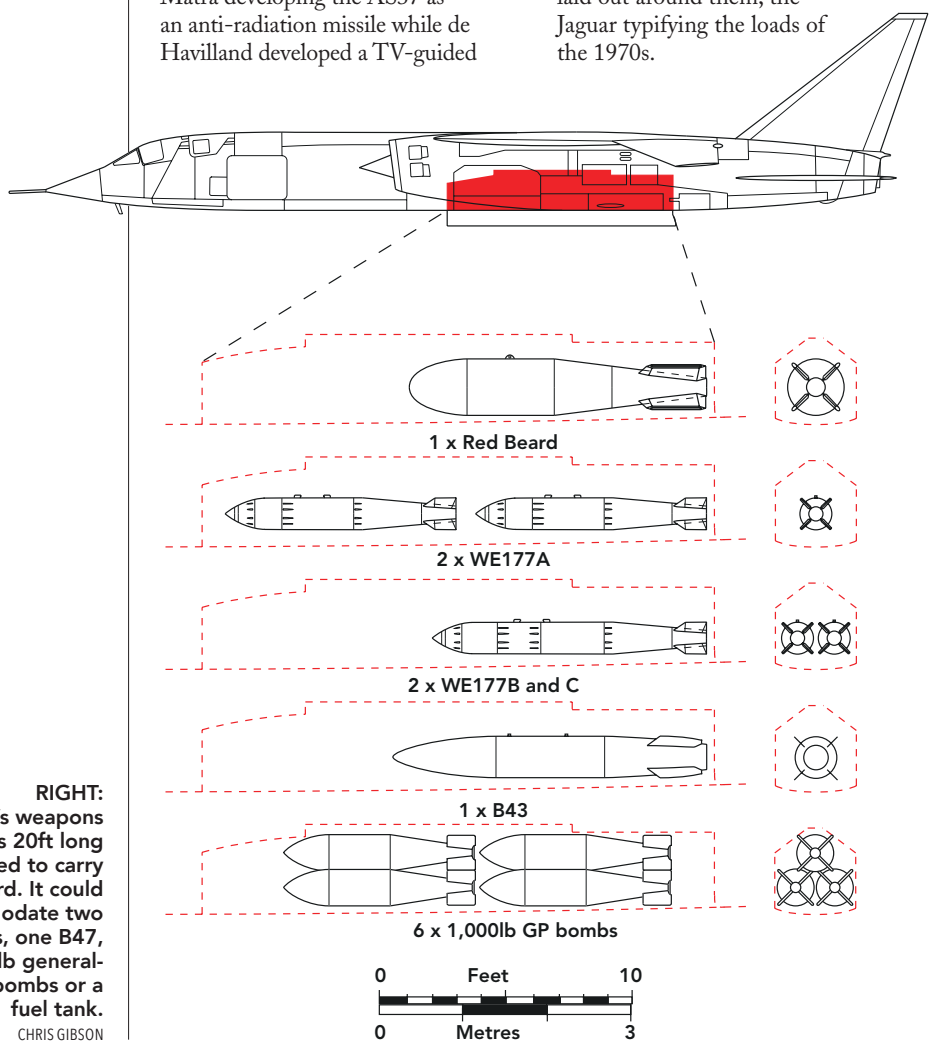
performed a turn onto a bearing whose reciprocal took the Momentum Bomb onto the target.

The Admiralty and Air Staff in 1962 drew up a joint requirement, NASR1168, to cover a powered guided weapon for use by strike aircraft such as the TSR2 against ships, bridges and other pinpoint targets. This prompted tenders from Bristol and de Havilland with the former proposing the Tychon and the latter the RG10. The Tychon was a modular weapon whose seeker and warhead could be swapped out to provide TV or anti-radar guidance and conventional or nuclear warheads, plus the option for a reconnaissance pack. The TSR2 could carry up to four Tychons on the wing pylons

de Havilland's RG10 became part of an Anglo-French project based on the Matra AS37 anti-radiation missile. The deal basically involved Matra developing the AS37 as an anti-radiation missile while de Havilland developed a TV-guided version designated AJ168 but known as TV-Martel, the name Martel being derived from Missile, Anti-Radiation, Television. The TSR2 would have used both TV-guided and anti-radiation weapons but if the Martel's use on the TSR2 had mirrored that on the Buccaneer, only three TV-Martels could be carried as one wing pylon would be required for the missile's datalink pod, and more likely one on each inboard pylon.

> **“ Skybolt was never a serious option for the TSR2, but the aircraft did enter the strategic nuclear deterrent business ”**

As a tactical strike aircraft, the TSR2 would have toted the air-to-ground weapons in the RAF's arsenal including 1,000lb bombs, with six in the weapons bay and five under each wing. Rockets were to go in underwing pods, the Matra pods being loaded with 68mm SNEB rockets. For a better idea of the probable weapons fit, examine photographs of types such as the Buccaneer or Jaguar with their stores laid out around them, the Jaguar typifying the loads of the 1970s.



RIGHT: The TSR2's weapons bay was 20ft long and sized to carry Red Beard. It could accommodate two WE177s, one B47, six 1,000lb general-purpose bombs or a fuel tank.
CHRIS GIBSON

As noted above, the WE177A with its 10kT yield was the model originally intended for RAF use, so where does the 450kT WE177B fit in? In 20-odd years of researching UK aerospace matters, the events of January 1963 and the resulting ministerial correspondence provide the only instance of what this writer can describe as a governmental 'flap'. Her Majesty's Government had in 1960 ordered the Douglas AGM-48 as the UK's deterrent. Better known as Skybolt, it was an air-launched ballistic missile (ALBM) and the British examples were to be carried by Bomber Command's Avro Vulcans. The existing Vulcan B2 with two Skybolts would in turn be replaced by long-duration patrol missile carriers, known as 'Pofflers', based on either highly modified Vulcans and Victors or a transport — the VC10 being the front-runner, carrying eight Skybolts.

The Ministry of Aviation had in 1960 examined arming the TSR2 with Skybolt. With a payload in excess of 20,000lb it could carry a pair. Proposals involved the simple expedient of mounting a Skybolt on the fuselage centreline, but this blanked off the TSR2's Doppler antenna, affecting the aircraft's navigation system, while the airframe covered the Skybolt star-tracker window. Fitting a Skybolt under each wing cured these problems but caused aerodynamic interference with the tailplane, while the wing structure might need strengthening.

The third option was overwing carriage, which solved the aerodynamic interference of the tailplane, but transferred the problem to the tail fin. The wing structure would need strengthening, too. One further feature of the overwing pylons would be the need to invert the aircraft to get an astro fix and launch the Skybolts. The UK and US Skybolts were to be identical apart from the warhead with the attachment lugs and interfaces on the upper side of the missile, which would need to be mounted upside-down with the star tracker pointing to the ground. Launch would involve the aircraft rolling inverted and maintaining this attitude until the missile had achieved a fix, when it was released.

Skybolt was never a serious weapon option for the TSR2, it being a tactical strike and reconnaissance type, but in early 1963 the aircraft entered the strategic nuclear deterrent business. President Kennedy cancelled Skybolt outright on 22 December 1962, leaving the UK without a deterrent as Macmillan had put all of Britain's

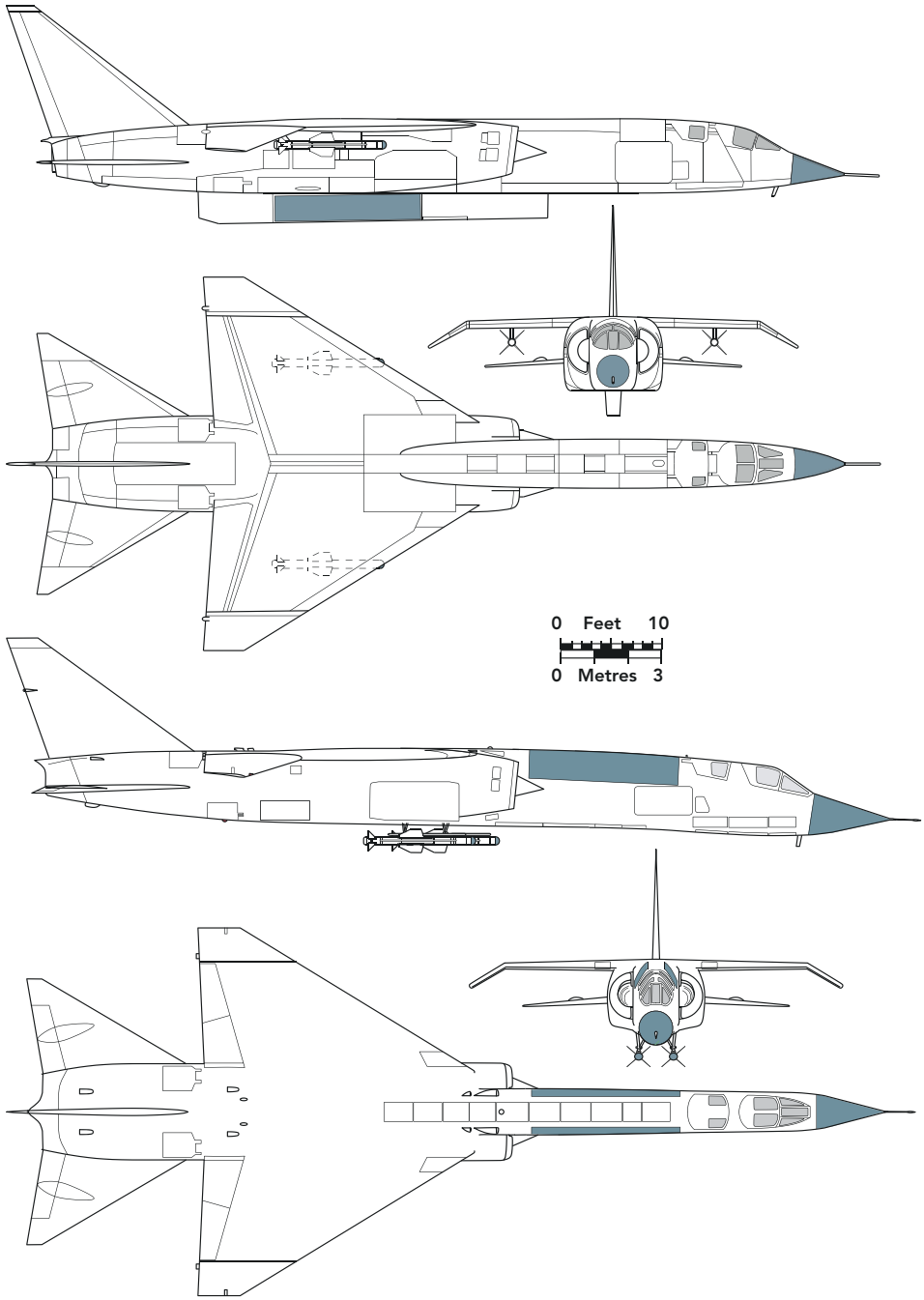
TSR2 AIR DEFENCE VARIANTS

In his 2010 book *TSR2: Britain's Lost Bomber*, Damien Burke presented the results of extensive research in the BAE Systems archives. With regard to the air defence TSR2, what was revealed was more than an interceptor: it was a long-endurance air defence platform. Although initially aimed at Soviet bombers with stand-off weapons coming across the North Sea, that would have changed.

Converting the TSR2 into an air defence aircraft could have been easy, substituting the strike aircraft's forward-looking radar for an airborne interception (AI) radar. The Ferranti FLR had evolved from the AI23 used in the Lightning, but things are never that simple. In the late 1950s and early '60s, interceptors worked with an air defence ground environment comprising early warning radars and ground controllers to co-ordinate interceptions. By the end of the 1950s the Soviets had adopted stand-off weapons and low-level incursion, depriving the controllers of early warning. The obvious solution was airborne early warning aircraft but at the time such systems were in their infancy. Vickers had examined an AEW system for the carrier-borne Types 582 and 583 that employed a fixed, electronically scanned radar antenna mounted along the centreline of the Type 583, which could patrol in a 'racetrack' pattern between the fleet and any approaching enemy.

When applied to the TSR2 the ventral antenna, associated hardware and fuel tank in the weapons bay meant that the air-to-air weapons were carried on the wing pylons. If two pylons were to be used for long-range fuel tanks this left room for a payload of two AAMs, the standard load for RAF interceptors. An alternative was to fit the radar antennae aft of the cockpit in an extended forward fuselage, allowing the weapons bay to be used for a pair of Red Top IR-guided AAMs.

If a radar-guided weapon was to be employed, the companies had a number of them on the drawing board, all aimed at the Fleet Air Arm to arm its Hawker P1154 fighters. These included the air-launched Sea Dart and SIG-16, both modified SAMs, and Blue Dolphin, a radar-guided version of Red Top. An alternative to the Blue Dolphin was the Radar Red Top that used the seeker from the French Matra R530, or even the R530 itself. To complete the weapons system, an AI radar was required, possibly in the form of the AI25 intended for the P1154.



Diagrams of the TSR2 air defence variants. The upper drawing shows the version with the ventral blade antenna and underwing Red Tops while the lower one illustrates the conformal antennae behind the cockpits and modified forward fuselage. CHRIS GIBSON

nuclear eggs in one basket. The Nassau Agreement of 21 December resulted in the UK acquiring the Polaris SLBM (submarine-launched ballistic missile) system, which unfortunately would not enter service until 1969 at the earliest. The RAF's deterrent comprised Yellow Sun freefall bombs and the 100nm-range Blue Steel stand-off missile that, due to improved Soviet air defences, was approaching obsolescence even before it entered service in 1963. The UK faced being without a credible deterrent for almost a decade.

The resulting flap in the first week of 1963 saw ministry officials and senior RAF officers casting around for a weapon that became known as the 'gap-filler'. The cheapest, simplest and ultimately easiest solution was to use the WE177B. The impression gained from ministry documents is that, indeed, it had put all their eggs in one basket, but as calm returned to Whitehall some surprising projects came out of the woodwork of the British aviation design offices. The diktat was that existing or earlier development work should be used. Some, such as One Club A and B, were cobbled together from the parts bin while others had been in progress as design studies for the TSR2.

On the more realistic front, a number of nuclear-capable guided weapons were being developed in

ABOVE: Hawker Siddeley's AJ168 TV-Martel being tested on a de Havilland Sea Vixen trials aircraft. As well as the TSR2, the AJ168 was to be carried by the Buccaneer, Nimrod and Phantom, although it did not enter service on the latter two types. BLUE ENVOY COLLECTION

RIGHT PAGE: Even before the 'gap-filler' flap, the TSR2 formed the basis of many design studies by weapons developers. The need for a deterrent system in the pre-Polaris era saw numerous missiles being proposed for the aircraft. CHRIS GIBSON

the UK at the start of the 1960s by the guided weapons divisions of British Aircraft Corporation and Hawker Siddeley Aviation. For the 'gap-filler', the weapons research division (WRD) at the Avro plant at Woodford had more than 50 design studies on stand-off weapons to choose from. BAC's Bristol Division had been working on ramjet-powered stand-off weapons while the Stevenage Division had examined rocket-powered missiles.

Hawker Siddeley's de Havilland Division at Hatfield proposed the Megaton Martel based on the AJ168 missile, whose 50nm range was considered ideal if delivered at low level. The Megaton Martel saw the AJ168 airframe being stretched by 1ft 10in to accommodate a WE177B warhead. The Air Staff were unconvinced by its performance, which despite having a speed of Mach 1.2 at launch slowed to Mach 0.4 at the end of its flight, making it vulnerable to anti-aircraft fire.

The Hatfield design offices proposed two ALBMs for the TSR2. The first was outlined in DH report RG17, which described a missile that weighed 4,600lb, was 19ft long and had a diameter of 28in. It stated that a low-altitude launch would give the RG17 a range of 120nm, or 200nm using in a loft manoeuvre. As with Skybolt, inertial guidance would be used with the short flight time having minimal effect on the accuracy. de Havilland also proposed Hatchet, a smaller unguided ALBM fitted with a WE177 warhead and a Foxhound rocket motor from the Seaslug SAM to give a range of 55nm.

Avro at Woodford had been ordered to concentrate on bringing the Blue Steel stand-off weapon into RAF service, but when the call came from Whitehall it was ready. In fact, its WRD had designed a stand-off weapon for Avro's proposal for OR339 in 1958 in the form of the Z34, based on a winged Red Beard with a rocket motor. Interestingly, the Air Staff had dismissed stand-off weapons for OR339/OR343 on the basis that the TSR2 was designed to penetrate at low level with the WE177. There was a school of thought that a stand-off range of 50nm was sufficient as that would keep the TSR2s out of range of Soviet air defences.

Having scrapped the Z34, Avro's WRD examined the Z122, a Blue Steel shortened by 5ft (1.5m) to be carried semi-recessed in the TSR2's underside. Realistically the Z122 was a non-starter, so WRD returned to the scaled test vehicles used for Blue Steel development, basing the 20ft-long Z128A on the 19/15 test vehicle by adding a 5ft bay to house a Skybolt or Polaris warhead. As noted above, the Air Staff wanted a range of 50nm but the Z128A could achieve 70nm, so the WRD was asked to reduce the range, achieved by reducing the size of the fuel and oxidiser tanks and shortening the airframe by 3ft to produce the Z128B.

Even before it was cancelled, as an insurance against Skybolt's potential cancellation the Air Staff had issued OR1182 for a long-range stand-off weapon. Two missiles were proposed: Bristol's ramjet powered X-12 and the Avro WRD's turbofan-powered W140. The X12 was 40ft 6in long with a ventral ramjet while the W140 was 37ft 4in long with a ventral RB153 turbofan. Both were aimed at the 'V-bombers', but brochures were prepared showing their use on the TSR2. Its 89ft length allowed large stores to be carried but these weapons were pushing that to the limit. The unmodified W140 could be carried ventrally, but the X12 had to be mounted, inverted and canted, on the inner wing pylons.

The main effort went into a weapon that WRD had intended for the TSR2 from the start: W170. During the original work on a weapon for OR339/OR343, WRD asked the Admiralty about a stand-off weapon for the Fleet Air Arm's Buccaneers and had taken a Blue Steel fuselage shortened by 10ft and fitted it with a Bristol BT-3 Thor ramjet to produce the Z126. This proved too long for the Buccaneer, so a further 5ft was removed from the airframe and an updated ramjet, BS1014, integrated into the rear fuselage to produce the W170A for both the TSR2 and Buccaneer.

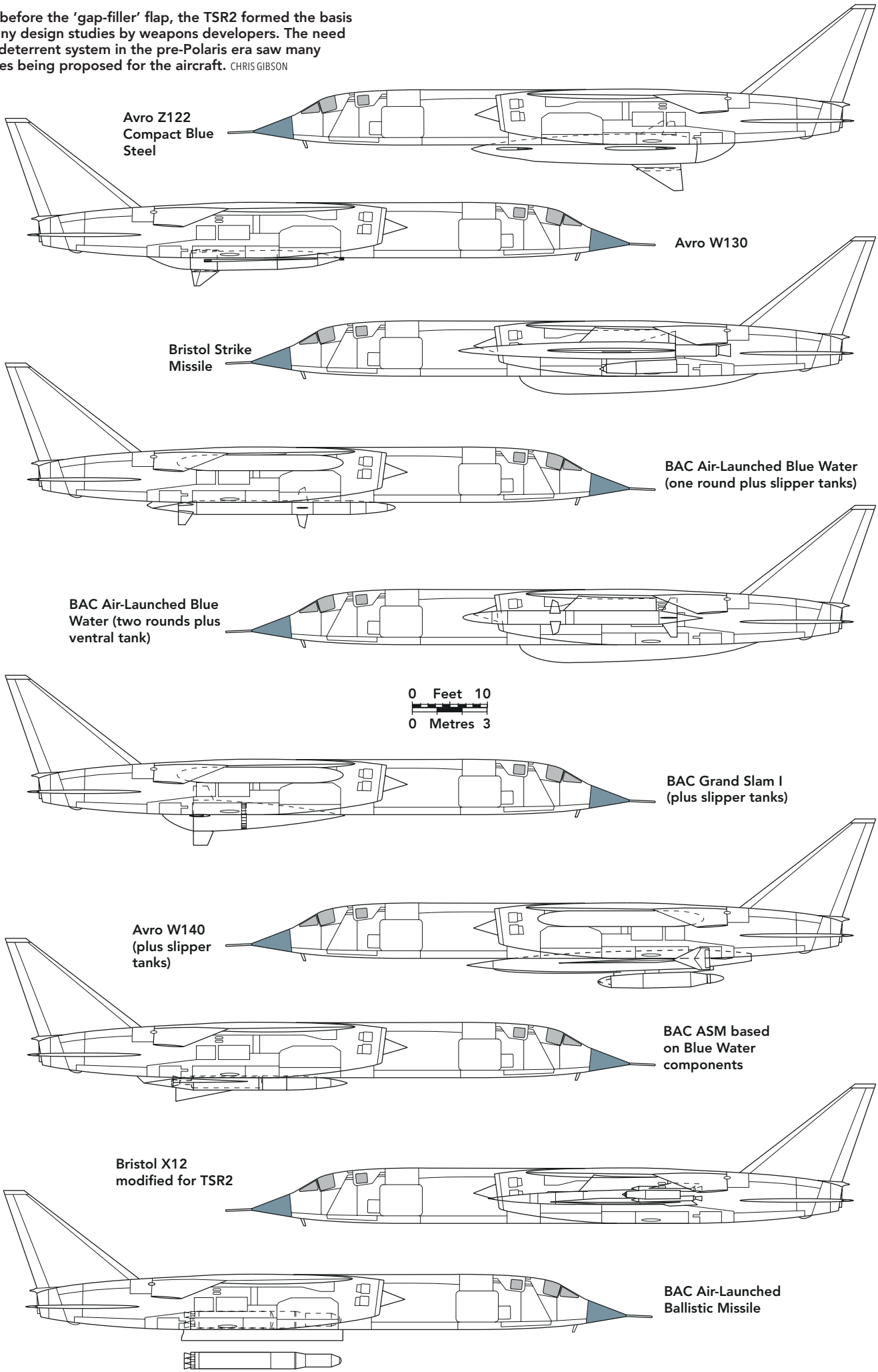
Meanwhile at Stevenage, BAC had been working on a surface-to-surface missile called Blue Water, but this had been cancelled in August 1962. Six months later, it dusted off earlier plans for an air-launched version and this was suggested as a weapon for the TSR2. Studies involved the TSR2 carrying a single Blue Water ventrally or on the inboard underwing pylons. Changes included increasing the length of the dual-mode rocket motor by 4ft, rotating the rear fin assembly by 45° and, to allow ventral carriage, making the upper two fins fold flat against the aircraft's underside. A more tailored approach saw Blue Water's warhead and systems installed in a new airframe more suitable for ventral carriage on the TSR2. This comprised a flattened fuselage with double delta wings and the dual-mode rocket motor replaced by two rocket motors enclosed in the fuselage, one each side of the systems bay.

One other interesting missile from the Stevenage office was a small air-launched ballistic missile which, at 19ft 8in long, was tailored to fit the TSR2's weapons bay. This single-stage missile was to use a Polaris re-entry vehicle (RV) boosted into a ballistic trajectory by four rocket motors housed within a 26in (66cm)-diameter airframe. When launched at low altitude the 5,000lb missile would have climbed to an apogee of over 250,000ft before the RV separated to re-enter and impact 350nm down-range. As with the Skybolt, range was dependent on launch altitude, something that also mitigated against Skybolt on the TSR2; one was designed for low altitude, the other for high altitude.

One of the more interesting proposals for the TSR2 arsenal was Grand Slam, designed by BAC's Bristol Division. This was not the 22,000lb earthquake bomb, but a 20ft-long, 7,500lb rocket-powered bomb. Released in a loft manoeuvre, Grand Slam was boosted to around 70,000ft by a modified Stonechat rocket motor from the Falstaff research rocket, which would then separate, allowing the RV to coast up to an apogee of almost 200,000ft. During this climb and subsequent re-entry, the RV would have dispensed decoys to counter Soviet defences before detonating its megaton warhead as an air-burst.

The fact that the TSR2 was designed as a weapons system means it cannot be discussed in isolation. The weapons intended for it were many and varied, and that variety increased in the three-year period between the scrapping of Skybolt in late 1962 and the cancellation of the aircraft itself in April 1965. Two weapons emerged from this effort and entered service. Neither the WE177 nor the AJ168 Martel was ever used in anger by the RAF.

Even before the 'gap-filler' flap, the TSR2 formed the basis of many design studies by weapons developers. The need for a deterrent system in the pre-Polaris era saw many missiles being proposed for the aircraft. CHRIS GIBSON



AFTER the

The machinations over replacing the cancelled TSR2 turned into a saga in low-level strike aircraft rather by default, but — via the F-111K and a host

ABOVE: TSR2 — or Eagle — XS944 in the markings of No 237 Operational Conversion Unit, earmarked as the OCU for the type. It went on to fulfil that role for the RAF's Buccaneers. CHRIS SANDHAM-BAILEY

BELOW: F-111K — or Merlin — XV884 in No 12 Squadron colours. This serial was allocated to the first production example. CHRIS SANDHAM-BAILEY

"Unless we abandon almost all our current commitments outside Europe we shall need an aircraft of the TSR2/F-111A class for the strike/reconnaissance role in the 1970s and no alternative aircraft will suffice."

Denis Healey, 31 March 1965

The British aviation enthusiast suffers a strange affliction: TSR2. Put two of them in a room and eventually they will discuss the subject: why its cancellation was a mistake, what a wonderful aircraft it was, why Wilson, Callaghan and Healey — especially Healey — should be denounced as enemies of the people, or at least the aviation industry, and what a waste it all was.

The received wisdom has been that in early 1965, in the wake of cancelling the 'big three' — TSR2, P1154 and HS681 — Defence Secretary Denis Healey hot-footed it to Washington to buy their American equivalents or substitutes in the form of the F-111, F-4 and C-130 at the expense of fantastic British aircraft. But is this view realistic? The British types were challenging designs, with the HS681 tactical transport possibly the most challenging of all. A retired Hawker Siddeley engineer has described an audible sigh of relief in the plant when the HS681's cancellation was announced. The F-4K Phantom was already on order for the Royal Navy and the C-130 Hercules — well, that was on its way to becoming the standard tactical transport of the western world. The F-111, on the other hand, was an unknown quantity that was touted as a swing-wing 'wonder-plane' but much, much cheaper than the TSR2. Perhaps a wider, less partisan look at the alternatives, and successors, is required.

THE F-111… AND ITS PECULIARITIES

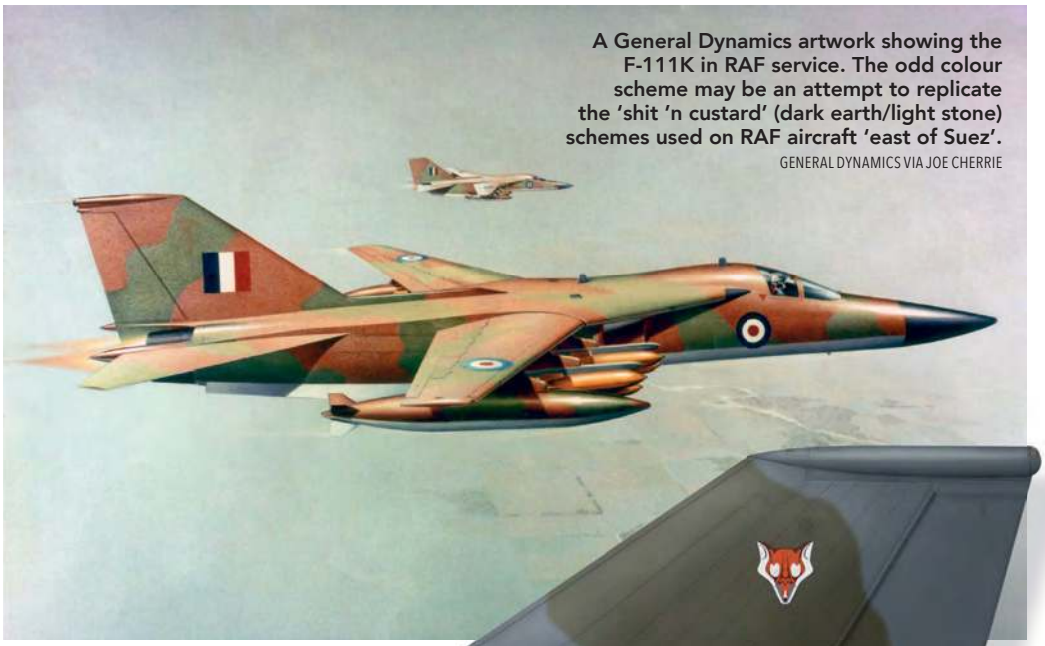
The United Kingdom had a long relationship with the General Dynamics F-111, one that ended with the departure of the last US Air Force F-111E from RAF Upper Heyford in December 1993. It started with a rather intriguing visit in December 1964 to GD's Fort Worth, Texas, plant by a 20-strong RAF technical team headed by the Deputy Chief of the Air Staff (DCAS), Air Marshal Sir Christopher Hartley. The purpose was to investigate the possibility of making the F-111 a joint US/UK project. This visit caused a buzz at GD. It was the earliest indication that

EAGLE

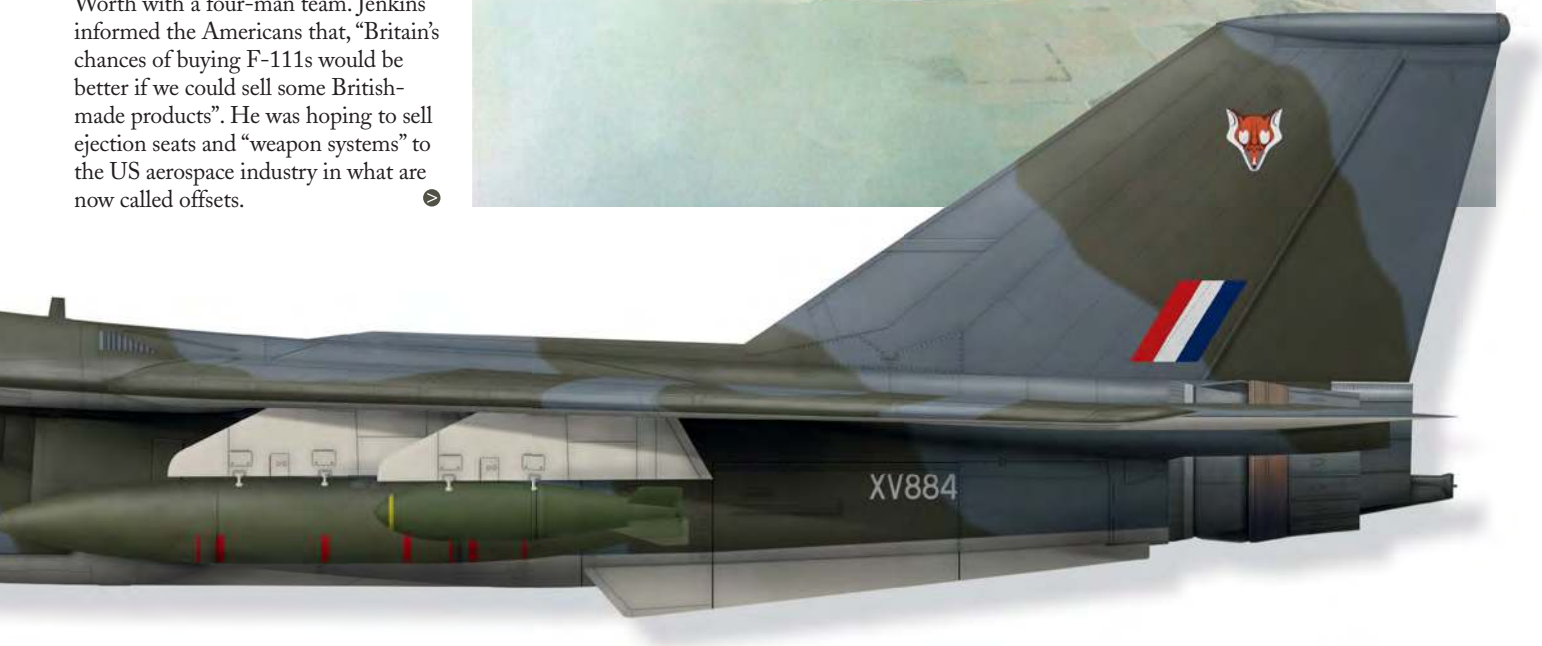
themselves. In the Buccaneer, the RAF ended up with a splendid of other contenders — it took a long time to get there **WORDS:** CHRIS GIBSON

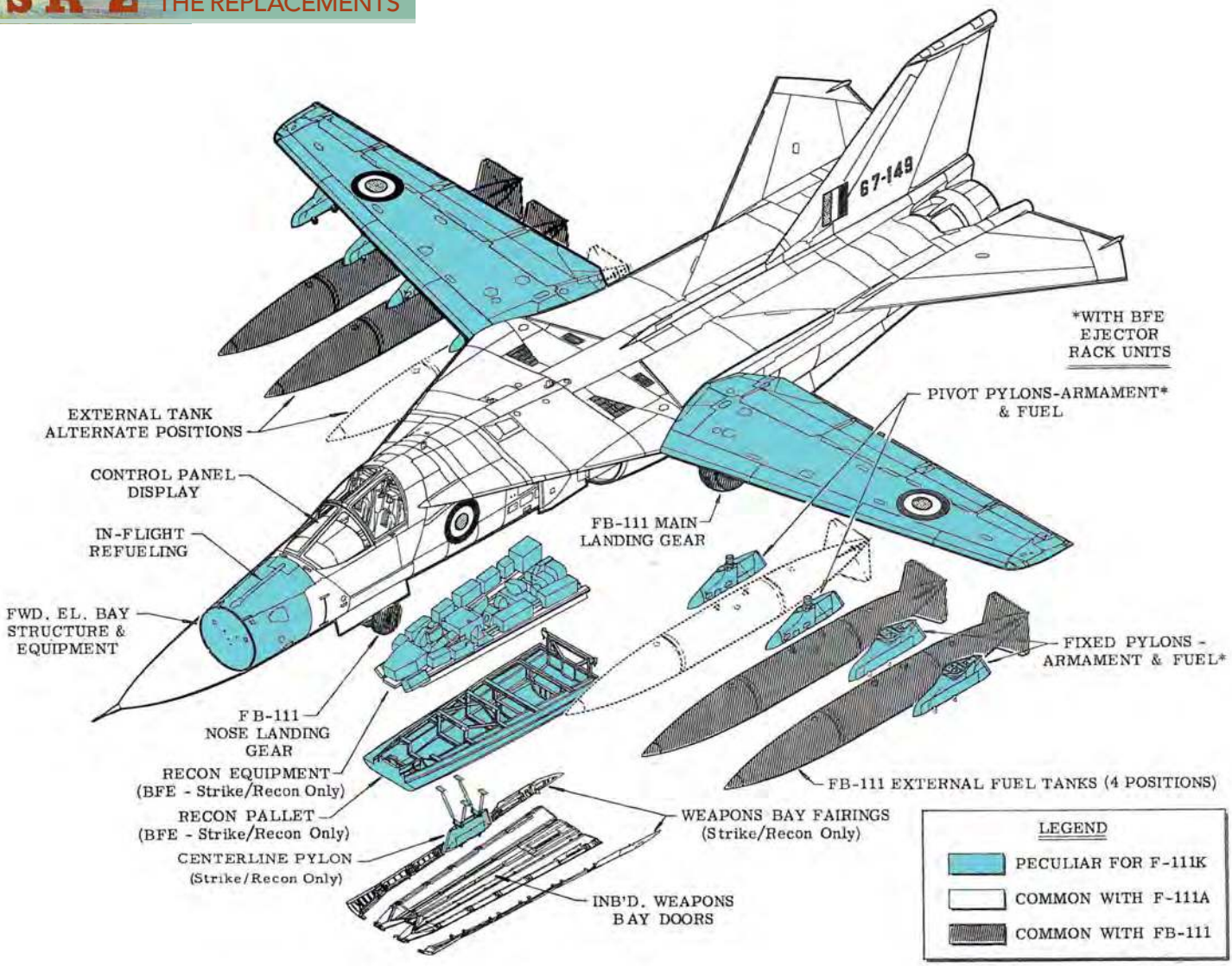
British government enthusiasm for the TSR2 was on the wane and that there might be a possibility of selling the F-111 to the British.

The following April, Denis Healey announced that the TSR2 would be cancelled and that an option had been taken on 10 F-111As, to be procured at a considerable cost saving, quoted as being around half that of the TSR2. The Air Staff Requirement for TSR2, ASR343 issue 2, was effectively rewritten around the F-111A as issue 3 and by June 1965 Minister of Aviation Roy Jenkins headed for Fort Worth with a four-man team. Jenkins informed the Americans that, "Britain's chances of buying F-111s would be better if we could sell some British-made products". He was hoping to sell ejection seats and "weapon systems" to the US aerospace industry in what are now called offsets.



A General Dynamics artwork showing the F-111K in RAF service. The odd colour scheme may be an attempt to replicate the 'shit 'n custard' (dark earth/light stone) schemes used on RAF aircraft 'east of Suez'. GENERAL DYNAMICS VIA JOE CHERRIE





F-111K PECULIAR COMPONENTS

ABOVE: Based on the F-111A, the F-111K's 'peculiarities', shown in blue, included the undercarriage from the FB-111A, a new forward equipment bay with in-flight refuelling probe, a removable reconnaissance pallet in the weapons bay and a centreline pylon extending from the weapons bay.
GENERAL DYNAMICS VIA JOE CHERRIE

RIGHT: The two F-111Ks under construction at the time of the order's cancellation in January 1968 comprised one trainer and one strike version.
GENERAL DYNAMICS VIA JOE CHERRIE

The British government signed for the first 10 F-111As in March 1966, with the intention of taking another 40 if authorised by 1 April 1967. By June 1966 the designation F-111K was being used in correspondence and representatives of the Ministry of Aviation and British aviation companies were in discussions about which of the 'peculiar' components could be built in the UK. September 1966 saw the F-111K receive the go-ahead for production, but then came the 'peculiarities'.

The F-111K was to be the F-111A, as projected for the USAF's Tactical Air Command, modified to operate at higher gross weight thanks to components from Strategic Air Command's FB-111A and incorporating British-furnished equipment (BFE). Two variants were envisioned: strike/reconnaissance, of which 40 were to be procured, and trainer/strike, comprising the balance. The first two F-111Ks off the line were to be examples of each, UK1 a strike/recon aircraft and UK2 a trainer/strike jet. UK1 was to be used for airframe and weapons separation testing while UK2 was to be an avionics testbed.

As for the peculiarities — described by GD as configuration departures — of the F-111K, the main change was the incorporation of the FB-111A's main and nose landing gear for the higher gross weight, eight wing pylons (with the inboard pairs pivoting) and a BFE reconnaissance pallet for the weapons bay, which could be fitted with a centreline pylon. Many of the changes were forward of the cockpit, the radome being based on that fitted to the F-111D and FB-111A plus a new forward equipment bay. This housed a retractable in-flight refuelling

probe on the upper centreline and a trio of F95 cameras, one vertical and two oblique, in its lower section.

One of the more detailed peculiarities was the modification of the weapons bay doors on the strike/recon variant to allow a centreline pylon to be fitted. The pylon, designed by GD's Convair Division, was to be mounted on four tubular supports that formed a truss to place the top of the pylon flush with the inboard bay doors that were to have cut-outs to seal around the pylon. This new pylon was to carry the datalink pod for the AJ168 TV Martel, the F-111K's weapon for its main role of long-range anti-shipping strikes east of Suez. The underwing pylons, four pivoting and four fixed, were to be fitted with British ERU115 ejector release units. The four inboard pylons could carry the same 600-US gallon (2,271-litre) fuel tanks earmarked for the FB-111 as well as British weapons such as the AJ168 Martel. Another 'configuration departure' from the F-111A was the proposal to fit the strike/recon variant with the night illumination system from the proposed RF-111A, installed on the centreline aft of the main undercarriage bay. The USAF tested the sole RF-111A during 1968 before giving up on the project as being just too complicated.

Some sources have stated that the F-111K was to use the longer wings of the FB-111A, but in fact it was to employ the standard F-111A wing. This may be derived from the Royal Australian Air Force's F-111Cs being fitted with the longer wing, but there was an option to fit extended ferry tips to the F-111A's wings, increasing the unswept span from 63ft (19.2m) to 70ft (21.3m). Another possibility is that, on cancellation of the British order, the UK1 and UK2 airframes were used to produce FB-111As, suggesting some commonality with the FB-111A.

The F-111K as the replacement for the TSR2, and its subsequent demise, is rarely discussed or examined. Of course, the ultimate replacement was the Panavia Tornado, but that process took many years. By the time it entered service in 1981, the surviving TSR2s had become well-established museum pieces, monuments to the pinnacle of valve technology and venerated by the faithful.

Perhaps the story of the TSR2's follow-on can be enhanced by casting the net wider than the narrow UK-oriented — blinkered, even — view that has prevailed until recent times. Another air force had a similar requirement to ASR343, in other words intervention east of Suez from mounting bases around the Indian Ocean, and the Royal Australian Air Force also required a Canberra replacement. The RAAF's needs were defined by requirement AIR 36, and it was involved with the TSR2 in more than mere observer status or Mountbatten's famous five-card trick. The Indonesian confrontation of 1961-66 was under way during the AIR 36 selection process, providing it with an element of urgency as Australia's requirement was driven by a need to counter Tupolev Tu-16KS-1 'Badger-Bs'. These posed a threat as they were armed with AS-1 'Kennel' stand-off missiles and had entered service in 1961.

The RAAF's selection process for a Canberra replacement included the TSR2, TFX (F-111), Mirage IV, RA-5C Vigilante and F-4C. Its preferred choice was the Vigilante. Oddly enough, the British Air Staff had been involved in the RAAF process and had advised that the RAAF should opt for the TFX as early as September 1963! The RAAF was impressed with the TSR2, considering it the most capable aircraft available for its needs, but it was unimpressed with the cost, stating that it was the same price as a Boeing 707 airliner and that not everyone felt a light tactical bomber was "worth this kind of money". Costs being quoted in Australian archives show that for 24 aircraft the TSR2 cost almost twice the TFX, A£110 million and A£60 million respectively.

Another factor was time, as the RAAF wanted the Canberra replaced as soon as possible. Therefore, it opted for the RA-5C, which was, in the words of the Australian evaluation team, "the quickest and most effective means of providing the RAAF with a strike/reconnaissance force". The Vigilante came at the bargain price, when compared with the TSR2, of A£88 million.

The Australian government thought otherwise, preferring the TFX. To support this, it stated that to use an aircraft as expensive as the TSR2 to

ABOVE: F-111C A8-127 carrying 24 Mk82 bombs. There is an irony in the British Air Staff having recommended the type to the RAAF before the TSR2 was cancelled. RAAF

> **"Oddly enough, the British Air Staff had been involved in the RAAF process and advised that it should opt for the TFX as early as September 1963! The RAAF was impressed with the TSR2, but was unimpressed with the cost"**

deliver high explosive was folly. In fact, deputy treasury secretary C. L. Hewitt said, "If defence is being planned in terms of non-nuclear war, then TSR2 is very much too expensive to think of using in conjunction with high explosive."

As for the RA-5C, E. J. Bunting, secretary of the Prime Minister's office, described it as coming a "long way third to the TFX and TSR2" and that the Australian Air Department "have been led up the financial path by US financial interests". Bunting also pointed out that the Vigilante would require in-flight refuelling and, if tanker aircraft were factored in, that would mean a 25 per cent cost increase, making the TSR2 look "not so much more expensive". Hewitt stated that there was little point in opting for an aircraft that neither the RAF nor the USAF — alongside whom the RAAF would no doubt be operating in a war — had any interest in. The Vigilante would need to be fitted with low-pressure tyres, anti-lock brakes and a braking parachute to allow it to operate from airfields in Australia and south-east Asia.

That is how the RAAF came to have a fleet of F-111s. As the F-111C, RF-111C and F-111G, the type served Australia well, despite delays, from 1973 until 2010. The RAAF (or rather, the Australian government) had also opted for the F-111 on cost grounds long before the TSR2 was cancelled. Its experience with the F-111 could serve as an example of what may have happened with the RAF had the F-111K continued.

If the RAAF's road to meeting its AIR36 requirement was convoluted, the British experience was ostensibly quite clean-cut. Realistically the F-111 was the only game in town when it came to meeting ASR343 issue 3. Healey's order for the replacements for the 'big three', including the F-111, suggests it was a foregone conclusion that the F-111 would be bought, but that was not necessarily the case. Alternatives, some more plausible than others, were available.

F-105F THUNDERCHIEF

The 'Thud' might be unfamiliar in the TSR2 saga. In reality, it wasn't exactly a direct replacement, but it provides an interesting example of the machinations of the British government. Republic's two-seat F-105F was suggested by Conservative MP Sir Theo Constantine on 1 April 1964 as a possible TSR2 trainer, what would be the mid-sixties equivalent of a LIFT (lead-in fighter trainer) for strike aircraft. The Thunderchief would have been fitted with TSR2 systems and, in the light of a series of studies, the Olympus BOl 21 engine.

As a trainer, according to Constantine who was parroting a Republic sales representative, the F-105F could "provide the most advanced tactical training under all-weather conditions". The F-105F was fully combat-capable and possessed high performance at sea level with terrain avoidance. Through its advanced bombing modes it "would give the RAF early and realistic experience for TSR2 crews", with the bonus that it could be fitted with TSR2 sub-systems. The 'Thud' could also provide groundcrews with training in the "handling of integrated weapons systems."

Sir Theo, or rather Republic, may not have been too wide of the mark as a pair of British types were earmarked as TSR2 trainers: the BAC Lightning for pilots and the two-seat Hawker Hunter (or the putative Folland Gnat T2) for navigators. The F-105F could have provided pilot and navigator training in a single platform.

WARTON'S P28

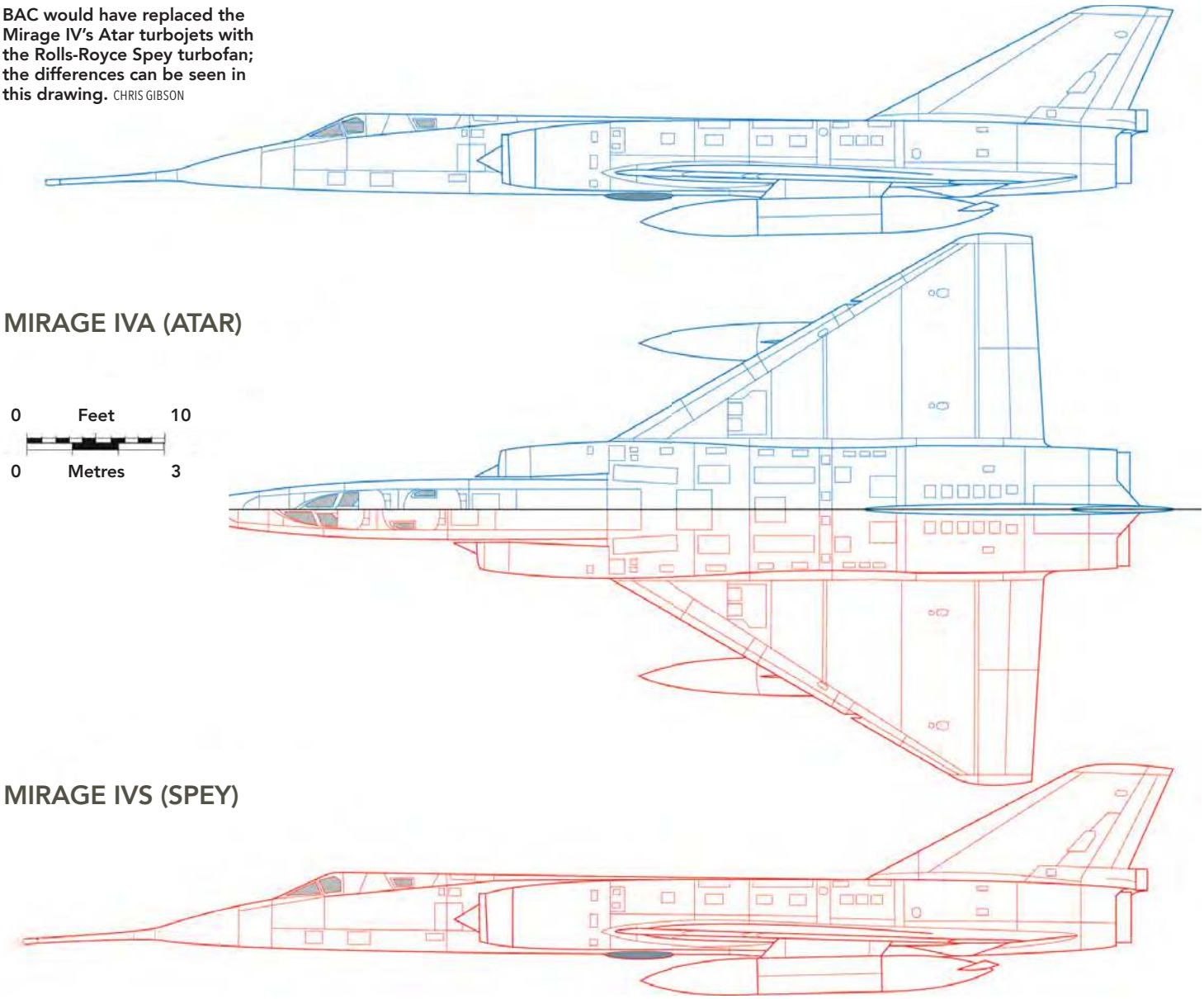
No Canberra could ever be described as the poor man's version of anything, but perhaps the Warton plant's P28 comes closest to the poor man's TSR2. The P28 dated back to the OR339 period around 1958. In the fall-out from the TSR2's cancellation in 1965, it was briefly resurrected as a Canberra B2 re-engined with Speys. The most obvious change was to the wings, with 6ft (1.8m) clipped from each. They were given powered ailerons and new 500-gallon (2,273-litre) fixed tip tanks that replaced the 122-gallon (555-litre) drop tanks. The engine nacelles would be redesigned to take the larger Rolls-Royce Spey turbofan, probably the 201 as used on the F-4K. The forward fuselage was based on the Canberra PR9's fighter-style cockpit, but with a terrain-following radar in the nose. At the rear the tailplanes were from the PR9 with an extended tailcone fitted.

MIRAGE IVO AND IVS

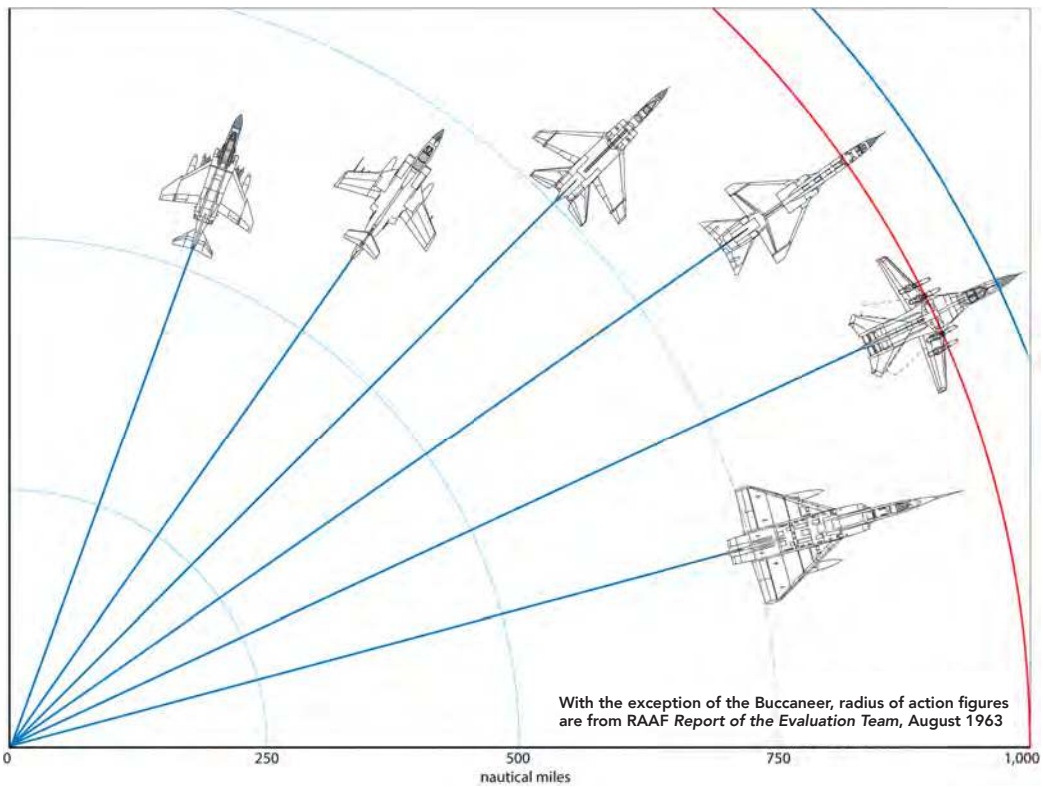
While not quite in the same class as the TSR2 or F-111, the Dassault Mirage IV figures in the RAF and RAAF's procurement process, although the British took the Mirage IV further than the Australians. The Mirage IVA was designed from the start to carry the AN-11 and AN-22 nuclear weapons for France's Force de Frappe in the deterrent role. The prototype made its first flight on 17 June 1959 and the type entered service with the Armée de l'Air in October 1964. It remained in use until its deterrent role (as the Mirage IVP with the ASMP missile) was taken on by the Mirage 2000N in 1996, the reconnaissance Mirage IVP being retired in 2005. The Mirage IV toted its payload, nuclear weapons or the CT-52 reconnaissance pack, in

BELOW: The third production F-105F, serial 62-4414. The two-seat Thunderchief was touted as a possible TSR2 lead-in trainer. USAF

BAC would have replaced the Mirage IV's Atar turbojets with the Rolls-Royce Spey turbofan; the differences can be seen in this drawing. CHRIS GIBSON



RIGHT: This interesting diagram shows radius of action figures for the TSR2 alternatives, based on data in the Australian archives. The Australian selection process is of interest because the RAAF and RAF envisioned similar operational roles for their Canberra replacement — long-range strike in the Far East. Without that role, neither the TSR2 nor the F-111K was required. CHRIS GIBSON



With the exception of the Buccaneer, radius of action figures are from RAAF *Report of the Evaluation Team*, August 1963

a ventral recess but could also carry bombs on wing pylons in lieu of drop tanks and electronic warfare pods, although this was a rarity.

The Mirage IVO had been proposed to the RAAF as a Canberra replacement, but the RAAF was never convinced by it, stating that it lacked range and was a "more old-fashioned type of aircraft that merely flies rather fast into the waiting anti-aircraft missiles". In the Mirage's defence, the RAAF studies and analysis pre-date those conducted by the RAF and the Armée de l'Air. It was to be fitted with a Cyrano II radar in the nose, the

ABOVE: BAC pushed hard for the Dassault Mirage IV — this is an early IVA version — as an alternative to the F-111K after cancellation of the TSR2. KEY COLLECTION

refuelling probe being relocated to forward of the cockpit.

Dassault and BAC's proposals for a Spey-powered variant of the Mirage IV in the aftermath of the TSR2's cancellation have been described as a 'spoiler' to prevent the UK buying the F-111 for the RAF. Variously described as the Mirage IVK (no evidence has been found of this designation in official use), Mirage IVS (for Spey) or Mirage IV*, France's big delta was to be modified for British use in the usual style — fitting British engines, weapons and systems — with airframe modifications to suit. Systems were to be based on those used on the Hawker P1154 V/STOL fighter, plus the Antilope terrain-following radar rather than the Ferranti equivalent developed for the TSR2, no doubt installed as per the Mirage IVO.

As far as the Australians were concerned, what had put them off the Mirage IV was its lack of range, poor low-level performance and the need to improve the region's airfields to cater for the aircraft's less-than-ideal take-off performance. By the time the Mirage IV was being proposed by Dassault and BAC to replace the TSR2, these were being addressed by the substitution of the SNECMA Atar engines for Rolls-Royce Speys.

The Atar 09K, rated at 11,000/15,960lbf (the second figure is with reheat) would be replaced with the Spey, rated at 12,250/20,500lbf. A 2ft (0.6m) fuselage extension and modified intakes were required to handle the almost 30 per cent increase in mass flow of the Spey turbofan. The fuselage stretch would allow more fuel to be carried but still not enough to meet the 1,000nm (1,852km) range requirement of ASR343.

Of course, the Mirage IV had been designed from scratch as a high-altitude supersonic bomber rather than as a low-altitude strike aircraft. The ride at low level would be bumpy, but in tests conducted during 1963, the French aircraft's performance in the low-altitude environment proved better than expected.

NAMING THE F-111K

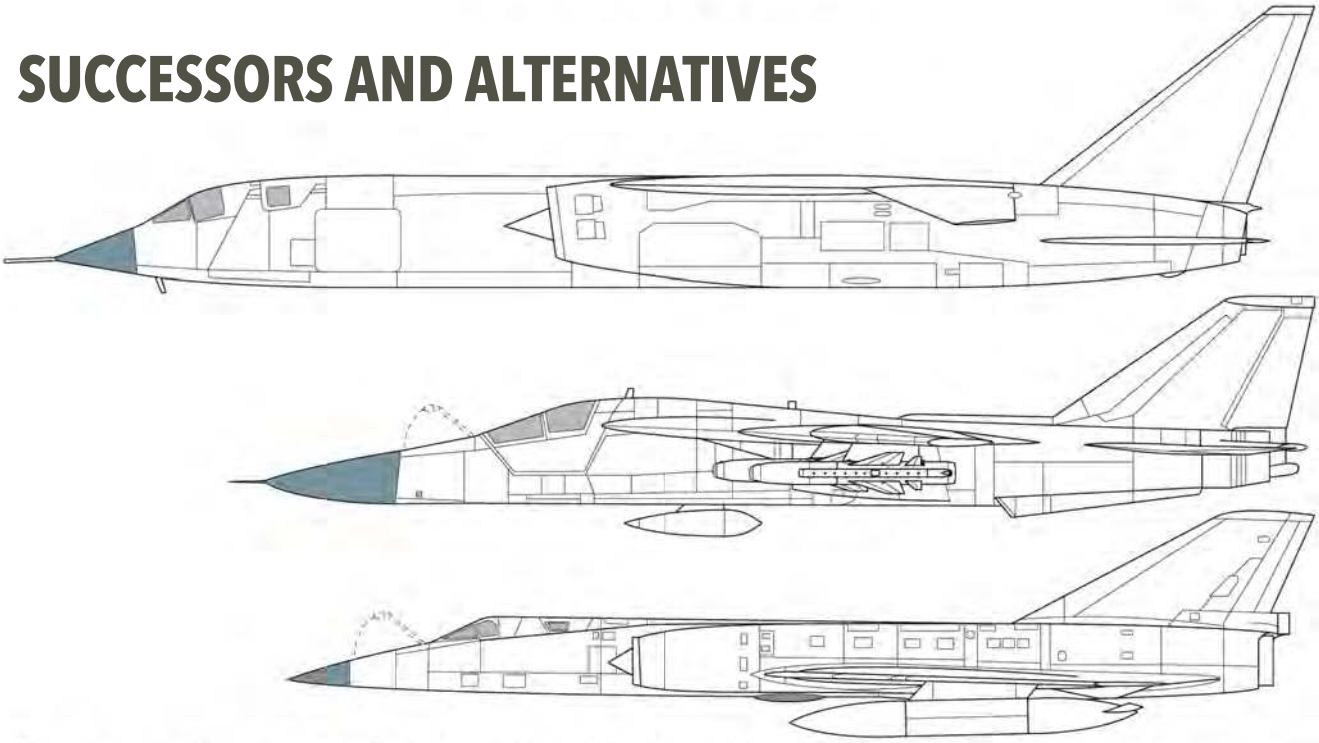
One interesting aspect of the TSR2/F-111K story is the background to the RAF service names of these aircraft. The name Eagle has been widely accepted as the name to be applied to the BAC type, but what about the General Dynamics jet? The intention was for the RAF, RAAF and USAF to adopt the same name for the F-111, but the USAF was not interested in naming the type — the Aardvark moniker, so long a nickname, was only applied officially upon its retirement by the USAF — while the RAAF's suggestions made little sense to the RAF. The UK Air Staff opined that since they had called the Canberra after the Australian capital it would be a case of quid pro quo if the F-111 were named London, while there was a town called London near Dayton, Ohio, home to the USAF's Wright-Patterson AFB.

The RAAF's suggestions included names in the many aboriginal languages of Australia, but it finally opted for Taipan, referring to the particularly fearsome — and venomous — Inland Taipan snake. With little knowledge of Australian wildlife on these shores in the mid-sixties, this very apt name meant nothing to the British, but the British suggestion meant an awful lot to the Australians.

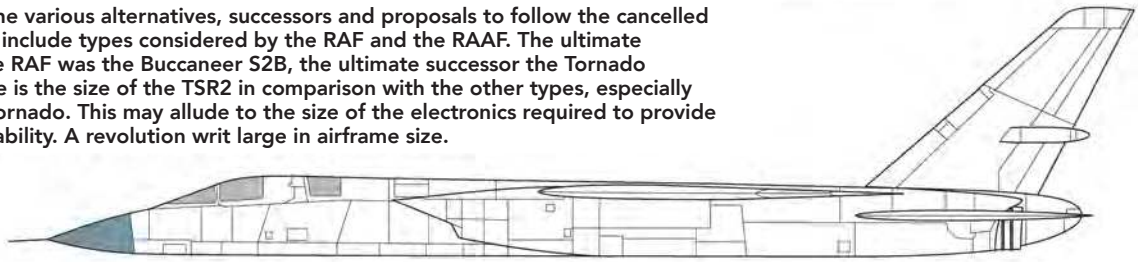
The RAF had policies for naming aircraft. Despite its 'F for fighter' USAF designation, the F-111K was a bomber and therefore should have been named after a British or Commonwealth inland town. Richmond was duly selected. The RAF's case was that it was common to towns in all three countries, so an ideal name as far as it was concerned. Again, the USAF showed little interest, but the Australian Air Staff was aghast at the suggestion. Australia, it explained, had a game called Australian Rules Football with a team called Richmond and it had a "strong and partisan" supporter base, as did its sporting rivals. So, Richmond was off the list.

After much to and fro the British Air Staff eventually decided to continue the avian theme and that Merlin was a fine name for the F-111K. Aside from the irony that the merlin is the smallest of the falcon family, it was deemed ideal as the RAAF would think it was named after the Rolls-Royce engine. In the end the RAAF didn't name its F-111Cs, unless you count 'Pig'.

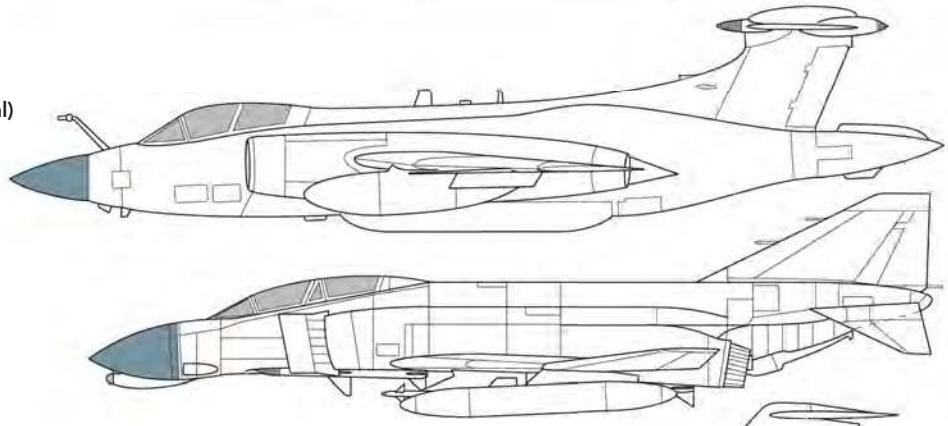
SUCCESSORS AND ALTERNATIVES



Shown here are the various alternatives, successors and proposals to follow the cancelled BAC TSR2. These include types considered by the RAF and the RAAF. The ultimate alternative for the RAF was the Buccaneer S2B, the ultimate successor the Tornado GR1/GR4. Of note is the size of the TSR2 in comparison with the other types, especially the F-111K and Tornado. This may allude to the size of the electronics required to provide the specified capability. A revolution writ large in airframe size.



Top to bottom:
BAC TSR2
General Dynamics F-111K
Dassault/BAC Mirage IVO (Provisional)
North American RA-5C Vigilante
Blackburn Buccaneer S2B
McDonnell Douglas F-4C Phantom
Blackburn P150
BAC P28 Phase 3
Panavia Tornado GR4



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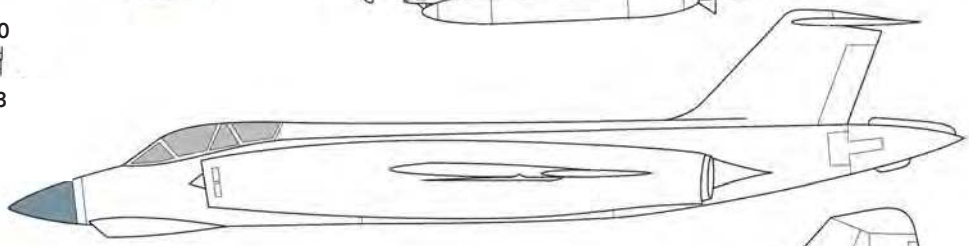

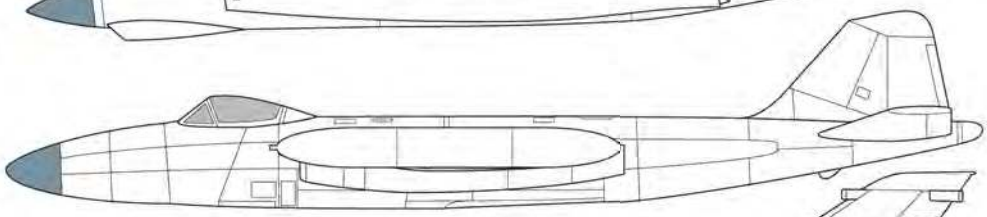

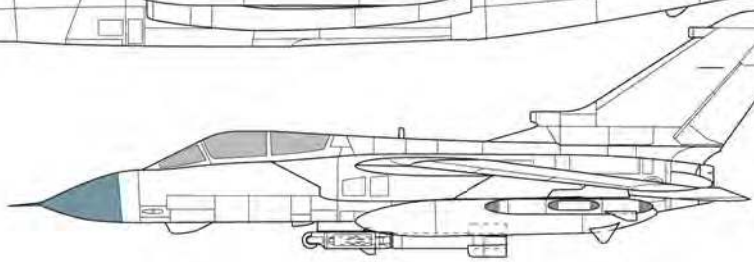

ABOVE: Buccaneers of No 208 Squadron, RAF, flying over Egypt during a detachment to Cyprus. The type proved an outstanding servant to the air force. KEY COLLECTION

BUCCANEER

Mountbatten's 'bird' took the place of the cancelled TSR2 and F-111K mainly because it could conduct the western Europe/north-east Atlantic-focused roles that the UK's new NATO-oriented defence posture demanded. It was also available for the RAF as the carrier force wound down, with the Fleet Air Arm's force of Spey-engined Buccaneer S2As being transferred to the RAF and additional new-build S2Bs being acquired for the RAF in Germany to meet ASR391.

While the Buccaneer S2A and S2B provided the strike capability, Hawker Siddeley produced several design studies aimed at the roles intended for the cancelled TSR2 and F-111K, although none of these came to fruition, possibly due to Air Staff bias against the original naval Buccaneer. The P145 built on the experience with the Buccaneer S2B but had a new radar and a bogie undercarriage, combined with rocket boosters, that allowed operation at higher all-up weights. Blackburn's P149 added a Q-band ground-mapping radar, Ferranti's FLR (forward-looking radar) and an RB162 turbofan that replaced the rockets in the rear fuselage. The P150 that followed, also known as the Buccaneer 2**, was a supersonic variant of the Buccaneer with a new thinner wing, stretched fuselage and reheated Speys combined with new nav/attack systems. As alternatives to the cancelled TSR2 and F-111K, none of Brough's proposals found favour until the Treasury strong-armed the RAF to accept the Buccaneer S2.

One intriguing question arising from the Buccaneer's adoption in lieu of the F-111K refers to Sir Theo Constantine and his F-105F. Might it have made the grade? Despite the Air Staff's misgivings, the Buccaneer proved ideal for the strike role in the north-west European theatre and even ventured into the TSR2's putative stamping ground during the 1991 Gulf War.

All this work on replacing the TSR2 was fruitless. As its role had all but disappeared by late 1967 there was no need for the TSR2, the F-111K or a direct replacement. The commitment to east of Suez had been scrapped. Western Europe and the north-east Atlantic was the RAF Buccaneer's operational area for much of the Cold War. Inadvertently successful or ideal from the start? The Buccaneer is yet another question that can be debated at length, but until the Tornado arrived in the eighties, it was the ideal alternative.

ACKNOWLEDGEMENTS:
The author thanks Damien Burke, Tony Buttler and Joe Cherrie for their help in the preparation of this article.

AST355: BIRTH OF A SUPER TSR2?

As ever, as soon as an aircraft was under development to meet an Air Staff Requirement, its replacement was already being examined. This was the case with the TSR2/F-111K that were under development to meet ASR343 (issues 2 and 3 respectively). In mid-1961 a draft Air Staff Target, AST354, was being discussed for a follow-on to TSR2. To avoid confusion with AST345, for what became the Harrier, the designation was changed to AST355.

The basic premise of the staff target was that the resulting aircraft, and one aircraft it would be, should be multi-role and capable of application to a range of roles including nuclear strike, battlefield interdiction, suppression of enemy defences and 'destroyer' in the air defence role — air-to-air operations against enemy aircraft. Effectively, it meant a Super TSR2. Or perhaps the Multi-Role Combat Aircraft (MRCA).

AST355 also suggested that the low/fast flight regime might be too vulnerable to improved air defences, so a high/fast regime, 70,000ft and Mach 2.5, might be more apt. However, the type should also be capable of high-speed automatic terrain-following flight and have STOL (short take-off and landing) performance! In addition, some form of compatibility with the Royal Navy was required although the DCAS, Air Marshal Sir Ronald Beresford Lees, saw little future for the carrier force.

As with all staff targets, AST355 was a wish-list for the future, used to identify areas for research. Among the items on that list were satellite communications and data distribution, no doubt to exploit new sensors such as reconnaissance radars, infra-red line-scan and high-resolution cameras.

Having read the Air Staff's wish list, the impression gained is that AST355 would have been very ambitious and repeated the perceived mistakes made with the TSR2. This was not the case, as AST355 was sent back to the drafting team with the advice that it lacked ambition. The Air Ministry's assistant scientific advisor (operations), J. E. Henderson, went as far as stating, "We must make a bold and major step forward, instead of asking for the marginal increases in speed and altitude of this AST". In similar vein, Air Cdre I. G. Esplin, director, operational requirements (air), wrote in AST355, "we had set our sights too low."

What Henderson and Esplin wanted was higher and faster — 150,000ft and Mach 3.5 — and, as the DCAS had said, to forget about the carriers and mounting bases. On the offensive side, new weapons were required such as stand-off missiles but the "newly discovered 'Laser' techniques should be carefully examined", especially for illuminating and the destruction of materials. The 16,000lb (7,257kg) weapons load should be mainly air-to-surface guided weapons rather than bombs for the strike role or air-to-air guided weapons in the destroyer role.

This perceived lack of ambition prompted the withdrawal of AST355 in December 1962 and the drafting of a new, unnumbered, AST incorporating the higher performance figures and new technology outlined by Henderson and Esplin.