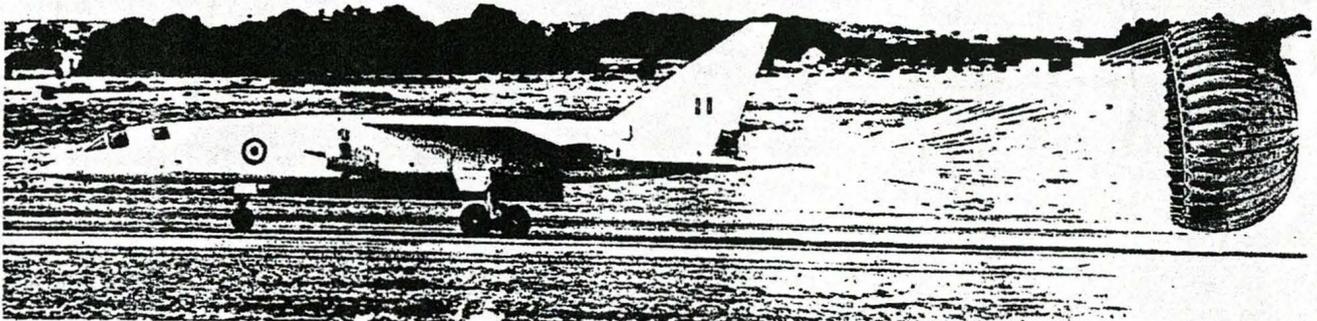


Few military aircraft programmes launched in the years since the end of World War II have provoked greater controversy than the TSR 2. Conceived by British Aircraft Corporation to meet an operational requirement drawn up by the RAF in the late 'fifties, TSR 2 was put into production in 1960, successfully embarked upon its flight test programme in 1964 — and was then cancelled outright in April 1965. The politico-economic grounds for that cancellation remain a subject for debate to this day and there remains a body of opinion that believes not only that the TSR 2 was technically excellent but that it could still usefully serve Britain's operational needs for many years to come. Vigorous support for a "re-launch the TSR 2" campaign recently led the Secretary for Defence, Francis Pym, to examine the proposal; his conclusion was that such a project would be "dauntingly expensive" and that the TSR 2 "could not meet the threat". Whether that assessment is justified remains a matter for debate, but there is no denying that when the TSR 2 made its first flight on 27 September 1964 it was, by a very considerable margin, the most advanced and most complex military aeroplane ever built in Britain. In this article Graham Wilmer presents the first published full technical description of the TSR 2.

TSR 2: YESTERDAY'S ANSWER TO TOMORROW'S PROBLEM



THE TSR 2 had its origins in the need that developed during the 'fifties for the RAF to replace its front-line force of English Electric Canberras. They were employed primarily in the rôle of high-altitude bombers using free-fall "iron bombs", but by the mid 'fifties it was becoming clear that the advent of a new generation of supersonic fighters and the introduction of surface-to-air guided missiles would soon render such bombers obsolete. Thus was born the concept of the very low-level high-speed bomber that would be able to penetrate enemy defences "under the radar", and the RAF's requirement for such an aeroplane, as at first spelled out in General Operational Requirement (GOR) 339, was one of the few manned aircraft projects to survive the Sandys Defence White Paper in February 1959.

Wanted for operational introduction by the mid-'sixties, the aeroplane defined by GOR.339 was intended to allow the RAF to meet its commitments to SACEUR (Supreme Allied Commander Europe), but also would have to play its part in the wider context of Britain's (then) overseas treaty commitments. The evolution of GOR.339 into the specific OR 343 and the many steps in the evolution of the TSR 2 design from separate projects by Vickers-Armstrong at Weybridge (through its former Supermarine design team from South Marston) and English Electric at Warton is a complex story that has been told elsewhere* and is outside the scope of this particular account.

By the end of 1958, OR 343 had set the scene for the development of a two-seat aircraft that would almost represent a complete air force in a single airframe. Its key requirements were as follows:

- (i) Capability to attack targets up to the extended range specified.
- (ii) Fly the specified proportion of this range at very low level and high subsonic speed.
- (iii) Attain $M=2.0$ at the tropopause when required.
- (iv) Deliver nuclear or conventional weapons from low and medium altitude in poor visibility and at night.
- (v) Perform all-weather photo-reconnaissance.
- (vi) Capability of operation from small and dispersed airfields, with restricted maintenance facilities.
- (vii) No defensive armament required.
- (viii) Primary emphasis on low altitude penetration.
- (ix) Have best gust response characteristics consistent with airfield performance, to ensure maximum operating efficiency of crew members comprising pilot and navigator.
- (x) Carry maximum photographic and/or radar equip-

*See in particular, "Project Cancelled" by Derek Wood (Macdonald and Jane's, London 1975) and "Phoenix to Ashes" by Roland Beamont (William Kimber, 1968).

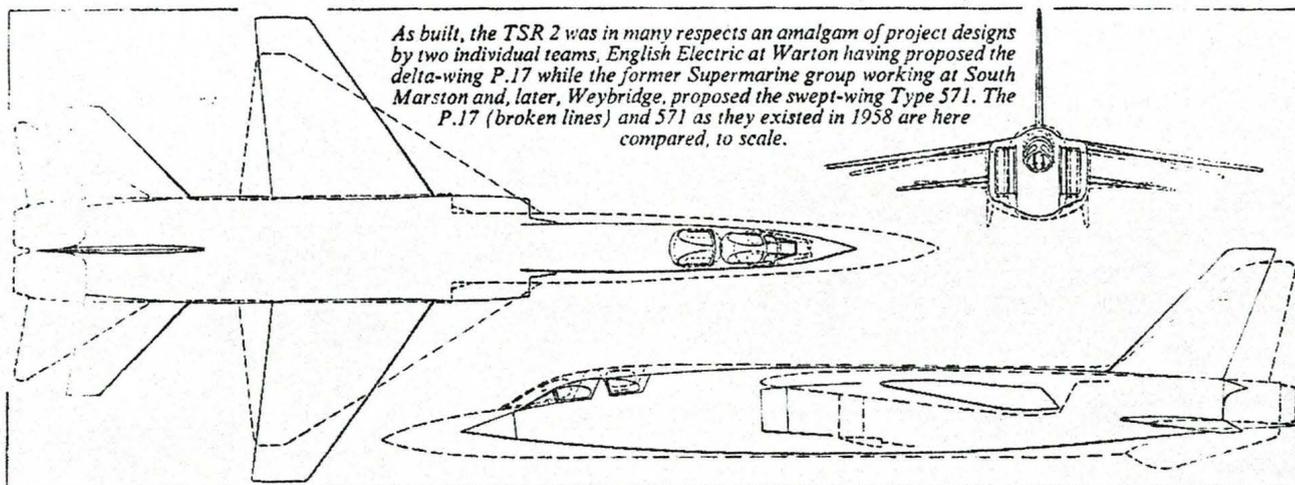
ment for reconnaissance without prejudice to the strike rôle.

- (xi) Remain serviceable in the open with no servicing support for three days, and with a minimum of support for 30 days. General serviceability to be at a premium.
- (xii) To be weather proof in flight and suitable for global operation.
- (xiii) Windscreen to be capable of withstanding the impact of a 3-lb (1.4-kg) bird at 750 kts (1 390 km/h) EAS, and to be kept clear of rain and insect debris at all times.
- (xiv) Escape and survival capability essentially over the entire flight envelope of the aircraft.
- (xv) Protection against low pressure, high altitude and low temperatures, high acceleration forces, atomic flash and vibration.

Of the many projects considered by the RAF, that which eventually found most favour was the English Electric P.17, but many aspects of the Supermarine 571 also were found to be of special interest. Since this was the era of mergers in the aircraft industry, largely through the encouragement of the Ministry of Supply (which did not hesitate to threaten to withhold contracts from companies that did not conform to the official policy) it became politic for English Electric and Vickers-Armstrong (Aircraft) to accept a joint contract, which was announced on 1 January 1959. Thus were sown the seeds from which grew not only the TSR 2, but the British Aircraft Corporation itself, as a merger of those two companies together with Bristol Aircraft and Hunting Aircraft. The TSR 2 designation was adopted to indicate the "tactical strike-reconnaissance" rôle of the aircraft (no-one has ever explained what happened to TSR 1!).

The TSR designation was in fact something of an oversimplification for what was designed to be an all-weather deep-penetration strike aircraft that could be employed tactically or strategically, using both nuclear and conventional weapons, and provide a very high standard of reconnaissance information in all weathers by day and by night.

The philosophy behind TSR 2 was to exploit a combination of high speed and low altitude in order to gain every possible advantage from the difficulties an enemy would face in trying to provide effective defence under these conditions. In order to achieve operational flexibility, however, the aircraft was designed also to be able to cruise at $Mach=2$ plus, at medium and very high altitudes. Its tactical flexibility was greatly augmented by the ability to operate from very small airstrips having only rudimentary surfaces, and the ability to operate regardless of maintenance facilities. This, together with a long ferry range, enabled the aircraft to be deployed very quickly to almost anywhere in the world.



Summary History of English Electric P.17/TSR 2

October 1956	Preliminary work on Canberra Replacement begins.	September 1958	Quarter scale model to Bristol's.
November 1956	Preliminary performance investigation. Podded engines — leading to Rolls-Royce RB.134.	November 1958	OR 339 (third draft).
December 1956	First wind tunnel tests (low speed) on rough model.	Mid-November 1958	First joint discussion at technical level between EEC and VA at Weybridge.
January 1957	Two Rolls-Royce RB.133 in fuselage. Straight wing.	December 1958	OR 339 (fourth draft).
January 1957	High-speed tunnel tests on trapezoidal half-wing.	December 1958	BSE Olympus engines chosen in lieu of RB.133/RB.134 proposed.
19 February 1957	Near final configuration. Two RB.133 engines.	January 1959	Parliamentary statement by Minister of Supply that VA and EEA were to undertake joint development of TSR 2.
February 1957	EEA Report P.103 entitled "Possibilities for a multi-purpose Canberra Replacement" (English Electric Project P.17).	February 1959	Joint VA/EEA design team formed at Weybridge.
March 1957	Issue of GOR 339 (1st draft to MOA).	March 1959	OR 343 (final draft).
May 1957	Eighth-scale full model (low speed) for tunnel tests.	Early April 1959	Design study contract to VA/EEA. Discussions begin.
June 1957	High-speed tunnel tests on delta half-wing. P.17 project with larger engines.	May 1959	OR 343 (first issue).
July 1957	OR 3044 issued (Navigation, Bombing and Reconnaissance and Flight Control System).	3 June 1959	Design study contract (covering period Jan 1959-Dec 1959).
July 1957	OR 3596 issued (Line Scan Navigation and Reconnaissance System).	11 June 1959	Vickers purchase order on EEA (WX. 6701)
August 1957	High-speed tunnel tests on eighth scale half model.	July 1959	VA/EEA Preliminary Brochure.
August 1957	Issue of GOR 339 to Industry. Submissions invited from Blackburn and General Aircraft, Fairey Aviation, Bristol Aircraft, Handley Page, Short Bros, de Havilland Aircraft, Vickers-Armstrong, Hawker Siddeley Aviation and English Electric.	October 1959	EEA Team returned to Warton from Weybridge.
October/ November 1957	English Electric Co — Short Bros collaboration begins.	11 March 1960	Draft Contract to VA from Ministry.
October 1957	First examination of Short P.17D VTO platform to launch P.17, and P.17 ventral take-off study.	17 June 1960	Interim Design study contract (covering Jan 1960-Sept 1960).
November 1957	Joint English Electric Co — Short Bros programme set up.	22 June 1960	Vickers Purchase Order on EEA (WF. 4043A).
November 1957	Half model — blown flaps.	Early August 1960	Draft Contract for nine development batch aircraft received.
December 1957	Short tests on P.17D.	August 1960	Specification RB 192D arrived in respect of TSR 2 development batch.
January 1958	Brochure submitted to GOR 339.	6 October 1960	Contract KD/2L/02/CB42(a) nine development batch aircraft (serials XR219-XR227).
February 1958	OR 339 (first draft).	14 November 1960	EEA internal contract issued (for first nine aircraft).
March 1958	Report on the selection of firms.	24 November 1960	Vickers Purchase Order on EEA.
April 1958	OR 339 (Issue 1).	2 February 1962	Firing of first free flight model at Aberporth. Spinning model tests at Larkhill.
April 1958	Exchange of views between EEC and Vickers Armstrong on equipment.	28 June 1963	Contract KD/2L/13/CB42(a) for second batch (11 aircraft, serials XS660 to XS670)
June 1958	Final MOA assessment.	20 March 1964	Contract KD/2L/16/CB42(a) first full-production batch (30 aircraft, serials XS944 to XS954 and XS977 to XS995).
July 1958	High speed tunnel tests on eighth scale complete model.	27 September 1964	First prototype first flight (Boscombe Down).
July 1958	Quarter scale intake model to Rolls-Royce.	22 February 1965	First aircraft arrived at Warton from Boscombe Down.
August 1958	New low speed model.	31 March 1965	Last flight of prototype, at Warton.
August 1958	OR 339 (second draft).	6 April 1965	Announcement by Chancellor of Exchequer (J Callaghan) of cancellation of TSR 2 in "Budget speech".
		4 June 1965	Turning down of proposal to use TSR 2 for research work.
		6 July 1965	Closure of TSR 2 contract.

TSR 2 had a remarkable radius of action: at its normal take-off weight (originally planned as 75,000 lb/34 020 kg) and using only internally carried fuel, it could fly a high-low-high subsonic/supersonic sortie to reach targets up to 1,000 naut miles (1 850 km) away from base, and with the addition of externally carried fuel this range could be doubled.

The need for accurate weapon delivery in the sort of weather conditions that might have been encountered over these long distances, coupled with the emphasis upon low level flight in the interest of surprise and invulnerability, demanded a very comprehensive navigation and attack system, and a very reliable flight control system. Both these systems are described in detail later, but, in general, the flight control system embodied an automatic terrain-following radar that would maintain the aircraft's height, selected at the pilot's discretion, down to 200 ft (61 m) above the ground at speeds of up to $M=0.9$. The navigation/attack system was based on a doppler/inertia mix, monitored by radar or visual fixes. The system could operate on either doppler or inertia above, and the two together supplemented each other's operational characteristics, resulting in an accurate and flexible system.

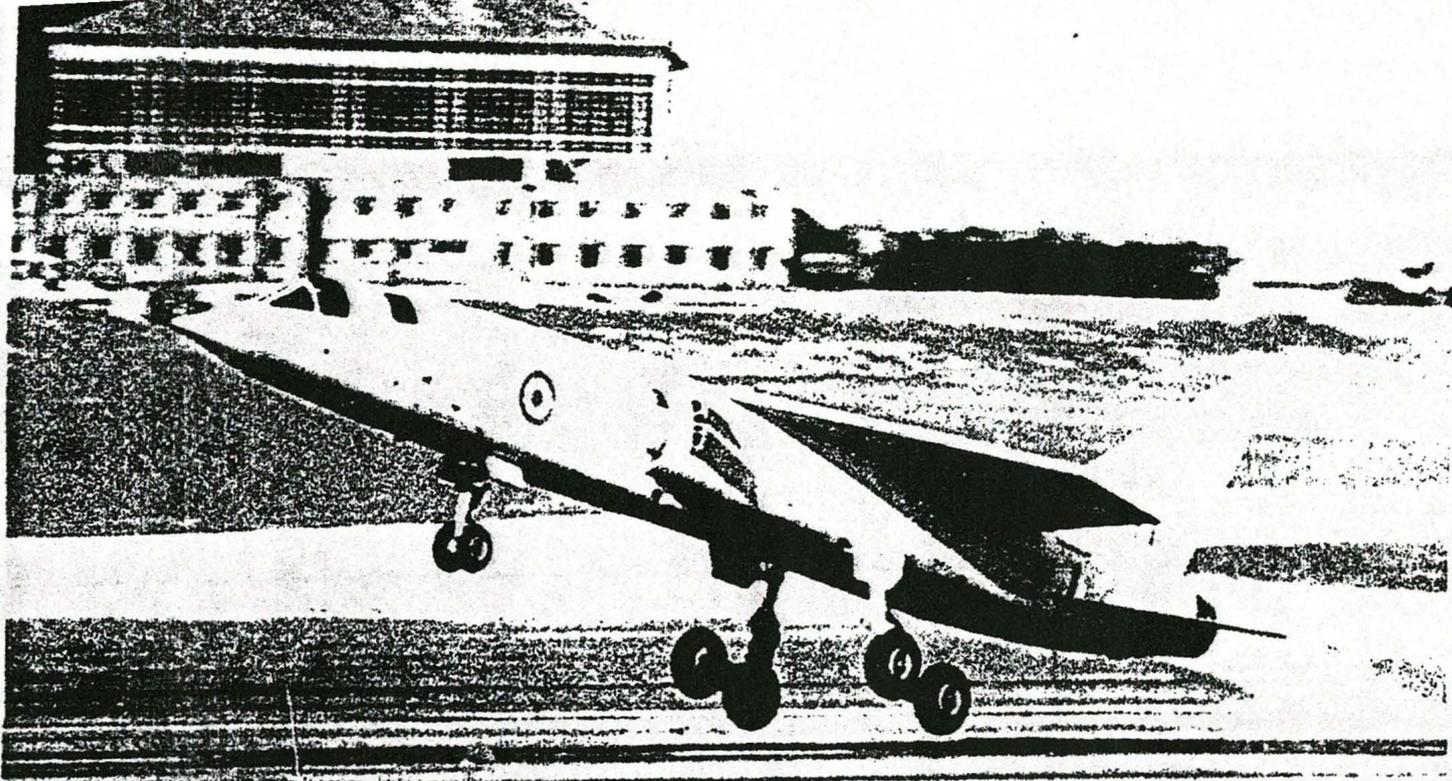
Radar fixes could be obtained from a sideways looking

radar, supplemented on occasions by a forward looking radar. The sideways looking radar presented its information on a rapid photographic process display. The computed fix position, derived from the doppler/inertia system, was automatically inserted into the radar picture. From this the navigator could quickly compare true and computed fix positions and any necessary error correction was automatically fed back to the navigation system.

Structural design

The structural form of TSR 2 was dictated largely by considerations of fatigue loadings and heating. Fatigue loadings in this case would have arisen mainly from manoeuvring at ground level at speeds between $M=0.8$ and $M=1.2$, especially during attack and terrain following. The design compromised on an 8g load factor for ground attack and a fatigue life in excess of 3,000 hours.

The problems caused by heating arose principally at the tropopause where the peak ram temperature would have reached 360 deg F and damage from "heat-soak" was most likely. The materials chosen for aeroplane construction therefore had to exhibit three main features: good fatigue



(Above) With full reheat thrust from its two Bristol Siddeley Olympus B.O1.22R engines, the sole prototype of the TSR 2 to reach flight test status leaves the ground for the first time: the date, 27 September 1964; the place, the Aircraft and Armament Experimental Establishment at Boscombe Down, Wilts, where the aircraft is depicted (below) undergoing pre-flight preparation.

characteristics, no deterioration after exposure to high temperatures, and maximum structural efficiency at high temperature.

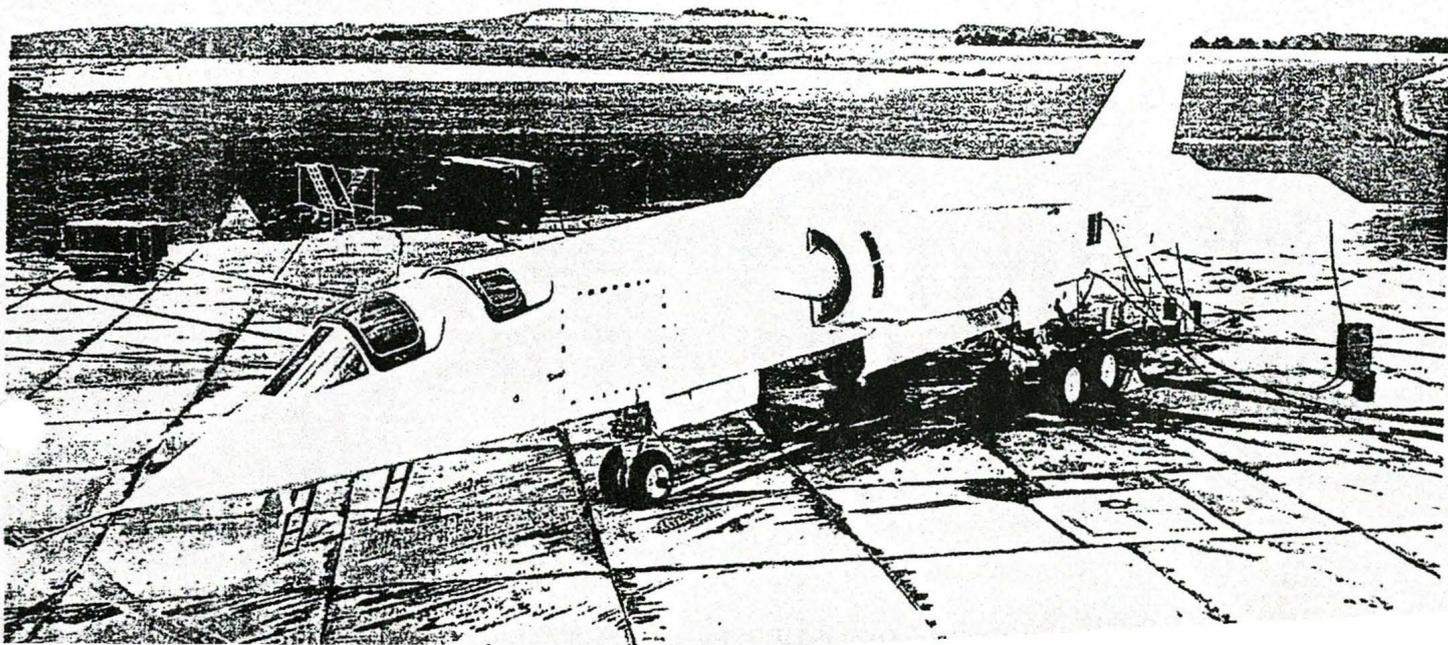
Aluminium alloys which have these characteristics are rich in copper and at the time of TSR 2 design the commonly used four per cent Cu family (DTD 5020, L71, RR58) were adequate for the job. In several areas however, the structure required a material that could cope with both excessive local loads and very high temperatures. The answer to this need was found in a new material that had just been developed called X2020, a high strength lithium-bearing alloy which showed great promise under test in that its strength was totally unaffected by high temperature.

Also timely for the TSR 2 development were a new range of vacuum-melted steels which could take loads of up to 270,000 psi (19,000 kg/cm²) and still remain ductile. Limited use was

also made of titanium, mainly for engine heat shields. The combination of these materials provided for all the known problem areas and allowed a wide margin for developing the aircraft beyond the specification.

In constructing the TSR 2 airframe, the techniques used were conventional and essentially "state of the art", in that they only slightly extended techniques used on other high-performance aircraft that had successfully met high temperature and fatigue problems. The structure was laid out in parallel with the design of both the systems and their installation, the aim being to minimise production costs and time spent on maintenance, but still come up with an efficient, light structure.

The fuselage, wing and tail surface skins were built up from machined planks which had stiffened surfaces and edges. Integral fuel tanks were built into the fuselage and wing: four



large tanks of approximately equal capacity in the fuselage, and one in the wing. The four fuselage tanks were situated in pairs at equal distance from the aircraft's centre of gravity which allowed a simple, duplicated fuel system to be used.

The forward fuselage, containing the crew and all the electronic equipment, was an open construction. All of the lower surface of the fuselage was also left open in order to give easy access to the longitudinal system runs. The doors and access panels which covered the lower structure were sealed against moisture, salt and sand. The upper part of the fuselage was basically a series of closed boxes which took the brunt of all torsional loads and gave good overall structural efficiency. They also provided housing for the fuel tanks and the engine tunnels. The engines were withdrawn through the rear of the aircraft so that the tunnels were free from large structural cut-outs.

The engine driven auxiliaries (described later) were mounted separately on a gearbox in a separate bay in the bottom of the fuselage. This gave good access and allowed the airframe services to be run without running the main engines. The engine tunnels had double skins with air flowing under pressure between them. This greatly reduced the fire risk as little engine heat reached the main structure.

Systems detail

As already mentioned, the fuel was carried in a wing tank and two pairs of fuselage tanks. Fuel balancing was maintained by using fuel from the forward and rear tanks simultaneously. The fuel pumps were situated inside the tanks and used high-pressure fuel as the driving medium. The engines would accept AVTAG, AVTUR-40, AVTUR-50, and AVCAT fuels.

The hydraulic system used DP47 (a fluid that operates happily under pressure at very high temperatures), pressurised to 4,000 psi (281 kg/cm²). There were four independent systems, two for general services (flaps, airbrakes, undercarriage and air intakes), and two for the flying controls. The two general services systems could feed the flying controls in the event of failure.

Electrical power was provided by two AC solid rotor alternators, both producing 30/55 kVA at 400 cycles per second. In the event of failure, either alternator would automatically supply the aircraft's total load demand. Each alternator was driven by a pneumatic/mechanical constant-speed drive unit, and a subsidiary supply with duplicated power sources provided DC power. Engine air tapped from the HP compressors cooled both crew compartments and the equipment bays. The cabins were pressurised to 5 psi (0.35 kg/cm²), and kept at an average temperature of 15 deg C, even under tropical conditions.

Terrain following

Survival in the sort of hostile environment the TSR 2 was designed to penetrate came down to one thing: Don't let the enemy's weapon system see you coming until you are on top of it. This would not prevent defence systems from operating, but by the time they had been activated the TSR 2 would be long gone. Most radar systems can see an aircraft coming at altitudes ranging from 75,000 ft (22,860 m) down to 1,000 ft (305 m), but at 200 ft (61 m) the effective range of weapon control radars is reduced to such a low value that adequate cover becomes prohibitively expensive.

The terrain following system designed for TSR 2 depended on a forward looking radar for its basic data. This was a monopulse radar having a double bar scan of U-form. The returns from the radar provided a computer with continuous information on the shape of the terrain ahead of the aircraft in terms of range and angle. From this data, the computer could determine the angle by which the aircraft flight path needed to be raised or lowered to follow the ground profile at a height selected by the pilot. As a simple analogy, imagine a stiff spring

extending forward from the aircraft and slightly convex on the side touching the ground. As the spring rides over the bumps in the ground, it raises and lowers the aircraft accordingly. The shape of this "spring", termed ski-toe locus, was defined within the forward looking radar.

As well as selecting the nominal flight altitude, the pilot could adjust the stiffness of the "spring" so that the system could be tuned for optimum performance according to the type of terrain being traversed and the roughness of ride tolerable by the crew.

Signals from the terrain following computer were fed to the automatic flight control computer and to the pilot's head-up display. The choice of either automatic or manual flight at low altitude was at the pilot's discretion. (Early experiments tended to show that the automatic system could always do better than the pilot. Later work however, proved that for periods of up to 10 minutes, the pilot was as good as the automatic system. After this, though, his performance would deteriorate rapidly due to fatigue.)

Navigation/Attack system

The basic navigation system for TSR 2 depended upon dead reckoning using vector information derived from the doppler and inertia sensors. These vectors were calculated by a navigation computer using heading data from the inertia platform, smoothed values of velocities from the doppler and the platform, and drift from the doppler. The system had two potential sources of error: heading errors due to the platform gyros drifting, and position errors due to the sum of small inaccuracies in velocity outputs, computing and input data. By taking fixes at intervals using a sideways looking radar, these errors could be continuously corrected.

The system could achieve blind delivery of a nuclear weapon accurate to within 100 ft (31 m), at ranges of more than 1,000 naut miles (1,850 km) from base using radar fixes every 100 naut miles (185 km) — the last being 30 naut miles (56 km) from the target.

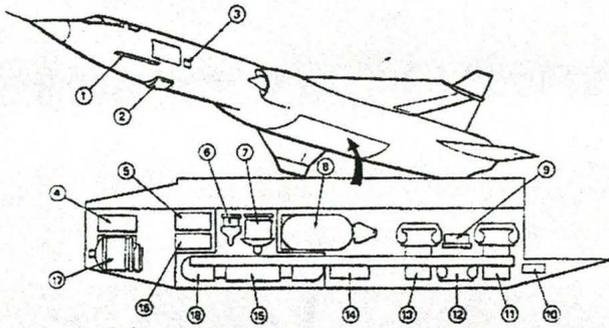
The forward looking radar was linked into the navigation/attack system and had several other modes when not being used for terrain following. The most important of these were: radar ranging for dive bombing and rocket attack; homing on flight refuelling tankers; ground mapping when approaching major radar targets or coastline; and a limited search capability over the sea or in areas where suitable radar targets could be found without excessive ground clutter.

In designing the system, particular attention was paid to finding methods of presenting information to the crew in a way that would not burden their concentration. Two examples of this were the pilot's head-up display and the navigator's sideways looking radar. The head-up display, in one of the first applications of this now commonly-used aid, presented information to the pilot by projecting figures on to the windscreen in front of him, collimated at infinity. The pilot could see both the terrain in front of him and essential flight information (including flight director). The sideways looking radar was devised to provide the navigator with a means of taking the highly accurate fixes which were essential in order to achieve the standard of navigation and weapon delivery demanded by the specification.

Reconnaissance system

The main reconnaissance system was carried in a bomb-bay pack and had to be carried as an alternative to any internal weapon load. This was not a disadvantage to the strike capability of the aircraft, however, as weapons of equal power could be carried externally mounted on wing stations. The pack contained equipment which could be changed according to the altitude at which the mission was going to be flown.

Reconnaissance equipment was also carried as a permanent fit in the forward part of the fuselage, giving the aircraft a



The contents of the TSR 2's reconnaissance pack (an optional installation in the weapon bay), are shown here diagrammatically. The numbered items are: 1, sideways looking nav radar; 2, retractable forward facing camera; 3, oblique cameras, port and starboard; 4, scanner supply and electronic units; 5, linescan power unit; 6, modulator; 7, power unit; 8, radar recorder; 9, camera control box; 10, radio link transmitter and aerial; 11, camera; 12, camera; 13, camera; 14, videotape recorder; 15, optical scanner unit; 16, recorder power unit; 17, radar TRU; 18, radar aerials.

reasonable reconnaissance capability in all configurations. This permanent equipment comprised three F.9 low-level cameras — one forward facing and two oblique — giving a coverage of 30 deg of arc each side of dead ahead, plus the X-band sideways looking navigation radar. This radar was capable of very high resolution and could provide reconnaissance information over a strip of country the width of which varied according to the aircraft's altitude. At 500 ft (153 m) for example, the coverage was 2.6 miles (4 km) each side, and at 40,000 ft (12 192 m) the coverage was 36.6 miles (59 km) each side.

The reconnaissance pack had three systems for recording information and was capable of transmitting information either instantaneously or at delayed intervals. For low level reconnaissance all three recording systems were used — radar, linescan and cameras. The radar was a "Q" band SLAR which "looked" through two 15-ft (4.6-m) aerials fitted longitudinally in the pack. Capable of picking out moving targets from 10,000 ft (3 050 m), the radar could transmit back to base a high resolution picture that also had latitude, longitude, track, height, drift angle and pitch information printed on it. The radar pictures were unaffected by weather conditions.

The linescan equipment was effective up to a height of 1,000 ft (305 m) and had a minimum resolution capable of picking up a single three-ton truck at night. The quality of its pictures were much improved when taken in daylight. The linescan's primary rôle was target mapping, and, like the radar, its information could be transmitted with interpretation data.

Photographic reconnaissance

The weapons bay pack contained three FX126 cameras in the rear compartment: two for medium altitude and one for low-level use. The two medium altitude cameras could be fitted with 24-in (63.5-cm) or 36-in (91-cm) lenses which gave a photographic scale of 1:10,000 from 20,000 ft (6 100 m) or 30,000 ft (9 145 m) respectively. The low altitude camera had a 6-in (15.2-cm) lens which gave a scale of 1:10,000 from a height of 5,000 ft (1 525 m). All three cameras were temperature controlled, and had both image movement compensation (IMC) and automatic exposure adjustment. Each contained 250-ft (76-m) of film in easily changed cassettes. The IMC and exposure intervals were controlled from the navigation system of the aircraft; a long track overlap of 60 per cent was provided and, for the two long-focus cameras, the across-track overlap was 10 per cent.

The film magazines were large enough to allow a 150 naut mile (278 km) strip to be covered 1.25 naut miles (1,175 km) wide from low altitude and 2.7 naut miles (5 km) wide from medium altitude. The latitude and longitude of the aircraft were marked on the edge of each camera exposure in binary

decimal form for automatic or visual read-out. When both the sideways looking reconnaissance radar and cameras were in use, the position of the camera shots was indicated on the radar data.

Communications

The internal and external communications facilities in TSR 2 were fully integrated. Both crew members had a single control unit which allowed either of them to operate all the radio equipment fitted. Communications with ground servicing personnel could be maintained up to the moment of wheels-rolling by means of pull-away couplings.

Long distance communication in an aircraft that spends most of its working life below radar levels is a problem that even today leaves room for improvement. However, like today's Tornado, TSR 2 was fitted with a single sideband HF radio that had a range of well over 1,000 naut miles (1 850 km), provided that the weather conditions were right. With a peak power output of 1 kW and more than 23,000 channels to choose from, the equipment was, to say the least, versatile.

TSR 2 was the second jet aircraft to make use of the then newly invented notch antenna, as part of its HF system, an idea developed in an attempt to overcome the drag penalties caused by traditional antennae. The problems associated with antenna drag had become more serious as aircraft had increased in speed. The drag of a wire antenna, for example, increases with the square of the aircraft velocity until it reaches $M=0.6$, whereafter it increases at a much greater rate and the penalties on performance and range quickly became unacceptable.

Working on studies that began in 1950 at the RAE Farnborough, the design team at Weybridge came up with the notch aerial solution. The Farnborough studies had looked at the possibility of using parts of the airframe itself to act as an antenna. In one experiment, the port wing of a Halifax bomber had been fitted with a large tuned inductance. The coil induced radiating currents in the wing which in turn caused the wing itself to radiate. Although it worked, the system was too complicated and very costly.

Using this as a base to work from, however, the Weybridge team went one step farther and discovered that a notch cut into a wing, or in fact anywhere on an airframe, could be made to induce currents and radiate. The first operational notch antenna was fitted onto the Valiant, and the "suppressed antenna", as it became known, has since been fitted to almost every type of high speed aircraft. The system designed for Tornado is almost a direct copy of the TSR 2 equipment, the exception being that Tornado has a single HF notch antenna cut into its fin, whereas TSR 2 had two, one in each wing root.

Short range line-of-sight communications (up to 200 naut miles/370 km) was by means of a VHF/UHF radio transmitter/receiver. The set had 3,600 channels in the UHF, band working between 224 and 400 Mc/s, and 600 channels between 110 and 140 Mc/s. The navigator could select any of these channels, while the pilot had a choice of 20 pre-selected channels.

The crew stations

There has always been a tendency for aircraft cockpits to become increasingly complex with the passage of time. In each generation more systems have been added and existing equipment has become more versatile, and hence more demanding on the pilot. It is interesting that until recently, with the advent of TV-type CRT displays, this progression resulted in an increase in the number of controls and indicators regarded as being essential to the efficient operation of the aircraft.

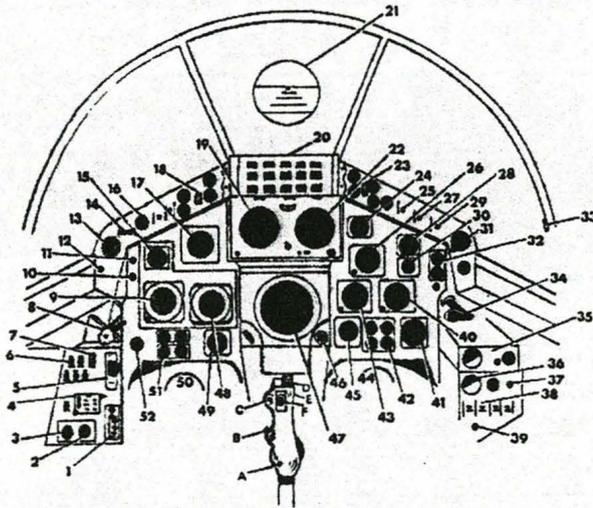
The design philosophy used in TSR 2 was to employ two crew members within the systems control loop. The efficient use of a man within such a system pre-supposed that he would

be left as free as possible to exercise his unique adaptive, assessor and decisive functions. With this in mind, it was decided to relieve the crew members of as many purely monitoring tasks as was possible and to aim at a simple and efficient cockpit, allowing the maximum time for the all-important task of decision making. During the various development stages of the project however, it was often found necessary to compromise this aim in order to meet conflicting requirements.

The major requirements laid down in OR 343 directly applicable to the cockpit layout were limited to a definition of the pilot's display only. In essence, these requirements were:

- (a) The essential flight instrumentation displays should be triplicated, in the form of:
 - (i) Head-Up Display — collimated display through the windscreen.
 - (ii) Head-Down Display — main instrument display on dashboard in front of pilot.
 - (iii) Standby Display — a standby instrument display also on the pilot's dashboard in front of him.

(The head-up display and the head-down display had to show, in addition to general flight data, director and information data for manoeuvring, navigation, weapon aiming and



The pilot's (front) cockpit of the TSR 2 is shown in a detailed, full-scale mock-up (below right). The instruments can be identified by reference to the diagram (above) and the following keys: On the control column, A, column lock button; B, radio (press to transmit); C, auto-pilot cut-out; D, arm/safe switch; E, weapon release trigger (not depicted); F, four-way toggle switch trim control. Main instruments and controls, as listed below:

1 Flap position selector	27 Pull up warning — speed
2 Roll indicator	28 Aircraft skin temperature indicator
3 Yaw indicator	29 Pull up warning — altitude
4 Undercarriage indicator	30 Local altimeter
5 Undercarriage selector	31 Accelerometer
6 Nose leg selector	32 Oxygen contents/pressure
7 Emergency undercarriage selector	33 Back-up lighting
8 Parking brake lever	34 Rudder pedal adjuster
9 Standby horizon	35 ILS controls
10 Flap position indicator	36 Channel selector (UHF)
11 Flap blown pressure indicator	37 Aerial selector
12 Wing stores jettison	38 UHF controls
13 Incidence meter	39 Tone control
14 Brake parachute jettison	40 Thrust RPM, starboard engine
15 Air speed indicator	41 Turbine temperature (starboard)
16 Parachute door selector	42 Intake cone/nozzle position
17 Combined speed indicator	43 Thrust RPM, port engine
18 Close reheat switch (port)	44 Starboard rudder pedal
19 Altitude display	45 Turbine temperature (port)
20 Centralised warning panel	46 Scale selector
21 Head-up display (on windscreen)	47 Moving map display
22 Navigation display	48 Standby altimeter
23 Close reheat switch (starboard)	49 Rate of climb indicator
24 Radio altimeter	50 Port rudder pedal
25 Pull up warning — direction	51 Brake pressure indicator
26 Altimeter	52 Air brake position

monitoring of the automatic flight control system.)

- (b) Provision of a topographic display, fed from the navigation equipment, which gave the best computed position of the aircraft continuously.

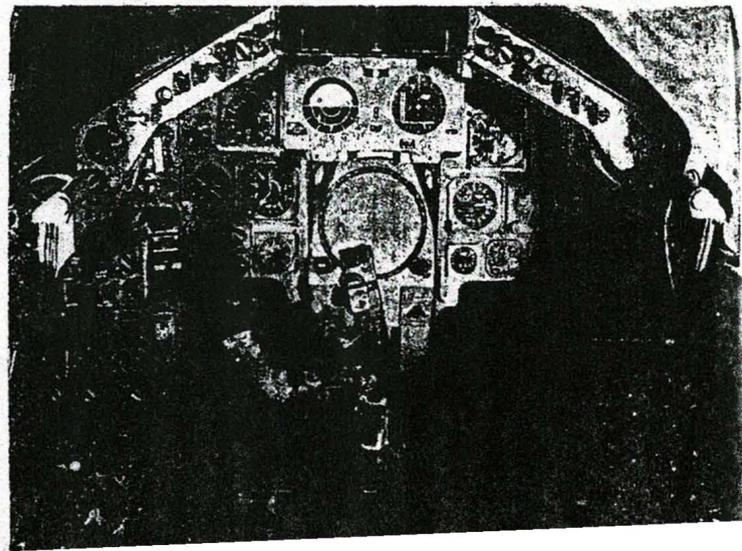
In designing the crew stations to meet the conditions of these requirements and allow the crew to work in comfort under difficult flight conditions, a multitude of influencing factors had to be sorted out into some sort of priority. A cockpit steering committee was set up to evaluate the problems and to control the ever-changing ideas which arose as the project progressed. The intention was that this steering committee should have the power to exercise decisions and change the design if necessary. In order to make such a committee work it was decided to limit its size to six members, comprising one from the Ministry of Aviation, one from the Ministry of Defence, one from A&AEE Boscombe Down, and three from BAC (the chief test pilot and two members of the design staff).

In common with so many of the good ideas behind the development of TSR 2, this simply did not work out, it just didn't happen as intended: key personnel from MOA and MOD were periodically changed during the development period because of their routine postings, and the numbers attending each meeting grew and grew until at times they reached sixty. The results were inevitable — too much time was wasted in explanation rather than assessment, and decision-making became almost impossible. What is perhaps remarkable is that despite the setbacks actually caused by the steering committee, the crew stations evolved reasonably quickly from the original mock-up stage to the definitive production aircraft and by the time the tenth aircraft design had been frozen, both crew stations were as good as they were ever going to be.

Although the instrumentation layout actually installed in the first aircraft differed considerably from the design of that for the 20th aircraft, fundamentally they were the same. What was certainly applicable to every aircraft in the two batches actually ordered were the design factors that influenced the geometry of the front section of the aircraft.

The specification called for two crew members but allowed a choice of seating arrangements, between tandem and the more sociable side-by-side seating. The advantage of the latter was that the crew would have direct physical contact, which would avoid the need for duplication of some of the instruments and displays. Also, for a given nose diameter, the view over the nose can be made slightly better.

On the other hand, given the basic aircraft configuration of a low aspect delta wing set well back on a slender compact fuselage, there were important aerodynamic advantages to be gained from tandem seating. For example, by doubling the cross sectional area to fit the crew side-by-side, the forebody and windscreen drag would have been increased three times, which would have added 20 per cent to the total profile drag of the aircraft.



Furthermore, in order to reduce the possibility of flow breakaway ahead of the intakes, the cross sectional area at the cockpit would have to have been retained as far back as the intake lips. This would have created a larger centre section, thereby increasing further the overall profile drag.

One more problem against sociable seating was that the space available for the navigator's displays and equipment would have been limited and the information at the time suggested that the equipment being proposed would simply not fit in the space available. The penalties associated with sociable seating were thus considered to outweigh its advantages and tandem seating was chosen.

The space required to accommodate the pilot and seat, allowing him functional control of the aircraft together with sufficient clearance for ejection in an emergency, imposed basic geometric criteria which did not prove to be a problem. The overall geometry definition was therefore essentially a question of the best possible compromise between the conflicting requirements of the pilot's view, electronic view, space provision for equipment and systems, and aerodynamic drag. For example, in order to ensure the minimum drag in the transonic region, the curve of the fuselage cross sectional area distribution had to be smooth and free from sudden changes in gradient; but three limiting points in this curve were the cross-sectional area at the nose radome, the pilot's cockpit and the intake position.

Nose geometry

The choice of a conical nose radome was largely dictated by the need for close electrical tolerances. At the time, the techniques used in manufacturing non-metal structures lagged behind developments in other materials. The choice of nose cone angle, however, was again a compromise between the requirements of electronic view for the forward looking radar, and ensuring that the cone could be constructed with, and maintain throughout its life, a minimum thickness all over. To satisfy the latter requirement, the problem of rain erosion had to be looked at, as any changes in the thickness of the radome outer surface would have caused adverse electronic effects. This meant the nose cone angle had to be at a minimum, but this minimum was dictated by the amount of radar refraction that was acceptable across the radome wall. The optimum angle turned out to be 30 per cent.

This restriction of angle meant, however, that the length of the cone itself became a direct function of the forward looking radar's dish dimensions; therefore, in order to achieve the minimum length for the sake of reduced drag and maximum pilot's view, the radar dish was kept to a diameter of 19 in (48

BAC TSR 2 Specification

(As at November 1962)

Power Plant: Two Bristol-Siddeley Olympus 22R Mk 320 twin-spool axial flow turbojets with water injection and variable reheat, rated at 19,600 lb st (8 898 kgp) dry and 30,610 lb st (13 897 kgp) with full reheat in ISA at sea level. Total usable internal fuel capacity, 5,588 Imp gal (25 400 l), comprising 1,474 Imp gal (6 700 l) in two wing tanks, 2,255 Imp gal (10 250 l) in two forward fuselage tanks, 1,900 Imp gal (8 637 l) in two aft fuselage tanks and 59 Imp gal (268 l) in forward and aft collector boxes. Provision for in-flight refuelling at 400 Imp gal (1 818 l) per min. Provision for 600 Imp gal (2 728 l) non-jettisonable ferry tank in weapons bay, two 450-Imp gal (2 045-l) wing drop tanks and 1,000-Imp gal (4 546-l) ventral drop tank.

Performance: Max cruising speeds, Mach = 0.9 to 1.1 at 200 ft (61 m), Mach = 2.05 above 36,000 ft (10 980 m), equivalent to a VNO of 725 kt (1 342 km/h) IAS; max design speed (VD) 800 kts (1 480 km/h)/Mach = 2.25; initial ratio of climb, over 50,000 ft/min (254 m/sec); max operating altitude, 54,000 ft (16 470 m); take-off ground roll (max take-off weight), 3,000 ft (915 m); landing ground roll (with brake parachute), 1,500 ft (457 m); radius of action with one 2,000 lb (908 kg) bomb internally, 1,150 mls (1 850 km) with 10 per cent at Mach = 1.7 above 40,000 ft (12 200 m) and 20 per cent at Mach = 0.9 at 200 ft (61 m), or 575 mls (925 km) at Mach = 2.0 at medium altitude or 800 mls (1 286 km) at Mach = 0.9 at 200 ft (61 m); radius of action with wing drop tanks, 1,725 mls (2 774 km); ferry range, up to 4,250 mls (6 850 km).

Weights: Normal take-off (1,150-ml/1 850 km sortie), 95,900 lb (43 539 kg); max take-off, 105,000 lb (47 670 kg); max landing, 57,200 lb (25 969 kg).

Dimensions: Span 37 ft 1 1/2 in (11,32 m); length, 86 ft 0 in (26,21 m); height, 23 ft 5 in (7,13 m); wing area, 700 sq ft (65,03 m²); sweepback at quarter chord, 50.8 deg; aspect ratio, 1.96:1; tip anhedral, 30 deg.

Armament: Internal weapons bay, 20 ft by 3 ft by 1.5 ft (6,1 m by 0,92 m by 0,46 m), carrying nuclear or six 1,000-lb (454-kg) HE bombs; four wing pylons, with provision for nuclear (inner pylons only) or up to four 1,000-lb (454-kg) HE bombs or four ASMs or four 37-rocket packs.

- 13 Pilot's canopy
- 14 Martin-Baker Mk 8A ejector seat
- 15 Ejection seat rocket pack
- 16 Tactical instrument displays
- 17 Navigator's canopy
- 18 Navigator's ejector seat
- 19 Oblique camera
- 20 Sideways looking radar
- 21 Stand-by pitot head
- 22 Avionics equipment bay
- 23 IFF antenna
- 24 Air conditioning system water separator

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DRAWING

BAC TSR.2 Cutaway Drawing Key

- 1 Pilot head
- 2 Radome
- 3 Radar scanner
- 4 Windscreen rain repelling ducts
- 5 ECM aerial
- 6 Forward looking, terrain following and attack radar
- 7 UHF aerial
- 8 Windscreen frame

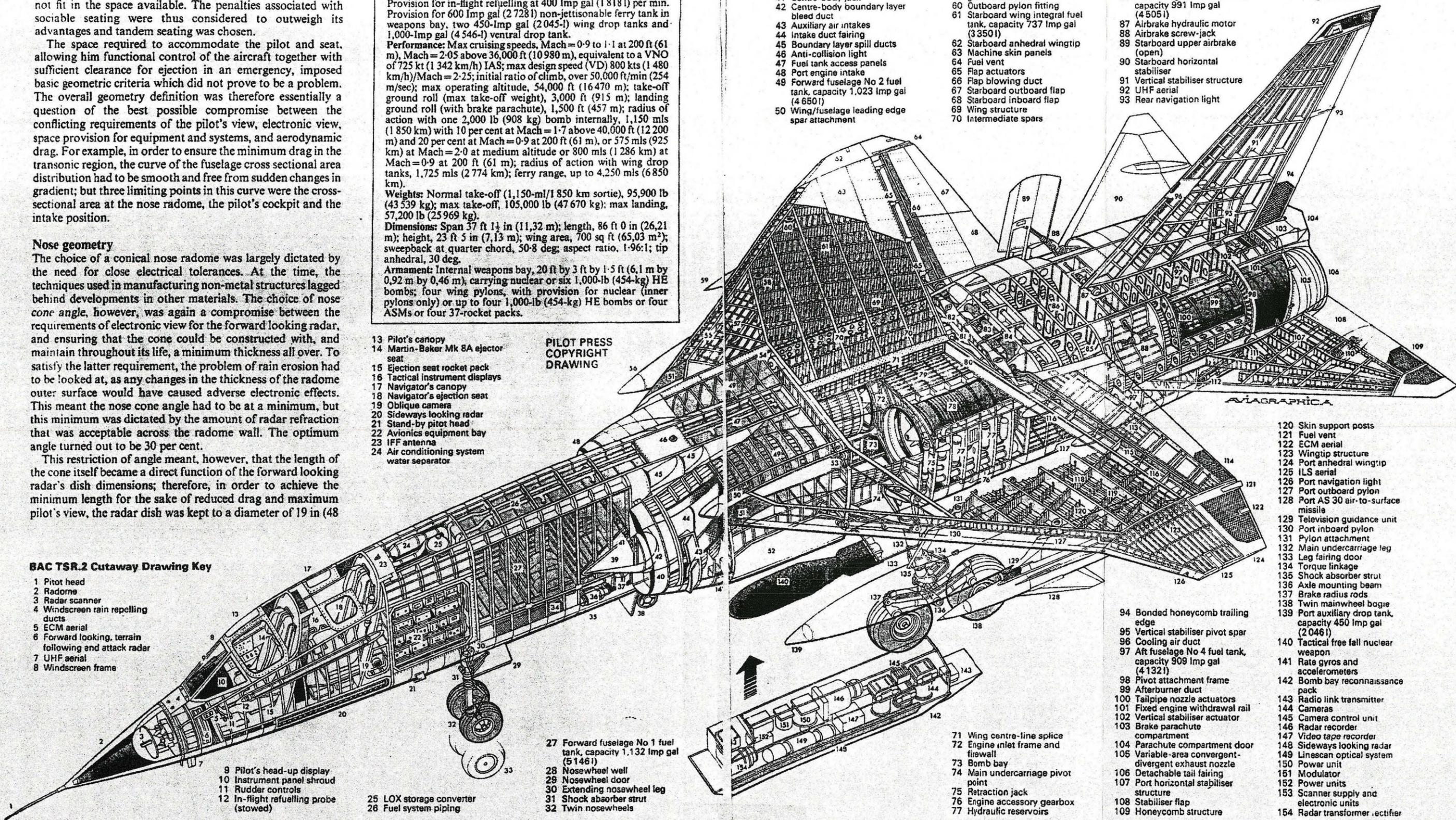
- 9 Pilot's head-up display
- 10 Instrument panel shroud
- 11 Rudder controls
- 12 In-flight refuelling probe (stowed)

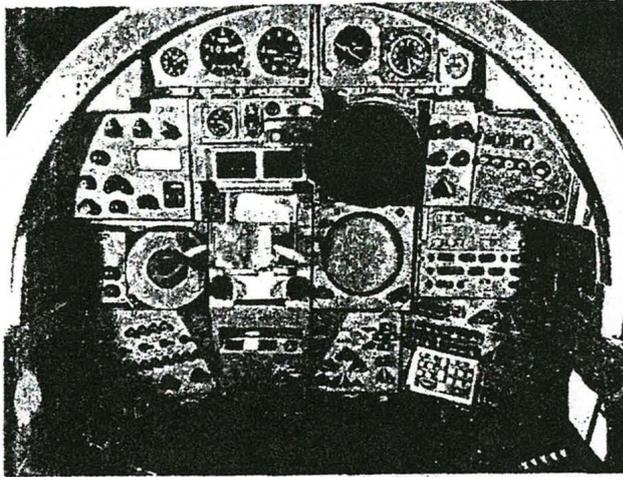
- 25 LOX storage converter
- 26 Fuel system piping

- 27 Forward fuselage No 1 fuel tank, capacity 1,132 Imp gal (5 146 l)
- 28 Nosewheel well
- 29 Nosewheel door
- 30 Extending nosewheel leg
- 31 Shock absorber strut
- 32 Twin nosewheels

- 33 Nosewheel extended position (take-off)
- 34 Pre-closing nosewheel doors
- 35 Doppler navigation aerial
- 36 Emergency generator
- 37 Air conditioning heat exchanger
- 38 Airborne auxiliary power unit (lowered)
- 39 Intake movable centre body, half cone
- 40 Port engine intakes
- 41 Centre-body jack
- 42 Centre-body boundary layer bleed duct
- 43 Auxiliary air intakes
- 44 Intake duct fairing
- 45 Boundary layer spill ducts
- 46 Anti-collision light
- 47 Fuel tank access panels
- 48 Port engine intake
- 49 Forward fuselage No 2 fuel tank, capacity 1,023 Imp gal (4 650 l)
- 50 Wing/fuselage leading edge spar attachment
- 51 HF notch aerial
- 52 Main undercarriage doors
- 53 Wing/fuselage attachment frame forging
- 54 Front spar attachment
- 55 Leading edge structure
- 56 Starboard auxiliary drop tank, capacity 450 Imp gal (2 046 l)
- 57 Fuel pipes in leading edge
- 58 Inboard pylon fitting
- 59 Starboard AS 30 air-to-ground missile
- 60 Outboard pylon fitting
- 61 Starboard wing integral fuel tank, capacity 737 Imp gal (3 350 l)
- 62 Starboard anhedral wingtip
- 63 Machine skin panels
- 64 Fuel vent
- 65 Flap actuators
- 66 Flap blowing duct
- 67 Starboard outboard flap
- 68 Starboard inboard flap
- 69 Wing structure
- 70 Intermediate spars

- 78 Bristol Siddeley Olympus 22R turbojet
- 79 Water injection tank, capacity 80 Imp gal (364 l)
- 80 Rear spar
- 81 Wing fuel system piping
- 82 Wing/fuselage aft attaching frame
- 83 Flap gearbox and hydraulic motors
- 84 Bleed air ducting
- 85 Engine tunnel duct
- 86 Aft fuselage No 3 fuel tank, capacity 991 Imp gal (4 505 l)
- 87 Airbrake hydraulic motor
- 88 Airbrake screw-jack
- 89 Starboard upper airbrake (open)
- 90 Starboard horizontal stabiliser
- 91 Vertical stabiliser structure
- 92 UHF aerial
- 93 Rear navigation light
- 110 Stabiliser flap actuator
- 111 Pivot spar
- 112 Horizontal stabiliser actuator
- 113 Port flaps
- 114 Honeycomb trailing edge structure
- 115 Flap blowing air duct
- 116 Flap actuator fairings
- 117 Port lower airbrakes
- 118 Port wing integral fuel tank, capacity 737 Imp gal (3 350 l)
- 119 Wing structure





A mock-up of the observer's (rear) cockpit in the TSR 2, showing the tactical instrument displays, including the primary navigation instruments. Sideways-looking radar (SLAR) built into the forward fuselage was one of the primary nav aids.

cm). This compromise was well within the limits acceptable for the required radar performance.

The attitude of the nose cone again required compromise, this time between OR 343's requirement that the pilot must have a real downward view of 11 deg and the drag penalties associated with the various possible nose cone positions. The optimum conditions were finally achieved by positioning the nose cone so that its top line was co-incident with the pilot's line of sight.

The choice of windscreen was between a flat-fronted panel and a "vee" panel, and the final preference was for the flat fronted type, the decision being influenced by four major factors.

First, the rôle of the aircraft made it essential to delay the drag rise at all critical points up to a speed of $M=0.95$. Drag data at the time was somewhat limited and, in some areas, conflicting. The general thought was that the "vee" windscreen had the lower drag rise of the two, but had much higher drag characteristics at the top end of the flight envelope. Secondly, the pilot would have to sit three inches lower down with the "vee" type, because of the required head/canopy clearance; this would restrict his downward view, relatively, by about three degrees. Thirdly, it was much easier to fair a flat windscreen into the fuselage and canopy; and finally, the "vee" type was more prone to the reflection of internal cockpit light from the windscreen panels.

As far as drag was concerned, a shallow windscreen angle was best, but this contradicted the requirement for good pilot view, particularly downward. In the end, the windscreen rose out of the fuselage at an angle of 35 deg to the vertical.

Several factors affected the internal geometry of the cockpits, the most difficult being the space provision and layout of equipment, systems and display panels. Predictions had to be based on very limited information, since proposed new equipment and systems were generally in a very early stage of development. This problem was made worse by the high installation density required. During later development, growth and complexity began to exceed the predictions, which gave rise to penalties in installation and functional layout.

Cockpit dimensions

The key geometry of the crew compartment was, as far as possible, made to conform to the recommendations of a study carried out by the Ministry of Aviation, which laid down a recommended cockpit layout for British Military aircraft. There were, however, four significant variations from this standard:

First, the angle between the back of the ejection seat and its

gun centreline was reduced, in order to reduce the acceleration load component normal to the pilot, and the front face of the headrest was moved aft to improve the pilot's sitting position.

Secondly, in order to achieve the required downward view for the pilot, the eye position was raised by 2 in (5 cm), reducing the recommended clearance between the pilot's head and the canopy by the same amount. This raised eye position allowed the pilot a much better view, especially during take-off and landing, and was used as the origin point to measure the pilot's downward sight line.

Thirdly, the dashboard depth (defined by the downward sight line and knee clearance requirements) was considered marginal. To obtain the maximum usable area for instrument displays, the dashboard was inclined forward until it became normal to the glare shield, and the lower edge was set as low as was possible.

Finally, the predicted control characteristics of the aircraft meant that plus/minus 2 in (5 cm) of rudder pedal travel would suffice, the recommended travel being plus/minus 4 in (10 cm). The adjustment of the pedals was limited to 5 in (13 cm).

The development phase of the aircraft, including flight assessments, proved that the internal geometry satisfied 98 per cent of pilot's body measurements.

Cockpit layout

Like the internal geometry, the cockpit layout chosen was basically conventional in its design. Early investigations had shown no significant advantages in departing from the standard type of controls. For example, a side stick control column was considered in an attempt to increase the pilot's view of the dashboard. This idea was abandoned mainly because of the limitations of single handed operation and need to use the essential side console space. Some doubts were also experienced on the aircraft handling characteristics with a side stick. Similarly, a cantilever mounted miniature centre stick was also discarded because it would have encroached an essential dashboard space. A further contributory factor to the layout design was the insistence by the Air Staff that flight instrumentation should be based on existing techniques as far as possible, in order to save time and money. This insistence ruled out BAC's idea for strip display instruments as a general feature.

The frontal display area facing the pilot was dominated by the requirement for three levels of essential flight instruments, together with the topographical display. The aim of the head-up display was to provide an image of essential flight instrumentation data, superimposed on the pilot's view of the outside world. As already mentioned, this was required to avoid the hazards associated with continuous re-orientation of the pilot's view from outside to inside the cockpit. This data was repeated in more detail on the primary instruments forming the head-down display — both being fed from the same source. OR 343 stipulated, however, that the aircraft must be able to continue its mission without loss of performance after a single failure — in which case parts of the standby display would need to be used.

It followed, therefore, that all three sets of display should be concentrated within what was known as the "gold plated space", comprising the central area of the dashboard and windscreen which fell within the primary visual scan of the pilot. However, the shape and size of the equipment and instruments that evolved precluded the achievement of this aim, particularly with the inclusion of the topographical display.

Numerous arrangements were studied to resolve this problem. A head-up display based on the reflector gunsight principle offered advantages in compactness, together with a stable and clear reflected display (due to an integral reflector). The disadvantage was that it dominated the "gold plated space", as the unit which projected the display onto the

windscreen had to be located forward of the dashboard. The cockpit designers became involved in a detailed and rather tedious tailoring exercise which, although finishing up with compromises such as the attitude and navigation display (to the requirements of OR 946) projecting almost 3 in (7.6 cm) from the dashboard, proved to be largely successful. It is likely, in any case, that had the TSR 2 continued, these problems would have been resolved completely.

The critical feature in designing both the left and right-hand consoles in the front cockpit was the installation density dictated by the internal geometry specification, together with a requirement for easy access and rapid servicing. The consoles were based on a continuous (fore and aft) open topped duct which carried all the electrical looms. The display panels and equipment boxes formed an assembly and were an integral part of the rigid box-like structure, but were independent and easily removed.

Originally, both consoles had angled tops to provide the maximum area for controls and the best viewing angles for the pilot. However, to utilise remaining console space effectively with the selected type of throttle assembly within the left-hand console (ie. incorporation of both throttles and their electrical transmitters as an integral and hence larger unit), the console top was made flat.

The depth of structure associated with the retractable flight refuelling probe, housed in the left-hand side of the nose fuselage, virtually excluded the use of the left sidewall for controls or displays. The rapid start panel, housed in the right-hand sidewall, was designed to concentrate in one area all the switches necessary for take-off in the operational rôle, including the master switches for all the systems under the pilot's control.

Power plants

TSR 2 was powered by two Bristol-Siddeley Olympus 22R engines, housed side-by-side in separate tunnels in the rear fuselage, each engine with its vertical centreline rotated through 21 deg. Each engine had a water injection system and variable reheat, which when used in conjunction produced around 30,600 lb (13,880 kg) of thrust at sea level and ISA + 20 deg C. The main features of the engine were two compound axial-flow compressors, two axial-flow single-stage turbines each driving one compressor, straight-flow flame-tube

combustion chambers, and a fully variable reheat system with a fixed shroud aerodynamic nozzle.

Both engines had three mounting attachments: a main thrust trunnion located at the top of the delivery casing, a locating spigot and spherical bush at the front of the engine, and a transverse strut for torsional restraint. Alternative left and right mounting attachment positions made the engines non-handed. The engine change unit, complete with jet pipe, could be installed from the rear of the airframe, after the rear engine fairing had been removed.

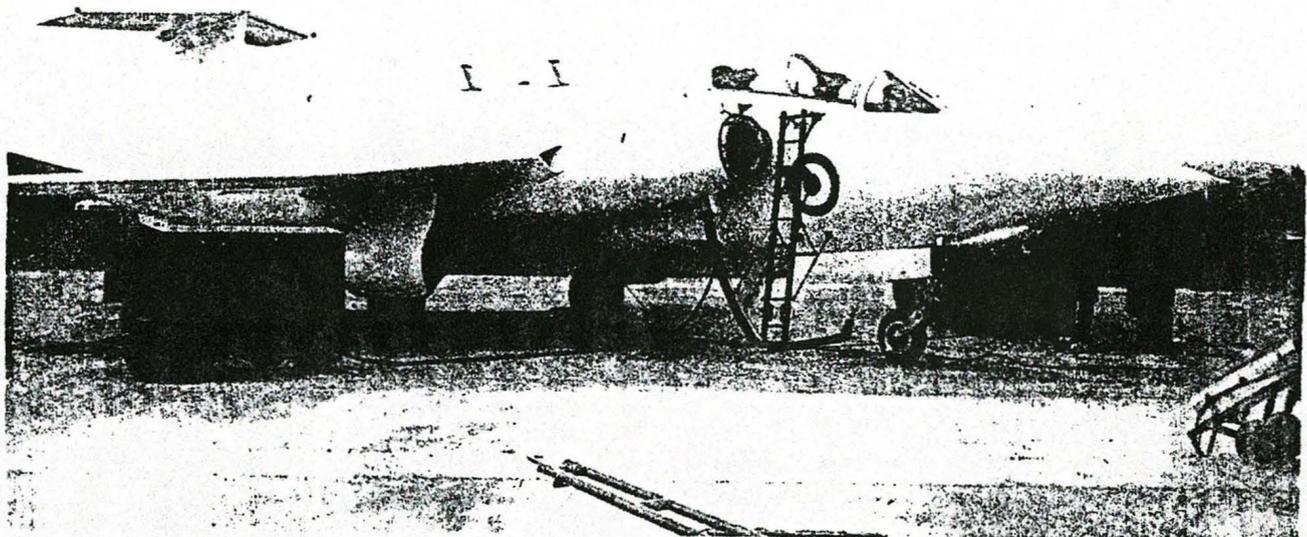
The engines were fed with air from the semi-circular intakes mounted on the side of the fuselage, forward of the wing leading edge. Each intake had a variable cone in its centre which controlled the speed at which air was presented to the low pressure compressors. Auxiliary intake doors, at the rear of the intake lips, provided additional intake area for low speed flight.

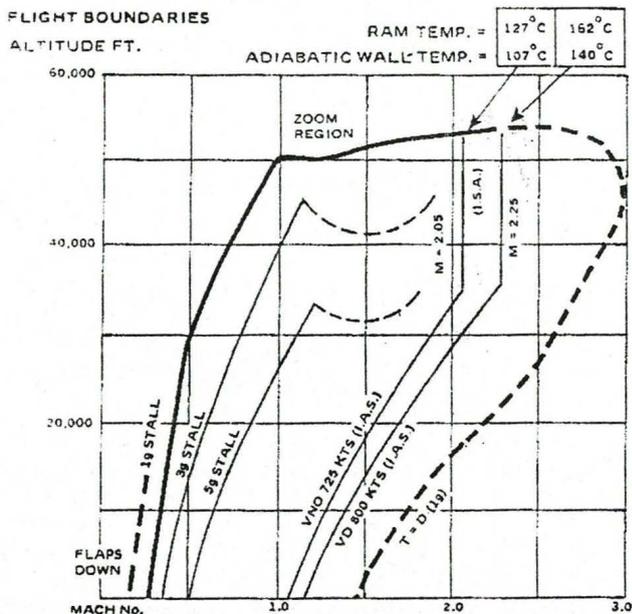
Each engine had an automatic electrical control, the normal system being AC, with a standby DC system. The control system provided a linear relationship between the pilot's throttle lever angle and the actual engine thrust, from flight idling to maximum thrust with full reheat. Both engines drove accessory gearboxes which could be de-clutched to allow the aircraft systems to be run on the ground. The accessories driven by the gearboxes included a constant speed drive starter, an alternator, two fuelhydraulic motors and two hydraulic pumps.

The engines were situated in fireproof zones and the area around each engine was protected by detection and suppression equipment. Triple firewire would detect any increase in heat above normal and indicate to the pilot both visually and audibly that there was a fire. The pilot could then initiate various sequences of methyl bromide extinguishers according to the severity of the fire. In the event of a crash landing, the extinguishers would automatically go off, initiated by inertia switches, in order to prevent a fire starting, or an existing fire from spreading.

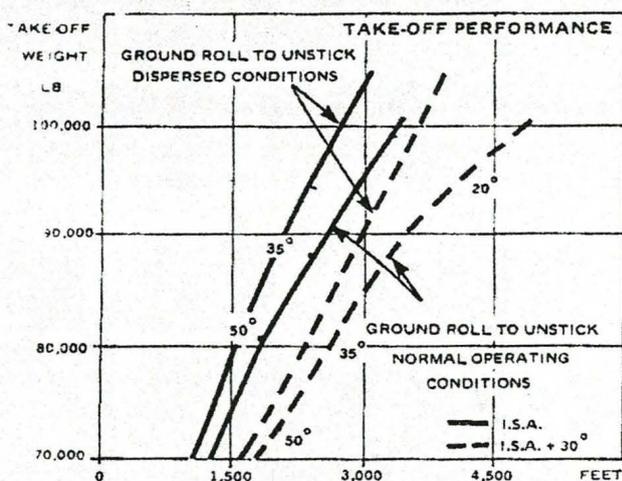
An airborne auxiliary power plant (AAPP) was stowed ventrally inside the fuselage just forward of the weapons bay. Whilst on the ground, the AAPP could be lowered by hydraulic jacks and, once started (by hydraulic motor fed from an accumulator in the aircraft), would provide low pressure air for engine starting, electrical power for the fuel pumps,

For development of the forward-looking radar associated with the Ferranti terrain-following system in the TSR 2, this Blackburn Buccaneer was fitted with the nose radar and operated from Edinburgh.





Although performance estimates for the TSR 2 changed in detail during the life of the project, these diagrams show representative data for (above) the flight envelope and (below) the take-off performance. (Unstick distances of 1,500 ft (457 m) or less could be achieved for 500-mi (805-km) missions.



throttles and inertia platform, ground running of the main engine gearboxes, and air conditioning for the crew stations and equipment bays.

Performance

The high reheated thrust required to meet the demanding take-off requirements gave TSR 2 large thrust margins at supersonic speeds. The use of reheat at altitude pushed the aircraft's maximum speed to well above Mach=2 according to atmospheric conditions. Since the structural limitations were more dependent on temperature than Mach number, the limit was that which corresponded to a ram temperature of 146 deg C. Thus, in a maximum temperature atmosphere, the operational top speed was limited to Mach=2.0, whereas in standard or minimum temperature atmosphere the top speed could be pushed up to Mach=2.16 and Mach=2.5 respectively. However, for the flight development phase, the first prototype of the TSR 2 was initially limited to a placard top speed of Mach=2.05. At low altitudes (down to 200 ft/61 m) the top speed was limited to 725 kts (1 343 km/h), equivalent to a sea level Mach number of 1.1. The aircraft was designed to

have a 10 per cent margin over these figures, giving a design maximum Mach number of 2.75.

At subsonic speeds, the limiting factor on manoeuvres was the maximum usable trimmed lift. With a delta wing, a clearly defined stall is unlikely so the limitations had to be determined by lesser considerations such as buffet. The limiting factor at supersonic speeds was the tailplane travel, which limited the available g. However, this did not present a problem as the limit was well above the g likely to be encountered.

The absolute thrust ceiling was about 56,000 ft (17 070 m) at supersonic speeds, the tailplane power being adequate to trim the aircraft at this altitude. For short periods it would have been possible to reach 70,000 ft (21 336 m) in a zoom climb by making use of the kinetic energy available at high supersonic speeds. The most economic ceiling for the aircraft was 55,000 ft (16 764 m), cruising at Mach=2.0.

To achieve the shortest possible unstick distance, blown flaps were used. Water injection was used to augment the thrust regardless of atmospheric temperature. A full flap configuration gave the minimum unstick distance, but this involved the inherent risk of a short delay before single-engine safety speed was achieved. Provided the specified balanced ground roll distance was available, a partial flap setting would therefore be used, to ensure full single-engine safety throughout the take-off.

A "no flare-out" landing technique was employed which, at the time of TSR 2 development, was a fairly new idea greatly reducing the length of runway required for landing as it allowed very precise touchdown points. Full blown flap was used during the approach and a large reefed parachute was streamed at touchdown, greatly reducing the ground roll.

A basic sortie was devised to contain all the main performance parameters considered desirable in a tactical system for the mid-'sixties. Any aircraft capable of meeting this basic sortie obviously would have been able to fly a wide variety of different sorties according to the demands of varying tactical situations — each one of these sortie variants producing a significant radius of action.

Details of the basic sortie and some alternatives are shown in the accompanying diagrams; at the same take-off weight, a sortie could be flown at 200 ft (61 m) over a total distance of 1,400 naut miles (2 253 km), or a high altitude sortie could be flown at Mach=2 over a total distance of 1,100 naut miles (1 770 km). All of these sorties could be flown without the use of externally carried fuel.

Nuclear weapon delivery

In a tactical nuclear rôle, TSR 2 would have delivered its weapon in an automatically-programmed forward loft manoeuvre. The bomb would have been released after the aircraft had pulled up from the 200-ft (61-m) terrain following mode and reached a height of 1,840 ft (561 m). Using a chandelle escape manoeuvre, the aircraft would have continued to climb until it reached 10,600 ft (3 230 m). By using this method of attack, the aircraft would have been immune even to short reaction time ground-to-air defence systems, such as possible enemy equivalents to Mauler and PT.428, since the bomb burst would have destroyed the defence radar before the missiles could reach the aircraft.

In a strategic nuclear rôle, however, the targets to be attacked were expected to have been protected by considerable numbers of this type of defence system. Under these conditions it would have been unsafe to go above the 200-ft (61-m) terrain following height. For this reason, the lay-down technique would have been used. The TSR 2 would have remained at 200 ft (61 m) throughout the attack and released a lay-down bomb which would have exploded when the aircraft had reached a safe distance. At the time, a British lay-down weapon was being developed to meet the RAF requirement OR 1177. TSR 2 would have been able to carry up to four

examples of the low-yield version of this weapon within its weapons bay, but had it entered service, it was more likely that two of the high yield version would have been carried.

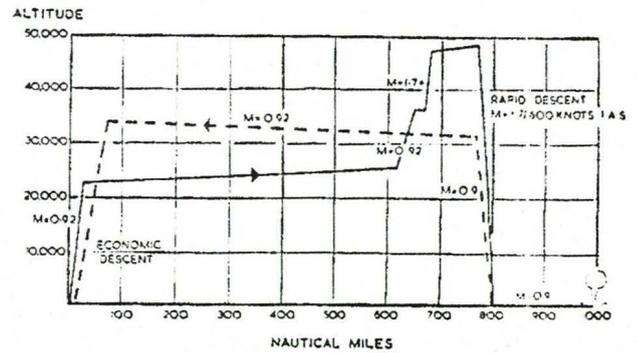
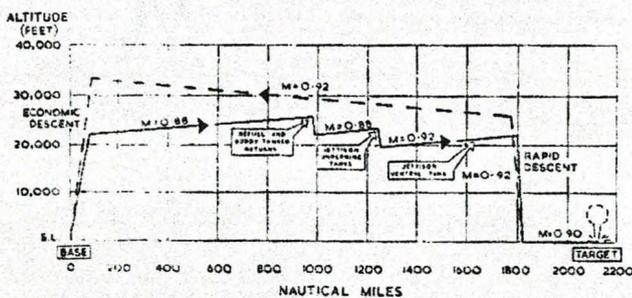
The use of a stand-off missile to avoid the need for an aircraft to penetrate to the target itself, with the possibility of exposing the crew to the effects of previous nuclear explosions, and to permit the use of the air-burst technique, was also studied in conjunction with TSR 2. The Blue Water missile was under development as a tactical surface-to-surface nuclear weapon system until August 1962, (up to which date a total of £16.6 million had been spent on its development). By fitting Blue Water with a megaton warhead and carrying one under each wing of TSR 2, a very economic strategic weapon system could have been achieved. Blue Water had an entirely self-contained inertial guided system which in combination with the precise navigation system already fitted to TSR 2 would have eliminated the need for star tracking or other additional sensing equipment, making the weapon system all-weather and immune to ECM.

Blue Water was originally conceived as a vehicle-transported inertia guided nuclear weapon for the Army. It was propelled by a two-stage solid fuel rocket motor and was capable of use within 10 minutes of being brought to the ground launch point. The proposed air-launched weapon itself used a very high proportion of Blue Water techniques and components, and required only minor modifications to the aircraft. The complete weapon system could therefore have been realised in an attractively short time-scale for relatively modest expenditure.

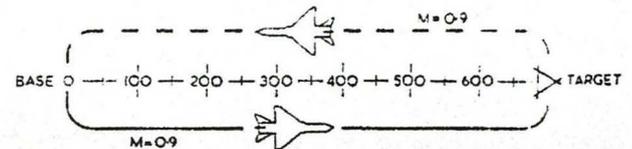
For the air-launched use as a strategic deterrent a number of modifications were required. Firstly, the warhead needed increasing to megaton size. Some structural strengthening and additional thermal insulation was necessary to meet the aircraft environment. Modifications to the guidance and fusing systems were also needed but none of these changes was of a fundamental or major nature. Cooling equipment would have been required to condition the missile guidance system. Preliminary studies proposed an evaporative total-loss Freon 12 refrigeration system, built into the missile pylon and requiring less than one pint (about 0.51) of Freon 12. With a 1,000-lb (454-kg) warhead, the airborne Blue Water had an estimated launch weight of 5,600 lb (2,540 kg) and was 31 ft (9.45 m) in length.

In the Army application of Blue Water, the tangent angle at release was standardised at 50 deg. To meet the same angle the aircraft would have been required to pull up to this angle in an approximately 4g manoeuvre, release the missile and then perform a chandelle manoeuvre to escape to the terrain following altitude. This would have resulted in unnecessary exposure to ground defences, so it was proposed instead to release the missile in horizontal flight at 200 ft (61 m) and to require the missile to turn itself into the required flight angle by the normal operation of the missile navigation system, accepting a range penalty of about 4 mls (6 km) as a result. The

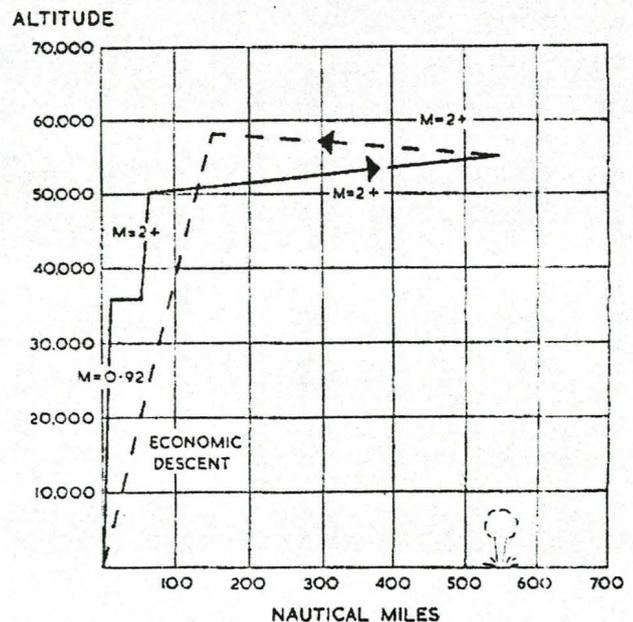
(Right) With ventral and underwing drop tanks, the TSR 2 could strike a target at a distance of 1,480 naut mls (2,740 km) from base. (Below) A range of 2,120 naut mls (3,930 km) could be achieved with the help of drop tanks and one refuelling from a TSR 2 buddy tanker.



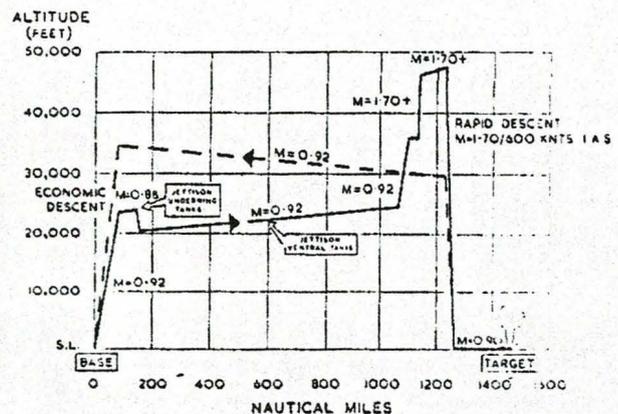
(Above) The "basic sortie" devised for the TSR 2 is shown here diagrammatically. It included high altitude subsonic cruise to and from the target, with a very high-altitude supersonic dash to penetrate the enemy borders and a very low-level run in to the target at high subsonic speed.

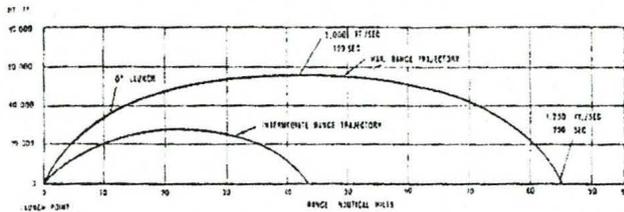


(Above) The performance capability that allowed the TSR 2 to perform its basic sortie allowed it to perform numerous other sorties, such as this all low-level, subsonic attack on a target 700 naut mls (1,300 km) from base.

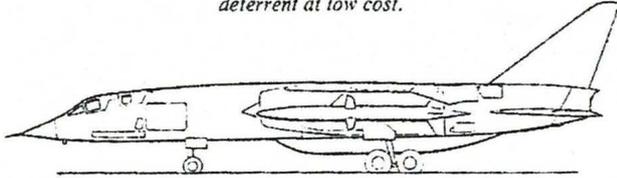


(Above) Another optional TSR 2 sortie, in which a target at a distance of 550 naut mls (1,020 km) could be attacked at supersonic speed from high altitude.





While the TSR 2 was still being developed, its use was projected to carry two modified Blue Water IRBMs, to produce a nuclear strategic deterrent at low cost.



TSR 2 would have been required to take-off at a weight of 120,800 lb (54 800 kg) with the two missiles carried plus belly fuel tank.

The TSR 2 system philosophy

A single team monitored the design and development of the complete TSR 2 system for the manufacturers from the time that work began in 1957. This enabled a consistent approach to be maintained on the compromise between weapon system performance and cost, and, with progressive studies on engineering feasibility, led rationally to the detail design development stage. Performance was built up from considerations of the airframe/equipment/weapon performances under ideal conditions and the losses of performance due to vulnerability, accidents or unserviceability. Detail numbers produced by such work were unlikely to be accurate, but the work as a whole provided valuable guidance to studies of feasibility and to the essential decisions day by day on which progress depended.

Flexibility was considered essential: high performance was required over a wide band of conditions. The aircraft configuration evolved on such grounds. The high level of thrust with a highly-developed low-speed wing configuration, in combination with low pressure tyres, were chosen in part because the aircraft thus became inherently suitable for overloading. Wing and engine were chosen to give good performance, both subsonic and supersonic. In addition to the required rôles of operation, studies continued on further applications and on the blind delivery of high explosive. This allowed design solutions to be adopted which favoured the

basic rôles while permitting eventual development with little modification.

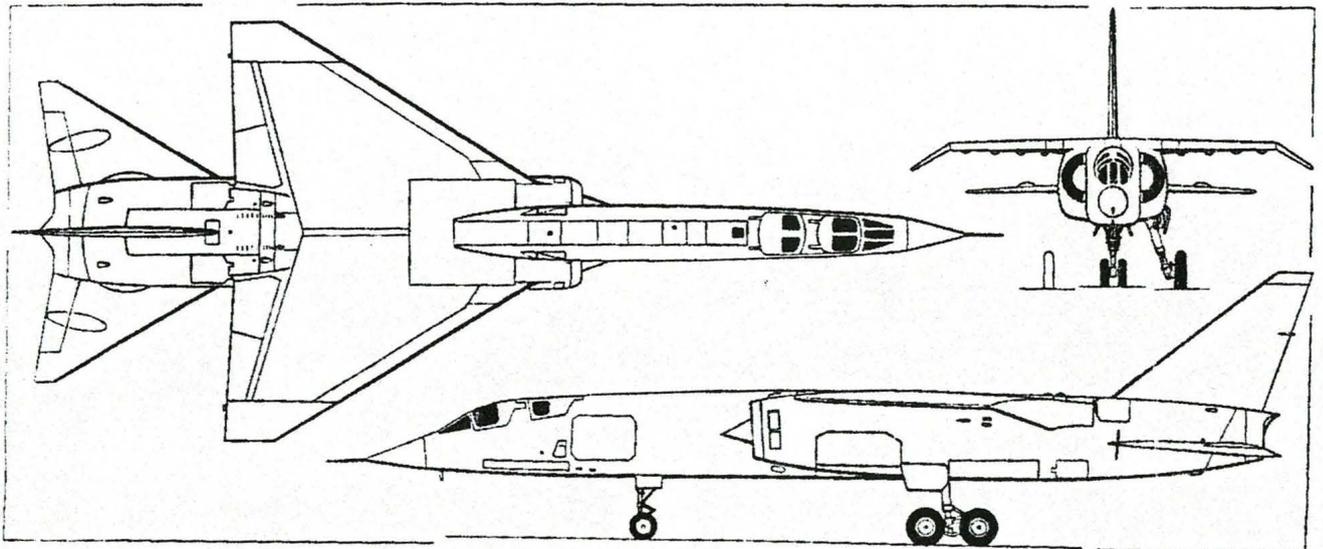
The terms of the requirement were developed in greater detail in parallel with design work. This process continued right up to the time of cancellation, when work was being concentrated on detail interpretations of requirements, concerning, for example, the exact conditions to be met after a double engine failure.

In the early stages, particularly late 1957 and early 1958, attention was given to a small, light, expendable weapon system, based on a lower range/take-off vehicle performance than was later required. A larger, high performance aircraft had been studied in parallel and it was eventually agreed that this second alternative would be preferable. Very briefly, this was seen to result in fewer systems but each of these would have had greater flexibility. They would be highly mobile and operate from rudimentary airstrips in a variety of rôles without massive ground support facilities. The overall result was increased operational freedom.

A major problem faced at this time was the need to achieve accuracies beyond the scope of manual operation of aircraft and systems, coupled with the need to reduce the crew work load. Automatic operation of some sub-systems provided the answer, but these had to be made completely safe without reliance on complex checkout equipment. For example, the bombing and terrain following systems were high authority systems and capable of breaking the aircraft after a failure unless this possibility was designed out of them. Reliability and a self-checking ability had to be built in. Some aircrew assistance would be involved in the checking process and, by design, this was extended to the point where the systems could be operated and controlled even after failures. Detail work and examination of existing and proposed systems supported this approach.

The results of these efforts became apparent in many areas. Squadrons of what were then current and next generation aircraft, required support by ground test equipment. Separate and quite complex checkout equipment was required in some cases even for daily inspections, for testing the hydraulics system, the fuel system, cooling and conditioning systems. Before electronic or airframe equipment could be tested, an equivalent to the aircraft power source had to be available. Moreover, in the case of TSR 2, this had to be provided and maintained at operational readiness for 30 days entirely in the open. After considerable study of the problem it was decided to carry a subsidiary prime mover which would solve this problem and also provide self-contained engine starting. All

The TSR 2 first prototype is depicted here in the form in which it was flight-tested during 1964/65.



this equipment was effectively carried in the airframe, without significant increase in airframe complexity or weight.

The same approach was followed during the development of each airframe system. Unrestricted operation and high accuracy was available when the system was fully serviceable. Continued safe operation was possible after single failures, but the conditions of usage, accuracy, or simplicity of usage were restricted. Second failures were safe where the operation, after a single failure, was likely to be continued. An example of this philosophy can be given in the case of the fuel system: Four nearly equal capacity fuselage tanks were used, and these were drained by four double-ended pumps that catered fully for the complete flight envelope including negative *g* flight. These pumps were arranged so that, without crew action or any complex electronic system, the loss of one pump had no effect on availability of fuel or fuel balance. After this failure, limitations would only arise when the fuel state was less than that normally remaining on landing. In this case, while normal full thrust was still usable, the pilot had to retrim fuel before using reheat.

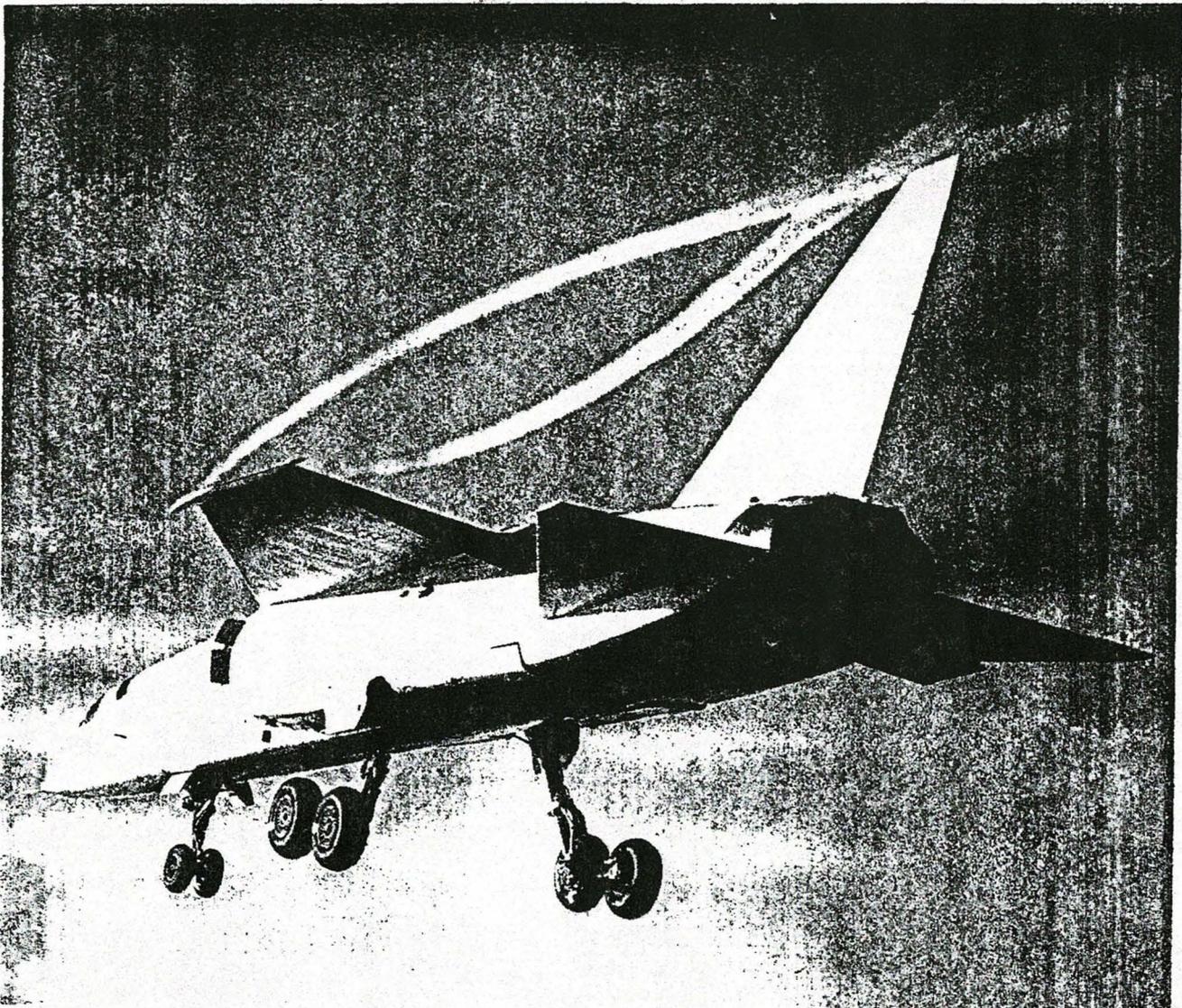
In a similar fashion, the hydraulic and cooling systems were split to provide restricted operation under conditions of failure when service aircraft normally return immediately to base. Very little additional complication or weight was involved.

As has been mentioned, the Navigation/Attack System was

TSR 2 FLIGHT TEST LOG

Flight Date	Duration (minutes)	Pilot	Crew Navigator
1 27 Sep 64	14	R P Beamont	D J Bowen
2 31 Dec 64	14	R P Beamont	D J Bowen
3 2 Jan 65	8	R P Beamont	D J Bowen
4 8 Jan 65	20	R P Beamont	D J Bowen
5 14 Jan 65	22	R P Beamont	D J Bowen
6 15 Jan 65	24	J L Dell	D J Bowen
7 22 Jan 65	28	R P Beamont	P Moneypenny
8 23 Jan 65	27	J L Dell	P Moneypenny
9 27 Jan 65	22	R P Beamont	D J Bowen
10 6 Feb 65	29	R P Beamont	D J Bowen
11 8 Feb 65	38	J L Dell	P Moneypenny
12 10 Feb 65	36	D M Knight	P Moneypenny
13 16 Feb 65	45	J Dell	D J Bowen
14 22 Feb 65	41	R P Beamont	P Moneypenny
15 26 Feb 65	70	J Dell	P Moneypenny
16 26 Feb 65	47	R P Beamont	P Moneypenny
17 8 Mar 65	52	J Dell	B McCann
18 8 Mar 65	35	J Dell	B McCann
19 11 Mar 65	33	J Dell	B McCann
20 12 Mar 65	46	J Dell	P Moneypenny
21 26 Mar 65	33	J Dell	B McCann
22 26 Mar 65	35	J Dell	B McCann
23 27 Mar 65	34	D M Knight	P Moneypenny
24 31 Mar 65	32	J Dell	B McCann

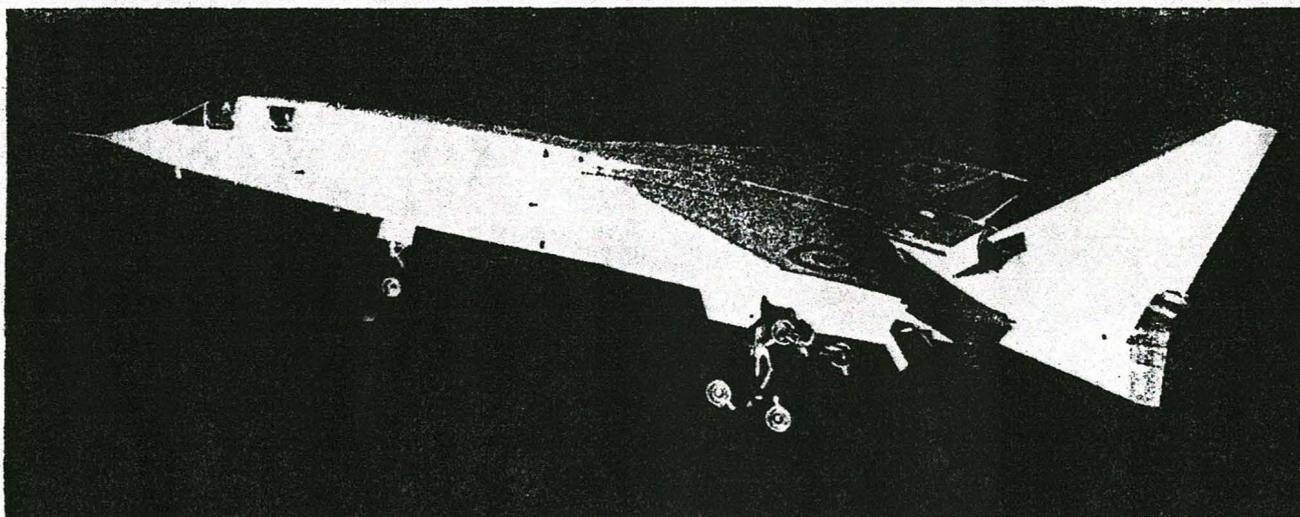
On the final approach to land at the end of one of its early test flights, the TSR 2 produces visible vortices from the leading and trailing edges of the wing tips. In this view, wing flaps are down and air brakes are open a fraction.



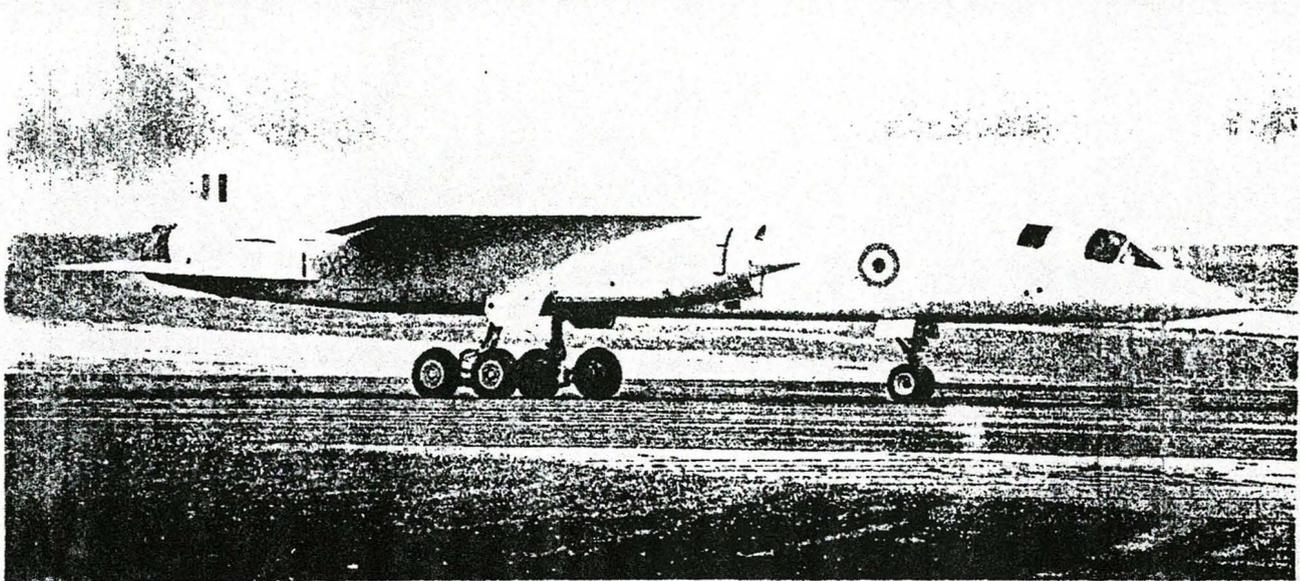
based on doppler/inertia mixing and operation in a reversionary mode was possible after a single failure. Similarly, the central computer was formed from two identical digital computers, one being used, broadly, for bombing and the other for navigation. Either could do the other's tasks, and the basic navigation data was stored in both computers at all times. Thus, failure of the navigation computer would not cause loss of "present position" or steering information. The fundamental aim throughout was to arrive at — and consistently maintain — the best compromise between maximum performance and flexibility and minimum cost, compatible with the given timescale.

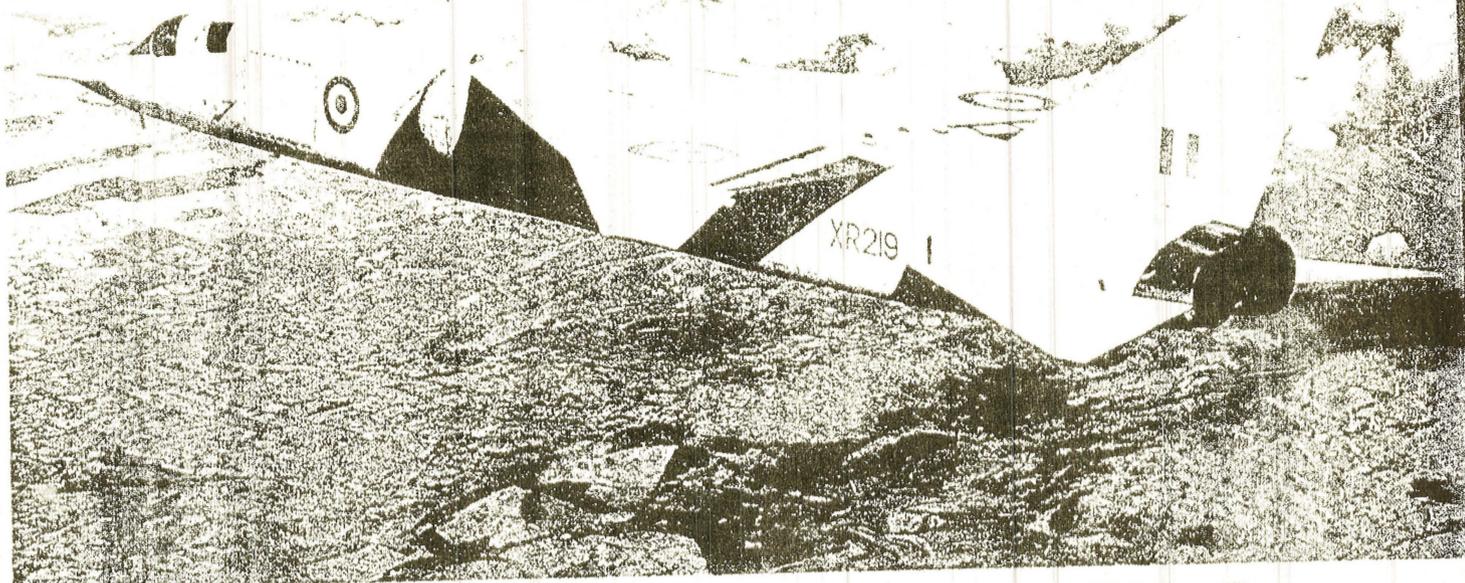
On 27 September 1964, the first of the TSR 2s made its initial flight at Boscombe Down, in the hands of R P Beamont with D J Bowen as flight observer in the second cockpit. It was a year later than originally intended and was the first of 20 flights made by this aircraft, destined to be the only one of its type actually to fly. When the axe fell, the second aircraft was complete and close to first flight and all seven others of the initial development batch were in various stages of completion. Additional contracts had been placed in 1963 and 1964 for 11 and 30 aircraft, respectively, so that a total of 50 TSR 2s had been ordered at the time the aircraft was cancelled and it had assumed the status of the largest military programme in Britain.

Not unnaturally, so complex a new aircraft suffered a goodly share of teething problems, notably in respect of the undercarriage and of the engines, the slow development of which had been in part responsible for the 12-month slippage in first flight date. Nevertheless, in the space of only 20 flights totalling less than 11 hrs of airborne time, substantial progress was made towards solving these problems and enough was achieved to leave little doubt that TSR 2 would be well able to accomplish the tasks that were required of it. Whether or not its cancellation was justified remains, as said in the introduction to this account, a subject for debate, and many remain eager to argue the case, both for and against. Certainly there was much evidence that the programme costs were getting out of control, and the changes in Britain's overseas defence commitments in 1965, under the Labour Government elected the year before, eliminated some of the mission requirements. However, the primary TSR 2 mission, of high-speed low-level attack in all weathers within Europe, has not changed and no better aeroplane than the TSR 2 has yet been introduced into RAF service for that particular rôle, while very large sums have been spent meanwhile to develop the Tornado, which will become operational in 1981. Only then will Britain have in service the "Canberra replacement" that GOR 339 began to define some 25 years ago, and TSR 2 was designed to be! □



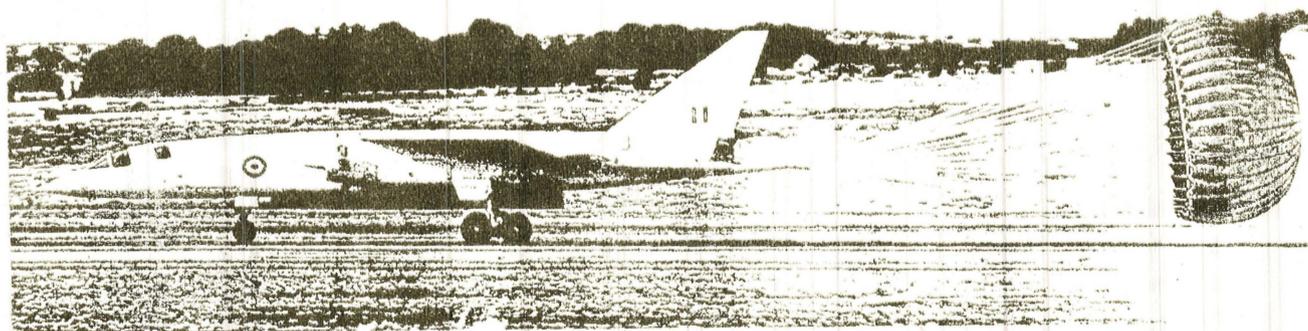
Air and ground perspectives of the TSR 2 during its flight testing at Boscombe Down. Of 24 flights, 14 were made from Boscombe, and the final 10 from the company's own base at Warton, near Preston, Lancs. Three pilots and three navigator/flight observers shared in the test flying.





Few military aircraft programmes launched in the years since the end of World War II have provoked greater controversy than the TSR 2. Conceived by British Aircraft Corporation to meet an operational requirement drawn up by the RAF in the late 'fifties, TSR 2 was put into production in 1960, successfully embarked upon its flight test programme in 1964 — and was then cancelled outright in April 1965. The politico-economic grounds for that cancellation remain a subject for debate to this day and there remains a body of opinion that believes not only that the TSR 2 was technically excellent but that it could still usefully serve Britain's operational needs for many years to come. Vigorous support for a "re-launch the TSR 2" campaign recently led the Secretary for Defence, Francis Pym, to examine the proposal; his conclusion was that such a project would be "dauntingly expensive" and that the TSR 2 "could not meet the threat". Whether that assessment is justified remains a matter for debate, but there is no denying that when the TSR 2 made its first flight on 27 September 1964 it was, by a very considerable margin, the most advanced and most complex military aeroplane ever built in Britain. In this article Graham Wilmer presents the first published full technical description of the TSR 2.

TSR 2: YESTERDAY'S ANSWER TO TOMORROW'S PROBLEM



THE TSR 2 had its origins in the need that developed during the 'fifties for the RAF to replace its front-line force of English Electric Canberras. They were employed primarily in the rôle of high-altitude bombers using free-fall "iron bombs", but by the mid 'fifties it was becoming clear that the advent of a new generation of supersonic fighters and the introduction of surface-to-air guided missiles would soon render such bombers obsolete. Thus was born the concept of the very low-level high-speed bomber that would be able to penetrate enemy defences "under the radar", and the RAF's requirement for such an aeroplane, as at first spelled out in General Operational Requirement (GOR) 339, was one of the few manned aircraft projects to survive the Sandys Defence White Paper in February 1959.

Wanted for operational introduction by the mid-'sixties, the aeroplane defined by GOR.339 was intended to allow the RAF to meet its commitments to SACEUR (Supreme Allied Commander Europe), but also would have to play its part in the wider context of Britain's (then) overseas treaty commitments. The evolution of GOR.339 into the specific OR 343 and the many steps in the evolution of the TSR 2 design from separate projects by Vickers-Armstrong at Weybridge (through its former Supermarine design team from South Marston) and English Electric at Warton is a complex story that has been told elsewhere* and is outside the scope of this particular account.

By the end of 1958, OR 343 had set the scene for the development of a two-seat aircraft that would almost represent a complete air force in a single airframe. Its key requirements were as follows:

- (i) Capability to attack targets up to the extended range specified.
- (ii) Fly the specified proportion of this range at very low level and high subsonic speed.
- (iii) Attain $M=2.0$ at the tropopause when required.
- (iv) Deliver nuclear or conventional weapons from low and medium altitude in poor visibility and at night.
- (v) Perform all-weather photo-reconnaissance.
- (vi) Capability of operation from small and dispersed airfields, with restricted maintenance facilities.
- (vii) No defensive armament required.
- (viii) Primary emphasis on low altitude penetration.
- (ix) Have best gust response characteristics consistent with airfield performance, to ensure maximum operating efficiency of crew members comprising pilot and navigator.
- (x) Carry maximum photographic and/or radar equip-

ment for reconnaissance without prejudice to the strike rôle.

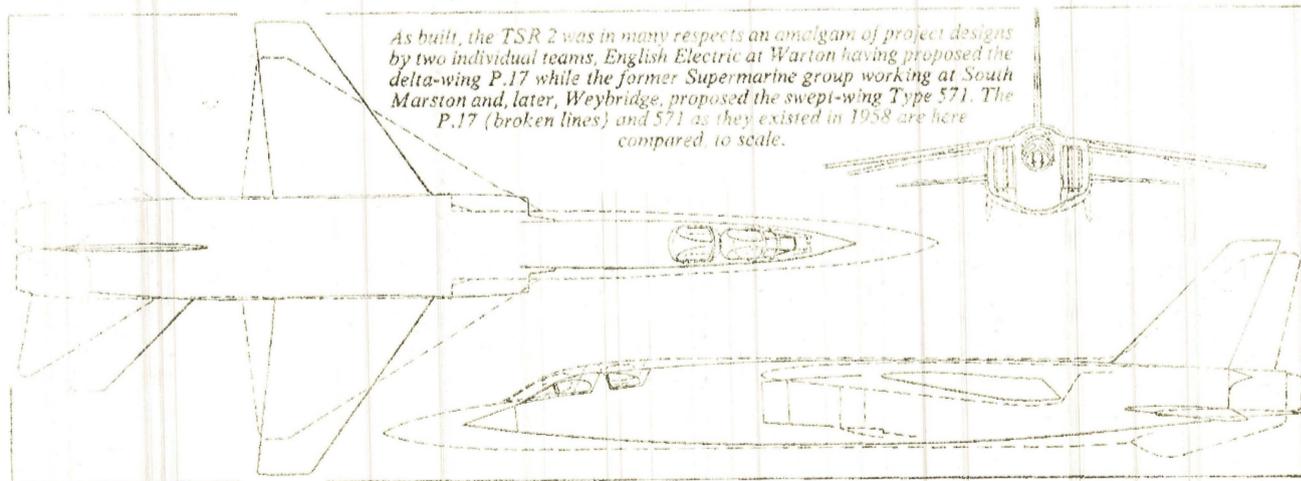
- (xi) Remain serviceable in the open with no servicing support for three days, and with a minimum of support for 30 days. General serviceability to be at a premium.
- (xii) To be weather proof in flight and suitable for global operation.
- (xiii) Windscreen to be capable of withstanding the impact of a 3-lb (1.4-kg) bird at 750 kts (1 390 km/h) EAS, and to be kept clear of rain and insect debris at all times.
- (xiv) Escape and survival capability essentially over the entire flight envelope of the aircraft.
- (xv) Protection against low pressure, high altitude and low temperatures, high acceleration forces, atomic flash and vibration.

Of the many projects considered by the RAF, that which eventually found most favour was the English Electric P.17, but many aspects of the Supermarine 571 also were found to be of special interest. Since this was the era of mergers in the aircraft industry, largely through the encouragement of the Ministry of Supply (which did not hesitate to threaten to withhold contracts from companies that did not conform to the official policy) it became politic for English Electric and Vickers-Armstrong (Aircraft) to accept a joint contract, which was announced on 1 January 1959. Thus were sown the seeds from which grew not only the TSR 2, but the British Aircraft Corporation itself, as a merger of those two companies together with Bristol Aircraft and Hunting Aircraft. The TSR 2 designation was adopted to indicate the "tactical strike-reconnaissance" rôle of the aircraft (no-one has ever explained what happened to TSR 1!).

The TSR designation was in fact something of an oversimplification for what was designed to be an all-weather deep-penetration strike aircraft that could be employed tactically or strategically, using both nuclear and conventional weapons, and provide a very high standard of reconnaissance information in all weathers by day and by night.

The philosophy behind TSR 2 was to exploit a combination of high speed and low altitude in order to gain every possible advantage from the difficulties an enemy would face in trying to provide effective defence under these conditions. In order to achieve operational flexibility, however, the aircraft was designed also to be able to cruise at $Mach=2$ plus, at medium and very high altitudes. Its tactical flexibility was greatly augmented by the ability to operate from very small airstrips having only rudimentary surfaces, and the ability to operate regardless of maintenance facilities. This, together with a long ferry range, enabled the aircraft to be deployed very quickly to almost anywhere in the world.

* See in particular, "Project Cancelled" by Derek Wood (Macdonald and Jane's, London 1975) and "Phoenix to Ashes" by Roland Beamont (William Kimber, 1968).



Summary History of English Electric P.17/TSR 2

October 1956	Preliminary work on Canberra Replacement begins.	September 1958	Quarter scale model to Bristol's.
November 1956	Preliminary performance investigation. Podded engines — leading to Rolls-Royce RB.134.	November 1958	OR 339 (third draft)
December 1956	First wind tunnel tests (low speed) on rough model.	Mid-November 1958	First joint discussion at technical level between EEC and VA at Weybridge
January 1957	Two Rolls-Royce RB.133 in fuselage. Straight wing.	December 1958	OR 339 (fourth draft).
January 1957	High-speed tunnel tests on trapezoidal half-wing.	December 1958	BSE Olympus engines chosen in lieu of RB.133/RB.134 proposed.
19 February 1957	Near final configuration. Two RB.133 engines.	January 1959	Parliamentary statement by Minister of Supply that VA and EEA were to undertake joint development of TSR 2.
February 1957	EEA Report P.103 entitled "Possibilities for a multi-purpose Canberra Replacement" (English Electric Project P.17).	February 1959	Joint VA/EEA design team formed at Weybridge.
March 1957	Issue of GOR 339 (1st draft to MCA).	March 1959	OR 343 (final draft).
May 1957	Eighth-scale full model (low speed) for tunnel tests.	Early April 1959	Design study contract to VA/EEA.
June 1957	High-speed tunnel tests on delta half-wing. P.17 project with larger engines.	Discussions begin.	
July 1957	OR 3044 issued (Navigation, Bombing and Reconnaissance and Flight Control System).	May 1959	OR 343 (first issue).
July 1957	OR 3596 issued (Line Scan Navigation and Reconnaissance System).	3 June 1959	Design study contract (covering period Jan 1959-Dec 1959).
August 1957	High-speed tunnel tests on 1/4th scale half model.	11 June 1959	Vickers purchase order on EEA (WX 6701).
September 1957	Issue of GOR 339 to Industry. Submissions invited from Blackburn and General Aircraft, Fairey Aviation, Bristol Aircraft, Handley Page, Short Bros, de Havilland Aircraft, Vickers-Armstrong, Hawker Siddeley Aviation and English Electric.	July 1959	VA/EEA Preliminary Brochure
October/November 1957	English Electric Co — Short Bros collaboration begins.	October 1959	EEA Team returned to Warton from Weybridge.
October 1957	First examination of Short P.17D VTO platform to launch P.17, and P.17 ventral take-off study.	11 March 1960	Draft Contract to VA from Ministry.
November 1957	Joint English Electric Co — Short Bros programme set up.	17 June 1960	Interim Design study contract (covering Jan 1960-Sept 1960).
November 1957	Half model — blown flaps.	22 June 1960	Vickers Purchase Order on EEA (WF 4043A).
December 1957	Short tests on P.17D.	Early August 1960	Draft Contract for nine development batch aircraft received.
January 1958	Brochure submitted to GOR 339.	August 1960	Specification RB 192D arrived in respect of TSR 2 development batch.
February 1958	OR 339 (first draft).	6 October 1960	Contract KD/2L/02/CB42(a) nine development batch aircraft (serials XR219-XR227).
March 1958	Report on the selection of firms.	14 November 1960	EEA internal contract issued (for first nine aircraft).
April 1958	OR 339 (issue 1).	24 November 1960	Vickers Purchase Order on EEA.
April 1958	Exchange of views between EEC and Vickers Armstrong on equipment.	2 February 1962	Firing of first free flight model at Aberporth.
June 1958	Final MOA assessment.	28 June 1963	Spinning model tests at Larkhill.
July 1958	High speed tunnel tests on 1/4th scale complete model.	20 March 1964	Contract KD/2L/13/CB42(a) for second batch (11 aircraft, serials XS660 to XS670).
July 1958	Quarter scale intake model to Rolls-Royce.	27 September 1964	Contract KD/2L/16/CB42(a) first full-production batch (30 aircraft, serials XS944 to XS954 and XS977 to XS995).
August 1958	New low speed model.	22 February 1965	First prototype first flight (Boscombe Down).
August 1958	OR 339 (second draft).	31 March 1965	First aircraft arrived at Warton from Boscombe Down.
		6 April 1965	Last flight of prototype, at Warton.
		4 June 1965	Announcement by Chancellor of Exchequer (J Callaghan) of cancellation of TSR 2 in "Budget speech".
		6 July 1965	Turning down of proposal to use TSR 2 for research work.
			Closure of TSR 2 contract.

TSR 2 had a remarkable radius of action: at its normal take-off weight (originally planned as 75,000 lb/34,020 kg) and using only internally carried fuel, it could fly a high-low-high subsonic/supersonic sortie to reach targets up to 1,000 naut miles (1,850 km) away from base, and with the addition of externally carried fuel this range could be doubled.

The need for accurate weapon delivery in the sort of weather conditions that might have been encountered over these long distances, coupled with the emphasis upon low level flight in the interest of surprise and invulnerability, demanded a very comprehensive navigation and attack system, and a very reliable flight control system. Both these systems are described in detail later, but, in general, the flight control system embodied an automatic terrain-following radar that would maintain the aircraft's height, selected at the pilot's discretion, down to 200 ft (61 m) above the ground at speeds of up to $M=0.9$. The navigation/attack system was based on a doppler/inertia mix, monitored by radar or visual fixes. The system could operate on either doppler or inertia alone, and the two together supplemented each other's operational characteristics, resulting in an accurate and flexible system.

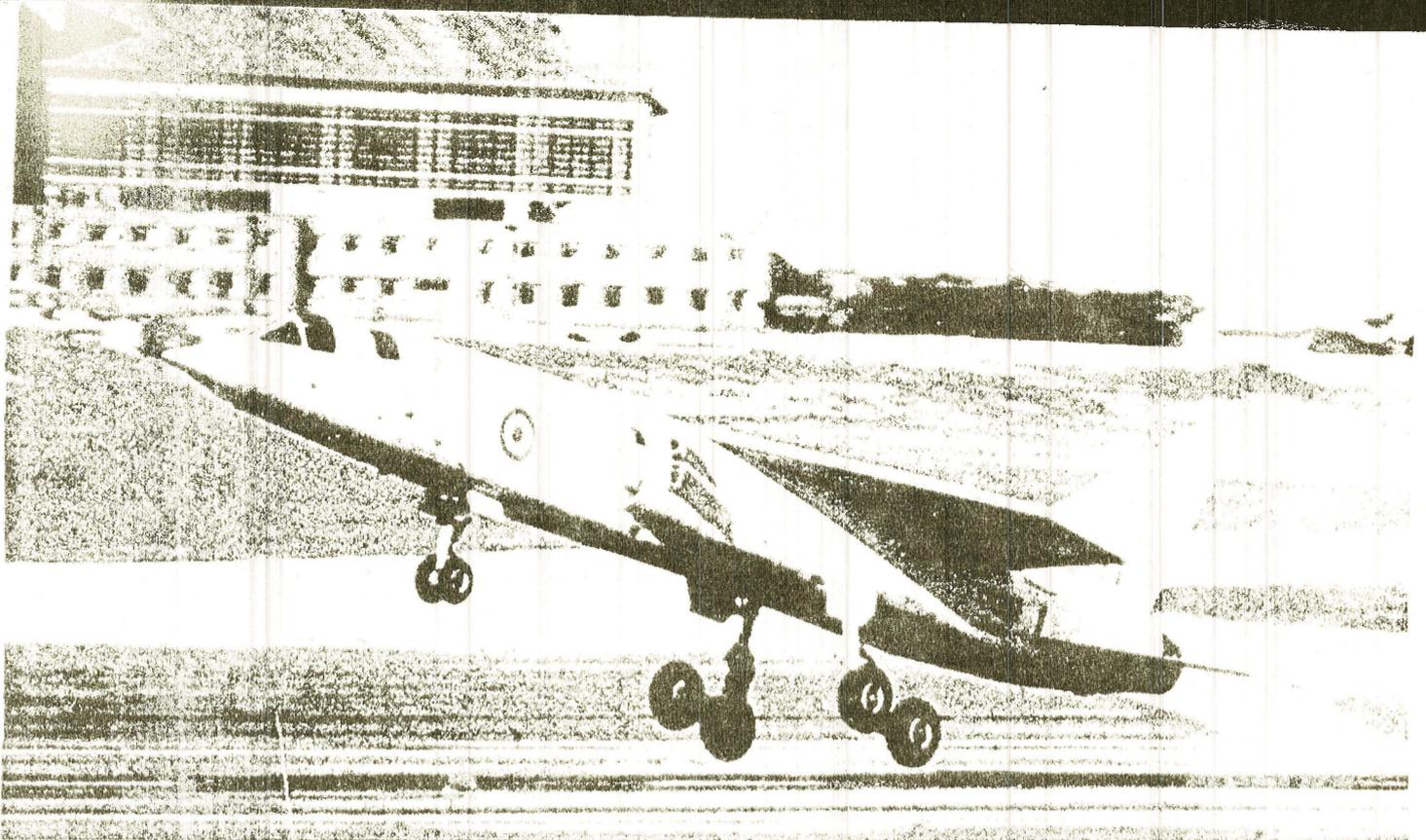
Radar fixes could be obtained from a sideways looking

radar, supplemented on occasions by a forward looking radar. The sideways looking radar presented its information on a rapid photographic process display. The computed fix position, derived from the doppler/inertia system, was automatically inserted into the radar picture. From this the navigator could quickly compare true and computed fix positions and any necessary error correction was automatically fed back to the navigation system.

Structural design

The structural form of TSR 2 was dictated largely by considerations of fatigue loadings and heating. Fatigue loadings in this case would have arisen mainly from manoeuvring at ground level at speeds between $M=0.8$ and $M=1.2$, especially during attack and terrain following. The design compromised on an 8g load factor for ground attack and a fatigue life in excess of 3,000 hours.

The problems caused by heating arose principally at the tropopause where the peak ram temperature would have reached 360 deg F and damage from "heat-soak" was most likely. The materials chosen for aeroplane construction therefore had to exhibit three main features: good fatigue



(Above) With full reheat thrust from its two Bristol Siddeley Olympus B.01.22R engines, the sole prototype of the TSR 2 to reach flight test status leaves the ground for the first time; the date, 27 September 1964; the place, the Aircraft and Armament Experimental Establishment at Boscombe Down, Wilts, where the aircraft is depicted (below) undergoing pre-flight preparation.

characteristics, no deterioration after exposure to high temperatures, and maximum structural efficiency at high temperature.

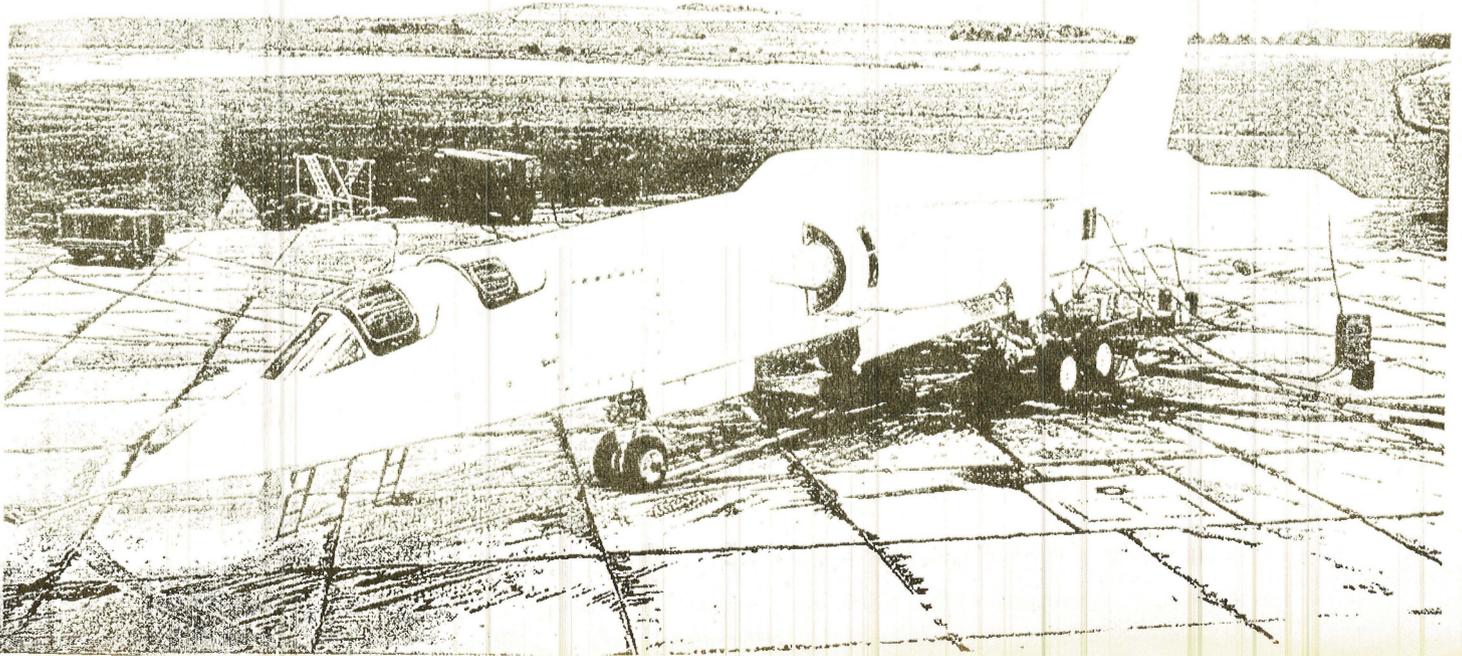
Aluminium alloys which have these characteristics are rich in copper and at the time of TSR 2 design the commonly used four per cent Cu family (DTD 5020, L71, RR58) were adequate for the job. In several areas however, the structure required a material that could cope with both excessive local loads and very high temperatures. The answer to this need was found in a new material that had just been developed called X2020, a high strength lithium-bearing alloy which showed great promise under test in that its strength was totally unaffected by high temperature.

Also timely for the TSR 2 development were a new range of vacuum-melted steels which could take loads of up to 270,000 psi (19,000 kg/cm²) and still remain ductile. Limited use was

also made of titanium, mainly for engine heat shields. The combination of these materials provided for all the known problem areas and allowed a wide margin for developing the aircraft beyond the specification.

In constructing the TSR 2 airframe, the techniques used were conventional and essentially "state of the art", in that they only slightly extended techniques used on other high-performance aircraft that had successfully met high temperature and fatigue problems. The structure was laid out in parallel with the design of both the systems and their installation, the aim being to minimise production costs and time spent on maintenance, but still come up with an efficient, light structure.

The fuselage, wing and tail surface skins were built up from machined planks which had stiffened surfaces and edges. Integral fuel tanks were built into the fuselage and wing; four



fuel tanks of approximately equal capacity in the fuselage, and one in the wing. The four fuselage tanks were situated in pairs at equal distance from the aircraft's centre of gravity which allowed a simple, duplicated fuel system to be used.

The forward fuselage, containing the crew and all the electronic equipment, was an open construction. All of the lower surface of the fuselage was also left open in order to give easy access to the longitudinal system runs. The doors and access panels which covered the lower structure were sealed against moisture, salt and sand. The upper part of the fuselage was basically a series of closed boxes which took the brunt of all torsional loads and gave good overall structural efficiency. They also provided housing for the fuel tanks and the engine tunnels. The engines were withdrawn through the rear of the aircraft so that the tunnels were free from large structural cut-outs.

The engine driven auxiliaries (described later) were mounted separately on a gearbox in a separate bay in the bottom of the fuselage. This gave good access and allowed the airframe services to be run without running the main engines. The engine tunnels had double skins with air flowing under pressure between them. This greatly reduced the fire risk as little engine heat reached the main structure.

Systems detail

As already mentioned, the fuel was carried in a wing tank and two pairs of fuselage tanks. Fuel balancing was maintained by using fuel from the forward and rear tanks simultaneously. The fuel pumps were situated inside the tanks and used high-pressure fuel as the driving medium. The engines would accept AVTAG, AVTUR-40, AVTUR-50, and AVCAT fuels.

The hydraulic system used DP47 (a fluid that operates happily under pressure at very high temperatures), pressurised to 4,000 psi (281 kg/cm²). There were four independent systems, two for general services (flaps, airbrakes, undercarriage and air intakes), and two for the flying controls. The two general services systems could feed the flying controls in the event of failure.

Electrical power was provided by two AC solid rotor alternators, both producing 30/55 kVA at 400 cycles per second. In the event of failure, either alternator would automatically supply the aircraft's total load demand. Each alternator was driven by a pneumatic/mechanical constant-speed drive unit, and a subsidiary supply with duplicated power sources provided DC power. Engine air tapped from the HP compressors cooled both crew compartments and the equipment bays. The cabins were pressurised to 5 psi (0.35 kg/cm²), and kept at an average temperature of 15 deg C, even under tropical conditions.

Terrain following

Survival in the sort of hostile environment the TSR 2 was designed to penetrate came down to one thing: Don't let the enemy's weapon system see you coming until you are on top of it. This would not prevent defence systems from operating, but by the time they had been activated the TSR 2 would be long gone. Most radar systems can see an aircraft coming at altitudes ranging from 75,000 ft (22 860 m) down to 1,000 ft (305 m), but at 200 ft (61 m) the effective range of weapon control radars is reduced to such a low value that adequate cover becomes prohibitively expensive.

The terrain following system designed for TSR 2 depended on a forward looking radar for its basic data. This was a monopulse radar having a double bar scan of U-form. The returns from the radar provided a computer with continuous information on the shape of the terrain ahead of the aircraft in terms of range and angle. From this data, the computer could determine the angle by which the aircraft flight path needed to be raised or lowered to follow the ground profile at a height selected by the pilot. As a simple analogy, imagine a stiff spring

extending forward from the aircraft and slightly convex on the side touching the ground. As the spring rides over the bumps in the ground, it raises and lowers the aircraft accordingly. The shape of this "spring", termed ski-toe locus, was defined within the forward looking radar.

As well as selecting the nominal flight altitude, the pilot could adjust the stiffness of the "spring" so that the system could be tuned for optimum performance according to the type of terrain being traversed and the roughness of ride tolerable by the crew.

Signals from the terrain following computer were fed to the automatic flight control computer and to the pilot's head-up display. The choice of either automatic or manual flight at low altitude was at the pilot's discretion. (Early experiments tended to show that the automatic system could always do better than the pilot. Later work however, proved that for periods of up to 10 minutes, the pilot was as good as the automatic system. After this, though, his performance would deteriorate rapidly due to fatigue.)

Navigation/Attack system

The basic navigation system for TSR 2 depended upon dead reckoning using vector information derived from the doppler and inertia sensors. These vectors were calculated by a navigation computer using heading data from the inertia platform, smoothed values of velocities from the doppler and the platform, and drift from the doppler. The system had two potential sources of error: heading errors due to the platform gyros drifting, and position errors due to the sum of small inaccuracies in velocity outputs, computing and input data. By taking fixes at intervals using a sideways looking radar, these errors could be continuously corrected.

The system could achieve blind delivery of a nuclear weapon accurate to within 100 ft (31 m), at ranges of more than 1,000 naut miles (1 850 km) from base using radar fixes every 100 naut miles (185 km) — the last being 30 naut miles (56 km) from the target.

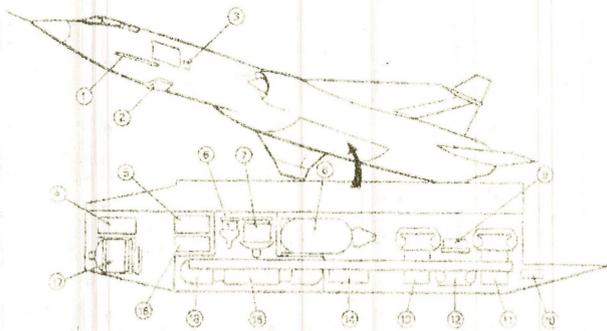
The forward looking radar was linked into the navigation, attack system and had several other modes when not being used for terrain following. The most important of these were: radar ranging for dive bombing and rocket attack, homing on flight refuelling tankers; ground mapping when approaching major radar targets or coastline; and a limited search capability over the sea or in areas where suitable radar targets could be found without excessive ground clutter.

In designing the system, particular attention was paid to finding methods of presenting information to the crew in a way that would not burden their concentration. Two examples of this were the pilot's head-up display and the navigator's sideways looking radar. The head-up display, in one of the first applications of this now commonly-used aid, presented information to the pilot by projecting figures on to the windscreens in front of him, collimated at infinity. The pilot could see both the terrain in front of him and essential flight information (including flight director). The sideways looking radar was devised to provide the navigator with a means of taking the highly accurate fixes which were essential in order to achieve the standard of navigation and weapon delivery demanded by the specification.

Reconnaissance system

The main reconnaissance system was carried in a bomb-bay pack and had to be carried as an alternative to any internal weapon load. This was not a disadvantage to the strike capability of the aircraft, however, as weapons of equal power could be carried externally mounted on wing stations. The pack contained equipment which could be changed according to the altitude at which the mission was going to be flown.

Reconnaissance equipment was also carried as a permanent fit in the forward part of the fuselage, giving the aircraft a



The contents of the TSR 2's reconnaissance pack (an optional installation in the weapon bay), are shown here diagrammatically. The numbered items are: 1, sideways looking nav radar; 2, retractable forward facing camera; 3, oblique cameras, port and starboard; 4, scanner supply and electronic units; 5, linescan power unit; 6, modulator; 7, power unit; 8, radar recorder; 9, camera control box; 10, radio link transmitter and aerial; 11, camera; 12, camera; 13, camera; 14, videotape recorder; 15, optical scanner unit; 16, recorder power unit; 17, radar TRU; 18, radar aerials.

reasonable reconnaissance capability in all configurations. This permanent equipment comprised three F.9 low-level cameras — one forward facing and two oblique — giving a coverage of 30 deg of arc each side of dead ahead, plus the X-band sideways looking navigation radar. This radar was capable of very high resolution and could provide reconnaissance information over a strip of country the width of which varied according to the aircraft's altitude. At 500 ft (153 m) for example, the coverage was 2.6 miles (4 km) each side, and at 40,000 ft (12 192 m) the coverage was 36.6 miles (59 km) each side.

The reconnaissance pack had three systems for recording information and was capable of transmitting information either instantaneously or at delayed intervals. For low level reconnaissance all three recording systems were used — radar, linescan and cameras. The radar was a "Q" band SLAR which "looked" through two 15-ft (4.6-m) aerials fitted longitudinally in the pack. Capable of picking out moving targets from 10,000 ft (3 050 m), the radar could transmit back to base a high resolution picture that also had latitude, longitude, track, height, drift angle and pitch information printed on it. The radar pictures were unaffected by weather conditions.

The linescan equipment was effective up to a height of 1,000 ft (305 m) and had a minimum resolution capable of picking up a single three-ton truck at night. The quality of its pictures were much improved when taken in daylight. The linescan's primary rôle was target mapping, and, like the radar, its information could be transmitted with interpretation data.

Photographic reconnaissance

The weapons bay pack contained three FX126 cameras in the rear compartment: two for medium altitude and one for low-level use. The two medium altitude cameras could be fitted with 24-in (63.5-cm) or 36-in (91-cm) lenses which gave a photographic scale of 1:10,000 from 20,000 ft (6 100 m) or 30,000 ft (9 145 m) respectively. The low altitude camera had a 6-in (15.2-cm) lens which gave a scale of 1:10,000 from a height of 5,000 ft (1 525 m). All three cameras were temperature controlled, and had both image movement compensation (IMC) and automatic exposure adjustment. Each contained 250-ft (76-m) of film in easily changed cassettes. The IMC and exposure intervals were controlled from the navigation system of the aircraft; a long track overlap of 60 per cent was provided and, for the two long-focus cameras, the across-track overlap was 10 per cent.

The film magazines were large enough to allow a 150 naut mile (278 km) strip to be covered 1.25 naut miles (1,175 km) wide from low altitude and 2.7 naut miles (5 km) wide from medium altitude. The latitude and longitude of the aircraft were marked on the edge of each camera exposure in binary

decimal form for automatic or visual read-out. When both the sideways looking reconnaissance radar and cameras were in use, the position of the camera shots was indicated on the radar data.

Communications

The internal and external communications facilities in TSR 2 were fully integrated. Both crew members had a single control unit which allowed either of them to operate all the radio equipment fitted. Communications with ground servicing personnel could be maintained up to the moment of wheels-rolling by means of pull-away couplings.

Long distance communication in an aircraft that spends most of its working life below radar levels is a problem that even today leaves room for improvement. However, like today's Tornado, TSR 2 was fitted with a single sideband HF radio that had a range of well over 1,000 naut miles (1 850 km), provided that the weather conditions were right. With a peak power output of 1 kW and more than 23,000 channels to choose from, the equipment was, to say the least, versatile.

TSR 2 was the second jet aircraft to make use of the then newly invented notch antenna, as part of its HF system, an idea developed in an attempt to overcome the drag penalties caused by traditional antennae. The problems associated with antenna drag had become more serious as aircraft had increased in speed. The drag of a wire antenna, for example, increases with the square of the aircraft velocity until it reaches $M = 0.6$, whereafter it increases at a much greater rate and the penalties on performance and range quickly became unacceptable.

Working on studies that began in 1950 at the RAE Farnborough, the design team at Weybridge came up with the notch aerial solution. The Farnborough studies had looked at the possibility of using parts of the airframe itself to act as an antenna. In one experiment, the port wing of a Halifax bomber had been fitted with a large tuned inductance. The coil induced radiating currents in the wing which in turn caused the wing itself to radiate. Although it worked, the system was too complicated and very costly.

Using this as a base to work from, however, the Weybridge team went one step farther and discovered that a notch cut into a wing, or in fact anywhere on an airframe, could be made to induce currents and radiate. The first operational notch antenna was fitted onto the Valiant, and the "suppressed antenna", as it became known, has since been fitted to almost every type of high speed aircraft. The system designed for Tornado is almost a direct copy of the TSR 2 equipment, the exception being that Tornado has a single HF notch antenna cut into its fin, whereas TSR 2 had two, one in each wing root.

Short range line-of-sight communications (up to 200 naut miles/370 km) was by means of a VHF/UHF radio transmitter/receiver. The set had 3,600 channels in the UHF, band working between 224 and 400 Mc/s, and 600 channels between 110 and 140 Mc/s. The navigator could select any of these channels, while the pilot had a choice of 20 pre-selected channels.

The crew stations

There has always been a tendency for aircraft cockpits to become increasingly complex with the passage of time. In each generation more systems have been added and existing equipment has become more versatile, and hence more demanding on the pilot. It is interesting that until recently, with the advent of TV-type CRT displays, this progression resulted in an increase in the number of controls and indicators regarded as being essential to the efficient operation of the aircraft.

The design philosophy used in TSR 2 was to employ two crew members within the systems control loop. The efficient use of a man within such a system pre-supposed that he would

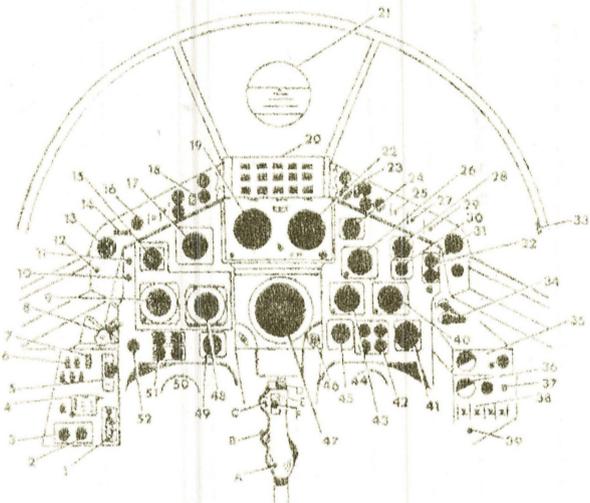
be left as free as possible to exercise his unique adaptive, sensitive and decisive functions. With this in mind, it was decided to relieve the crew members of as many purely monitoring tasks as was possible and to aim at a simple and efficient cockpit, allowing the maximum time for the all-important task of decision making. During the various development stages of the project however, it was often found necessary to compromise this aim in order to meet conflicting requirements.

The major requirements laid down in OR 343 directly applicable to the cockpit layout were limited to a definition of the pilot's display only. In essence, these requirements were:

(a) The essential flight instrumentation displays should be triplicated, in the form of:

- (i) Head-Up Display — collimated display through the windscreen.
- (ii) Head-Down Display — main instrument display on dashboard in front of pilot.
- (iii) Standby Display — a standby instrument display also on the pilot's dashboard in front of him.

(The head-up display and the head-down display had to show, in addition to general flight data, director and information data for manoeuvring, navigation, weapon aiming and



The pilot's (from) cockpit of the TSR 2 is shown in a detailed, full-scale mock-up (below right). The instruments can be identified by reference to the diagram (above) and the following keys: On the control column, A, column lock button; B, radio (press to transmit); C, auto-pilot cut-out; D, arm/safe switch; E, weapon release trigger (not depicted); F, four-way toggle switch trim control. Main instruments and controls, as listed below:

1 Flap position selector	27 Pull up warning — speed
2 Roll indicator	28 Aircraft skin temperature indicator
3 Yaw indicator	29 Pull up warning — altitude
4 Undercarriage indicator	30 Local altimeter
5 Undercarriage selector	31 Accelerometer
6 Nose leg selector	32 Oxygen contents/pressure selector
7 Emergency undercarriage selector	33 Back-up lighting
8 Parking brake lever	34 Rudder pedal adjuster
9 Standby horizon	35 ILS controls
10 Flap position indicator	36 Channel selector (UHF)
11 Flap blown pressure indicator	37 Aerial selector
12 Wing stores jettison incidence meter	38 UHF controls
14 Brake parachute jettison	39 Tone control
15 Air speed indicator	40 Thrust RPM, starboard engine
16 Parachute door selector	41 Turbine temperature (starboard)
17 Combined speed indicator	42 Intake cone/nozzle position
18 Close reheat switch (port)	43 Thrust RPM, port engine
19 Altitude display	44 Starboard rudder pedal
20 Centralised warning panel	45 Turbine temperature (port)
21 Head-up display (on windscreen)	46 Scale selector
22 Navigation display	47 Moving map display
23 Close reheat switch (starboard)	48 Standby altimeter
24 Radio altimeter	49 Rate of climb indicator
25 Pull up warning — direction	50 Port rudder pedal
26 Altimeter	51 Brake pressure indicator
	52 Air brake position

monitoring of the automatic flight control system.)

(b) Provision of a topographic display, fed from the navigation equipment, which gave the best computed position of the aircraft continuously.

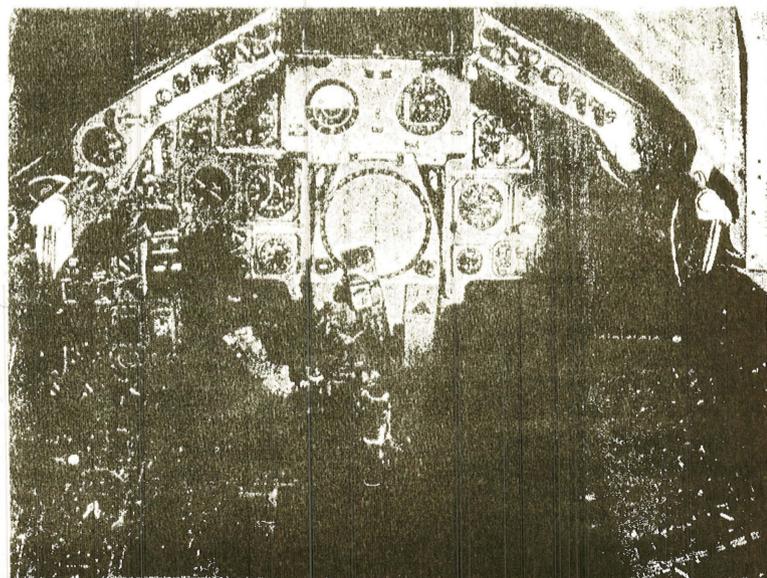
In designing the crew stations to meet the conditions of these requirements and allow the crew to work in comfort under difficult flight conditions, a multitude of influencing factors had to be sorted out into some sort of priority. A cockpit steering committee was set up to evaluate the problems and to control the ever-changing ideas which arose as the project progressed. The intention was that this steering committee should have the power to exercise decisions and change the design if necessary. In order to make such a committee work it was decided to limit its size to six members, comprising one from the Ministry of Aviation, one from the Ministry of Defence, one from A&AEE Boscombe Down, and three from BAC (the chief test pilot and two members of the design staff).

In common with so many of the good ideas behind the development of TSR 2, this simply did not work out, it just didn't happen as intended: key personnel from MOA and MOD were periodically changed during the development period because of their routine postings, and the numbers attending each meeting grew and grew until at times they reached sixty. The results were inevitable — too much time was wasted in explanation rather than assessment, and decision-making became almost impossible. What is perhaps remarkable is that despite the setbacks actually caused by the steering committee, the crew stations evolved reasonably quickly from the original mock-up stage to the definitive production aircraft and by the time the tenth aircraft design had been frozen, both crew stations were as good as they were ever going to be.

Although the instrumentation layout actually installed in the first aircraft differed considerably from the design of that for the 20th aircraft, fundamentally they were the same. What was certainly applicable to every aircraft in the two batches actually ordered were the design factors that influenced the geometry of the front section of the aircraft.

The specification called for two crew members but allowed a choice of seating arrangements, between tandem and the more sociable side-by-side seating. The advantage of the latter was that the crew would have direct physical contact, which would avoid the need for duplication of some of the instruments and displays. Also, for a given nose diameter, the view over the nose can be made slightly better.

On the other hand, given the basic aircraft configuration of a low aspect delta wing set well back on a slender compact fuselage, there were important aerodynamic advantages to be gained from tandem seating. For example, by doubling the cross sectional area to fit the crew side-by-side, the forebody and windscreen drag would have been increased three times, which would have added 20 per cent to the total profile drag of the aircraft.



Furthermore, in order to reduce the possibility of flow breakaway ahead of the intakes, the cross sectional area at the cockpit would have to have been retained as far back as the intake lips. This would have created a larger centre section, thereby increasing further the overall profile drag.

One more problem against sociable seating was that the space available for the navigator's displays and equipment would have been limited and the information at the time suggested that the equipment being proposed would simply not fit in the space available. The penalties associated with sociable seating were thus considered to outweigh its advantages and tandem seating was chosen.

The space required to accommodate the pilot and seat, allowing him functional control of the aircraft together with sufficient clearance for ejection in an emergency, imposed basic geometric criteria which did not prove to be a problem. The overall geometry definition was therefore essentially a question of the best possible compromise between the conflicting requirements of the pilot's view, electronic view, space provision for equipment and systems, and aerodynamic drag. For example, in order to ensure the minimum drag in the transonic region, the curve of the fuselage cross sectional area distribution had to be smooth and free from sudden changes in gradient; but three limiting points in this curve were the cross-sectional area at the nose radome, the pilot's cockpit and the intake position.

Nose geometry

The choice of a conical nose radome was largely dictated by the need for close electrical tolerances. At the time, the techniques used in manufacturing non-metal structures lagged behind developments in other materials. The choice of nose cone angle, however, was again a compromise between the requirements of electronic view for the forward looking radar, and ensuring that the cone could be constructed with, and maintain throughout its life, a minimum thickness all over. To satisfy the latter requirement, the problem of rain erosion had to be looked at, as any changes in the thickness of the radome outer surface would have caused adverse electronic effects. This meant the nose cone angle had to be at a minimum, but this minimum was dictated by the amount of radar refraction that was acceptable across the radome wall. The optimum angle turned out to be 30 per cent.

This restriction of angle meant, however, that the length of the cone itself became a direct function of the forward looking radar's dish dimensions; therefore, in order to achieve the minimum length for the sake of reduced drag and maximum pilot's view, the radar dish was kept to a diameter of 19 in (48

BAC TSR 2 Specification

(As at November 1962)

Power Plant: Two Bristol-Siddeley Olympus 22R Mk 320 twin-spool axial flow turbojets with water injection and variable reheat, rated at 19,600 lb st (8,898 kgp) dry and 30,610 lb st (13,897 kgp) with full reheat in ISA at sea level. Total usable internal fuel capacity, 5,588 Imp gal (25,400 l), comprising 1,474 Imp gal (6,700 l) in two wing tanks, 2,255 Imp gal (10,250 l) in two forward fuselage tanks, 1,900 Imp gal (8,637 l) in two aft fuselage tanks and 59 Imp gal (268 l) in forward and aft collector boxes. Provision for in-flight refuelling at 400 Imp gal (1,818 l) per min. Provision for 600 Imp gal (2,728 l) non-jettisonable ferry tank in weapons bay, two 450-imp gal (2,045 l) wing drop tanks and 1,000-imp gal (4,546 l) ventral drop tank.

Performance: Max cruising speeds, Mach = 0.9 to 1.1 at 200 ft (61 m), Mach = 2.05 above 36,000 ft (10,980 m), equivalent to a VNO of 725 kt (1,342 km/h) IAS; max design speed (VD) 800 kts (1,480 km/h)/Mach = 2.25; initial ratio of climb, over 50,000 ft/min (254 m/sec); max operating altitude, 54,000 ft (16,470 m); take-off ground roll (max take-off weight), 3,000 ft (915 m); landing ground roll (with brake parachute), 1,500 ft (457 m); radius of action with one 2,000 lb (908 kg) bomb externally, 1,150 mls (1,850 km) with 10 per cent at Mach = 1.7 above 40,000 ft (12,200 m) and 20 per cent at Mach = 0.9 at 200 ft (61 m), or 575 mls (925 km) at Mach = 2.0 at medium altitude or 800 mts (1,286 km) at Mach = 0.9 at 200 ft (61 m); radius of action with wing drop tanks, 1,725 mls (2,774 km); ferry range, up to 4,250 mls (6,850 km).

Weights: Normal take-off (1,150-ml/1,850 km sortie), 95,900 lb (43,539 kg); max take-off, 105,000 lb (47,670 kg); max landing, 57,200 lb (25,969 kg).

Dimensions: Span 37 ft 11 in (11,32 m), length, 86 ft 0 in (26,21 m); height, 23 ft 5 in (7,13 m); wing area, 700 sq ft (65,03 m²); sweepback at quarter chord, 50.8 deg; aspect ratio, 1.96:1; tip anhedral, 30 deg.

Armament: Internal weapons bay, 20 ft by 3 ft by 1.5 ft (6.1 m by 0.92 m by 0.46 m), carrying nuclear or six 1,000-lb (454-kg) HE bombs; four wing pylons, with provision for nuclear (inner pylons only) or up to four 1,000-lb (454-kg) HE bombs or four ASMs or four 37-rocket packs.

- 13 Pilot's canopy
- 14 Martin-Baker Mk 8A ejector seat
- 15 Ejection seat rocket pack
- 16 Tactical instrument displays
- 17 Navigator's canopy
- 18 Navigator's ejection seat
- 19 Oblique camera
- 20 Sideways looking radar
- 21 Stand-by pitot head
- 22 Avionics equipment bay
- 23 IFF antenna
- 24 Air conditioning system water separator

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DRAWING

BAC TSR.2 Cutaway Drawing Key

- 1 Pilot head
- 2 Radome
- 3 Radar scanner
- 4 Windscreen rain repelling ducts
- 5 ECM aerial
- 6 Forward looking, terrain following and attack radar
- 7 UHF aerial
- 8 Windscreen frame

- 9 Pilot's head-up display
- 10 Instrument panel shroud
- 11 Rudder controls
- 12 In-flight refuelling probe (stowed)

- 25 LOX storage converter
- 26 Fuel system piping

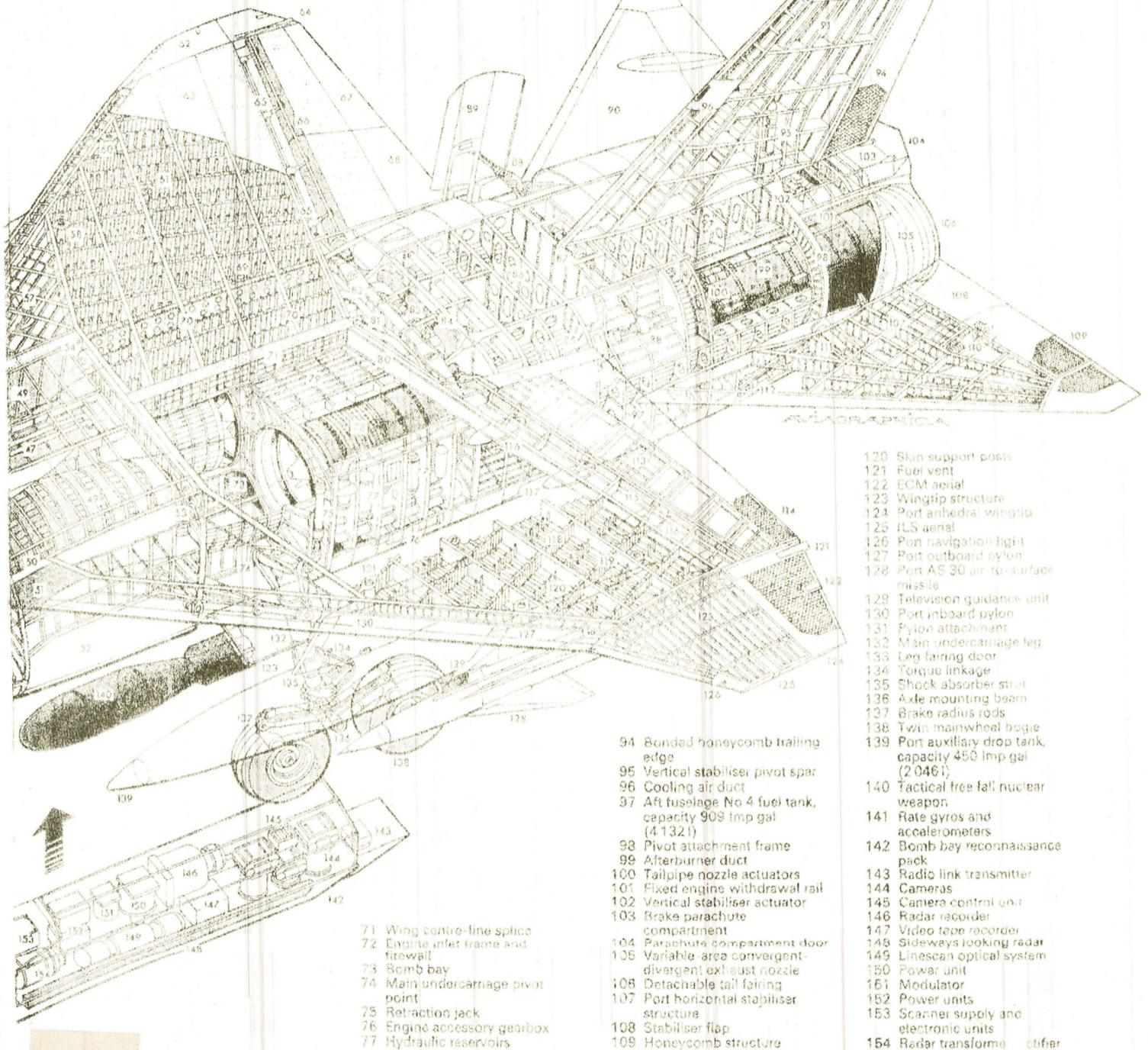
- 27 Forward fuselage No 1 fuel tank, capacity 1,132 Imp gal (5,148 l)
- 28 Nosewheel well
- 29 Nosewheel door
- 30 Extending nosewheel leg
- 31 Shock absorber strut
- 32 Twin nosewheels

- 37 Mainwheel extended position (take-off)
- 38 Flap blowing nosewheel doors
- 39 Doppler navigation aerial
- 40 Emergency generator
- 41 Air conditioning heat exchanger
- 42 Airborne auxiliary power unit (powered)
- 43 Intake movable centre body bell cone
- 44 Port engine intakes
- 45 Centre-body jack
- 46 Centre-body boundary layer bleed duct
- 47 Auxiliary air intakes
- 48 Intake duct fairing
- 49 Boundary layer spill ducts
- 50 Anti-collision light
- 51 Fuel tank access panels
- 52 Port engine intake
- 53 Forward fuselage No 2 fuel tank, capacity 1,023 imp gal (4 850 l)
- 54 Wing/fuselage leading edge spar attachment

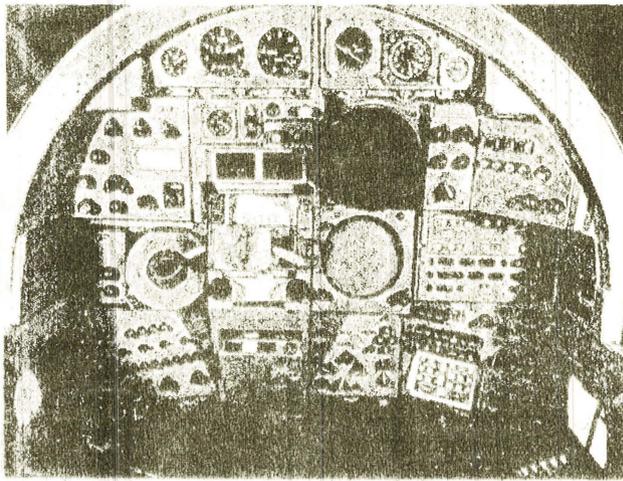
- 51 HF notch aerial
- 52 Main undercarriage doors
- 53 Wing/fuselage attachment frame forging
- 54 Front spar attachment
- 55 Leading edge structure
- 56 Starboard auxiliary drop tank, capacity 450 imp gal (2 046 l)
- 57 Fuel pipes in leading edge
- 58 Inboard pylon fitting
- 59 Starboard AS 30 air-to-ground missile
- 60 Outboard pylon fitting
- 61 Starboard wing integral fuel tank, capacity 737 imp gal (3 350 l)
- 62 Starboard anhedral wingtip
- 63 Machine skin panels
- 64 Fuel vent
- 65 Flap actuators
- 66 Flap blowing duct
- 67 Starboard outboard flap
- 68 Starboard inboard flap
- 69 Wing structure
- 70 Intermediate spars

- 78 Bristol Siddeley Olympus 22R turbojet
- 79 Water injection tank, capacity 80 imp gal (364 l)
- 80 Rear spar
- 81 Wing fuel system piping
- 82 Wing/fuselage aft attaching frame
- 83 Flap gearbox and hydraulic motors
- 84 Bleed air ducting
- 85 Engine tunnel duct
- 86 Aft fuselage No 3 fuel tank, capacity 991 imp gal (4 505 l)
- 87 Airbrake hydraulic motor
- 88 Airbrake screw-jack
- 89 Starboard upper airbrake (open)
- 90 Starboard horizontal stabiliser
- 91 Vertical stabiliser structure
- 92 UHF aerial
- 93 Rear navigation light

- 110 Stabiliser flap actuator
- 111 Pivot spar
- 112 Horizontal stabiliser actuator
- 113 Port flaps
- 114 Honeycomb trailing edge structure
- 115 Flap blowing air duct
- 116 Flap actuator fairings
- 117 Port lower airbrakes
- 118 Port wing integral fuel tank, capacity 737 imp gal (3 350 l)
- 119 Wing structure



- 120 Skin support posts
- 121 Fuel vent
- 122 ECM aerial
- 123 Wingtip structure
- 124 Port anhedral wingtip
- 125 ILS aerial
- 126 Port navigation light
- 127 Port outboard pylon
- 128 Port AS 30 air-to-surface missile
- 129 Television guidance unit
- 130 Port inboard pylon
- 131 Pylon attachment
- 132 Main undercarriage leg
- 133 Leg fairing door
- 134 Torque linkage
- 135 Shock absorber strut
- 136 Axle mounting beam
- 137 Brake radius rods
- 138 Twin mainwheel bogie
- 139 Port auxiliary drop tank, capacity 450 imp gal (2 046 l)
- 140 Tactical free fall nuclear weapon
- 141 Rate gyros and accelerometers
- 142 Bomb bay reconnaissance pack
- 143 Radio link transmitter
- 144 Cameras
- 145 Camera control unit
- 146 Radar recorder
- 147 Video tape recorder
- 148 Sideways looking radar
- 149 Lincscan optical system
- 150 Power unit
- 151 Modulator
- 152 Power units
- 153 Scanner supply and electronic units
- 154 Radar transformer



A mock-up of the observer's (rear) cockpit in the TSR 2, showing the tactical instrument displays, including the primary navigation instruments. Sideways-looking radar (SLAR) built into the forward fuselage was one of the primary nav aids.

cm). This compromise was well within the limits acceptable for the required radar performance.

The attitude of the nose cone again required compromise, this time between OR 343's requirement that the pilot must have a real downward view of 11 deg and the drag penalties associated with the various possible nose cone positions. The optimum conditions were finally achieved by positioning the nose cone so that its top line was co-incident with the pilot's line of sight.

The choice of windscreen was between a flat-fronted panel and a "vee" panel, and the final preference was for the flat fronted type, the decision being influenced by four major factors.

First, the rôle of the aircraft made it essential to delay the drag rise at all critical points up to a speed of $M = 0.95$. Drag data at the time was somewhat limited and, in some areas, conflicting. The general thought was that the "vee" windscreen had the lower drag rise of the two, but had much higher drag characteristics at the top end of the flight envelope. Secondly, the pilot would have to sit three inches lower down with the "vee" type, because of the required head/canopy clearance; this would restrict his downward view, relatively, by about three degrees. Thirdly, it was much easier to fair a flat windscreen into the fuselage and canopy; and finally, the "vee" type was more prone to the reflection of internal cockpit light from the windscreen panels.

As far as drag was concerned, a shallow windscreen angle was best, but this contradicted the requirement for good pilot view, particularly downward. In the end, the windscreen rose out of the fuselage at an angle of 35 deg to the vertical.

Several factors affected the internal geometry of the cockpits, the most difficult being the space provision and layout of equipment, systems and display panels. Predictions had to be based on very limited information, since proposed new equipment and systems were generally in a very early stage of development. This problem was made worse by the high installation density required. During later development, growth and complexity began to exceed the predictions, which gave rise to penalties in installation and functional layout.

Cockpit dimensions

The key geometry of the crew compartment was, as far as possible, made to conform to the recommendations of a study carried out by the Ministry of Aviation, which laid down a recommended cockpit layout for British Military aircraft. There were, however, four significant variations from this standard.

First, the angle between the back of the ejection seat and its

gun centreline was reduced, in order to reduce the acceleration load component normal to the pilot, and the front face of the headrest was moved aft to improve the pilot's sitting position.

Secondly, in order to achieve the required downward view for the pilot, the eye position was raised by 2 in (5 cm), reducing the recommended clearance between the pilot's head and the canopy by the same amount. This raised eye position allowed the pilot a much better view, especially during take-off and landing, and was used as the origin point to measure the pilot's downward sight line.

Thirdly, the dashboard depth (defined by the downward sight line and knee clearance requirements) was considered marginal. To obtain the maximum usable area for instrument displays, the dashboard was inclined forward until it became normal to the glare shield, and the lower edge was set as low as was possible.

Finally, the predicted control characteristics of the aircraft meant that plus/minus 2 in (5 cm) of rudder pedal travel would suffice, the recommended travel being plus/minus 4 in (10 cm). The adjustment of the pedals was limited to 5 in (13 cm).

The development phase of the aircraft, including flight assessments, proved that the internal geometry satisfied 98 per cent of pilot's body measurements.

Cockpit layout

Like the internal geometry, the cockpit layout chosen was basically conventional in its design. Early investigations had shown no significant advantages in departing from the standard type of controls. For example, a side stick control column was considered in an attempt to increase the pilot's view of the dashboard. This idea was abandoned mainly because of the limitations of single handed operation and need to use the essential side console space. Some doubts were also experienced on the aircraft handling characteristics with a side stick. Similarly, a cantilever mounted miniature centre stick was also discarded because it would have encroached an essential dashboard space. A further contributory factor to the layout design was the insistence by the Air Staff that flight instrumentation should be based on existing techniques as far as possible, in order to save time and money. This insistence ruled out BAC's idea for strip display instruments as a general feature.

The frontal display area facing the pilot was dominated by the requirement for three levels of essential flight instruments, together with the topographical display. The aim of the head-up display was to provide an image of essential flight instrumentation data, superimposed on the pilot's view of the outside world. As already mentioned, this was required to avoid the hazards associated with continuous re-orientation of the pilot's view from outside to inside the cockpit. This data was repeated in more detail on the primary instruments forming the head-down display — both being fed from the same source. OR 343 stipulated, however, that the aircraft must be able to continue its mission without loss of performance after a single failure — in which case parts of the standby display would need to be used.

It followed, therefore, that all three sets of display should be concentrated within what was known as the "gold plated space", comprising the central area of the dashboard and windscreen which fell within the primary visual scan of the pilot. However, the shape and size of the equipment and instruments that evolved precluded the achievement of this aim, particularly with the inclusion of the topographical display.

Numerous arrangements were studied to resolve this problem. A head-up display based on the reflector gunsight principle offered advantages in compactness, together with a stable and clear reflected display (due to an integral reflector). The disadvantage was that it dominated the "gold plated space", as the unit which projected the display onto the

screen had to be located forward of the dashboard. The cockpit designers became involved in a detailed and rather tedious tailoring exercise which, although finishing up with compromises such as the attitude and navigation display (to the requirements of OR 946) projecting almost 3 in (7.6 cm) from the dashboard, proved to be largely successful. It is likely, in any case, that had the TSR 2 continued, these problems would have been resolved completely.

The critical feature in designing both the left and right-hand consoles in the front cockpit was the installation density dictated by the internal geometry specification, together with a requirement for easy access and rapid servicing. The consoles were based on a continuous (fore and aft) open topped duct which carried all the electrical looms. The display panels and equipment boxes formed an assembly and were an integral part of the rigid box-like structure, but were independent and easily removed.

Originally, both consoles had angled tops to provide the maximum area for controls and the best viewing angles for the pilot. However, to utilise remaining console space effectively with the selected type of throttle assembly within the left-hand console (ie. incorporation of both throttles and their electrical transmitters as an integral and hence larger unit), the console top was made flat.

The depth of structure associated with the retractable flight refuelling probe, housed in the left-hand side of the nose fuselage, virtually excluded the use of the left sidewall for controls or displays. The rapid start panel, housed in the right-hand sidewall, was designed to concentrate in one area all the switches necessary for take-off in the operational rôle, including the master switches for all the systems under the pilot's control.

Power plants

TSR 2 was powered by two Bristol-Siddeley Olympus 22R engines, housed side-by-side in separate tunnels in the rear fuselage, each engine with its vertical centreline rotated through 21 deg. Each engine had a water injection system and variable reheat, which when used in conjunction produced around 30,600 lb (13,880 kg) of thrust at sea level and ISA + 20 deg C. The main features of the engine were two compound axial-flow compressors, two axial-flow single-stage turbines each driving one compressor, straight-flow flame-tube

combustion chambers, and a fully variable reheat system with a fixed shroud aerodynamic nozzle.

Both engines had three mounting attachments: a main thrust trunnion located at the top of the delivery casing, a locating spigot and spherical bush at the front of the engine, and a transverse strut for torsional restraint. Alternative left and right mounting attachment positions made the engines non-handed. The engine change unit, complete with jet pipe, could be installed from the rear of the airframe, after the rear engine fairing had been removed.

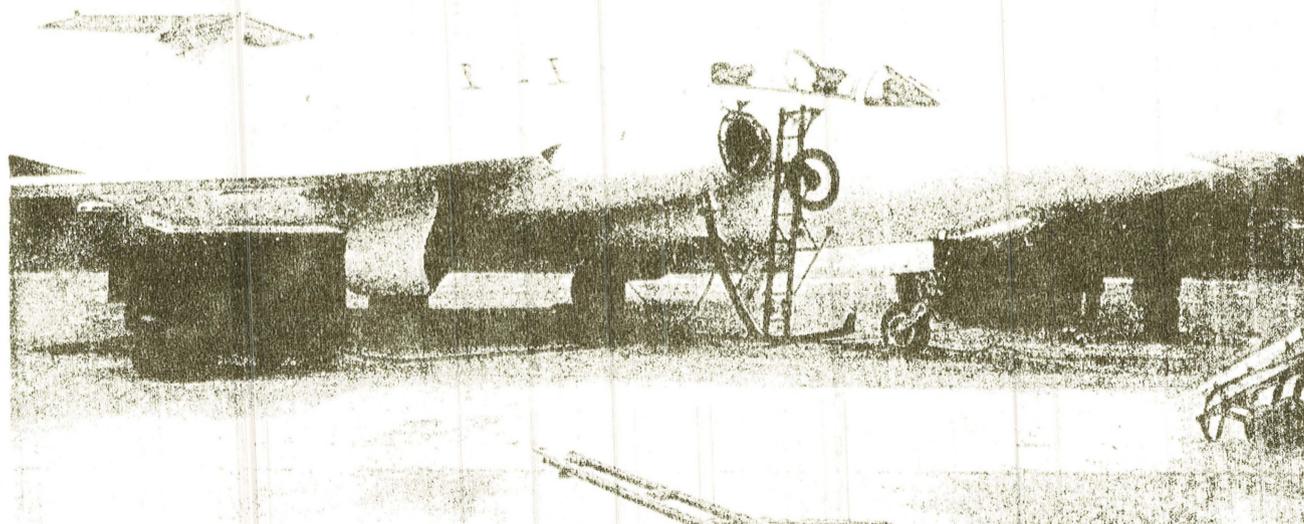
The engines were fed with air from the semi-circular intakes mounted on the side of the fuselage, forward of the wing leading edge. Each intake had a variable cone in its centre which controlled the speed at which air was presented to the low pressure compressors. Auxiliary intake doors, at the rear of the intake lips, provided additional intake area for low speed flight.

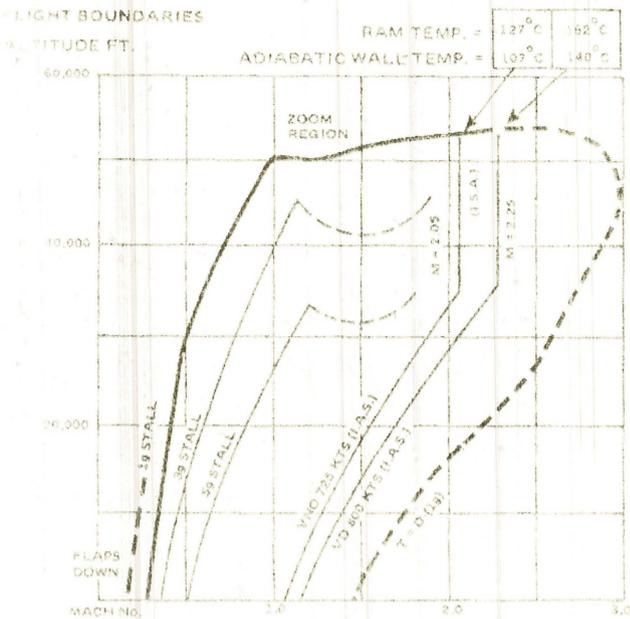
Each engine had an automatic electrical control, the normal system being AC, with a standby DC system. The control system provided a linear relationship between the pilot's throttle lever angle and the actual engine thrust, from flight idling to maximum thrust with full reheat. Both engines drove accessory gearboxes which could be de-clutched to allow the aircraft systems to be run on the ground. The accessories driven by the gearboxes included a constant speed drive starter, an alternator, two fuel/draulic motors and two hydraulic pumps.

The engines were situated in fireproof zones and the area around each engine was protected by detection and suppression equipment. Triple firewire would detect any increase in heat above normal and indicate to the pilot both visually and audibly that there was a fire. The pilot could then initiate various sequences of methyl bromide extinguishers according to the severity of the fire. In the event of a crash landing, the extinguishers would automatically go off, initiated by inertia switches, in order to prevent a fire starting, or an existing fire from spreading.

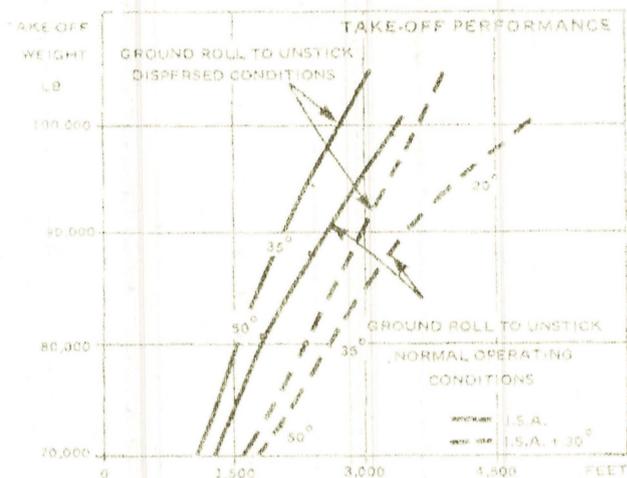
An airborne auxiliary power plant (AAPP) was stowed ventrally inside the fuselage just forward of the weapons bay. Whilst on the ground, the AAPP could be lowered by hydraulic jacks and, once started (by hydraulic motor fed from an accumulator in the aircraft), would provide low pressure air for engine starting, electrical power for the fuel pumps,

For development of the forward-looking radar associated with the Ferranti terrain-following system in the TSR 2, this Blackburn Buccaneer was fitted with the nose radar and operated from Edinburgh.





Although performance estimates for the TSR 2 changed in detail during the life of the project, these diagrams show representative data for (above) the flight envelope and (below) the take-off performance. (Unstick distances of 1,500 ft (457 m) or less could be achieved for 500-mi (805-km) missions.



throttles and inertia platform, ground running of the main engine gearboxes, and air conditioning for the crew stations and equipment bays.

Performance

The high reheated thrust required to meet the demanding take-off requirements gave TSR 2 large thrust margins at supersonic speeds. The use of reheat at altitude pushed the aircraft's maximum speed to well above Mach=2 according to atmospheric conditions. Since the structural limitations were more dependent on temperature than Mach number, the limit was that which corresponded to a ram temperature of 146 deg C. Thus, in a maximum temperature atmosphere, the operational top speed was limited to Mach=2.0, whereas in standard or minimum temperature atmosphere the top speed could be pushed up to Mach=2.16 and Mach=2.5 respectively. However, for the flight development phase, the first prototype of the TSR 2 was initially limited to a placard top speed of Mach=2.05. At low altitudes (down to 200 ft/61 m) the top speed was limited to 725 kts (1 343 km/h), equivalent to a sea level Mach number of 1.1. The aircraft was designed to

have a 10 per cent margin over these figures, giving a design maximum Mach number of 2.75.

At subsonic speeds, the limiting factor on manoeuvres was the maximum usable trimmed lift. With a delta wing, a clearly defined stall is unlikely so the limitations had to be determined by lesser considerations such as buffet. The limiting factor at supersonic speeds was the tailplane travel, which limited the available g. However, this did not present a problem as the limit was well above the g likely to be encountered.

The absolute thrust ceiling was about 56,000 ft (17 070 m) at supersonic speeds, the tailplane power being adequate to trim the aircraft at this altitude. For short periods it would have been possible to reach 70,000 ft (21 336 m) in a zoom climb by making use of the kinetic energy available at high supersonic speeds. The most economic ceiling for the aircraft was 55,000 ft (16 764 m), cruising at Mach=2.0.

To achieve the shortest possible unstick distance, blown flaps were used. Water injection was used to augment the thrust regardless of atmospheric temperature. A full flap configuration gave the minimum unstick distance, but this involved the inherent risk of a short delay before single-engine safety speed was achieved. Provided the specified balanced ground roll distance was available, a partial flap setting would therefore be used, to ensure full single-engine safety throughout the take-off.

A "no flare-out" landing technique was employed which, at the time of TSR 2 development, was a fairly new idea greatly reducing the length of runway required for landing as it allowed very precise touchdown points. Full blown flap was used during the approach and a large reefed parachute was streamed at touchdown, greatly reducing the ground roll.

A basic sortie was devised to contain all the main performance parameters considered desirable in a tactical system for the mid-'sixties. Any aircraft capable of meeting this basic sortie obviously would have been able to fly a wide variety of different sorties according to the demands of varying tactical situations — each one of these sortie variants producing a significant radius of action.

Details of the basic sortie and some alternatives are shown in the accompanying diagrams; at the same take-off weight, a sortie could be flown at 200 ft (61 m) over a total distance of 1,400 naut miles (2 253 km), or a high altitude sortie could be flown at Mach=2 over a total distance of 1,100 naut miles (1 770 km). All of these sorties could be flown without the use of externally carried fuel.

Nuclear weapon delivery

In a tactical nuclear rôle, TSR 2 would have delivered its weapon in an automatically-programmed forward loft manoeuvre. The bomb would have been released after the aircraft had pulled up from the 200-ft (61-m) terrain following mode and reached a height of 1,840 ft (561 m). Using a chandelle escape manoeuvre, the aircraft would have continued to climb until it reached 10,600 ft (3 230 m). By using this method of attack, the aircraft would have been immune even to short reaction time ground-to-air defence systems, such as possible enemy equivalents to Mauler and PT.428, since the bomb burst would have destroyed the defence radar before the missiles could reach the aircraft.

In a strategic nuclear rôle, however, the targets to be attacked were expected to have been protected by considerable numbers of this type of defence system. Under these conditions it would have been unsafe to go above the 200-ft (61-m) terrain following height. For this reason, the lay-down technique would have been used. The TSR 2 would have remained at 200 ft (61 m) throughout the attack and released a lay-down bomb which would have exploded when the aircraft had reached a safe distance. At the time, a British lay-down weapon was being developed to meet the RAF requirement OR 1177. TSR 2 would have been able to carry up to four

... of the low-yield version of this weapon within its ... bay, but had it entered service, it was more likely that ... of the high yield version would have been carried.

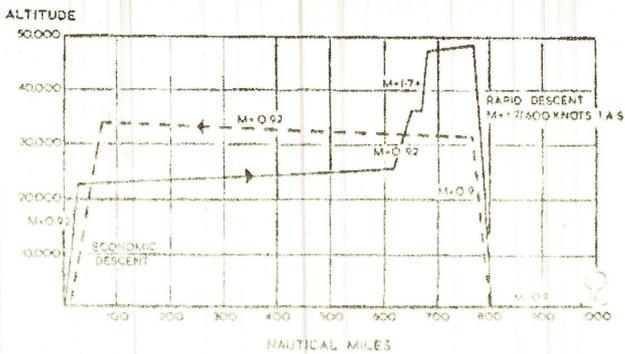
The use of a stand-off missile to avoid the need for an aircraft to penetrate to the target itself, with the possibility of exposing the crew to the effects of previous nuclear explosions, also permitted the use of the air-burst technique, was also studied in conjunction with TSR 2. The Blue Water missile was under development as a tactical surface-to-surface nuclear weapon system until August 1962, (up to which date a total of £16.6 million had been spent on its development). By fitting Blue Water with a megaton warhead and carrying one under each wing of TSR 2, a very economic strategic weapon system could have been achieved. Blue Water had an entirely self-contained inertial guided system which in combination with the precise navigation system already fitted to TSR 2 would have eliminated the need for star tracking or other additional sensing equipment, making the weapon system all-weather and immune to ECM.

Blue Water was originally conceived as a vehicle-transported inertia guided nuclear weapon for the Army. It was propelled by a two-stage solid fuel rocket motor and was capable of use within 10 minutes of being brought to the ground launch point. The proposed air-launched weapon itself used a very high proportion of Blue Water techniques and components, and required only minor modifications to the aircraft. The complete weapon system could therefore have been realised in an attractively short time-scale for relatively modest expenditure.

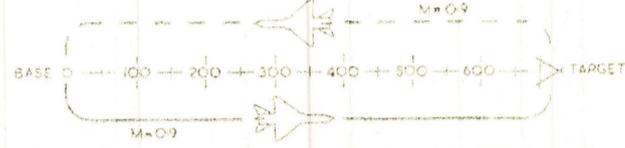
For the air-launched use as a strategic deterrent a number of modifications were required. Firstly, the warhead needed increasing to megaton size. Some structural strengthening and additional thermal insulation was necessary to meet the aircraft environment. Modifications to the guidance and fusing systems were also needed but none of these changes was of a fundamental or major nature. Cooling equipment would have been required to condition the missile guidance system. Preliminary studies proposed an evaporative total-loss Freon 12 refrigeration system, built into the missile pylon and requiring less than one pint (about 0.51) of Freon 12. With a 1,000-lb (454 kg) warhead, the airborne Blue Water had an estimated launch weight of 5,600 lb (2,540 kg) and was 31 ft (9.45 m) in length.

In the Army application of Blue Water, the tangent angle at release was standardised at 50 deg. To meet the same angle the aircraft would have been required to pull up to this angle in an approximately 4g manoeuvre, release the missile and then perform a chandelle manoeuvre to escape to the terrain following altitude. This would have resulted in unnecessary exposure to ground defences, so it was proposed instead to release the missile in horizontal flight at 200 ft (61 m) and to require the missile to turn itself into the required flight angle by the normal operation of the missile navigation system, accepting a range penalty of about 4 mls (6 km) as a result. The

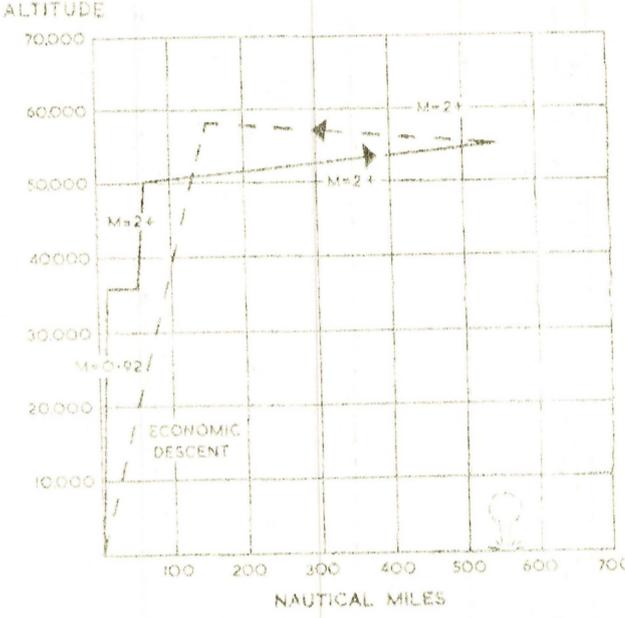
(Right) With ventral and underwing drop tanks, the TSR 2 could strike a target at a distance of 1,480 naut mls (2,740 km) from base. (Below) A range of 2,120 naut mls (3,930 km) could be achieved with the help of drop tanks and one refuelling from a TSR 2 buddy tanker.



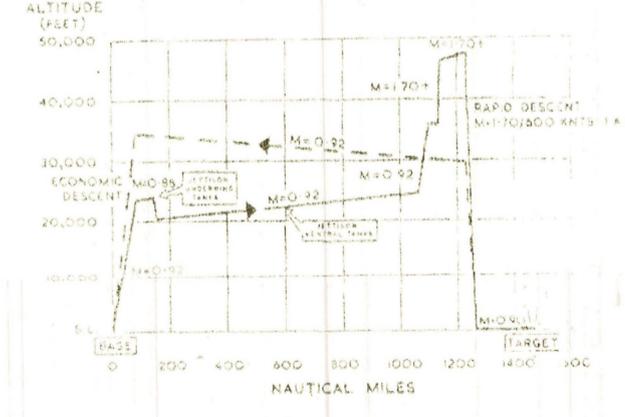
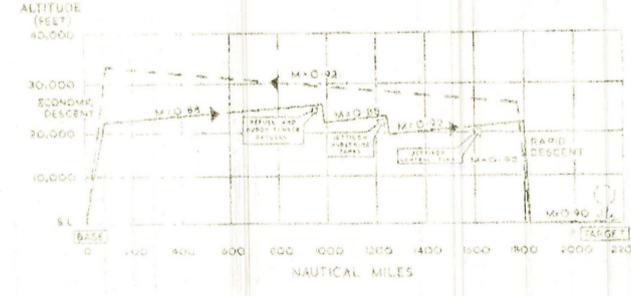
(Above) The "basic sortie" devised for the TSR 2 is shown here diagrammatically. It included high altitude subsonic cruise to and from the target, with a very high-altitude supersonic dash to penetrate the enemy borders and a very low-level run in to the target at high subsonic speed.

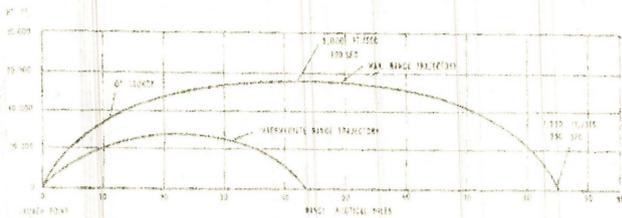


(Above) The performance capability that allowed the TSR 2 to perform its basic sortie allowed it to perform numerous other sorties, such as this all low-level, subsonic attack on a target 700 naut mls (1,300 km) from base.

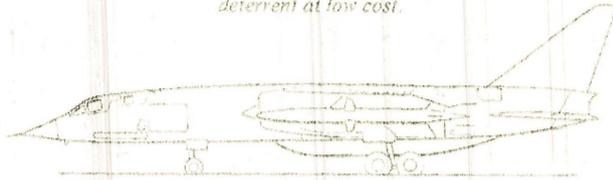


(Above) Another optional TSR 2 sortie, in which a target at a distance of 550 naut mls (1,020 km) could be attacked at supersonic speed from high altitude.





While the TSR 2 was still being developed, its use was projected to carry two modified Blue Water IRBMs, to produce a nuclear strategic deterrent at low cost.



TSR 2 would have been required to take-off at a weight of 120,800 lb (54 800 kg) with the two missiles carried plus belly fuel tank.

The TSR 2 system philosophy

A single team monitored the design and development of the complete TSR 2 system for the manufacturers from the time that work began in 1957. This enabled a consistent approach to be maintained on the compromise between weapon system performance and cost, and, with progressive studies on engineering feasibility, led rationally to the detail design development stage. Performance was built up from considerations of the airframe/equipment/weapon performances under ideal conditions and the losses of performance due to vulnerability, accidents or unserviceability. Detail numbers produced by such work were unlikely to be accurate, but the work as a whole provided valuable guidance to studies of feasibility and to the essential decisions day by day on which progress depended.

Flexibility was considered essential: high performance was required over a wide band of conditions. The aircraft configuration evolved on such grounds. The high level of thrust with a highly-developed low-speed wing configuration, in combination with low pressure tyres, were chosen in part because the aircraft thus became inherently suitable for overloading. Wing and engine were chosen to give good performance, both subsonic and supersonic. In addition to the required rôles of operation, studies continued on further applications and on the blind delivery of high explosive. This allowed design solutions to be adopted which favoured the

basic rôles while permitting eventual development with little modification.

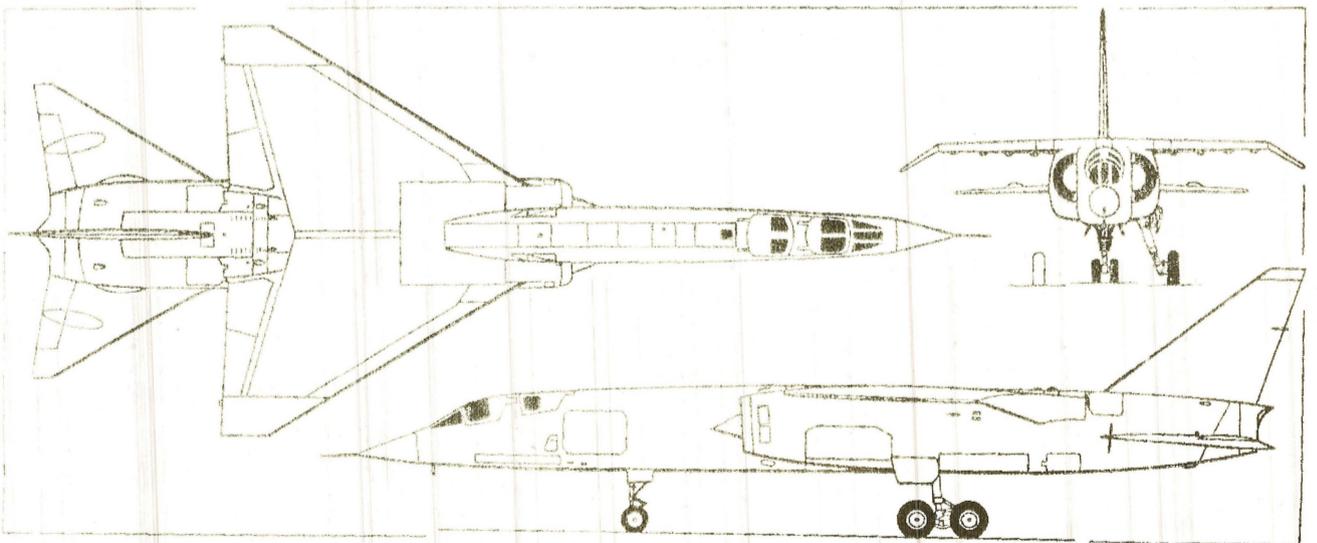
The terms of the requirement were developed in greater detail in parallel with design work. This process continued right up to the time of cancellation, when work was being concentrated on detail interpretations of requirements, concerning, for example, the exact conditions to be met after a double engine failure.

In the early stages, particularly late 1957 and early 1958, attention was given to a small, light, expendable weapon system, based on a lower range/take-off vehicle performance than was later required. A larger, high performance aircraft had been studied in parallel and it was eventually agreed that this second alternative would be preferable. Very briefly, this was seen to result in fewer systems but each of these would have had greater flexibility. They would be highly mobile and operate from rudimentary airstrips in a variety of rôles without massive ground support facilities. The overall result was increased operational freedom.

A major problem faced at this time was the need to achieve accuracies beyond the scope of manual operation of aircraft and systems, coupled with the need to reduce the crew work load. Automatic operation of some sub-systems provided the answer, but these had to be made completely safe without reliance on complex checkout equipment. For example, the bombing and terrain following systems were high authority systems and capable of breaking the aircraft after a failure unless this possibility was designed out of them. Reliability and a self-checking ability had to be built in. Some aircrew assistance would be involved in the checking process and, by design, this was extended to the point where the systems could be operated and controlled even after failures. Detail work and examination of existing and proposed systems supported this approach.

The results of these efforts became apparent in many areas. Squadrons of what were then current and next generation aircraft, required support by ground test equipment. Separate and quite complex checkout equipment was required in some cases even for daily inspections, for testing the hydraulics system, the fuel system, cooling and conditioning systems. Before electronic or airframe equipment could be tested, an equivalent to the aircraft power source had to be available. Moreover, in the case of TSR 2, this had to be provided and maintained at operational readiness for 30 days entirely in the open. After considerable study of the problem it was decided to carry a subsidiary prime mover which would solve this problem and also provide self-contained engine starting. All

The TSR 2 first prototype is depicted here in the form in which it was flight-tested during 1964/65.



...ment was effectively carried in the airframe, without ... increase in airframe complexity or weight.

The same approach was followed during the development of ... system. Unrestricted operation and high ... was available when the system was fully serviceable. ... safe operation was possible after single failures, but the ... of usage, accuracy, or simplicity of usage were restricted. Second failures were safe where the operation, after a single failure, was likely to be continued. An example of this philosophy can be given in the case of the fuel system: Four nearly equal capacity fuselage tanks were used, and these were drained by four double-ended pumps that catered fully for the complete flight envelope including negative g flight. These pumps were arranged so that, without crew action or any complex electronic system, the loss of one pump had no effect on availability of fuel or fuel balance. After this failure, limitations would only arise when the fuel state was less than that normally remaining on landing. In this case, while normal full thrust was still usable, the pilot had to retrim fuel before using reheat.

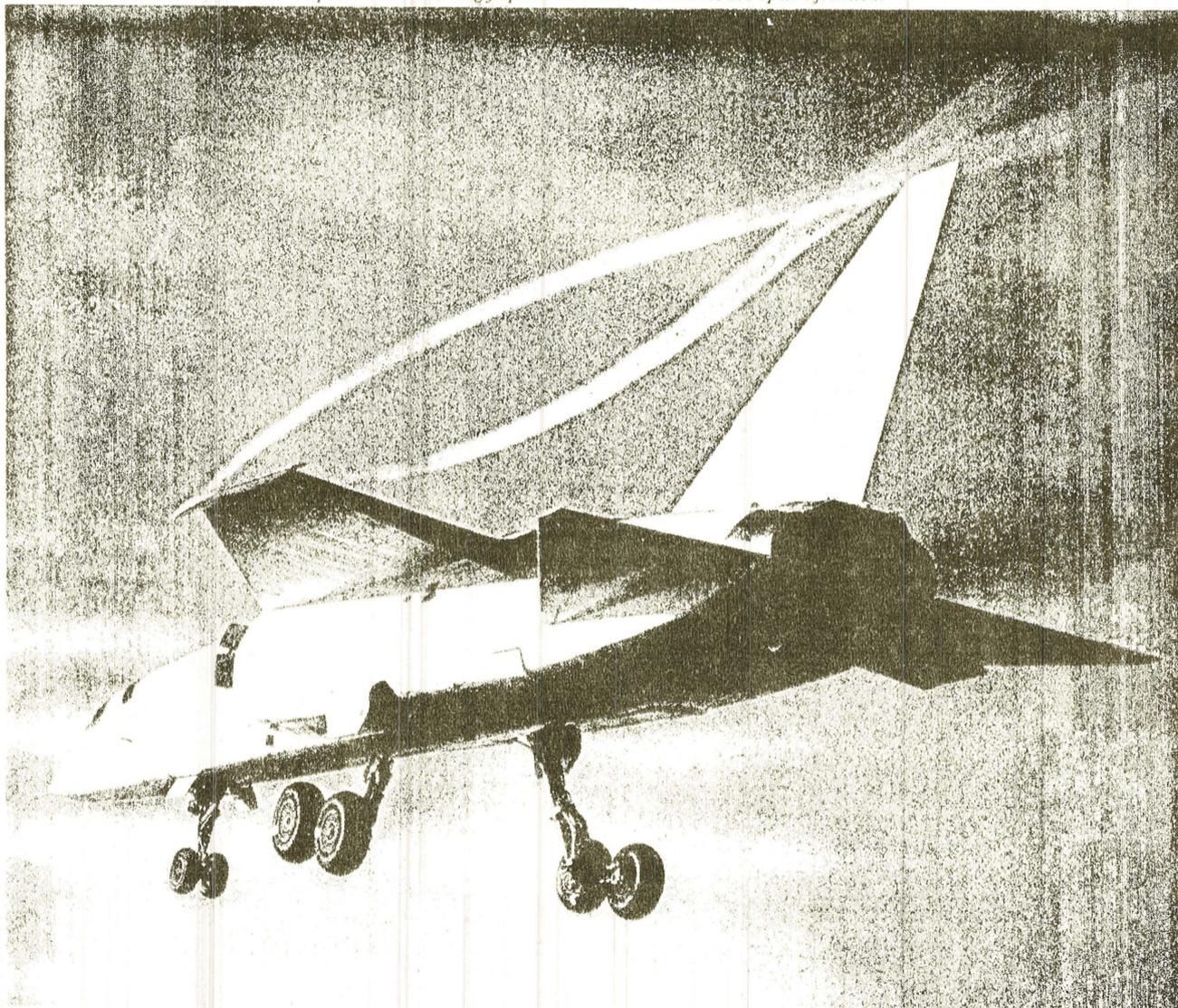
In a similar fashion, the hydraulic and cooling systems were split to provide restricted operation under conditions of failure when service aircraft normally return immediately to base. Very little additional complication or weight was involved.

As has been mentioned, the Navigation/Attack System was

TSR 2 FLIGHT TEST LOG

Flight Date	Duration (minutes)	Pilot	Crew	Navigator
1 27 Sep 64	14	R P Beamont		D J Bowen
2 31 Dec 64	14	R P Beamont		D J Bowen
3 2 Jan 65	8	R P Beamont		D J Bowen
4 8 Jan 65	20	R P Beamont		D J Bowen
5 14 Jan 65	22	R P Beamont		D J Bowen
6 15 Jan 65	24	J L Dell		D J Bowen
7 22 Jan 65	28	R P Beamont	P Moneyppenny	
8 23 Jan 65	27	J L Dell		P Moneyppenny
9 27 Jan 65	22	R P Beamont		D J Bowen
10 6 Feb 65	29	R P Beamont		D J Bowen
11 8 Feb 65	38	J L Dell		P Moneyppenny
12 10 Feb 65	36	D M Knight		P Moneyppenny
13 16 Feb 65	45	J Dell		D J Bowen
14 22 Feb 65	41	R P Beamont		P Moneyppenny
15 26 Feb 65	70	J Dell		P Moneyppenny
16 26 Feb 65	47	R P Beamont		P Moneyppenny
17 8 Mar 65	52	J Dell		B McCann
18 8 Mar 65	35	J Dell		B McCann
19 11 Mar 65	33	J Dell		B McCann
20 12 Mar 65	46	J Dell		P Moneyppenny
21 26 Mar 65	33	J Dell		B McCann
22 26 Mar 65	35	J Dell		B McCann
23 27 Mar 65	34	D M Knight		P Moneyppenny
24 31 Mar 65	32	J Dell		B McCann

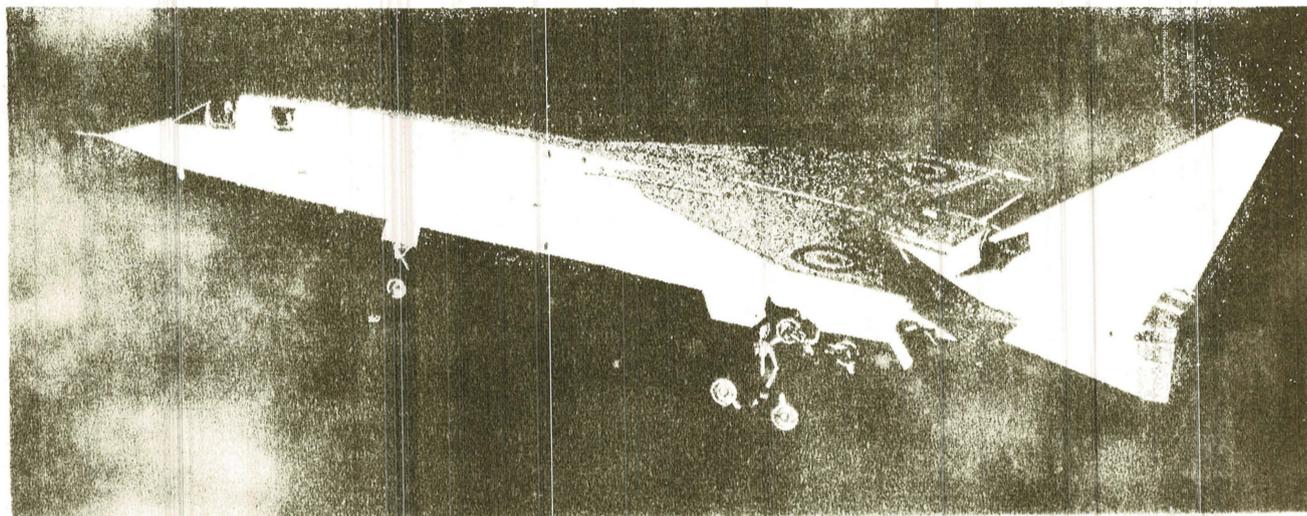
On the final approach to land at the end of one of its early test flights, the TSR 2 produces visible vortices from the leading and trailing edges of the wing tips. In this view, wing flaps are down and air brakes are open a fraction.



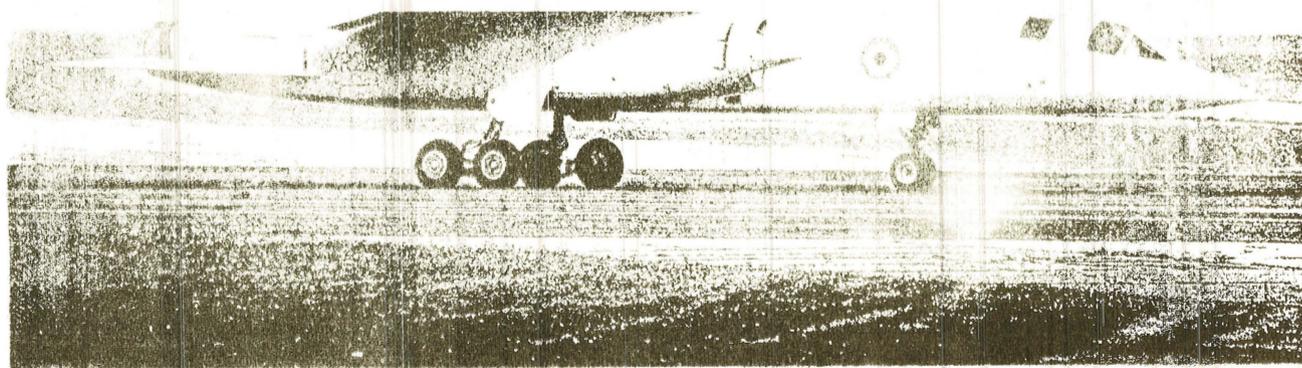
based on doppler/inertia mixing and operation in a emergency mode was possible after a single failure. Similarly, the central computer was formed from two identical digital computers, one being used broadly, for bombing and the other for navigation. Either could do the other's tasks, and the basic navigation data was stored in both computers at all times. Thus, failure of the navigation computer would not cause loss of "present position" or steering information. The fundamental aim throughout was to arrive at — and consistently maintain — the best compromise between maximum performance and flexibility and minimum cost, compatible with the given timescale.

On 27 September 1964, the first of the TSR 2s made its initial flight at Boscombe Down, in the hands of R P Beamont with D J Bowen as flight observer in the second cockpit. It was a year later than originally intended and was the first of 20 flights made by this aircraft, destined to be the only one of its type actually to fly. When the axe fell, the second aircraft was complete and close to first flight and all seven others of the initial development batch were in various stages of completion. Additional contracts had been placed in 1963 and 1964 for 11 and 30 aircraft, respectively, so that a total of 50 TSR 2s had been ordered at the time the aircraft was cancelled and it had assumed the status of the largest military programme in Britain.

Not unnaturally, so complex a new aircraft suffered a goodly share of teething problems, notably in respect of the undercarriage and of the engines, the slow development of which had been in part responsible for the 12-month slippage in first flight date. Nevertheless, in the space of only 20 flights totalling less than 11 hrs of airborne time, substantial progress was made towards solving these problems and enough was achieved to leave little doubt that TSR 2 would be well able to accomplish the tasks that were required of it. Whether or not its cancellation was justified remains, as said in the introduction to this account, a subject for debate, and many remain eager to argue the case, both for and against. Certainly there was much evidence that the programme costs were getting out of control, and the changes in Britain's overseas defence commitments in 1965, under the Labour Government elected the year before, eliminated some of the mission requirements. However, the primary TSR 2 mission, of high-speed low-level attack in all weathers within Europe, has not changed and no better aeroplane than the TSR 2 has yet been introduced into RAF service for that particular rôle, while very large sums have been spent meanwhile to develop the Tornado, which will become operational in 1981. Only then will Britain have in service the "Canberra replacement" that GOR 339 began to define some 25 years ago, and TSR 2 was designed to be! □



Air and ground perspectives of the TSR 2 during its flight testing at Boscombe Down. Of 24 flights, 14 were made from Boscombe, and the final 10 from the company's own base at Warton, near Preston, Lancs. Three pilots and three navigator/flight observers shared in the test flying.





TSR-2

BORN TO BOMB

It was the crowning moment in a career spanning many years, starting with an Avro 504 and going on to win RAF wings on Hawker Harts, fight with Hurricanes in France, play the central role in preventing cancellation of the Typhoon, leading the flight that shot down 638 flying bombs with Tempests and then making the first flight of the Canberra, P.1 and Lightning.

Now, Bee Beamont's left hand moved firmly forward unleashing the two most powerful jet engines ever made in Britain. They were at the other end of the needle-nosed TSR.2, almost 90 feet behind him.

Bee had much on his mind. TSR.2 had been born at a time when the British government had proclaimed the unbelievable doctrine that the Royal Air Force would never again need any more manned fighters or bombers! It had been created by a mixture of companies who had been thrown

together forcibly, and it was being flown at an airfield that did not belong to any of them, after months of wrangling by armies of committees and officials.

Britain had just elected a new government which openly campaigned against TSR.2, and – aided by a hostile media, who had taken on board all the “hate-TSR.2” propaganda – was trying to kill off the programme along with virtually all other new British aircraft.

Risk of engine explosion

To cap it all, at the last moment one of the mighty Olympus engines had exploded during testing, and though the cause was known this had added a very real element of danger to the first flight. If an engine were to explode on this first takeoff it would destroy not only XR219, the first prototype, but the entire programme as well.

Today, considering that the

RAF has been for so many years firmly of the opinion that “The only replacement for the Buccaneer is another Buccaneer, but with modern avionics”, it is hard to believe that from 1954 until 1968 the very mention of suggesting that this dedicated low-level attack aircraft might suit the RAF was likely to make the Air Staff burst their collective blood vessels.

Instead, the Air Staff went out of their way to think up the longest possible number of requirements that the Buccaneer could not meet, such as supersonic speed at sea level, Mach 2 at high altitude (though it had already become obvious that nobody was going to penetrate enemy airspace at high altitude), the ability to carry a worldbeating array of advanced reconnaissance sensors and the ability to blast out of extremely short unpaved airstrips.

Why did the RAF behave like this? To some degree it was

because in April 1957 the British Secretary of State for Defence had decreed that the RAF should have no more warplanes – but there was a tiny loophole in that for some time the RAF had been talking about a replacement for the Canberra.

The RAF Operational Requirements staff increasingly realised that this seemingly simple need was their last straw.

With all the other future fighters and bombers cancelled, this Canberra replacement was the only way to preserve the RAF as a normal flying service through the 1960s. Accordingly this requirement became loaded with every sort of demand that the ‘light blues’ could think up.

Using bombed airfields

A lot of the demands made sense. Runways might be bombed, so it was written in that the future aircraft had to be able to operate from bombed airfields,



“It’s a matter of practice, practice, practice. You can’t bring a sequence low until you’ve flown it at least 50 times.”

it one can see the ground. One can also see a few odd bits of aeroplane, including the ends of the exhaust pipes – and as I look now I find myself watching hungry red flames licking out of each stub . . .

“I erupt out of the cockpit like a human bang-seat, belt round the wing, slide to a stop on my knees, yank off a shoe, and clap it over the flames. This is efficacious, but not quite what I had in mind in the way of suave and smooth entrances . . . By mid-May I am much happier. The season is underway . . . Moreover I have now toughened up, and no longer feel sick, which is a considerable help.

“This would seem to be the time to more or less finalise my display sequences for the year . . . I have contrived to come to some sort of terms with the elusive Lomcevaks, and have even acquired a degree of success with that

other Waterloo, the half vertical flick . . . Some display pilots prefer to ad-lib at all times, but inside me there is a small cringing aviator who for one thing does not care for performing unrehearsed sequences close to the deck . . . By late July, about halfway through the season, things are going well, and I’m getting thoroughly used to the aeroplane.

“By mid-season, I feel that I’m growing together with the flying machine. It is a subtle

process. Some people seem to be able to jump into almost any aircraft and achieve an immediate deep rapport. For me it takes time: hundreds of hours and thousands of manoeuvres, from gentle turns to Lomcevaks, while the true feeling of the aeroplane soaks slowly into the fibre of my flying senses. It is an ongoing thing, this relationship with my aeroplane, and it will continue to progress for as long as we fly together.”

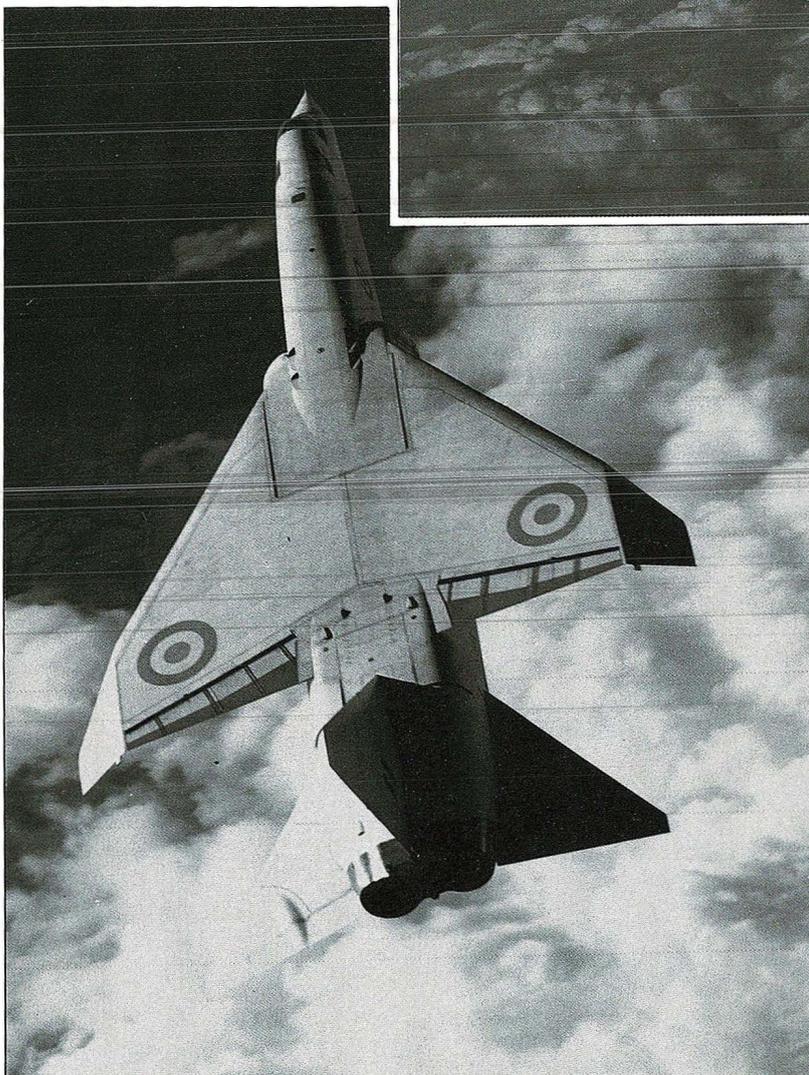
The short-span wings, four large ailerons and powerful engine of the Pitts, gives the aircraft a remarkable rate of roll.

Left: Had it not been murdered by the politicians, TSR.2 would have been in frontline service to this day, in the demanding nuclear strike and reconnaissance roles.

Below: TSR.2 turns finals at Boscombe Down during its maiden flight on 27 September 1964.

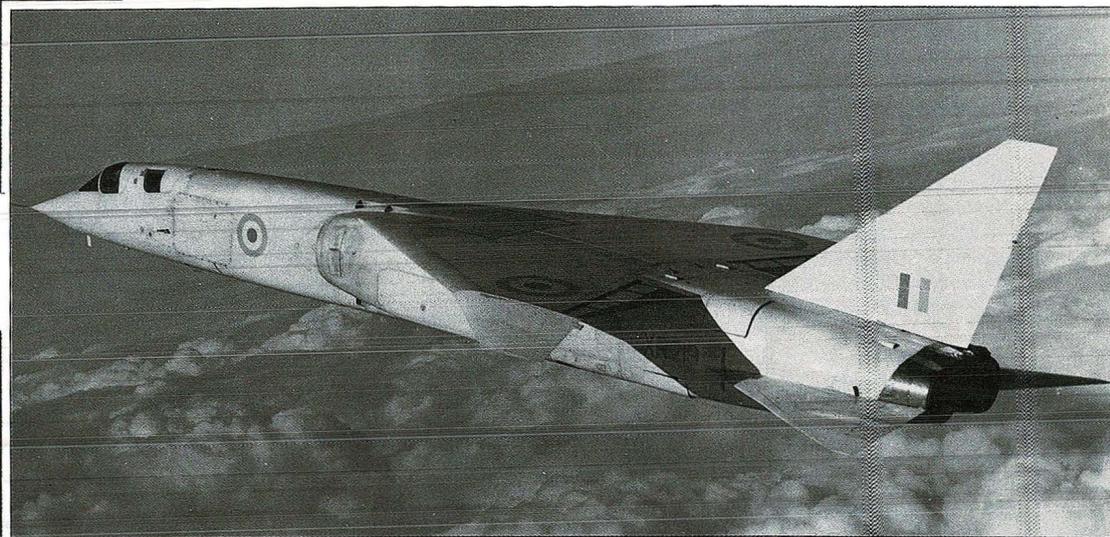


TSR.2's wing combined short span with generous area. Lift was augmented at low airspeeds by full span flap blowing.



either between the craters on runways or from the grass. Some Canberras were dedicated reconnaissance aircraft so the Canberra replacement had to be able to carry not just the cameras of the PR (photo recon) Canberras but also several new cameras as well as infrared linescan, which takes pictures of the different temperatures of everything on the ground

Below: On Flight 10, the undercarriage was retracted and the aircraft was given its head, and flown to Mach 0.8 at altitude, and to 511 knots in a fast run over the airfield at only 70 feet.



below, showing such details as where aircraft had been parked, which had just landed (with very cold fuel on board from flight in the stratosphere), and which had their engines running.

Another new device was the SLAR (sideways-looking airborne radar), which can take pictures at radar wavelengths extending from one distant horizon to the other. As it seemed unlikely that special reconnaissance versions of the new aircraft could be afforded, it was specified that it had to do everything, carrying a nuclear bomb on one mission, a heavy load of HE on the next and the full load of reconnaissance gear on the next (perhaps to view its own targets).

Even more troublesome were the political factors. There were at

that time 21 major British aircraft companies, but it looked as if there would be nothing for them to do, apart from airliners and missiles. On 16 September 1957 a big meeting was held at the Ministry of Supply, at Shell-Mex House in The Strand, London. Sir Cyril Musgrave, Permanent Secretary, said

"The requirement is called GOR, for General Operational Requirement, No. 339. This is the only future military aircraft we can foresee. The Ministry will place a contract only with a group of firms acting together. The Government hopes that the industry will amalgamate or rationalise into three or four large units."

On 1 January 1959 the programme, renamed TSR.2 from

First Flight: 27 September 1964

"There was no problem in flying this aeroplane. I was beginning to enjoy its firm, responsive but stable characteristics.

"I called Boscombe with intention to go on with the second wide circuit.

"On this we completed dutch roll stability checks, flap handling, a slow-down to the planned landing speed and an ASI 'position error' check with Jimmie Dell's Lightning. These were all satisfactory and then it was time to position for the landing. With landing flap set and power adjusted to one hundred and ninety knots I turned in over Thruxton airfield at 1,500 feet.

"The TSR.2 responded smoothly and rolled out precisely on the approach path at about five miles from the threshold of Boscombe 26 runway. This was splendid and confidence-making and I said into the intercom – 'OK, Don, we've got it made' – and so we had.

"The TSR.2 flew down its first approach as if on rails. Over the

boundary at exactly the right height I eased the nose up with the finely balanced tailplane control and flared out precisely as intended.

"Gently throttling power back, the rear bogies touched almost imperceptibly at five hundred yards down the runway – the declared aiming point – and after a brief period of severe undercarriage vibration we were riding smoothly on the runway, still nose-high and letting the nose settle gently – the pitch control was superb – and then pulling the drag 'chute which developed immediately giving a smooth and powerful deceleration so that I barely needed to use the wheel brakes.

"We opened our cockpit canopies to let in the clear air of the Plain – it had been a splendid experience."

**Wing Commander R. P. 'Bee' Beamont, DSO, DFC; TSR.2 test pilot
First Flight: 27 September 1964
British Aircraft Corporation TSR.2**

Tactical Strike and Reconnaissance, was awarded on a 50/50 basis to Vickers-Armstrong (Aircraft) and English Electric Aviation. Within a year these companies had merged and brought in Bristol Aircraft and Hunting to form British Aircraft Corporation (BAC). Despite protests from these companies, who wanted a Rolls-Royce engine, the contract for the engine went to the Bristol Olympus 22R. To build this, Bristol Aero-Engines merged with Armstrong Siddeley Motors to form Bristol Siddeley Engines Ltd (BSEL).

Partnership shared badly

One of the problems was that the main contract was placed with Vickers, which had practically no supersonic experience, whereas English Electric had more than any other firm in Britain, including Mach 2. From the start there were misunderstandings and a lack of confidence between the partners.

Having the main contract, Vickers insisted the aircraft should all be assembled in their works at Brooklands, though this had only a tiny airfield. Realising the problem, Vickers then said the first flight should be at another Vickers base, Wisley.

English Electric pointed out that if the aircraft were assembled at Warton they would be rolled out on to a superb airfield already used as the base for a Mach 2 programme (for Lightnings). Vickers would not agree, so eventually it was arranged for each aircraft to be taken by road to the Ministry base at Boscombe Down!

As English Electric had experience of Mach 2 they were responsible for the aerodynamics, including the wing and tail. Vickers kept the part that controlled the design, the front fuselage, which was stuffed with a mass of incredibly advanced systems. Of course, both firms had their own aircraft designs, and the first task was to somehow merge them so that the Vickers fuselage added to the EECo wing and tail resulted in the best aircraft possible. This was done, in spite of the activities of armies of officials in various ministries. As these gentlemen had no other project to get their teeth into, they were formed into many gigantic committees, which held interminable meetings, argued endlessly, deferred most of the crucial decisions and tended to ensure that every molehill was turned into a mountain.

It is amazing that any progress was made, but at last the first TSR.2, serial XR219, took shape

in the Brooklands works. Nothing like it had been seen before. It looked almost like a rocket, because the beautifully streamlined 89 foot fuselage had only the tiniest delta wing sitting on top. It had been realised from the start that, as TSR.2 was to fly most of its missions thundering across enemy territory at full throttle and at treetop height, the span and area of the wing had to be as small as possible.

With a wing of normal size the gust response would result in violent buffeting, which would not only quickly use up the fatigue life of the structure but would shake the crew so badly that they could not do their job. (It is for this reason that many of today's low-level attack aircraft, such as the F-15E and Mirage 2000N, are fundamentally unsuited to the mission). TSR.2 was the first aircraft

Cockpit

The TSR.2 crew had probably the most advanced cockpit of its era. It included a modern head-up display, a head-down display and a projected moving map driven by Doppler and inertial inputs, as well as the TFR monitor. Tandem seating was chosen for minimum drag.

in the world designed to fly with very little buffet at the speed of sound at sea level.

Of course, the tiny wing is just what the designers do not need if they are going to make an aircraft able to operate from short airstrips. The answer was to fit the most powerful blown flaps ever designed, extending from wingtip to wingtip and taking a gigantic flow of air under very high pressure from the engines, blasted at supersonic speed over the tops of the flap sections. This transformed the performance of the wing, giving it fantastic lifting capability at takeoff and landing, without increasing its size.

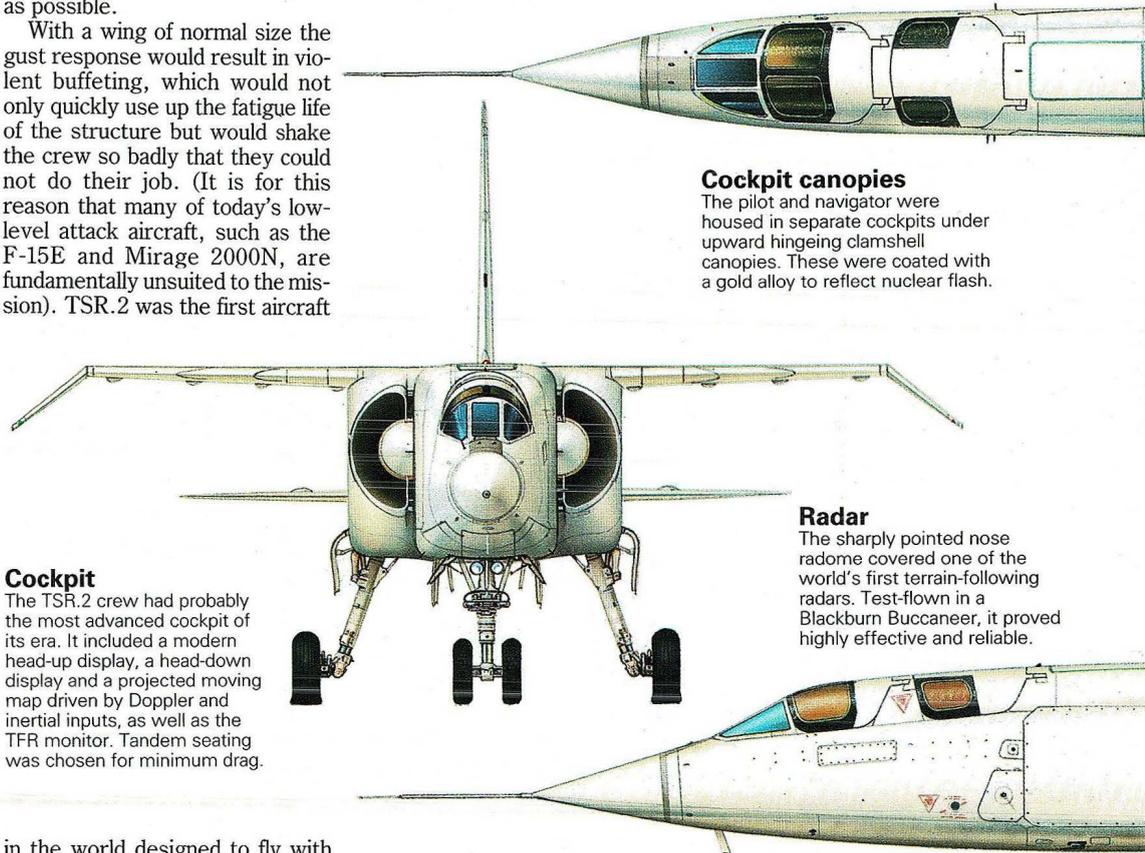
Futuristic control surfaces

For stability reasons the wing needed anhedral (downward slope). This was found to interfere with flow over the tail, so the wing was made horizontal and given sharply anhedralled tips.

Of course, full-span flaps made it impossible to have ailerons, but

British Aircraft Corporation TSR.2

The TSR.2 prototypes were completed in the overall gloss 'anti-flash' white colour scheme worn by the RAF's Vulcan, Victor and Valiant V-bombers, with roundels, serials and stencils toned down to pastel shades of pink and blue. By the time it entered service it would have received a camouflage finish to fit it for the low level role. TSR.2 looked every inch a purposeful, efficient fighting machine, graceful in a rather brutal and functional way. The Tornado, which entered service in 1981, is in some respects better than the TSR.2, but is not really any more capable.



Cockpit canopies

The pilot and navigator were housed in separate cockpits under upward hinging clamshell canopies. These were coated with a gold alloy to reflect nuclear flash.

Radar

The sharply pointed nose radome covered one of the world's first terrain-following radars. Test-flown in a Blackburn Buccaneer, it proved highly effective and reliable.

'Burners blazing, twin Bristol Olympus 22Rs blasting out 61,220 lbs of thrust, the TSR.2 prototype gets airborne from the long runway at Boscombe Down for its first flight.'



Intake

The engines were fed by semi-circular intakes on the fuselage sides. Variable shock cones controlled the speed of the incoming air as it entered the low pressure compressor.

Wing

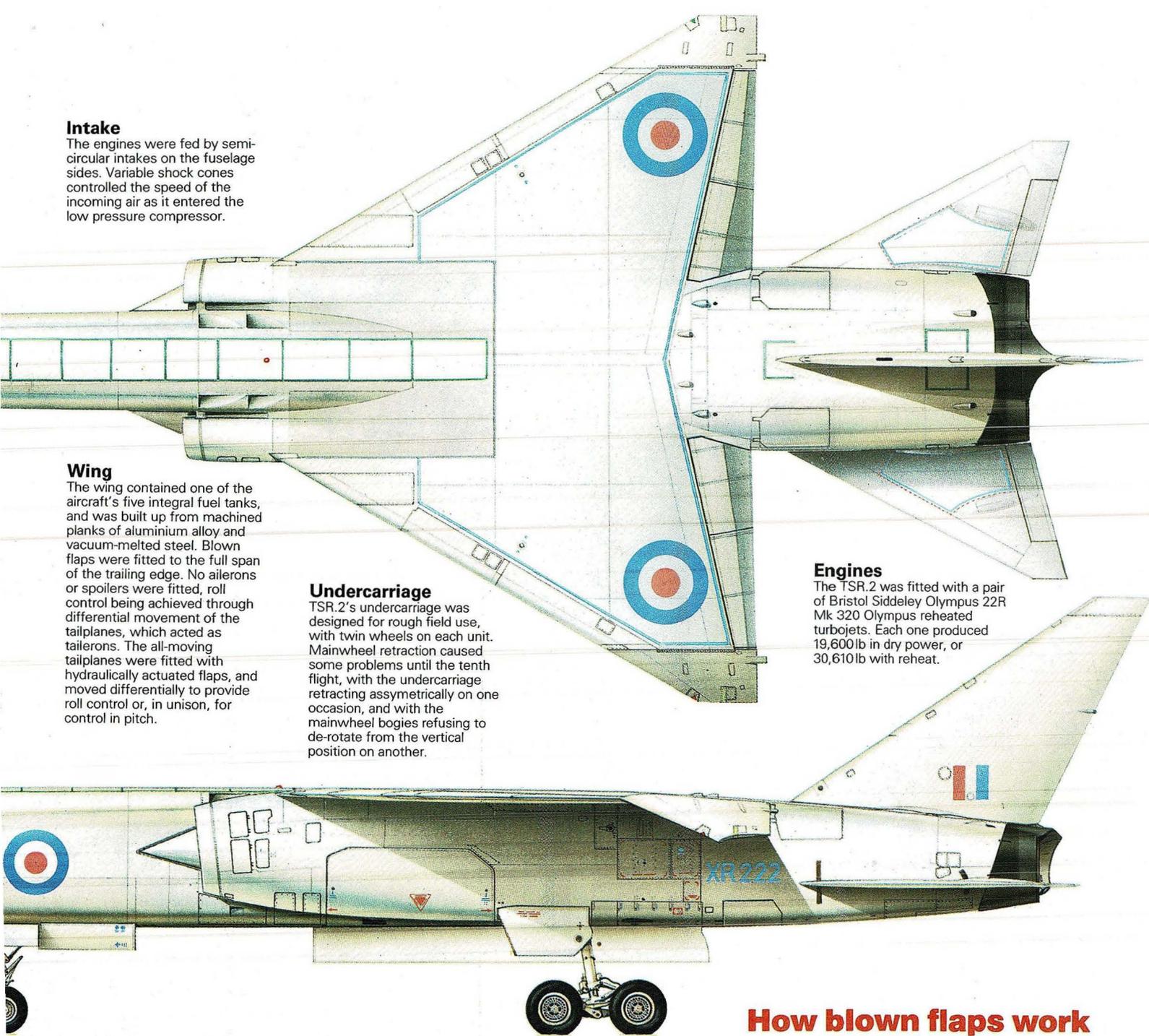
The wing contained one of the aircraft's five integral fuel tanks, and was built up from machined planks of aluminium alloy and vacuum-melted steel. Blown flaps were fitted to the full span of the trailing edge. No ailerons or spoilers were fitted, roll control being achieved through differential movement of the tailplanes, which acted as tailerons. The all-moving tailplanes were fitted with hydraulically actuated flaps, and moved differentially to provide roll control or, in unison, for control in pitch.

Undercarriage

TSR.2's undercarriage was designed for rough field use, with twin wheels on each unit. Mainwheel retraction caused some problems until the tenth flight, with the undercarriage retracting asymmetrically on one occasion, and with the mainwheel bogies refusing to de-rotate from the vertical position on another.

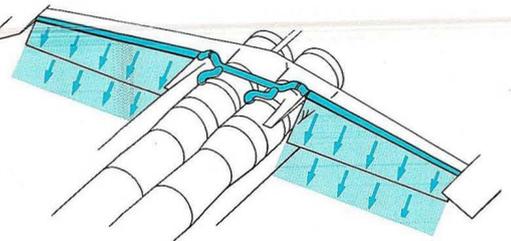
Engines

The TSR.2 was fitted with a pair of Bristol Siddeley Olympus 22R Mk 320 Olympus reheated turbojets. Each one produced 19,600lb in dry power, or 30,610lb with reheat.



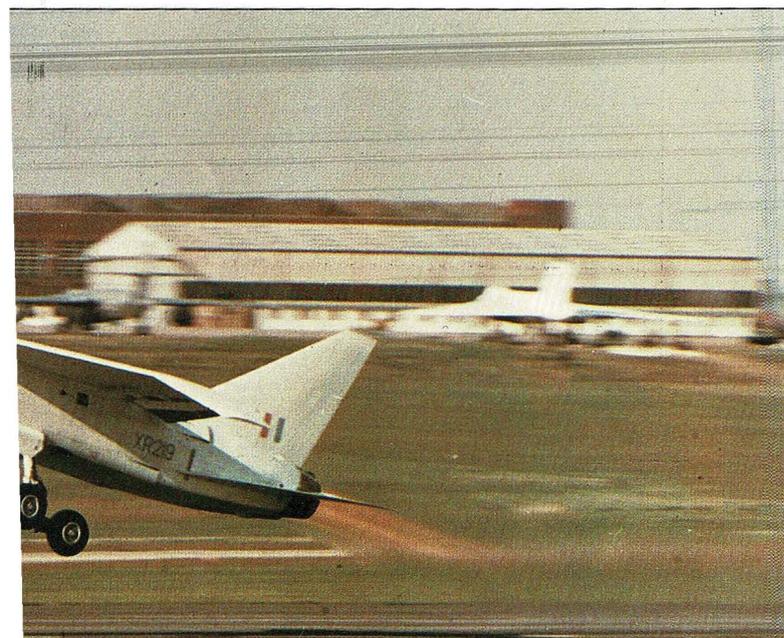
How blown flaps work

High-pressure, high-temperature air is bled from the engine compressors and piped to the trailing edge of the wing. At low airspeeds it is blown over the extended flaps to re-energise the 'tired' airflow.



Without flap blowing, the airflow over the upper surfaces of the wing and flaps can begin to break up and become turbulent at low airspeed, leading to a loss of lift and an increase in drag.

With flap blowing selected, the airflow remains in contact with the upper surfaces of the wings and flaps, and does not break away. Lift is increased quite dramatically.



Race for the Skies

Originally designed as a long range, low-level tactical bomber to replace the Canberra, the TSR.2 project became enormously important after the infamous 1957 Defence White Paper, which cancelled all other manned aircraft programmes. The aircraft became more and more capable as the Air Marshalls began to regard it as a 'back door' V-bomber replacement and as the manufacturer added more and more sophisticated systems and equipment. TSR.2 was designed from the outset to take advantage of the latest technology, and each successive design study looked more and more promising. By the time it first flew, TSR.2 was far ahead of its contemporaries in every respect, and had it entered service it would have been the world's most capable strike aircraft, offering a quantum leap in capability over the aircraft it was to have replaced. Here we trace the development of the TSR.2, and show how the RAF had to wait until the introduction of the Tornado in 1982 to make up the lost ground.



Canberra B.Mk 2

The Canberra was a classic light bomber, with some remaining in service with foreign air arms today. In the mid-1950s huge numbers of Canberras were in service in the nuclear strike, interdiction, conventional bombing, photographic reconnaissance and ECM roles. However, it had many limitations, and even by 1956 would clearly be in need of replacement in the near future.

The Blackburn NA-39 was designed as a naval strike fighter, optimised for the low level nuclear strike role. The RAF resisted all proposals that they should procure the aircraft, preferring to develop an even more advanced, longer-range machine which would be capable of supersonic flight at low level. The NA-39 became the Buccaneer, and the Royal Navy bought 60 of the initial version.



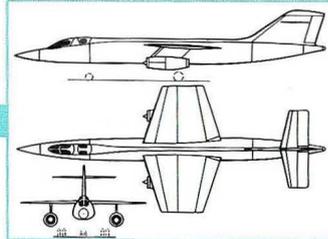
Blackburn NA.39

October 1956

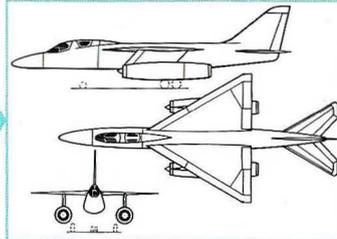
November 1956

February 1957

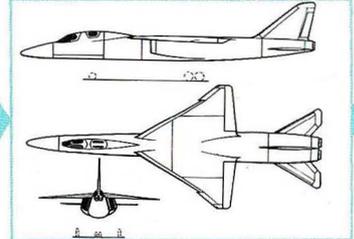
April 1957



Originally designed as a private venture Canberra replacement, the original English Electric P.17 of December 1956 combined trapezoidal wings with podded engines.



Studies showed that a delta wing might be more efficient in providing good gust response characteristics and a short take off run. This resulted in a new P-17.



By 1957 the aircraft had been refined into the P-17A, and this aircraft, with engines buried in the fuselage, was put forward to meet requirements GOR.339.



Even today, TSR.2 does not look dated. In 1964, compared with its contemporaries, it was revolutionary.

Even with its early development engines TSR.2 was capable of exceeding the speed of sound comfortably, at all levels

this was no problem. Roll control was handled by the very powerful horizontal tails – tailerons – which could move either in unison or in opposition. The vertical tail was also a single slab surface, instead of being made up of a separate fin and rudder. Aerodynamically and structurally TSR.2 was far ahead of any other aircraft of its day.

A particular feature was that, even though vibration of the airframe could not be eliminated in low-level attack, the cockpits were arranged at a node, a point where the amplitude of vibration was zero, so the pilot and navigator had a really smooth ride.

TSR.2 was one of the first British aircraft in which the avionics, for navigation and weapon delivery, cost almost as much as the bare aircraft. Navigation was handled by a mixture of precision inertial system and a doppler-type radar (which measures the exact speed and drift angle across the ground), assisted by the first TFR (terrain-following radar) to be fitted in a British aircraft. All these were linked together and to the autopilot

by the first digital computer in a British aircraft. The side-looking radar was also installed in two forms, one for navigation and the other for reconnaissance. Other equipment included a radar altimeter, ILS (instrument landing system) receiver, moving-map display and HUD (head-up display).

New engine destroys Vulcan

Public visibility of the project had been almost zero, but a few words leaked out in 1962, predicting a first flight in 1963. Then on 3 December 1962 a Vulcan B.1 bomber appeared to explode on the ground at Filton airfield, Bristol. What was less obvious to the public was that the two were linked. Attached under the Vulcan had been one of the new Olympus 22R engines for TSR.2, and it was this that had exploded, destroying the Vulcan. The cause was far from obvious. A little later another engine blew up on the testbed in the BSEL factory, and later still a third, plus various minor problems. The third failure occurred in August 1964, long after the first

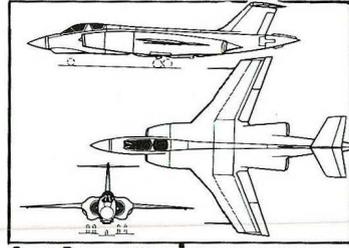




Victor B.Mk 1

The Sandys Defence White Paper of 1957 announced that Britains Strategic Nuclear Deterrent would in the future rest with ballistic missiles, and not with manned bombers. The Avro 730, a high flying supersonic bomber intended as a replacement for the V-bombers, was therefore cancelled. The RAF made it clear that they expected TSR.2 to replace more than just the Canberra.

Blackburn kept trying to interest the RAF in an updated, re-winged, bigger-engined supersonic Buccaneer. The RAF was not keen to procure an aircraft designed for the Royal Navy and in any case, the aircraft was not anything like as capable as the TSR.2 promised to be, and every approach was firmly rebuffed.



Super Buccaneer



F-111 prototype

The F-111 prototype flew soon after the TSR.2, on 21 December 1964, but the programme soon ran into major problems.

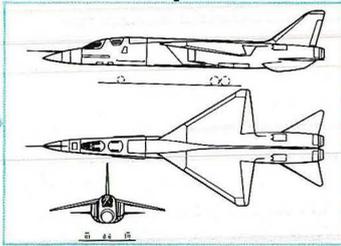
September 1957

December 1958

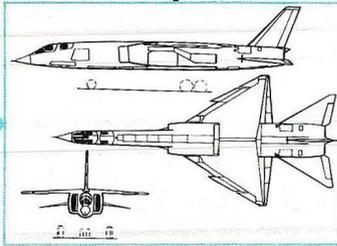
April 1960 1962

September 1964

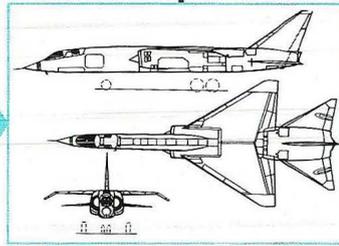
December 1964



During 1958 the design was further refined. In June, the Ministry of Supply selected the designs of English Electric and Vickers, which were to be merged.



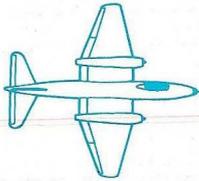
The first joint design by Vickers and English Electric was the Type 571, which bore a striking resemblance to the TSR.2 as it was finally completed.



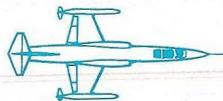
The design was frozen in 1960, by which time the aircraft had gained its characteristic delta wing with turned-down tips, and the semi-circular intakes.



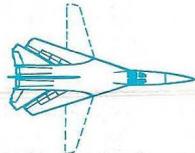
The TSR.2 made its maiden flight on 27 September 1964, despite problems with the Olympus engines. The flight confirmed that the aircraft was very much a pilots' aeroplane, with superb handling characteristics. The flight test programme was initially plagued by minor problems, but these could not obscure the tremendous potential of the aircraft, nor did they cause serious delays. The contrast with the disaster-prone F-111 programme could hardly have been greater.



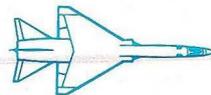
The Canberra's big, broad wing was designed for high level operations, and gave its crew a rough ride at low level, although take-off performance was good.



The tiny wing of the F-104 Starfighter gave the pilot an incredibly smooth ride at high speed or at low level, but take off and landing performance was appalling, even with flaps and slats deployed.



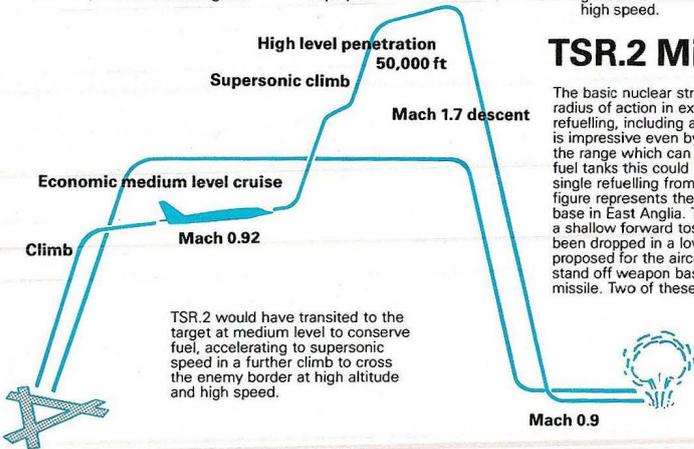
The swing-wing of the F-111 gives the best of both worlds. Swept forward it generates lots of lift and gives good low speed performance, swept back it gives a good smooth ride at low level and high speed.



The wing of the TSR.2 combined small span for high speed performance and low level ride comfort, with relatively generous area and extensive high lift devices, including flap blowing, to give the required low speed handling.

TSR.2 Mission Profile

The basic nuclear strike profile devised for the TSR.2 gave the aircraft a radius of action in excess of 1,000 miles without external fuel or inflight refuelling, including a 200 mile supersonic dash to and from the target. This is impressive even by today's standards, being roughly half as much again as the range which can be achieved by the Tornado. With ventral and underwing fuel tanks this could have been extended to 1,500 miles, or to 2,120 miles if a single refuelling from a buddy-pack-equipped TSR.2 was made. This latter figure represents the ability to hit a Moscow target having taken off from a base in East Anglia. The weapon would usually have been delivered either in a shallow forward toss from ultra-low-level, or a retarded weapon could have been dropped in a low-level laydown attack. A wide variety of weapons were proposed for the aircraft, including a megaton yield, long range, air-launched stand off weapon based on the Blue Water tactical surface to surface missile. Two of these missiles could have been carried underwing.



TSR.2 would have transitioned to the target at medium level to conserve fuel, accelerating to supersonic speed in a further climb to cross the enemy border at high altitude and high speed.

The aircraft would descend to low level for a final high-speed run in to the target.

aircraft should have flown. The engine came apart so catastrophically that it wrecked the test house.

Mach 2.2 for 45 minutes

It took months of research, starting with the Vulcan blow-up, to discover the cause. One of the many pointless demands made by the Air Staff had been that the Olympus 22R should be able to run at full throttle, in maximum afterburner, at the maximum aircraft Mach number of 2.2 for no less than 45 minutes. It was inconceivable that this could ever be necessary, and in fact every mission envisaged in the European theatre

involved low-level flight at less than half this speed, but to meet the crazy demand the engine had to be completely redesigned in special high-temperature materials and with complex internal cooling air systems. Deep inside the engine the high-pressure turbine drove the HP compressor via a tubular shaft of large diameter. This shaft would have got very hot (almost red heat) had not jets of cooling air played upon it.

What had not been realised was that these powerful jets made the tubular shaft ring just like a bell. This dangerous resonance happened at between 98.5 and 99 per cent of maximum engine speed, so

the time when the engines were likely to blow was on takeoff. As the engines were packed tightly into the rear fuselage and surrounded by fuel and the tail controls the chances of surviving even one engine blowing up were roughly zero.

Eventually, on this first takeoff, on 27 September 1964, Beamont knew he had behind him two highly lethal engines which could explode if he opened the throttles to beyond 97 per cent! In fact, as the complex long-stroke landing gears – which were needed because of the requirement to operate from rough surfaces – had not then been cleared for retraction, Bea-

mont pointed out that if for any other reason one engine were to fail, the other would have to be run at 100 per cent.

He was well aware of the threat of the British Labour Party to cancel the whole programme if it won the imminent General Election, and the pressure to get flight testing was so great he said, "We'll use 100 per cent for takeoff and initial climb. After that, nothing over 97 per cent." Even this meant acceptance of great potential danger.

A problem on landing

On the first flight everything went like a dream. The white projectile thundered off and away in an impressive manner, despite having to keep the gear down, and in the air handled beautifully. The first landing approach was "as if on rails", and the touchdown was gentle. Then all hell broke loose. Beamont, and test observer Don Bowen in the back seat, felt such shattering vibration that their eyeballs almost left their sockets, and they were blinded. Then vision returned and they found they were rolling smoothly, nose high, along the runway centreline.

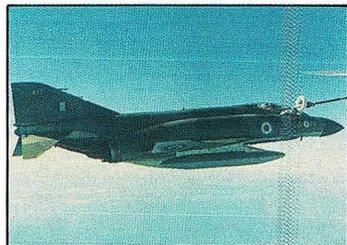
This vicious vibration caused by the landing gear was mainly lateral (side-to-side), and extremely unpleasant. It took a long time to cure, as did other problems with the landing gears such as on the fifth flight, when the tandem wheels refused to rotate into their

When TSR.2 was cancelled on cost grounds 6 April 1965, the F-111 was ordered in its place, and was then itself cancelled. The F-111 price had escalated wildly, due to problems.

With no TSR.2 and no F-111, the Canberra force was refurbished and soldiered on for another decade. The last B(1) Mk8s were eventually replaced by Phantoms and Buccaneers in 1972.

The Phantom lacked range and attack avionics, and was at best only an interim measure. The Buccaneer offered greater range and strike-power, but only five squadrons were equipped.

With the introduction of the Jaguar in 1974 the RAF gained a measure of all-weather, blind-first-pass attack capability. The aircraft had no terrain-following or attack radar, however.



April 1965

1969

1971

1974



'If it looks right, it will fly right' runs the old pilots' adage. The three test pilots lucky enough to sample the aircraft confirmed that in the case of the TSR.2 this was absolutely right. Potentially a world-beater, a uniquely capable aircraft years ahead of its time, the TSR.2 was murdered by politicians who were determined to damage Britain's aircraft industry and defences.

proper landing position and a tip-toe landing had to be made on the front wheels!

There were also further prolonged hair-raising difficulties with the engines caused by faulty afterburner fuel pumps, electrical failures and other things not actually connected with the engines at all. When all these pinpricks had been sorted out, what was left was a superb aeroplane, which handled like a dream and was unquestionably the most formidable long-range low-level strike and reconnaissance aircraft in the world – the contemporary F-111 notwithstanding.

On Flight 10 the TSR.2 was cleaned up for high-speed flight at what was then the flutter limit of 500 knots IAS, or about 700mph at medium heights. Beamont brought XR219 back across Salisbury Plain at an exciting 100 feet, all in rock-steady smoothness while the accompanying Lightning chase pilot was buffeted severely by turbulence. Altogether XR219 flew 24 times, and once the troubled early phase had been

passed every flight was sheer joy.

According to Beamont, in a lecture in May 1988, "From the viewpoint of 20 years on, the overall success of TSR.2 from the start can be seen to have been phenomenal."

Unfortunately for the programme, the Labour Party did win the 1964 election, and it won largely by campaigning violently against the British aircraft industry, which, it proclaimed, was "an overgrown and mentally retarded child in our midst". The new government said it would do away with British aircraft, replacing everything with "cheaper" aircraft from the United States.

It cancelled the Hawker P.1154

COCKPIT

Pilot and navigator sat in tandem cockpits on Martin Baker Mk 8a zero-zero ejector seats. The cockpits were exceptionally well designed and well equipped, with modern instruments and displays for the radars and moving map.

RADAR

Shown in green on the accompanying illustrations are the scanner for the TFR (Terrain Following Radar) and the antenna for the high resolution Q-band SLAR (Sideways Looking Airborne Radar). The latter would have been used for navigation and reconnaissance.

and Whitworth Gloster 681 jet-lift aircraft, replacing them with the Phantom and Hercules. It said it would not take a decision on TSR.2 until June 1965, but the government became extremely embarrassed at the obviously brilliantly successful progress of the flight test programme, and decided it had to stop this without more ado. Accordingly the whole programme was terminated in the Budget on 6 April. The government specially ordered that the production tooling in the factories should be torn up, and that the four further prototypes that were about to fly should be sent to the Shoeburyness firing range to be used as targets.

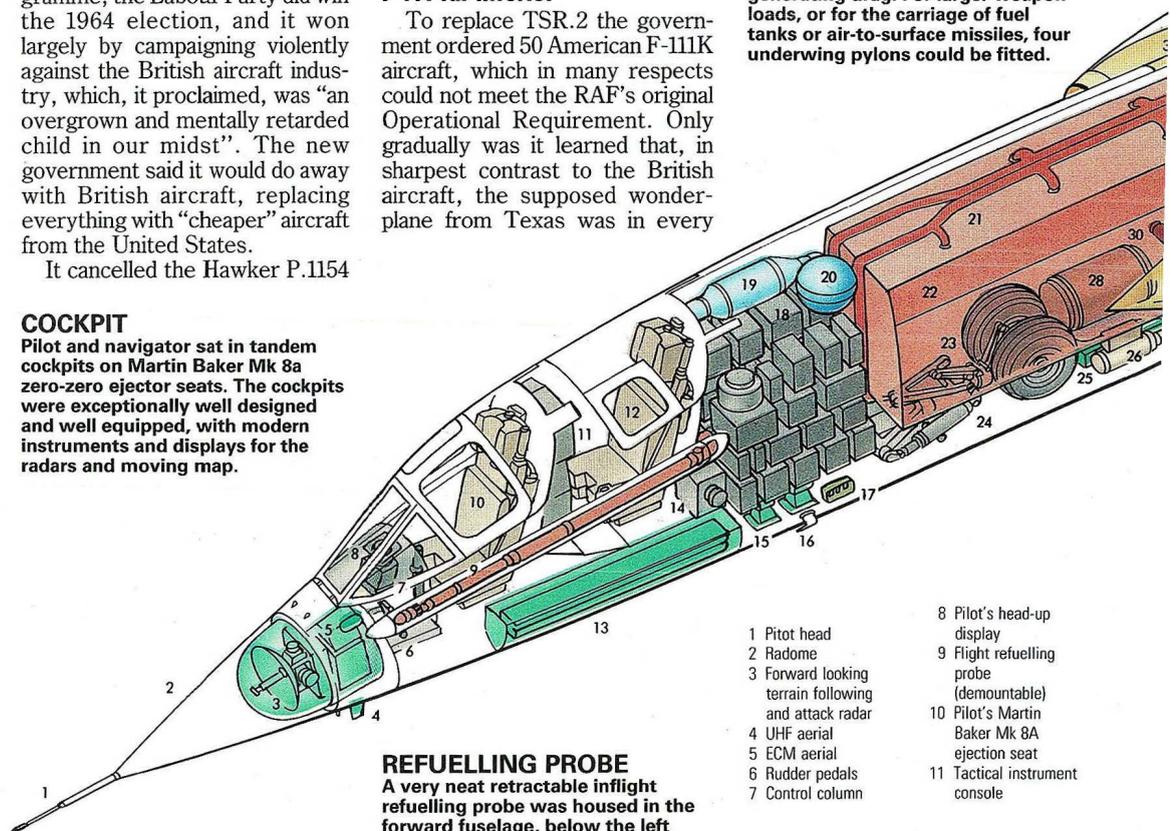
F-111 far inferior

To replace TSR.2 the government ordered 50 American F-111K aircraft, which in many respects could not meet the RAF's original Operational Requirement. Only gradually was it learned that, in sharpest contrast to the British aircraft, the supposed wonder-plane from Texas was in every

kind of trouble. It was overweight, the engines and airframe were mismatched, the main wing pivots suffered fatigue, and there were many other problems which got wide publicity and made nonsense of the British government's claim that it was getting "a much better and cheaper aircraft". Eventually the F-111K contract was also cancelled, the excuse being that "with the withdrawal west of Suez we no longer have need for such aircraft". But the RAF and British aircraft industry have felt the loss of TSR.2 to this day.

UNDERWING PYLONS

TSR.2 was designed with a large internal weapons bay, so that bombs could be carried without generating drag. For larger weapon loads, or for the carriage of fuel tanks or air-to-surface missiles, four underwing pylons could be fitted.



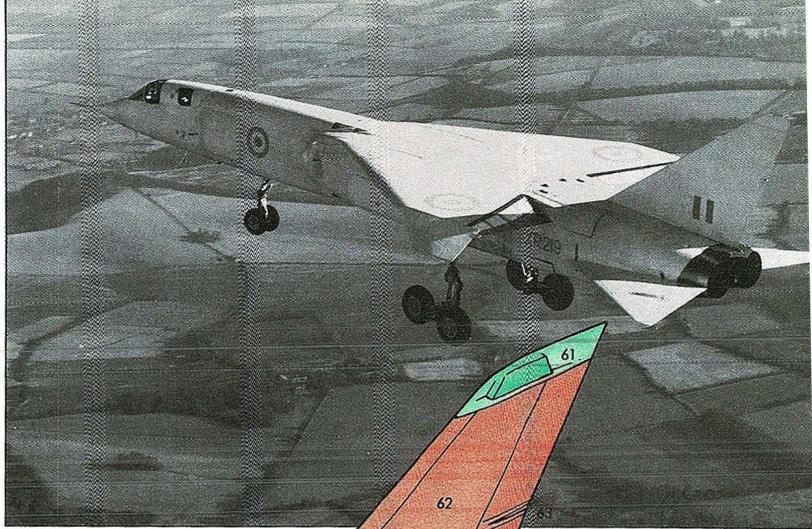
REFUELLING PROBE

A very neat retractable inflight refuelling probe was housed in the forward fuselage, below the left hand edge of the cockpits.

- 1 Pitot head
- 2 Radome
- 3 Forward looking terrain following and attack radar
- 4 UHF aerial
- 5 ECM aerial
- 6 Rudder pedals
- 7 Control column
- 8 Pilot's head-up display
- 9 Flight refuelling probe (dismountable)
- 10 Pilot's Martin Baker Mk 8A ejector seat
- 11 Tactical instrument console



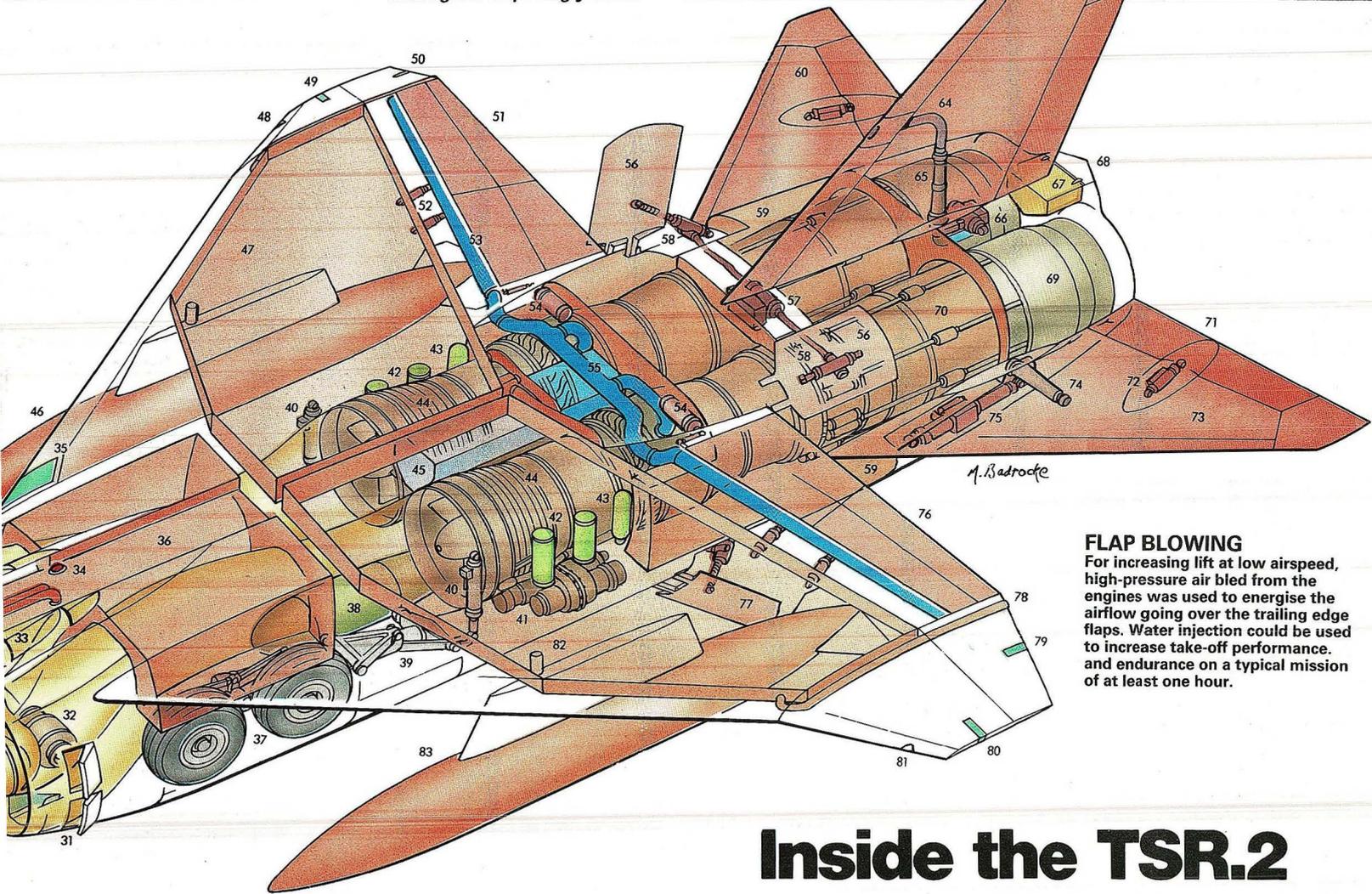
Only with the introduction of Tornado in 1982 did the RAF gain a frontline strike aircraft equipped for fully automatic terrain-following, and true precision bombing capability. If TSR.2 had not been cancelled this capability would have reached the Squadrons 14 years earlier, and the prospects for large export orders were great. Many expected Tornado, originally known as the Multi-Role Combat Aircraft (MRCA) to be cancelled, just as the TSR.2 and F-111 had been. Small wonder that some suggested that the acronym MRCA actually stood for 'Must Refurbish Canberra Again'.



1982

1990

On finals, with flaps down and blowing selected, the aircraft's handling was docile, and the landing run surprisingly short.



FLAP BLOWING

For increasing lift at low airspeed, high-pressure air bled from the engines was used to energise the airflow going over the trailing edge flaps. Water injection could be used to increase take-off performance, and endurance on a typical mission of at least one hour.

Inside the TSR.2

- 12 Navigator's Martin Baker ejection seat
- 13 Sideways looking radar (SLAR)
- 14 Oblique camera
- 15 Radar altimeter aerials
- 16 Stand-by pitot
- 17 Systems ground connectors
- 18 Avionics equipment racks

- 19 Air system water separator
- 20 Liquid oxygen converter (LOX)
- 21 Fuel system piping
- 22 Forward fuselage fuel tank
- 23 Nose undercarriage
- 24 Hydraulic retraction jack
- 25 Ventral doppler aerial

- 26 Emergency generator
- 27 Air conditioning system regenerative heat exchanger
- 28 Inertial platform
- 29 Intake moveable centre-body half cone
- 30 Centre body jack

- 31 Intake suction relief doors
- 32 Airborne auxiliary power unit (AAPU)
- 33 Boundary layer spill ducts
- 34 Anti-collision light
- 35 HF notch aerial
- 36 Centre fuselage fuel tank
- 37 Main undercarriage
- 38 Tactical nuclear weapon in ventral bomb bay
- 39 Main undercarriage leg strut
- 40 Hydraulic retraction jack

- 41 Airframe mounted engine accessory equipment gearbox
- 42 Hydraulic reservoirs
- 43 Hydraulic accumulator
- 44 Bristol Siddeley Olympus 22R engines
- 45 Water injection tank
- 46 External fuel tank
- 47 Wing integral fuel tank
- 48 Starboard navigation light
- 49 ILS aerial
- 50 ECM aerial

- 51 Starboard blown flap
- 52 Flap actuators
- 53 Flap blowing air duct
- 54 Inboard flap drive motor
- 55 Engine bleed air ducting
- 56 Dorsal air brakes
- 57 Airbrake drive motor
- 58 Airbrake screw jacks
- 59 Rear fuselage fuel tank
- 60 Starboard all-moving tailplane

- 61 VHF/UHF aerial
- 62 All-moving fin
- 63 Tail navigation light
- 64 Cooling air duct
- 65 Fin hinge post
- 66 Fin hydraulic actuator
- 67 Brake parachute housing
- 68 Hinged parachute door
- 69 Variable area afterburner nozzles
- 70 Afterburner duct
- 71 Tailplane flap
- 72 Tailplane flap actuator

- 73 Port all-moving tailplane
- 74 Tailplane mounting spigot
- 75 All-moving tailplane hydraulic actuator
- 76 Port blown flap
- 77 Ventral airbrakes
- 78 Fuel vent
- 79 ECM aerial
- 80 ILS aerial
- 81 Port navigation light
- 82 Port wing integral fuel tank
- 83 450-gal external fuel tank

Tenerife Taxiway

By late March, the summer holiday season in the Canary Islands is well under way. As with many resorts, the transportation system is often cobbled together, only just capable of doing the job at hand on a good day; 27 March 1977 was very far from being a good day.

That morning, a bomb set by a separatist organisation had exploded at the island group's main airport, at Las Palmas. As a result, traffic was diverted to Los Rodeos, a smaller and less well-equipped field that serves the resort of Santa Cruz on the neighbouring island of Tenerife.

637 potential victims

Two of the diverted aircraft were Boeing 747s, an in-bound Pan American Airways charter, Flight PA 1736, bringing 373 holidaymakers from the other side of the Atlantic to join a cruise ship, and a KLM charter, Flight KL 4805, arriving from Holland with 234 passengers. There were sixteen crewmembers on board the American Boeing, fourteen on the Dutch aircraft.

Los Rodeos Airport is a narrow field, surrounded by mountains and prone to mist and fog. It's quite busy in its own right, especially at weekends. On that Sunday it was working at 200 per cent of capacity. The KLM Jumbo arrived at 1.38pm, and settled down to wait for Las Palmas to re-open. It was joined by the Pan Am flight some thirty minutes later,

Below: The twisted wreckage of KLM Jumbo PH-BUF on the runway at Los Rodeos testifies to the ferocity of the blaze which consumed it. All 248 passengers and crew on board perished.



Left: A passenger from Pam Am Clipper flight PA 1736 lies burned but alive in the hospital of Santa Cruz de Tenerife. In all, some 70 out of 396 survived the crash, although nine of the more seriously injured died in hospital.

bringing the number of aircraft on the ground to eleven, with visibility worsening.

The KLM Captain, Jaap van Zanten, was concerned that his aircraft's fuel load wouldn't be sufficient to survive the protracted landing stack he saw developing when Las Palmas did re-open and then get them back to Amsterdam. Rather than risk being stuck on the ground at Las Palmas, waiting to take on fuel and then for a take-off slot, he decided to replenish at Tenerife. At that point he had not been allocated a gate at Las Palmas, so could not have taken off in any case.

Chaotic arrangements

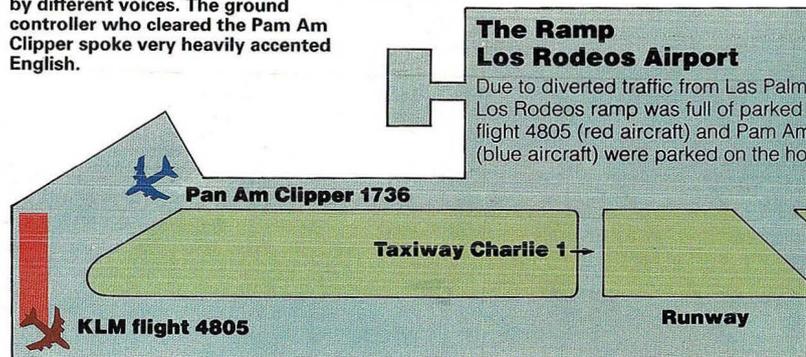
Because of the way in which aircraft were parked, this effectively blocked in the Pan Am aeroplane. Captain Victor Grubbs didn't need fuel himself; he still had 83,000 pounds on board.

The smaller aircraft which could get away did so before KL 4805's tanks were filled. By the time the two bigger aircraft's turns came, visibility was down to 500m - little enough on a 3,500m runway. The

"Clear to taxi . . ."

The two almost identical aircraft waited around three hours for clearance to make the short hop to Las Palmas and complete their flights. Too big to taxi across the apron and down the taxiway, they are both instructed to backtrack down the main runway. Both clearances to runway are given on the tower's 118.7MHz frequency, but by different voices. The ground controller who cleared the Pam Am Clipper spoke very heavily accented English.

At 1645 the KLM flight got their papers from the local agent. Refuelling was completed. At 1651, KL 4805 requested start clearance and started engines. Twenty seconds later PA 1736 followed suit. The controller was seeing Sunjet Flight 282 off, and held them for perhaps two minutes. No transcript is available for this portion.



KLM flight 4805 was cleared to depart after refuelling, but had to get to its take off point via the runway as the ramp and taxiway were obstructed. Immediately behind came Pan Am Clipper 1736.

Taxiway Charlie 1 led from the runway to the holding area, but was not in use.

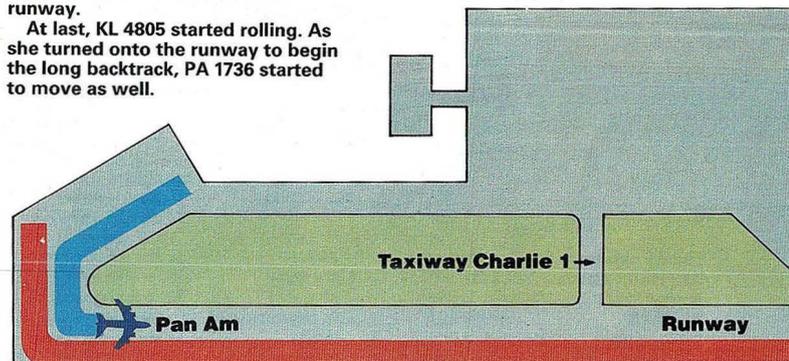
"Leave the runway three-one . . ."

KLM is given clearance to join the runway, and told to exit the third left. The Captain requests clarification, believing he has heard "first left", which would have taken him back onto the apron in front of the terminal. After some deliberation he is told to backtrack all the way to the head of the runway.

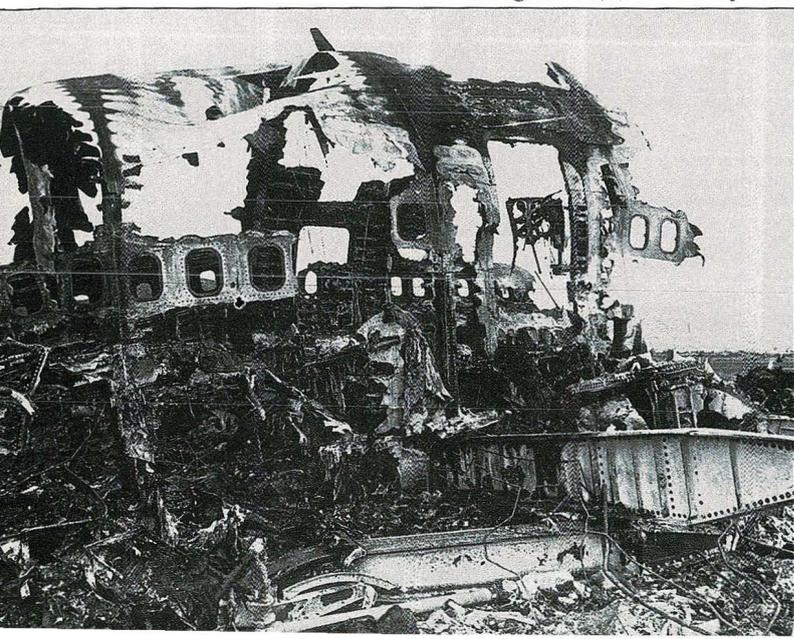
At last, KL 4805 started rolling. As she turned onto the runway to begin the long backtrack, PA 1736 started to move as well.

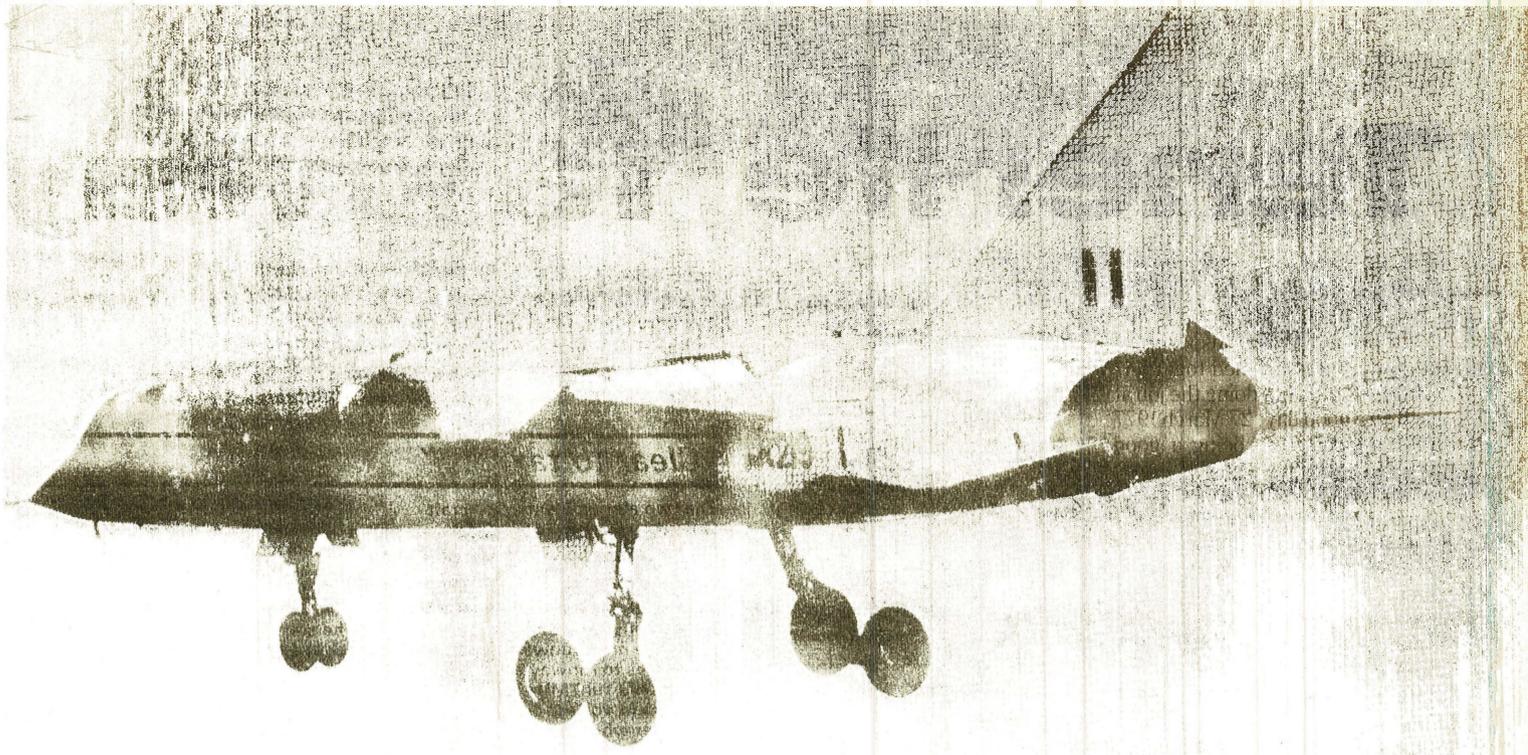
1700:43.5 Ground control to PAA

Clipper one seven three six cleared taxi into the runway following the seven four seven from KLM



As KLM 4805 taxied down the runway to the far end, Pan Am 1736 followed. The captain would have been happy to hold where he was until the Dutch plane took off, but was instructed to go down the runway and leave by the third exit.





CONCEPT *versus* REALITY-2

A detailed assessment of the TSR.2

There are indications that the TSR.2's airframe/engine combination was not all that it should have been, and that an alternative power source should have been considered. At the time BAC had shown a preference for the Rolls-Royce Medway, a smaller, less powerful engine than the Olympus. Unlike the Olympus, the Medway was a low-bypass turbofan, which offered a number of distinct advantages over the turbojet. A turbofan of similar size weighs some 20 per cent less because the central core of the engine is smaller than that of its counterpart in the pure jet engine. However, the mass flow is roughly the equivalent when the bypass flow is measured, allowing the turbofan to produce a similar output using less fuel.

Such an engine would have provided the TSR.2 with far more flexibility, and, had its development achieved the target power output, it would have given the TSR.2 far better fuel economy, particularly in the lower flight envelope, while at the same time giving a better ferry range and lessening the fuel load by a significant margin.

Another engine that had been proposed was the military version of the Rolls-Royce Conway, the RC617. This unit powered the Handley Page Victor, and was similar in dimension to the

FRANK BARNETT-JONES concludes his assessment of the controversial BAC TSR.2 strike aircraft, making it clear that opinions formed in hindsight do not always take account of the technology and defence policies which prevailed at the time

Olympus. It was a low-bypass turbofan producing a static thrust of 20,600lb. At the time both Rolls-Royce and BSEL lacked "hot end" experience, and at one point there were misgivings about the turbofan engine, primarily because problems were anticipated with reheat combustion in the jetpipe caused by the extra oxygen. Such concern was unfounded, as a Conway using a simple reheat system had already been demonstrated quite successfully in the USA.

However, such comparison is purely

hypothetical, and would have been so even at the time. The most damning reason for the Ministry of Supply (MoS) choosing the Olympus was not its reliability, or that it was already in production, but simply that Bristol Siddeley Engines had complied with the government's *diktat* by joining forces with a similar engine company, Armstrong Siddeley. Known as Bristol Siddeley Engines Ltd, its experience with gas turbines did not coincide with that of Rolls-Royce, but the politicians had removed any element of competition and had overruled the airframe designers.

Electronic warfare

One of the fundamental criticisms surrounding the TSR.2 centres on the development of electronic equipment that was to form a key element in the programme. In 1957 the OR office had attempted to foresee the requirements of the RAF well into the next decade and beyond. At the time there was little equipment available that could adequately support the needs in OR.343, and although development in electronics was ongoing, the costs of this type of equipment were ever increasing. It was not until the late 1960s that the general use of solid-state electronics and transistors made electronic equipment technically and financially

reasonable. The equipment available at the time appears to have been at the low end of this very expensive market, in that the digital computer was a direct derivative of a unit being used as a guidance system for the American Minuteman 1 missile.

As such, a great deal of modification was required simply to get the computer to manage the extra workload of an automatic flight control system. Although development was ongoing in other areas, such as navigation, radar and weapons aiming, it was generally on a one-to-one basis, whereby each component was being developed and evaluated as an individual item, rather than part of a multipurpose weapon system. The TSR.2 was to bring all such development to a conclusion, whereby the separate components were to be developed as part of a single unique system.

It is easy to say with hindsight that the direction the manufacturers chose in achieving their goal was the correct one, but it is the equipment in use today, together with the systems management, which confirms that fact. The methods used by the Tornado aircrew to achieve a successful mission are based on the very mechanisms developed from TSR.2 technology. It is certainly arguable that, had we followed the recommendations of using "off-the-shelf" equipment, there would have been no TSR.2 or even Tornado. The equipment that was readily available at the time was too big, too heavy and too slow to be adaptable to the demands in the OR. The advance in technology would merely have been a simple shuffle forward, leaving our aircrews vulnerable to the highly sophisticated equipment that was being

developed by other leading countries.

In comparison the F-111 was using electronics that were generally available off the shelf, with the exception of the terrain-following radar (TFR), and it was anticipated that the advanced equipment would be fitted once the aircraft had entered service, when the components had reached a suitable level of technical reliability and effectiveness. Such a policy leaves open to question the principal benefits of the American aeroplane, particularly as many were convinced that the advantages of the F-111 over the TSR.2 were significant.

While there may be certain benefits in cost terms to take such small strides in development and research, rather than the leap as in the the TSR.2 programme, it still leaves the question of development costs for the equipment that will eventually follow. All that will happen is that the expenditure will be spread over more accounting periods, thereby reducing the expenditure of the overall programme at the initial stage. This does not necessarily reduce equipment costs; on the contrary, it could increase them. Once preliminary development of the airframe is complete and production under way, the emphasis on cost reduction tends to be relaxed and the new equipment is considered as a separate entity. This allows the manufacturer to submit his development costs under a separate scheme which need not necessarily be questioned as part of the original programme.

A model computer

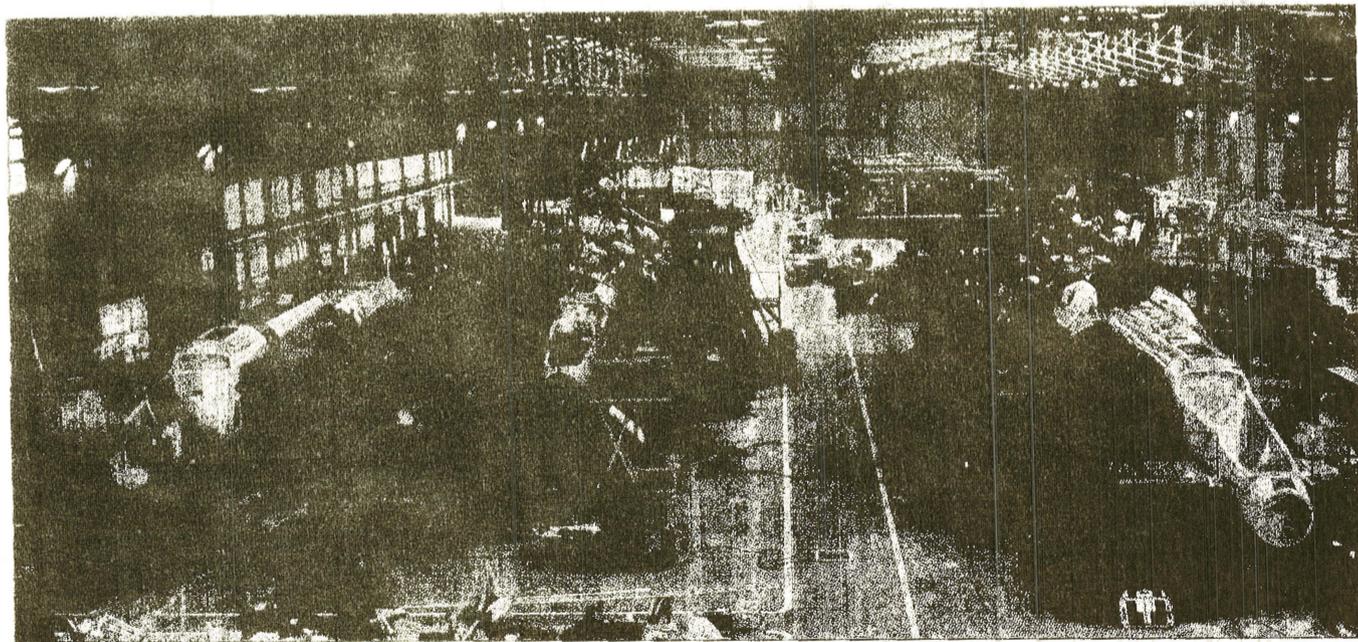
When, in the mid-1950s, proposals were first put forward for an aircraft in the TSR.2 category, computing was very much in its infancy, and a mechanism capable of carrying out the complex duties of an automatic flight control system was simply not available. Even by the time the design was completed and metal was being cut, technology was still limited, and even mainframes used in large industrial installations were

restricted by the amount of real storage that was available. However, advances in computer technology were to accelerate over the next decade. At the time of XR219's first flight the memory available for the system's digital computer was only 2k (1k is two to the tenth power, 1024 in decimal notation). To give some indication as to what this means in terms of size, a modern-day programmable pocket calculator has in excess of 50k.

Concerns that the computer would be unable to manage the multitude of complex tasks imposed upon it, and that it would simply fail, appeared justified at the time. A situation similar to this was to occur during the Apollo moon landing, when the onboard computer locked up, having failed to manage the thousands of inputs it was receiving. Even so, it was estimated that by the time the TSR.2 was scheduled to enter service in the early 1970s computer technology would have advanced to the stage where the equipment available would have been comparable in size to the 64k main computer, or MC, in the Tornado when it first entered service. The computer was just one of several pieces of essential equipment which formed an accurate navigation and attack system of revolutionary character. Its ability to direct the aircraft to within feet of its destination, or drop bombs with the same level of accuracy, was of prime importance. A manual system would have resulted in accuracy deviations akin to bombing raids during the Second World War.

The method used to pre-plot and load the information into the computer was in line with the technology being used in industry. The simple paper-tape system continues to be used today in a number of engineering companies as an accurate method of machining (numerical control). The technique used by Tornado crews today has altered very little, though the information is now pre-plotted on to magnetic tape before being loaded into the aircraft's system.

Heading picture, XR219, the only TSR.2 to fly. Note the vortices trailing back from the wingtips. Below, TSR.2 production at BAC's Weybridge factory shortly before cancellation of the project. Two aircraft, XR219 and XR220, were completed, and three more, XR221-XR223, were on the way to completion when the axe fell.



Aeroplane Monthly, August 1997

After the cancellation of the TSR.2 was announced, a number of firms in the electronics industry approached the government, requesting that they be allowed to continue with the development of specific projects. Elliott Automation in particular was keen to carry on development of the next generation of digital computers originally being developed for the production of the TSR.2. Solly Zuckerman obtained government agreement for this, and eventually Elliott produced the MCS920M digital computer which was eventually fitted in the Sepecat Jaguar. Other equipment being developed by Elliott, while accumulating a number of orders from the United States Air Force and Navy, appears to have been overlooked by the MoD, which failed to consider such equipment for new RAF aircraft.

Many other items of avionic equipment went on to be developed, and in fact much of the nav/attack equipment which was fitted to the British versions of the Phantom and the Jaguar was developed from systems designed for the TSR.2. The Harrier and the maritime Nimrod also benefited from this equipment, having a derivative of the systems based on equipment for the TSR.2 project. As a further measure of the equipment's credibility the nav/attack and terrain-avoidance systems and reconnaissance pod based on those for the TSR.2 were proposed for a Mirage IV, re-engined with the Rolls-Royce Spey 25R, which Dassault put forward as a replacement for the TSR.2 in preference to the F-111.

The statement that the nav/attack system in the TSR.2 was out of date can

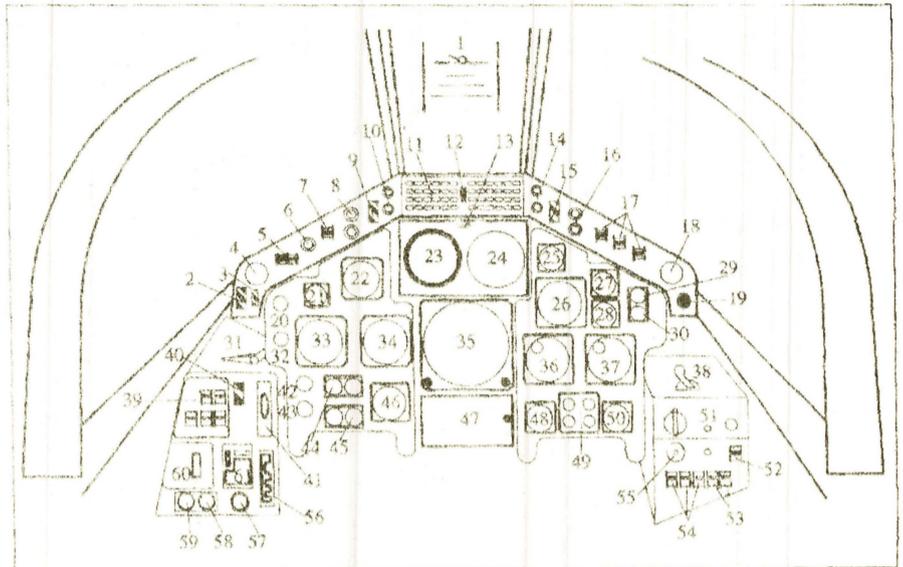
only be made with hindsight. In 1958 there was simply no way of knowing that technology would advance to the stage it did in the Tornado. The system in Tornado is there as a consequence of the development in the TSR.2, and of on-going research.

Terrain-following radar

The terrain-following radar (TFR) was perhaps the key element in the new systems being developed for the TSR.2. The Royal Signals and Radar Establishment at Malvern had previously accepted that the work being carried out by Ferranti in Scotland was ahead of a similar programme being conducted by Texas Instruments in the USA. It is a fact that Ferranti had overcome many of the problems associated with TFR well in advance of Texas Instruments.

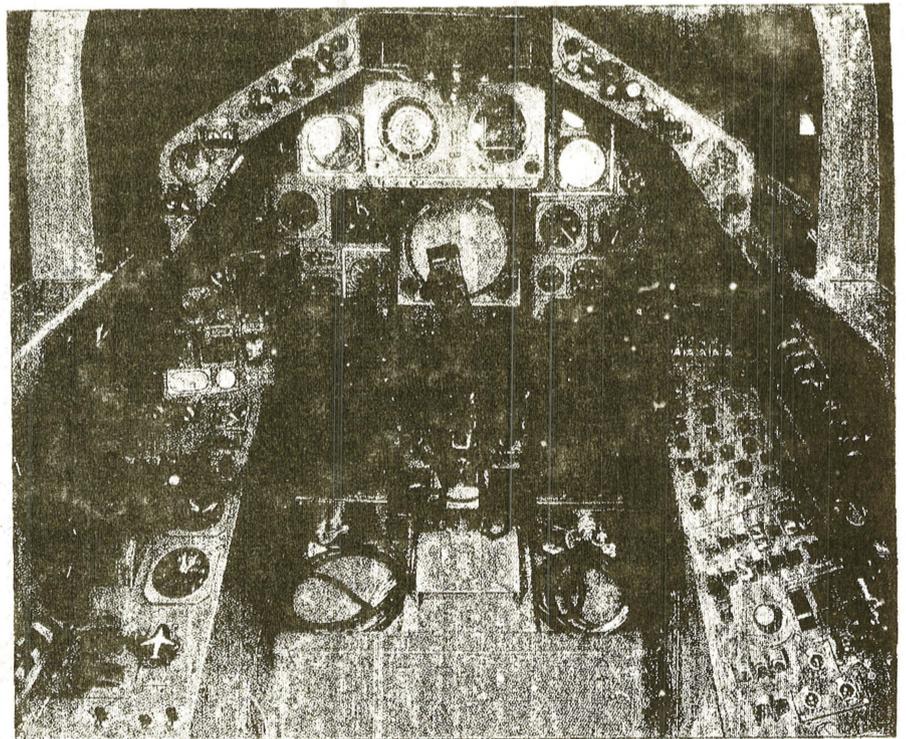
KEY to cockpit diagram

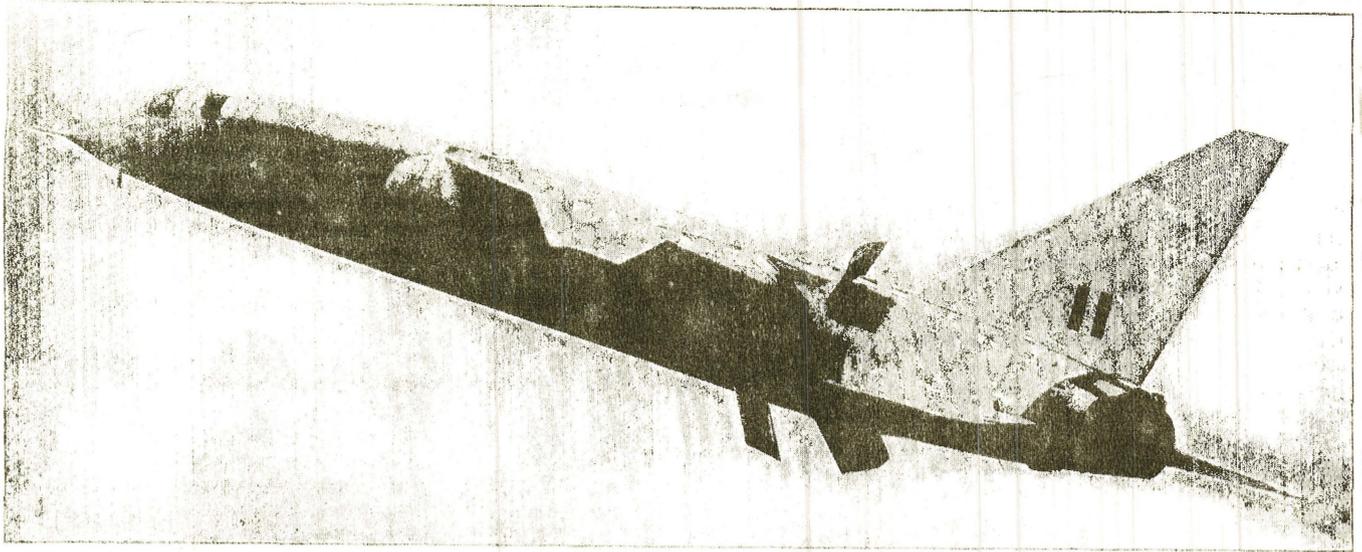
- 1 HUD display
- 2 Nose wheel extend switch
- 3 Manual flap blow switch
- 4 Incidence meter
- 5 Brake chute jettison switch
- 6 Brake chute door selector
- 7 Brake chute reefing switch
- 8 Port reheat warning
- 9 Port reheat LP cock
- 10 Fire warnings port engine
- 11 Central warning panel
- 12 Day/night switch
- 13 Turn indicator
- 14 Fire warnings starboard engine
- 15 Starboard reheat LP cock
- 16 Starboard reheat warning
- 17 AFC selector switches
- 18 Accelerometer
- 19 HUD brilliance
- 20 Flap pressure indicator
- 21 Air speed indicator
- 22 Combined speed indicator
- 23 Altitude display
- 24 Nav/ILS display
- 25 Radio altimeter
- 26 Altimeter
- 27 Air/rail skin temperature
- 28 Local altimeter
- 29 Oxygen content
- 30 Oxygen pressure
- 31 Parking brake handle
- 32 Flap position indicator
- 33 Standby horizon
- 34 Standby altimeter
- 35 Moving map display
- 36 Thrust r.p.m. port engine
- 37 Thrust r.p.m. starboard engine
- 38 Rudder pedal adjuster
- 39 Nose wheel short/normal switch
- 40 Undercarriage emergency switch
- 41 Undercarriage select lever
- 42 Air brake pressure indicator
- 43 All gear
- 44 Brake pressure indicators
- 45 Hydraulic accumulator gauges
- 46 Rate of climb indicator
- 47 Radio
- 48 Turbine temp. port engine
- 49 Intake cone/nozzle position
- 50 Turbine temp. starboard engine
- 51 ILS controls
- 52 Aerial selector switch
- 53 Intercom selector switches
- 54 VHF/UHF selector switches
- 55 Radio channel selector
- 56 Flap position lever
- 57 Flap indicator
- 58 Roll indicator
- 59 Yaw indicator
- 60 Airbrake standby
- 61 Undercarriage indicator



Above, diagram of TSR.2 front cockpit instrumentation.

Below, the same cockpit on the mock-up at Weybridge.





At the time no terrain-following radars were available, and the forward-looking radars (FLRs) lacked the capability to provide fast and accurate information, as well as being incapable of identifying objects such as pylons, masts and high-tension wires, a necessity when flying only 200ft above the ground.

Reconnaissance

Reconnaissance was an important role for the TSR.2, and to that end the aircraft was to employ several unique systems. Much has been said of the sideways-looking radar (SLR), and criticism has been aimed at the ineffectiveness of the techniques; particularly the fact that the rapid processor unit (RPU) took some 20sec to process the information, and that it was consequently some three miles behind the aircraft's actual position. It was claimed that the equipment was unnecessary, and that an FLR could have satisfied the needs of navigation and bomb aiming far more effectively. Perhaps the reasons for the use of SLR were not fully appreciated.

The device was to serve two important roles on board the TSR.2. First, the SLR would be used as a navigational aid to assist with the aircraft's accurate positioning. By scanning either side of the bomber and identifying the selected waypoint, the results would be processed within the RPU and then "painted" on a strip of material passed along the scan-

Above, an unusual shot of XR219 with its four airbrakes deployed. It was originally intended to have only three.

ner at a speed relative to that of the aircraft over the ground. Any deviation due to the small time lapse in the RPU was taken into consideration by the navigator when comparing the results with the pre-plotted course, allowing him to make corrections. There was no restriction in the radar's ability to carry out this task, as it was quite capable of operating in all weather conditions, day or night.

Secondly, in the reconnaissance role the SLR could be used to identify enemy ground activity, and after the data had been processed aboard the TSR.2 it could be transmitted directly back to a forward command post by onboard data-link for interpretation and immediate action.

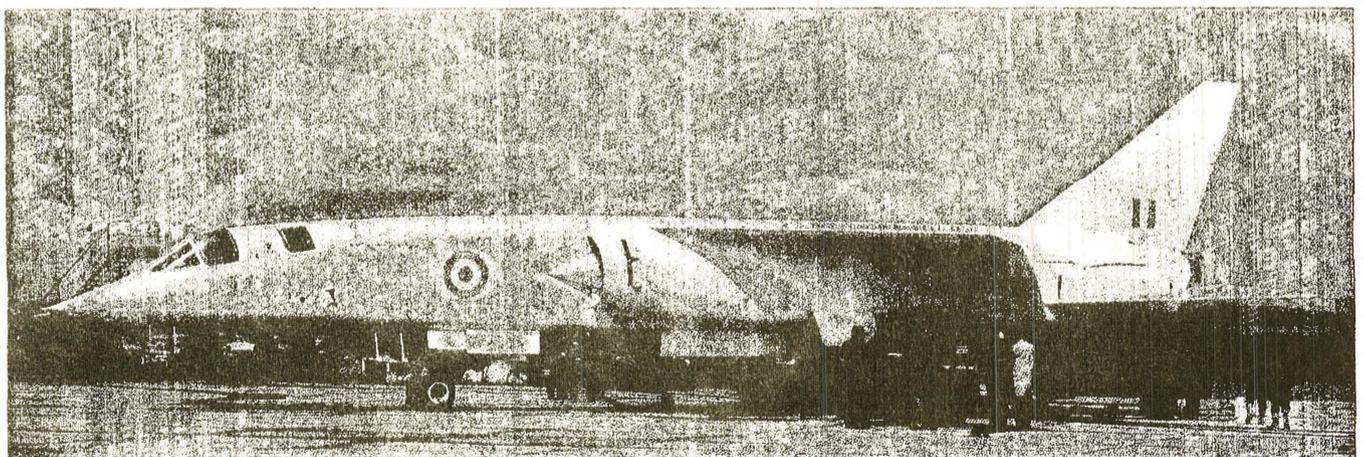
There was a belief that SLR was used simply because there had been insufficient room in the nose of the aircraft to locate FLR to carry out the bomb aiming. This was not the case, as the TFR had an air-to-surface ranging mode which formed a necessary part of the attack system. The SLR was complementary to the navigation aspect, but essential in the reconnaissance role.

Below, XR219 before its maiden flight. A great demand was to be made on TSR.2 for remote-field operations.

Government strategy

In 1955-56, when the government issued its White Paper on the Procurement of Military Aircraft, it was confidently assumed that the problems which had occurred during the development of previous projects had been identified and resolved, and that the necessary restrictions on expenditure would be implemented. Indeed, this was one of the reasons why the TSR.2 programme became the subject of so many committees in an attempt to eradicate development and construction problems while at the same time eliminating unnecessary expenditure in the development of new military aircraft. So why did the TSR.2 go seemingly unchecked?

The basic argument points to a lack of leadership within the industry, and the failure of BAC to appoint overall responsibility for the TSR.2 programme to a single figure. While this contains an element of truth, control in each of the manufacturing centres, Warton and Weybridge, was being overseen by a single representative; in Weybridge by H.H. Gardner, project director, and in Warton by F.W. Page. Gardner in Weybridge was also assisted by G.S. Henson, the project leader. It was not until late 1964, when the TSR.2's problems had become almost unmanageable, that BAC asked Page to assume overall control of the project.



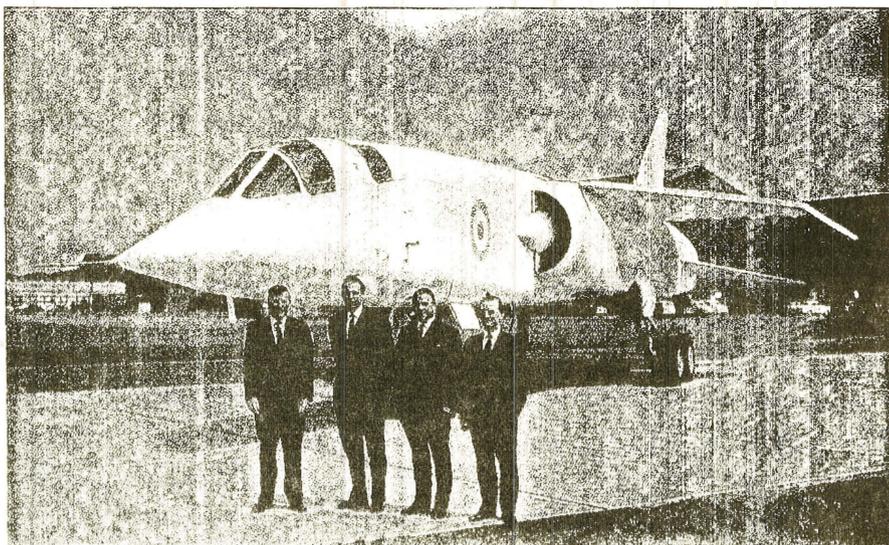
Right, TSR.2 crews pose in front of their charge. Left to right: test pilots J. L. Dell, D.M. Knight and R. P. Beaumont, and chief test navigator Donald Bowen.

Although this appears to confirm the argument, the project within BAC was being controlled by the Advanced Design Conference which, in itself, was influenced mainly by the Vickers contingent. As the lead contractor, Vickers was under constant pressure to agree a specification in areas where its knowledge was limited, while at the same time failing to heed the advice from its partner, English Electric.

Even so, from the accounts of that period it appears that any appointments within BAC had little effect on the outcome of TSR.2 affairs, mainly because of the bureaucracy at the time. From 1960 onwards the multitude of committees involved in the numerous aspects of the programme removed most of the control from the industry. In all cases the chair of the committee was appointed from outside the industry, and in some cases there was little, or even no representation from the manufacturer. While it accepted the mammoth challenge, BAC's management merely became an instrument swamped by bureaucracy, and as such had little freedom or ability to effect radical changes or impose stringent measures in areas where their ability was unquestionable, without reference to a committee.

Although it was not an issue in itself, the Ministry of Aviation dictated where two-thirds of the equipment was coming from, and half of that was procured direct by the ministry itself. What caused problems was the fact that the majority of these subcontractors bypassed BAC when seeking assurances on modification or cost increase. This left BAC with very little control, particularly with regard to cost.

One of the major influences on the



TSR.2 project was undoubtedly Duncan Sandys' Defence White Paper of 1957. It seemed there would be no other military aviation project of this magnitude, and the paper caused a great deal of concern, not only to the industry but also in the corridors of Whitehall and in the RAF.

The manufacturers had already been subject to the imposition of building methods, introduced from America, that were not totally conducive to the techniques originally developed by the industry itself. These controls merely added to the problems of development, mainly in that for the first time in Britain prototype aircraft were to be built in accordance with Weapon System Management, but, perhaps more significantly, to the Development Batch Procedure.

There was nothing to support the claim that Development Batch Procedure was as efficient as had been perceived; in fact it produced a nightmare of engineering problems. To have ten or more development batch aircraft, from

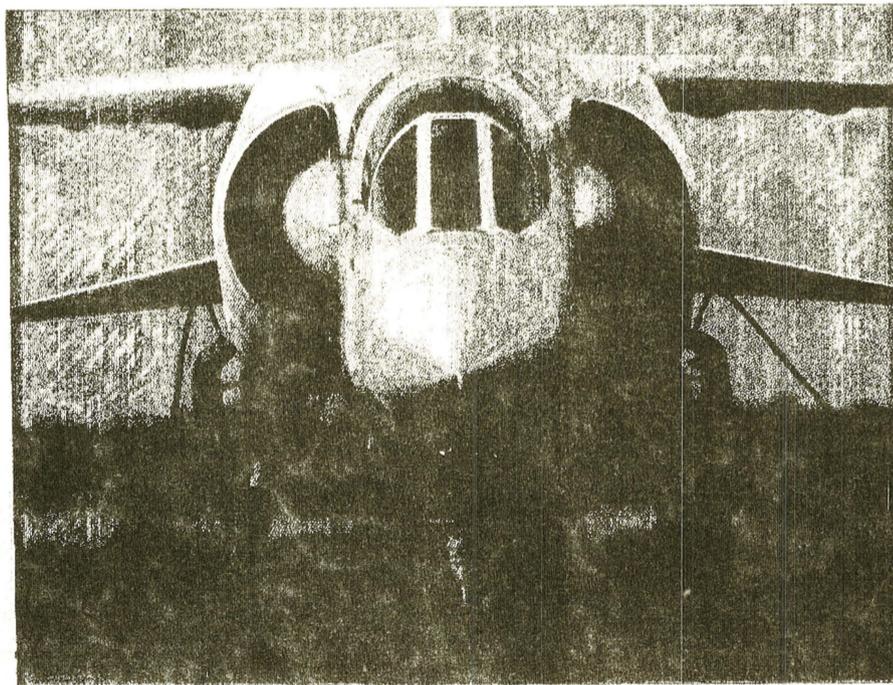
an early stage, creates tremendous problems simply because the initial design, construction and flight test programme always gives rise to a large number of modifications, in some cases quite extensive, which cause chaos in the development batch. This in itself is compounded by the fact that each development batch aircraft tends to be allocated a different task, and therefore has a different instrumentation and equipment standard. Thus any modification is only applicable to a specific development batch aircraft.

During the latter period of the TSR.2's development there was growing concern in America at the costs involved in developing new military aircraft in particular. A review of their methods indicated that a return to the experimental prototype system would be more beneficial, and in fact shortly after the F-111 programme the American industry began a reappraisal of this form of development, which led to the re-adoption of the prototype system.

The change in Britain's build policy had been introduced halfway through development of the Lightning, which had given the industry an insight into the associated problems with this method of manufacture. The turnaround in American policy substantiates the British industry's reluctance to adopt such alien working methods of build, particularly at a time when the manufacturer was also wrestling with the problems of a new and complex aeroplane. The abandonment of traditional methods was a significant factor in the costing of the TSR.2 programme.

Was the TSR.2 justified?

Some have questioned the validity of an aircraft with the capabilities of the TSR.2. Accepting that at the time the OR was drawn up with Britain's global commitment in mind, there is nothing to indicate that this requirement would not have continued well into the 1970s



Left, an imposing study of XR219 undergoing ground trials at Boscombe Down. Right, TSR.2s, the victims of a surfeit of committees, are rendered to scrap at Samlesbury.

and 1980s as a NATO commitment. During the period in question there was increasing speculation that any aggression would come from either the Far East or the USSR. This would require an aircraft to carry out deep-strike operations in these areas; and it should be borne in mind that at the time no other NATO country had an aircraft with the capabilities of those proposed for the TSR.2.

Even so, there was still the question of justification in a Europe where military co-operation had been on the increase through NATO. The belief that a bomber of the TSR.2's capabilities would have been somewhat of an overkill for operations within Europe led to the suggestion that a smaller aircraft be designed to carry out the strike role in this region, lacking the sophisticated electronics equipment. While there is no mention of specific aircraft numbers, it is difficult to assess the possible benefits of such a scheme. However, if the assumption was that the specification for a TSR.2 Mk I would remain as initially proposed, but with the aircraft numbers reduced, this leaves the benefits in savings open to question. Such a Mk I aircraft would still require the same amount of expenditure on development simply to produce a lesser number of airframes, while at the same time a TSR.2 Mk II would require extra funding to develop a bomber that would be carrying out a simplified strike role.

Questioning the technicalities

There was a belief that the TSR.2 programme was trying to achieve too much in too little time, and that insufficient research had been carried out into both its roles and equipment. As previously stated, much of this belief had come about as a result of the Sandys White Paper. The impending proposal by Duncan Sandys to place more reliance on missiles and rockets, rather than bombers and interceptors, meant that

many of the ongoing aviation projects were cancelled. This resulted in Whitehall staff who had any involvement whatsoever in the policies of military aviation looking to the TSR.2 as a form of salvation, and attempting to gain a foothold in the programme. Similar concerns within the RAF had the Service chiefs looking to the TSR.2 as an attempt to sustain the Service beyond what appeared to be virtual extinction. The programme became overwhelmed with sub-projects, resulting in some of the TSR.2's equipment becoming overdesigned and excessive in both weight and cost.

It seems clear from the proposals submitted by competing manufacturers that English Electric was the only company to have carried out detailed research work into an airframe which was capable of fulfilling the required role. This resulted in the contract being awarded to Vickers under the auspices of English Electric's design. Whether the lack of similar research by Vickers became detrimental to the outcome can only be a matter of conjecture, but certainly it caused an element of friction between the two companies when Vickers was appointed prime contractor.

Initially there seems to have been no official case presented against the actual requirement itself, although there were elements within the industry and the government who questioned the validity of some of the parameters. Vickers, as the prime contractor, was responsible for agreeing certain specifications, but its perception and expertise in key fields lacked detailed knowledge of the subject.

Initially English Electric had worked to a maximum of Mach 1.8 with the P.17A, a speed which they felt achievable and manageable. However, because the RAE and Boscombe Down had said the aircraft must achieve a service clearance of Mach 2, the aircraft had to be

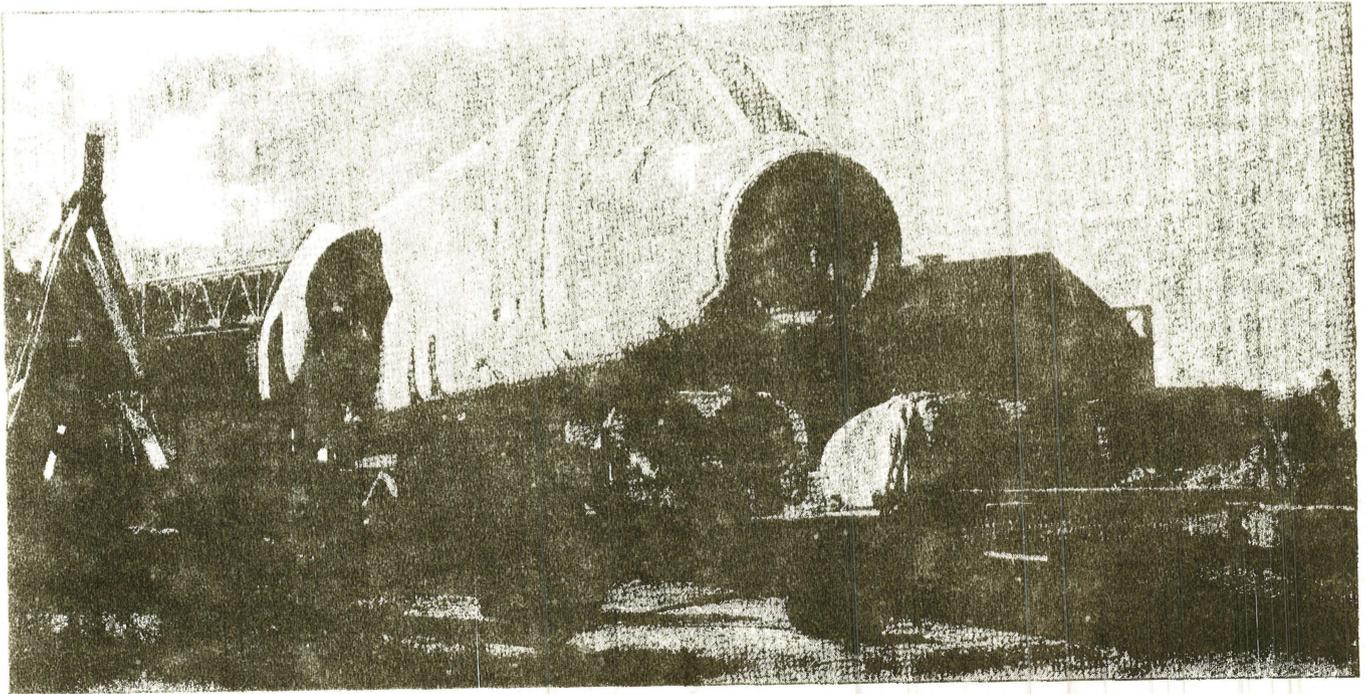
demonstrated with a ten per cent margin, Mach 2.2. Because the aircraft had a global requirement, the Service chief added that such a demonstration would have to be done at maximum worldwide temperature. Vickers's knowledge in this specific area was very limited, whereas English Electric's practical experience was renowned.

However, there appears to have been a breakdown in the consultation between the two companies, and English Electric's expertise was not consulted. If it had, a better understanding of the ensuing problems would have been realised, which would have generated more realistic figures. A maximum speed of Mach 1.8, plus the ten per cent margin, would have been better attainable and would have placed fewer demands on both the airframe and engines.

Wasted efforts

Other areas within the project were being agreed in a similar way. The specialist leaders who were looking after the various aspects of the aircraft such as electronics and hydraulics, who were appointed from the Vickers side, were agreeing parameters which, although attainable, would be very costly to implement. The stringent specifications had meant that many of the competing projects submitted for consideration had to be discarded simply because their concepts lacked the detail necessary to demonstrate the manufacturer's ability to build a bomber capable of conforming with the demands in the OR.

Although the parameters within OR.339 were said to have remained standard throughout, the OR itself was issued no fewer than four times between September 1957 and December 1958. Further modification to the specification resulted in a new OR being issued in March 1959, OR.343. Although this OR was to extend the parameters of OR.339 and incorporate further demands on the



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overall, it is claimed that the actual reason for its issue was to allow English Electric to sever its links with Short Brothers. These two companies had an agreement to develop and build an aircraft suitable for OR.339. Eliminating OR.339 effectively allowed English Electric to seek a new partner.

However, all the far-reaching demands appear to have come to nothing shortly after a meeting convened between the Chief of the Air Staff, Sir Robert Elworthy, and George Wigg, in which Elworthy was informed of the government's intention to cancel the TSR.2. Many of the essential systems within the OR, seemingly became relaxed, and the merits of the F-111 became sublime compared with the TSR.2. Why? Whatever the reason, political manipulation had forced the RAF to accept an aircraft whose specification fell short of the required standard.

There is increasing evidence to support the claim that the British government were manipulated by the USA into abandoning the British aviation industry, simply as a means of relieving the immediate pressure on Sterling.

In the same period the Ministry of Defence was seeking to replace its tactical transport aircraft. An OR had been issued, and a number of companies had submitted their tenders. In the autumn of 1964 the RAF visited the Shorts' fac-

tory in Northern Ireland to look at the Belfast. Shorts was told that the Belfast did not satisfy the tactical requirements of the RAF, but it was intimated that it should be proposed as a long-range freight aircraft. Meanwhile, when prime minister Harold Wilson returned from his visit to the USA in December, the Ministry of Aviation was instructed to alter certain parameters within the OR, but on no account was this information to be made known to the aircraft manufacturers. The manufacturers concerned were Hawker Siddeley and Shorts.

Although Shorts had an inkling that something was amiss, its new submission of the Belfast during the latter part of January, which included a STOL performance, was never put forward for consideration. On February 2 the government went ahead and announced the cancellation of the HS.681 and the intention to purchase the American Lockheed Hercules. Shorts asked why it had not been told of the change in specification, but it never received a response.

When Wilson was asked why the Shorts aircraft had not been presented for consideration, the answer was that the Belfast specification was inferior to that of the Hercules. It became apparent that the revised Belfast had not been studied simply because its specification proved far more in line than that of the

Hercules, but more importantly, the OR parameters had been changed simply to allow the Hercules to be the lead contender.

It seems that the Air Staff had been told of the political implications behind the cancellation of the TSR.2 and showed that, if a public issue was made of the fact, the government would have difficulties in procuring the F-111, not only because of the risk of confrontation with the opposition and the unions, but also because of public outcry that would inevitably ensue. This would certainly delay, if not endanger, any order for the overseas bomber.

The effects of cost, although significant in the cancellation statement, had been used to veil the principal reasons. The acceptance of a foreign aircraft whose capabilities fell short of the required standard, and whose own development was plagued with problems far in excess of anything the TSR.2 had encountered, indicates that substantial pressure had been placed on the British government.

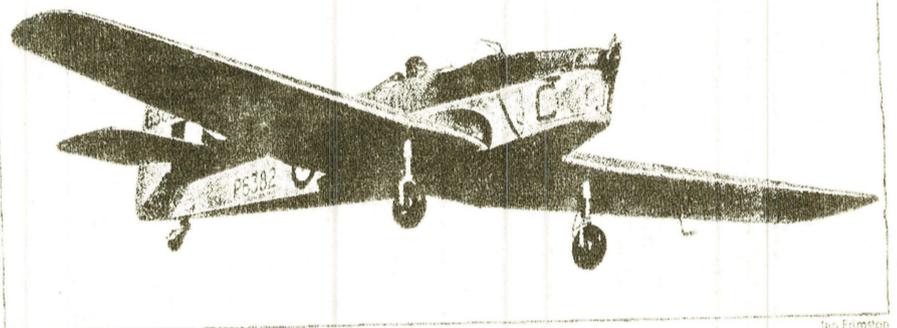
Final analysis

Was the TSR.2 the failure professed by the sceptics? No single answer can adequately refute the criticism directed at the TSR.2 project. To state that the project was the victim of its highly evolved technology is surely not taking

AIRSHOWS & EVENTS

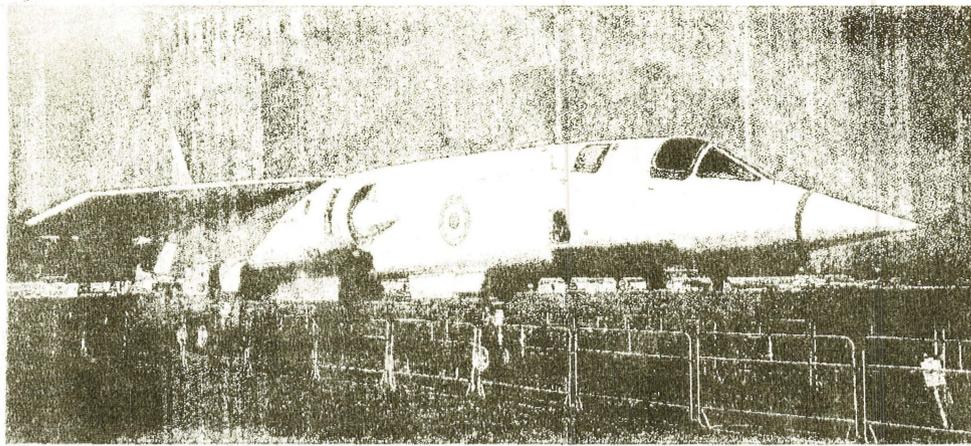
JULY

- 4-6 PFA International Air Rally & Exhibition: Cranfield, Beds; tel 01273 461610
- 4-6 Southampton Balloon & Flower Festival: Southampton Common, Hants; tel 01672 562277
- 5-6 Wings & Wheels Display: Booker, Bucks; tel 01494 520432
- 5-6 Wings, Wheels & Steam & Fly-in: Roughton Field, Bury St Edmunds, Suffolk; tel 01359 270238
- 6 Fenland Strawberry Fly-in: Fenland, Lincs; tel 01406 540461
- 6 Shuttleworth Summer Air Show: Old Warden Aerodrome, Beds; tel 01757 617288
- 6 Wings over Wales Collection Open Day: Swansea; tel 01656 729057
- 8-18 Guild of Aviation Artists Aviation Paintings of the Year Exhibition: Cansbrooke Gallery, 63 Seymour St, London W1; tel 0171 735 0634
- 11-13 Welsh Balloon Fiesta: Tredegar House, Newport; Tel 01672 562277
- 12-13 Flying Legends Air Show: Duxford, Cambs; tel 0891 516816
- 12-13 Manx Air Derby and Schneider Trophy Race: Jurby, Isle of Man; tel 011627 93913
- 12-13 Old Timers Flying Meeting — Wings & Wheels: North Coates Flying Club, Lincs; tel 01472 388850



Shuttleworth Collection Miles Magister P6382 performing at the Shuttleworth '97 Air Show at Old Warden on May 4.

- 12-13 Wings & Wheels Model Spectacular (inc full-size Pitts & Christen Eagle displays): North Weald, Essex; tel 01684 594505
- 13 D.H. & Biplane Fly-in: Popham Airfield, Hants; tel 01256 397733
- 13 International Helicopter Museum Open Cockpit Day: Weston-super-Mare, Somerset; tel 01934 635227
- 19 Shuttleworth Sunset Display III: Old Warden, Beds; tel 01767 627288
- 19-20 Families' Weekend: RAF Museum, Hendon, London NW9 5LL; tel 0181 200 1763
- 19-20 International Air Tattoo '97: Fairford, Glos; tel 01285 713300
- 19-20 International Bücker Fly-in: Brighton, N. Yorks; tel 01757 289065
- 20 D/F Radar, ASR reunion: Norfolk & Suffolk Aviation Museum, Flixton, Bungay, Suffolk; tel 0115 925 2879
- 20 Lancashire Aero Club 75th Anniversary Fly-in: Barton, Manchester; tel 0161 787 7326
- 20 Vintage Fly-in & Garden Party: Redhill, Surrey; tel 01737 822200
- 20 Yak Fly-in: Leicester, Leics; tel 0116 259 6804
- 23 HMS Heron Aviation Heritage Air Day: (no flying display): RNAS



Above, XR222 became the first TSR.2 to be exhibited publicly when it was shown at Cranfield in September 1973, as seen here. It is now at Duxford.

into account the fact that, during the initial stages of design and development, most of the electronics and avionics equipment was already at an advanced stage of its development and even went on to be used in other projects. Therefore this excuse can only be used as a fabrication to hide an alternative reason. Although the TSR.2 presented a steep learning curve, the majority of engineering difficulties uncovered during the development were overcome, and many

of the techniques used on the TSR.2 were adapted or modified for other projects.

The integration trials carried out on XR221 using the development nav/attack system proved extremely successful, and justified the industry's confidence in achieving its goal. A multipurpose weapon system of this calibre had never been considered on such a scale before, and the complex avionics which were destined for the programme had, up to that time, been considered as individual items. These were now to be brought together to form a weapons platform that would enable the TSR.2 to fly in such diverse environments that little regard would need to be given to the

weather and no form of self-defence would be required.

Given the advances that would be made in electronics and radar over the following decade, there was no reason to doubt that an updated version of the equipment would be available before the aircraft entered service. This is not to say that the project would have escaped further problems necessitating an increase in investment, but likewise the eventual outcome would have been far more beneficial, not only to the country by exporting this technology, but, perhaps more importantly, to the RAF.

There is little doubt that the Americans were concerned at the lead Britain had in this type of technology, and of the interest shown by other nations. Not only was Australia showing considerable interest in the bomber, but Sweden was also studying the TSR.2 as a possible alternative to its Viggen. After the cancellation Britain was seen as a country of waste, embarking on good sound projects only to cancel them just when they were beginning to show promise.

One of the main problems was Vickers being declared the prime contractor. It had little knowledge or experience in supersonic development, and was agreeing parameters on subjects in which its expertise was strictly limited. Although the parameters could be achieved, it would ultimately prove costly to do so.

Yeovil, Somerset, tel 01935 456711

- 24 Lowestoft Seafront Air Display: Lowestoft, Suffolk; tel 01502 562111
- 25-27 International Helicopter Museum Super Helidays: Weston-super-Mare seafront, Somerset; tel 01934 639227
- 26 Air Day: RNAS Culdrose, Cornwall; tel 01126 774421
- 26 Derby Aero Club Fly-in: Egginton, Derby; tel 01283 733803
- 26 Music in the Air: Museum of Army Flying, Middle Wallop, Hants; tel 01980 674428
- 27 Air & Classic Car Show: Braunton, Devon; tel 01297 880259
- 27 Allied Memorial Air Day: Perranporth Airfield, Plymouth; tel 01752 364850
- 27 Big Thunder Open Day: Bruntingthorpe, Leics; tel 0116 2478010
- 27 Brooklands Classic & Vintage Fly-in: Brooklands Museum, Weybridge, Surrey; tel 01932 857381
- 27 Julie Green Memorial Fly-in: Compton Abbas, Dorset; tel 01747 811767
- 27 Midsummer Fly-in: North Weald, Essex; tel 01992 524510
- 27 Wallop Challenge & Flying Display: Museum of Army Flying, Middle Wallop, Hants; tel 01980 674428

AUGUST

- 1 American Air Museum Official Opening: Duxford Airfield, Cambs; tel 01223 835000
- 1 Fly-by-Wire: lecture by Richard Collinson, Yorkshire Air Museum, Elvington, York; tel 01423 887313
- 2 American Air Force on Film: Cinema presentation in hangar at Duxford Airfield, Cambs; Huntley Film Archive; tel 0171 923 0990
- 2-3 Sunderland International Air Show: Sunderland, Tyne & Wear; tel 0191 533 2000
- 2-3 White Waltham Airshow '97: White Waltham, Berks; tel 01628 823272
- 2-4 Vintage & Classic Anglo-Irish Fly-in: Popnam Airfield, Hants; tel 01256 397713
- 3 Bognor Birdman Competition: Bognor Regis, Sussex; tel 01903 716133
- 3 Shuttleworth Military Pageant: Old Warden, Beds; tel 01767 627288
- 3 Wings over Wales Collection Open Day: Swansea; tel 01656 729057
- 6 International Air Day: RAF St Mawgan, Cornwall; tel 01637 872201
- 8-10 Bristol International Balloon Fiesta: Ashton Court, Bristol; tel 0117 953 5684 (plus Night Glow Aug 7)

OVERSEAS

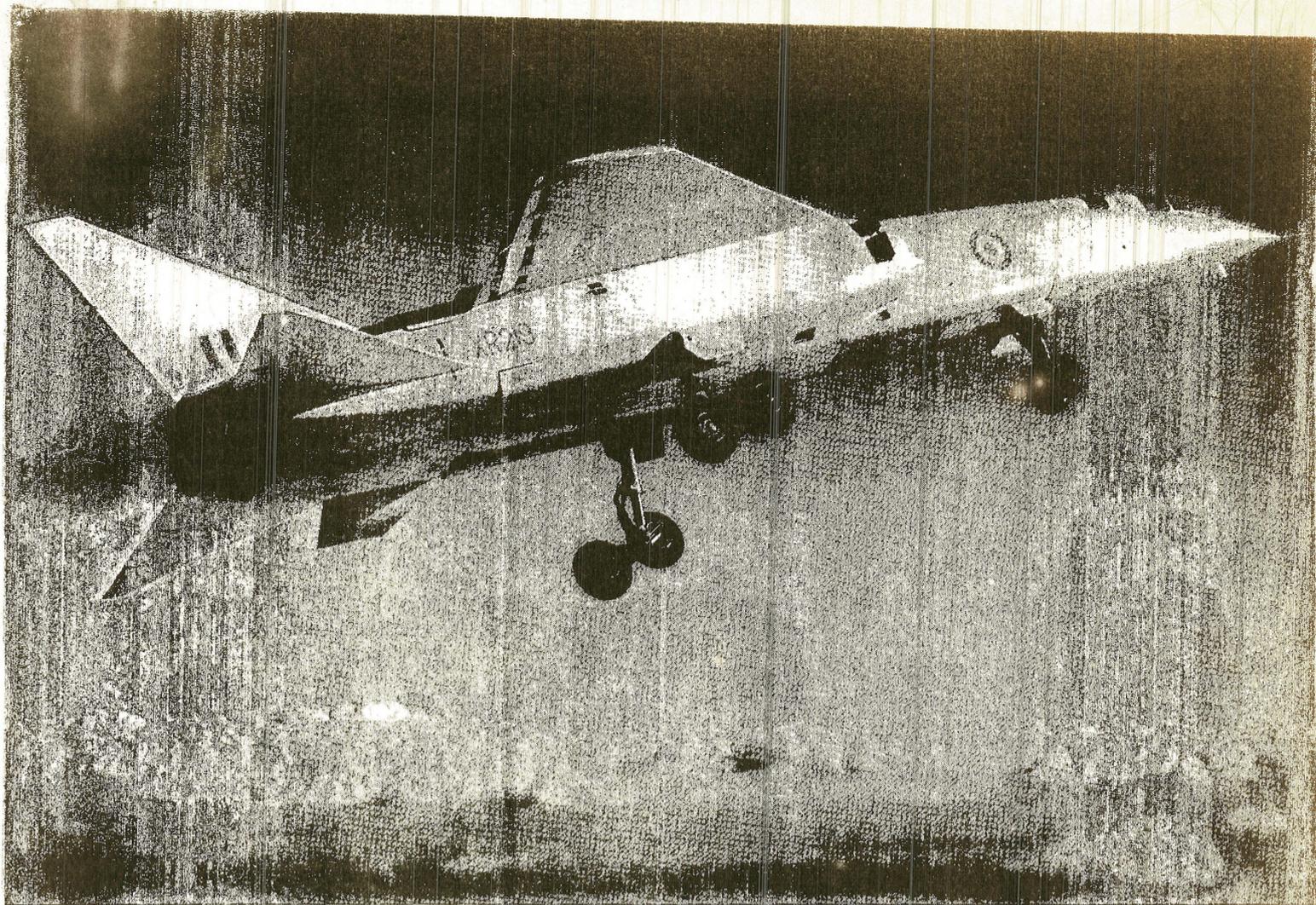
JULY

- 4-6 Belgian Air Force Display: Koksijde, Belgium
- 5-6 Flying Legends Air Show: Rotherburg, Germany; tel 00 49 374 431980
- 12-13 Kjevik Airshow '97: Kristiansand Airport, Norway; tel 00 47 38 01 20 50
- 12-13 Golden Age Biplane Fly-in: Old Rhinebeck, New York; tel 00 1 914 758 9610
- 18-20 50th RSA (French Horn) (Alders) International Rally: Epinal-Mirecourt, France; tel 00 33 1 4228 2354
- 19-20 Flying Legends Air Show: Barth-Straßburg, Germany; tel 00 49 374 431980
- 19-20 Homebuilt and Old-Times Fly-in: Karon, Switzerland; tel 00 49 28 211778
- 25-27 Norseman Floatplane Festival: Red Lake, Ontario, Canada; tel 00 1 807 727 2309/fax 00 1 807 727 3980
- 26-27 Flanders Fly-in: Ostend, Belgium; tel 00 32 16 256616
- 27 AC Sanicole Display: Leopoldsburg, Belgium; tel 00 32 1134 2739
- 30- Aug 5 CAA Oshkosh '97: Oshkosh, Wisconsin, USA; tel 00 1 414 426 4800/fax 00 1 414 426 4828

AUGUST

- 8-10 Abbotsford International Airshow: Abbotsford, British Columbia, Canada; tel 00 1 604 852 8511

Aeroplane's calendar of events is published throughout the airshow season. All information here is correct, to the best of our knowledge, at the time of press. Dates and details change, so check on the contact numbers given if you are in doubt. Notice to Show Organisers: is your event listed here? If not, telephone 0171 261 5819.



CONCEPT *versus* REALITY-1

A detailed assessment of the TSR.2

Aclaimed in its time as the world's most advanced aeroplane, the British Aircraft Corporation (BAC) TSR.2 has been making headlines in the aviation media since its inception during the late 1950s. Although much of the sophisticated equipment intended for it was never put to a conclusive test, there still remain mixed feelings over the actual potential of the aircraft and its equipment. This has resulted in a number of questions being raised, principally "Was the TSR.2 the aircraft we have been led to believe it was?" The story of the project is very emotive, and high emotions can often veil the truth. Opinions are now emerging which question the claims that the TSR.2 was indeed the leap in aviation technology we have been led to believe, and suggest that the aircraft, together with its equipment, was either the wrong combination or that its equipment was archaic in its design principles to the extent that the bomber would have failed to satisfy the needs of the RAF.

While the programme did help to bring about radical changes within the industry itself insisted upon by the government, it still failed to address the more complex issue of aircraft procurement which had been the subject of a White

Cancelled in 1965, the BAC TSR.2 strike aircraft was mourned as a tragic loss to the UK's defence potential. But was it really the technological leap it was made out to be? In this new two-part feature, FRANK BARNETT-JONES re-examines the evidence

Paper in 1955-56, following the controversy over the Supermarine Swift.

In the 1950s Britain needed an aircraft to maintain its global commitment. However, major changes occurred during the period of the TSR.2's development which were to alter significantly Britain's standing as a major world power. This led to the belief in certain quarters that there was no longer a need for a bomber with the capabilities of the

TSR.2, and that the requirement should therefore be reviewed and reissued. Although this alone would have reduced the primary role, there was no evidence to support the claims that it would have reduced the cost.

The systems within the TSR.2 were closely interrelated, and any major reappraisal and significant change midway through the development programme would have meant virtually discarding what had been achieved up to that point and beginning again. Even if new initiatives were to include equipment currently available, which was proposed, it would have required major changes simply to make the equipment adaptable to the new configuration, demanding further investment.

In an attempt to address some of the criticism, I shall review the more contentious points that have been directed at the the TSR.2 and its development programme.

Unorthodox design

Simplicity in engineering design, consistent with meeting design objectives, is normally considered a virtue, and certainly was in the case of the English Electric Canberra. However, the key design requirements for the TSR.2 were

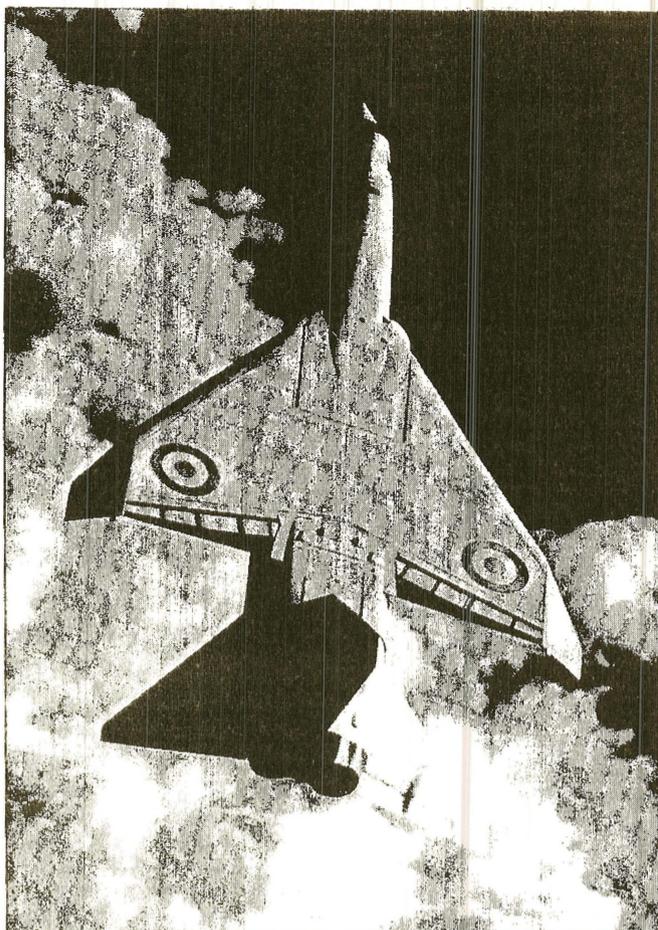
Heading photograph, taken during the maiden flight of TSR.2 XR219, on September 27, 1964; Roland Beamont was the pilot. Even 33 years later the design does not look out of date. **Right**, the TSR.2's small delta wing gave a high wing loading and was an extremely strong structure.

far more complex and demanding, including the ability to cruise at high speed at very low level for long distances, and a terrain-avoidance capability. Such a requirement was bound to impose additional and substantial loads on the airframe. Secondly, there was a need for long distance cruise at the tropopause (34,000–35,000ft) at Mach 2.

Aerodynamically, structurally, and including cost, reliability and fatigue considerations, both requirements were best met by employing a highly-swept, low-aspect-ratio fixed wing of the type chosen. The airfield requirements were met by large, relatively soft tyres, powerful brakes, heavily-blown flaps and a large brake parachute. There were no requirements for long-duration patrols or air-to-air combat, which would have dictated a variable-geometry wing and a lower wing loading.

Design consideration

The experience gained by English Electric in building Britain's first jet bomber, the Canberra, coupled with its knowledge of flight at high Mach numbers gained with the P.1A, the precursor to the Lightning, had provided the company with the potential to embark on an advanced programme known as the P.17A. This gave the company a distinct advantage over its rivals, as submissions proposed by competing manufacturers demonstrated. Theirs



were simply paper concepts of designs which lacked essential details necessary for an effective evaluation.

Much of English Electric's investment at the time had been made in equipment that would enable the company to attain a standard in supersonic research that would place it at the forefront of this aspect of flight technology. English Electric's initial detailed proposals for a

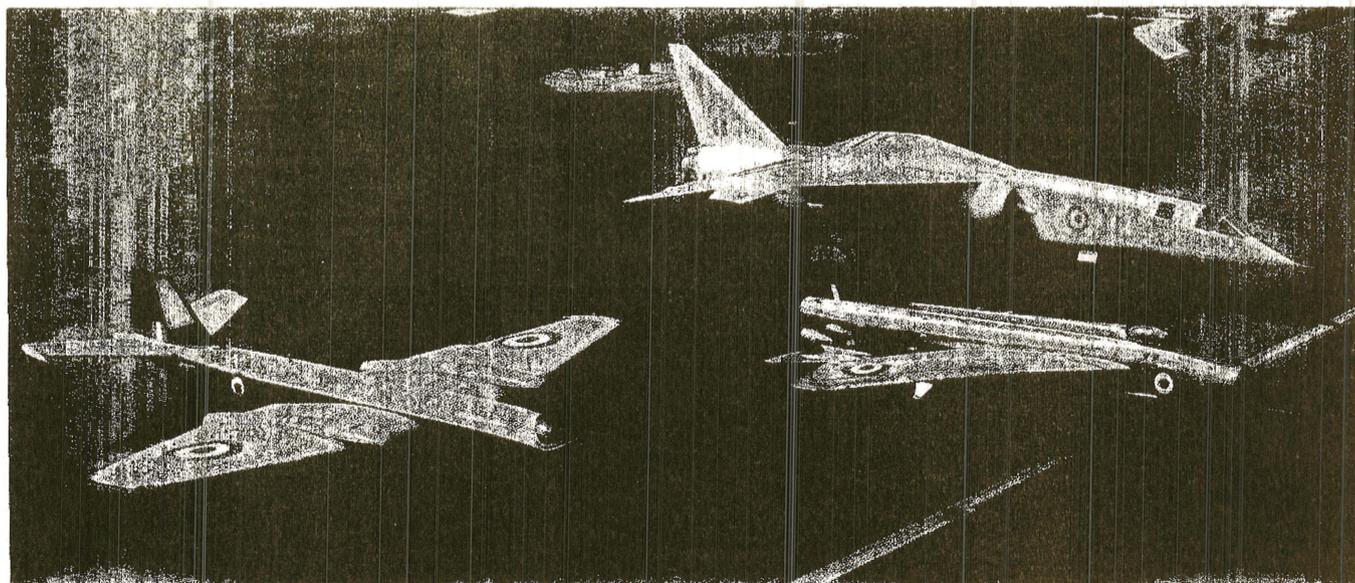
Below, English Electric's pedigree on show at Warton. Its lineage proved that the company was capable of building a suitable aircraft. TSR.2 XR219 shares the tarmac with Lightning XR755 and Canberra B.2 WD937.

Canberra replacement demonstrated its ability to undertake such a demanding programme and, had the company been allowed to proceed with the P.17A design unencumbered by political intervention, the outcome could have easily provided the RAF with a bomber earlier than the proposed TSR.2. Likewise, the ensuing creation of BAC would have caused far less damage to the programme simply because the P.17A would have been at an advanced stage of its development programme, and less pressure would have been placed on both the project and the associated companies.

Because of previous political restriction, the design of the TSR.2 was perhaps the first real attempt at producing a multi-role combat aircraft. This meant that the designers had to give a great deal of consideration to an aircraft that would have to fulfil a number of widely conflicting criteria, not only because of the varied flight envelope, but also because the fuselage would need to carry a great deal of equipment and an extensive fuel load.

The eventual design of the aircraft was carried out by what had been two separate, competing companies which had differing views on how the requirements should be met. While Vickers had gained experience in manufacturing techniques from its association with Supermarine and in production of the Viscount airliner, it was English Electric's experience in supersonics and its processing expertise with the Canberra that were to be the key elements.

Although some considered the design concept of the TSR.2 to be ineffectual, in that what was produced was a simple airframe pushed to the limits of its



Right, how the English Electric P.17A may have looked, had the company applied the swing-wing technology from the Swallow as proposed by Barnes Wallis.

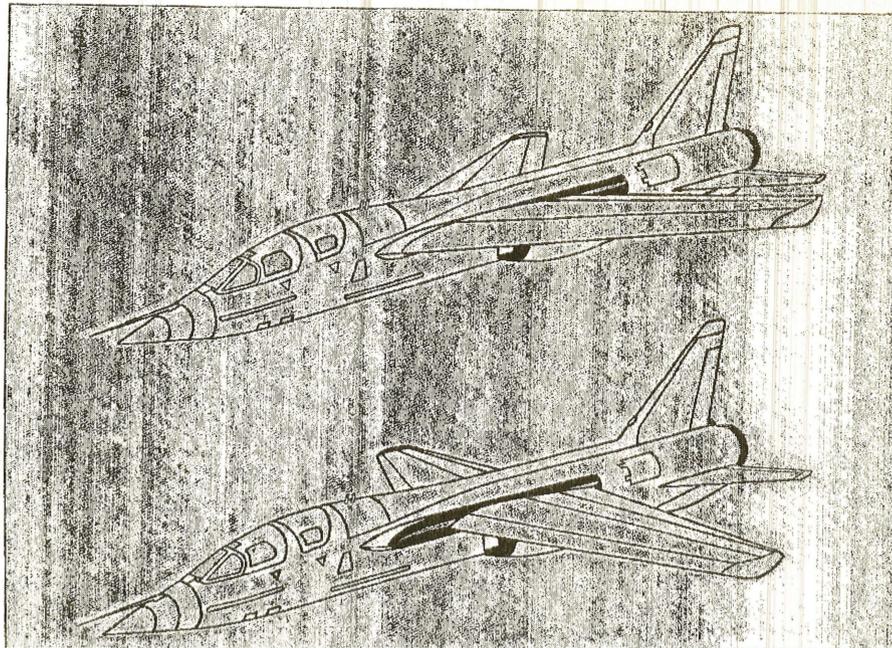
practical use, others, particularly Britain's main aerospace establishment, considered the design and structure to be a major advance in airframe technology. This actually gave the establishment significant insight into how such a modern airframe would stand up to attack, when TSR.2 airframes were used in lethality trials at the Proof and Experimental Establishment at Shoeburyness.

In recent years electronic management systems and fly-by-wire technology have allowed even greater flexibility in unorthodox design. At the time such systems were on the fringes of development, and would not be available for several decades.

Maintenance & serviceability

One of the main concerns was the way the airframe manufacturer had approached the problems of maintenance and serviceability. Previous aircraft on RAF charge had a somewhat poor reputation when it came to servicing and, with this in mind, the Operational Requirement (OR) insisted that consideration be given to that aspect. However, there were opinions expressed indicating that no such consideration had been made, and that the TSR.2 in no way differed from aircraft on charge at the time.

The TSR.2 was designed with backup systems, and in some cases these were even triplicated in an effort to ensure that no single failure would render the aircraft unserviceable. It was also intended that many of the aircraft services would incorporate systems whereby the groundcrew could easily and quickly locate and resolve faults. In an effort to ensure that problems in the electronics systems were quickly identifiable, BAC proposed to use TRACE. This



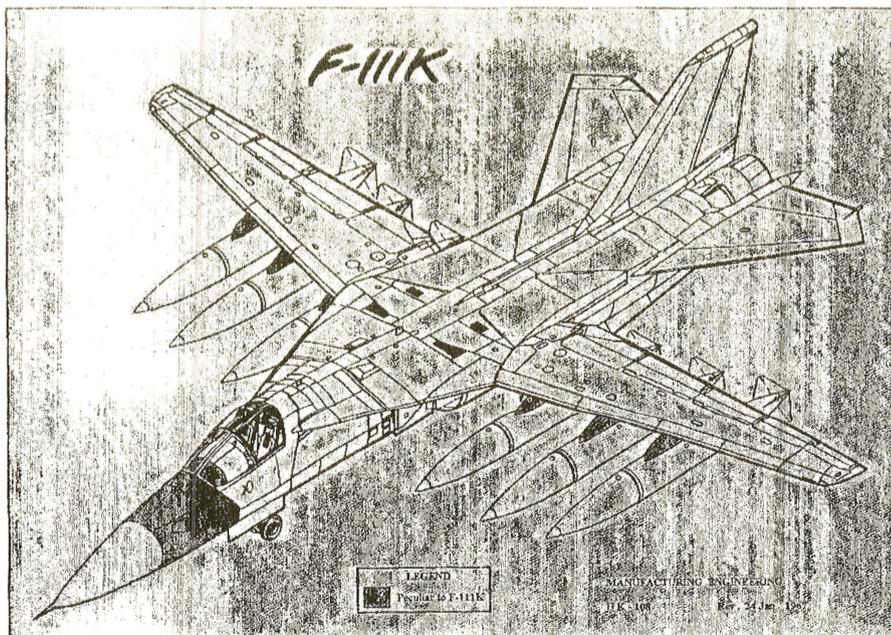
consisted of a portable, mobile test vehicle capable of carrying out 1,000 checks per hour. The unit was already in service with the Royal Navy, testing the Blackburn Buccaneer, and also with the French government. A civilian version was being used by BOAC to check both VC10 and Boeing 707 flight systems.

The unit was plugged into the aircraft and followed a concise set of instructions fed into it by tape. The initial checking was of TRACE itself, whereby it would examine all the relevant circuits relating to those it would be checking within the aircraft. Having determined its own integrity, it would then check the aircraft's equipment. The unit would probe the circuitry of the system being checked and, in the event of finding a fault, would first recheck the integrity of its own systems before displaying to the operator a unique error code specific to a set piece of equipment. This would enable the ground crew quickly to locate and replace the faulty component.

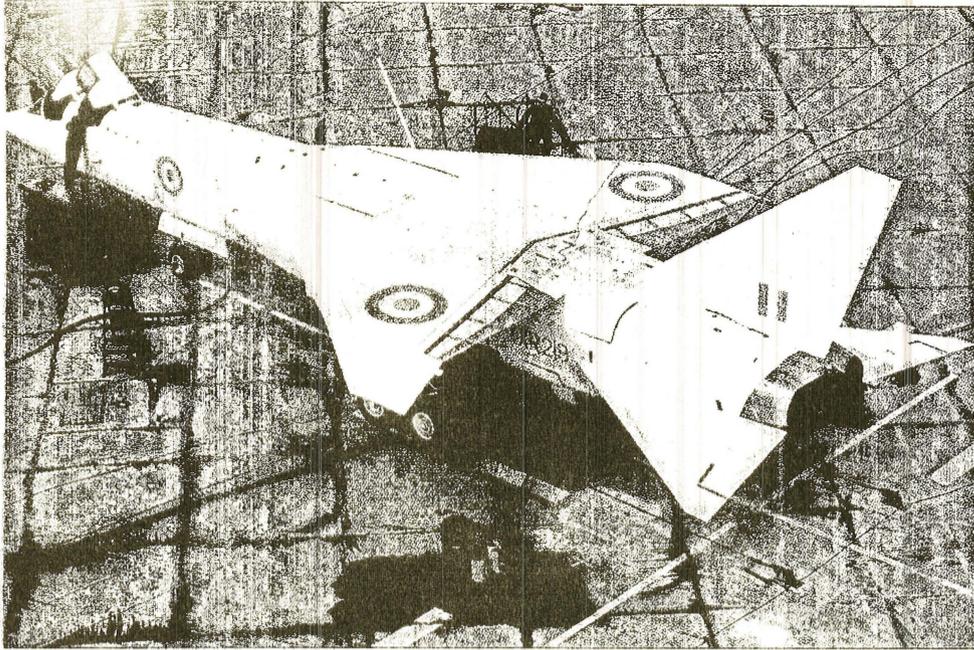
Being a mobile system and easily air-transportable, TRACE was capable of being used at main bases or forward tactical airstrips. It would have gone a long way in eliminating human error while providing a quick fault-detection system.

At the time, comparisons were also being made with the General Dynamics F-111, which was considered far less expensive to maintain than the TSR.2. What is not made clear is the level to which this applies. The F-111 had nowhere near the same amount of inbuilt redundancy, which would consequently impose a high standard of maintenance, whereas in the TSR.2 the multiple systems would allow a measure of leniency in maintaining the aircraft. This is borne out by the demand in the OR that the aircraft should be able to remain on readiness at a forward tactical airstrip for three days with no maintenance, and for a period of 30 days with minimal maintenance.

This particular aspect was also emphasised during the costing exercise between F-111 and TSR.2, although it appears that little consideration was given to the actual benefits of the TSR.2's multiple systems. The Specific Operational Requirement (SOR) issued for the F-111 had stipulated a reliability and maintainability clause, but it appears there was no similar clause stipulated in the TSR.2 contract. This led to the belief that the F-111 would not only be easier to maintain than the TSR.2, but would also be relatively inexpensive. The assessment process was based on previous experiences with RAF aircraft, rather than on the actual stipulations within the OR. The biggest cause for concern regarding TSR.2 servicing and maintenance lay in the engines.



Left, the F-111K. The shaded areas denote the major modifications which would have applied to the UK versions, particularly the refuelling probe and the avionics bay in the nose.



Left, TSR.2 XR219 on the line at Boscombe. The type would have made an ideal addition to the NATO commitment.

Variable geometry

One criticism put forward regarding airframe design centres on the lack of a variable-geometry wing on the TSR.2. This subject has been mentioned a number of times, and appears to be a bone of contention. Today the advantages of altering an aircraft's wing configuration in flight are more easily understood.

The wing of the TSR.2 was designed as a compromise in order that the aircraft could fulfil the varied demands in the OR and at the same time retain an acceptable performance together with a realistic fatigue life. The small delta wing gave a high wing loading with a minimal gust response. The anhedral section of the outer wing, together with high-lift devices on the trailing edge, gave stable control in the low-speed, low-level envelope.

The wing itself was an extremely strong structure, a point which had been demonstrated in fatigue tests at the Royal Aircraft Establishment (RAE) at Farnborough, when the wing had stood up to stresses far beyond the original design limits. The aircraft was given extended range by using most of the wing as a fuel tank. The argument appears to

concentrate on performance when operating from a semi-prepared, grass strip, defined as one that could accommodate the Douglas DC-3/C-47, which in public transport mode, fully loaded, required a take-off run of 1,298yd. The logistics of a variable-geometry wing for the TSR.2 had been studied by English Electric some three years before America had decided to adopt such a configuration for its F-111.

One of the biggest problems facing the British industry at the time was its inability to assess how competent it was at quickly overcoming the problems of unorthodox design concepts, and this went some way towards persuading the company to dismiss the possibilities of using such a wing. Even then, the benefits were still relatively unknown because of the limited research, which had virtually ceased in 1957 when the government had withdrawn its funding of the Barnes Wallis project. However, the more basic problems were those associated with the extra cost of develop-

Below, the huge brake chute on the TSR.2 raised fears that it may have been too large and imposed stresses on the the airframe for which it had not been designed.

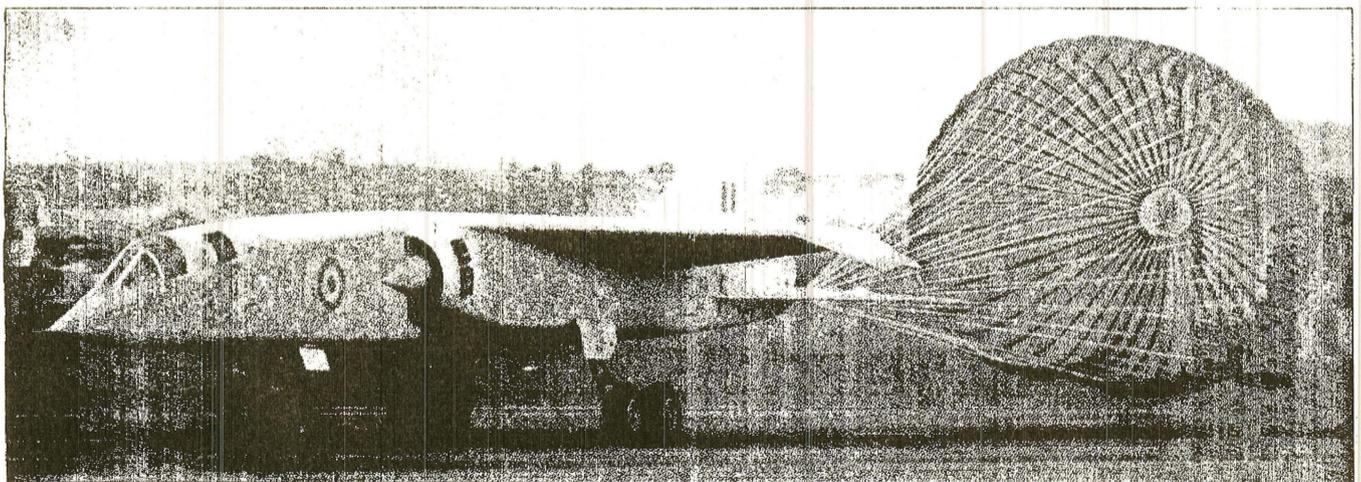
ment, together with the penalties of increased weight on the airframe, coupled with the prolonged delays such research would have caused.

The Barnes Wallis project was significant in assisting General Dynamics in the variable geometry of the F-111. However, the company was still hindered by massive problems, and in fact lost a number of aircraft during the development programme. The problem became one of the main areas of contention which contributed to the increases in cost and time overrun of the F-111 programme, and demonstrated that BAC was correct not to adopt variable geometry.

Out in the field

The operation of the TSR.2 from a semi-prepared field was to be considered as a "one-off" mission only, in the event of a pre-emptive nuclear strike. The aircraft and necessary stores would be installed at one of the many sites throughout Europe, where the aircraft would then wait until called upon to carry out a specific mission. The bomber would carry only a light weapon load, together with minimal fuel, topping up from a tanker either en route to the target or on its return leg. On completion of its mission the aircraft would then return to an available operational base, where it would receive the necessary line maintenance and servicing in readiness for further missions.

There were misgivings regarding the ability of an aircraft with the specification of the TSR.2 and its load to take off from a semi-prepared strip within the parameters laid out in the OR. Although the distances and weight limits were specific, the practicalities had never been assessed. Under the circumstances it is difficult to imagine that any such trial would be made other than within a strictly controlled environment. Likewise, whether such parameters would apply in the heat of battle, especially a nuclear attack, is highly improbable, and aircraft would have been scrambled re-



ardless of the practicalities.

It was discovered early in the flight trials that such was the taileron power and increased angle of attack from extending the noseleg, that it was calculated the aircraft would need a take-off run of 650yd. It was found, however, that the use of an extending noseleg would not be needed, as the taileron power was far greater than originally calculated.

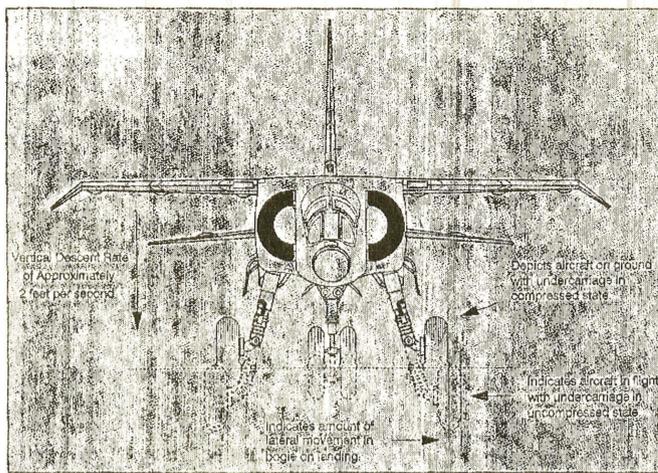
The argument claims that a variable-geometry wing would allow the aircraft to take off with a heavier payload using a similar length run, resulting in a more controllable and stable aircraft in the critical low-speed envelope. It has since been suggested that consideration ought to have been given to vectored thrust as an aid to short-field take-off and landings. But even in the 1990s research continues to probe the problems associated with supersonic VSTOL.

A field alternative

Although intended as a measure to reduce reliance on the use of fixed, concrete runways in the event of a nuclear strike, the concept of setting up a semi-prepared site, together with the installation of a single TSR.2, does not seem a logical or viable concept, especially as this no longer appears to be an essential requirement in today's bombers, such as the Panavia Tornado.

There were other ways in which the Air Staff could have approached the problem of moving away from runways while retaining the ability to land on a prepared surface. In 1959 Britain began a huge road-building programme which was eventually to provide a countrywide network of dual and three-lane carriageways. If, during a conflict, the

Right, the Canadian Avro Arrow, cancelled under similar circumstances to the TSR.2, illustrates some of the problems of having a long undercarriage leg that retracts into the wing. **Below**, a rare photograph of XR219 showing the noseleg extended. It was proposed to use such a device when taking off from unprepared fields.



Left, a diagram outlining one theory in the problems associated with the TSR.2's undercarriage problems.

Complex undercarriage

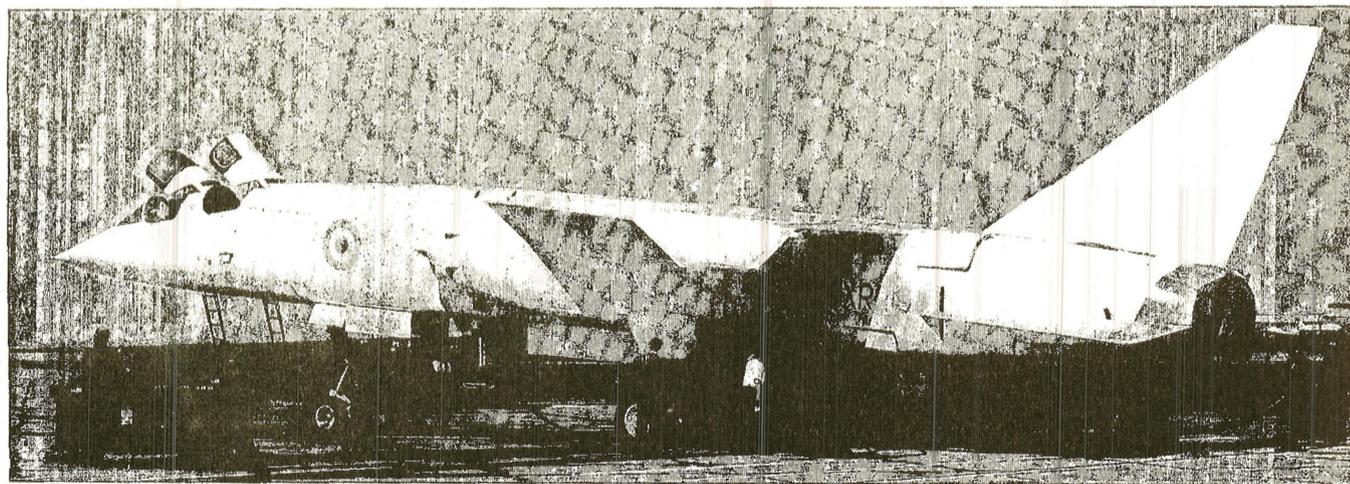
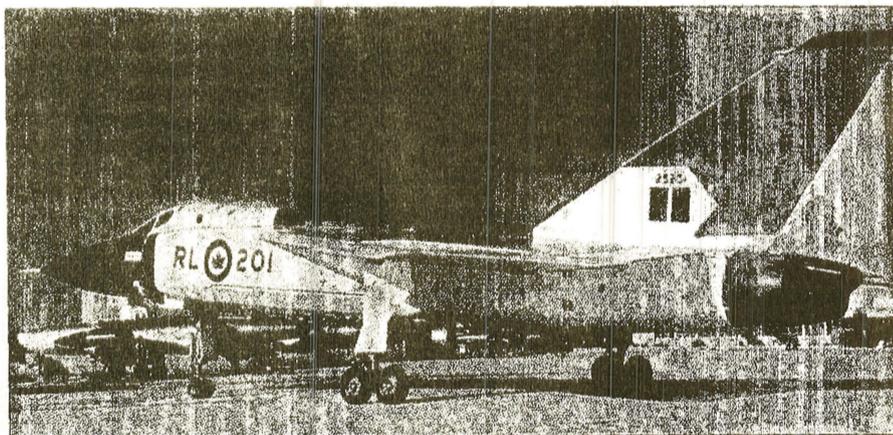
The prime consideration in the undercarriage design was the accommodation of a rough-field landing requirement. This necessitated a landing technique similar to that used by carrier-borne aircraft, so the system had to be strong to withstand a non-flare landing on a semi-prepared surface.

The responsibility for this part of the aircraft lay with Vickers, which designed the undercarriage with a simple hydraulic telescopic tube arrangement, together with a tandem-wheel configuration. A similar system was already in use on the Vickers Valiant, so the technicalities were understood. However, if one studies the undercarriage on the Valiant it will be seen that while the design characteristics are similar, because of the difference in physical layout the results are somewhat different. In the landing phase the weight of the aeroplane is transferred from the wing to the undercarriage, and the wheel makes vertical contact with the ground at approximately 2ft/sec. Ideally, therefore, the oleo compression should move at the same vertical angle to place less stress on the undercarriage.

On the TSR.2 this was not the case,

enemy was able to infiltrate our defences and damage the bomber bases, then it would seem only logical to move such aircraft to a motorway or dual carriageway, where it would have a virtually unlimited operating capacity. Such a possibility was demonstrated in 1981, when a Sepecat-BAC Jaguar took off and landed on a two-lane motorway just outside Blackpool.

Similar concerns regarding the vulnerability of runways led to NATO member countries using front-line aircraft to conduct similar trials from main roads and motorways. Had the TSR.2 been required to conform to these standards it should have presented little or no problem with its shoulder wing and narrow wingspan, which was less than that of many of the aircraft used in the trials.



Because the oleos splayed out to accommodate the maximum-track requirement. At the same time the large ankle on the bogie extended the wheels well beyond the point where the vertical weight was being applied. This meant that the compression of the telescopic legs was not vertical, as on the Valiant, but at an angle of approximately 15°. Therefore, as the wheels touched the runway and compression began, the bogies would be dragged inward as the legs compressed. Such a reaction not only imposed stress on the ankle, but also induced a strong weaving effect on the tandem wheels as the aircraft settled on the undercarriage. There was evidence to show that the system was vulnerable when the ankle on XR219 sheared without warning during trials at Shoeburyness.

When the Jaguar was built the designers had to consider a similar problem to that on the TSR.2: the legs needed to splay in order to conform with the maximum-track requirement. As a result the Jaguar employed a form of levered suspension which avoided lateral forces on the oleo strut and was thus ideal for rough-strip operation. Such a system would have been ideal for the TSR.2.

There was a suggestion that the TSR.2 should have employed an undercarriage system that retracted into the shoulder wing. Had such a mechanism been adopted, it might have created more problems than it solved. Apart from the obvious design and engineering problems of having a much longer under-

carriage leg, the wing itself would have required a stronger structure to cope with the effects associated with soft-field landings. Even more importantly, having the undercarriage retracting into the wing means the wing cannot be used to anywhere near the same extent, for the carriage of external stores, for example. Similarly, it would have reduced the amount of fuel the wing could carry.

Even today, designers employ similarly complex methods simply to get the gear in as small a space as possible. The undercarriage system on the TSR.2 was built to satisfy a number of requirements which no longer appear to be a prerequisite in modern-day military aircraft.

Problem engine

Of all the difficulties surrounding the TSR.2, perhaps those concerning the engines were the most notorious. Not only because of the problems that plagued their development, but also owing to the anticipated difficulties of on-board maintenance.

From the very beginning the airframe manufacturer had wanted an established engine in the airframe to remove the obvious problems of developing a new airframe in conjunction with a new engine. When Bristol Siddeley Engines Limited (BSEL) was given the contract, little did it realise the problems ahead. Although the Olympus was a reliable unit already in service, the transformation from subsonic to supersonic created an almost entirely new engine, resulting in untold engineering and financial problems and further damaging the programme's credibility.

Before the contract was awarded BSEL had submitted a realistic estimate, but the Ministry queried the figure and instructed BSEL to re-evaluate its tender. This it did, but the new esti-

mate was considerably more than the original submission.

The demands in the OR led to a number of discussions between the Air Staff and the engine manufacturer. Sir Stanley Hooker, BSEL's chief engineer, had challenged one of the Air Staff, Sir Geoffrey Tuttle, on the validity of the ranges and speeds insisted upon. Hooker believed that "the figures had simply been carved out of the sky and the development costs involved in attaining that range would be £1 million per mile over the last 100 miles". Such demands would be out of all proportion to the benefits, and Hooker therefore requested they accept a lesser figure of around 800 to 900 miles in an attempt to arrest the development costs and help reduce the fuel load. This warning went unheeded, and the original specification remained.

The OR stipulated a number of requirements that would impose a huge burden on those servicing the aircraft. The BSEL engineers had expressed concern at the problems of working on XR219 at Boscombe Down. Difficulties were arising from the simplest of tasks, created by the fine tolerances which restricted access to the engines. The method by which the engines were mounted in the airframe was very similar to that employed on several of the concurrent Dassault Mirage series of aircraft and, for that vintage, was not impractical. Specially-designed trolleys and practised crews were required.

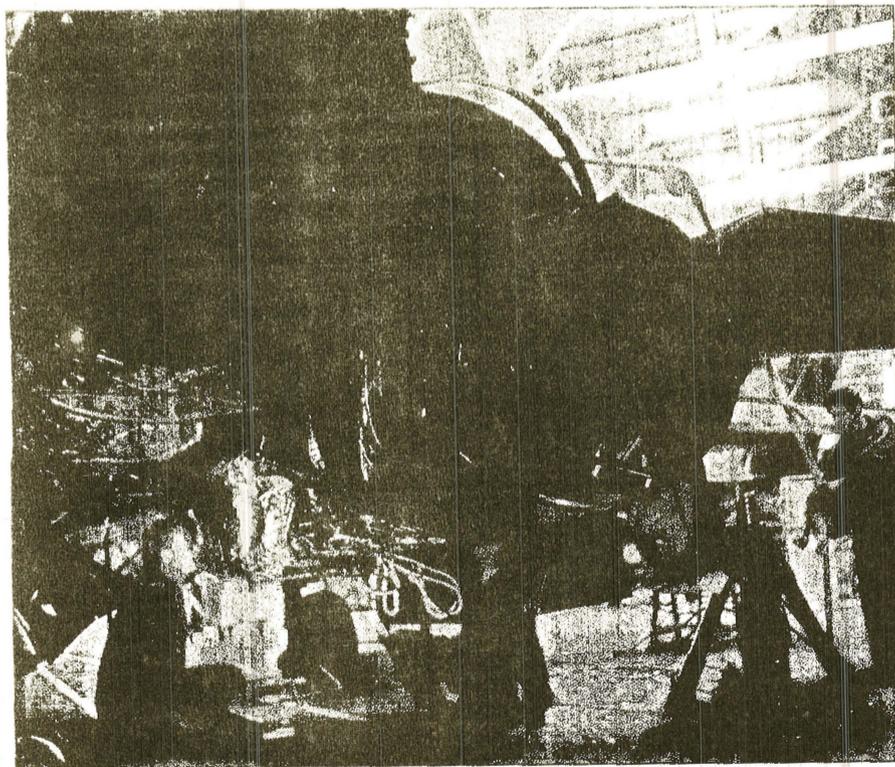
The overall design authority was Vickers, and pressure on clearances arose partly from the increasing pressure on performance, accepted by Vickers at a late stage, and partly from the development of the Olympus engine to meet those demands. English Electric proposed lower initial performance levels and somewhat less ambitious engine development. Even so, designers have to consider that in order to keep an aircraft such as a Tornado or TSR.2 together at 200ft at speeds near Mach 1 a compromise has to be reached, and for the TSR.2 this appears to have been the case.

Engine technology itself has improved tremendously since the Olympus was designed. The Tornado engine and maintenance system shows simplicity to be the key, and although it is commendable in that it has a design allowing quick and efficient engine-change routines, the Eurofighter demonstrates that considerable improvements have been made in the years since the Tornado entered service. As part of its OR the Eurofighter must be able to have both of its engines changed and be operational within 45min.

Again the technology of both the RB.199 and Euro 2000 engine systems have improved remarkably. Both engines are "module" types. This means that instead of having to change a complete engine simply to repair one faulty item, the section or module containing the faulty component can be changed, often without removing the engine.

To be continued

Below, this photograph shows the easy access to the Tornado's two "module" type 15,000lb thrust RB.199 turbofans. In the event of a fault the section or module containing the faulty item may be changed without removing the engine.



Aeroplane Monthly, July 1997

In the course of his Budget speech in the House of Commons on 6 April 1965, Chancellor of the Exchequer James (now Lord) Callaghan announced the cancellation of the TSR2 military aircraft project.

The tragedy of the TSR2

Derek Wood

The Chancellor in his 1965 Budget speech brought the demise of the most advanced long-range supersonic strike aircraft of its time. TSR2 had a performance envelope and equipment that would be considered modern even now – thirty years on.

The letters TSR stood for Tactical Strike Reconnaissance, and the aircraft had its origins in the RAF's need to replace the Avon-powered Canberra light bomber. Initial ideas on the aircraft the RAF wanted for this and other roles began to filter through to design teams in 1956.

were still to go ahead, and the following month the RAF issued General Operational Requirement 339 for a tactical strike reconnaissance aircraft. The primary mission was low-altitude subsonic attack.

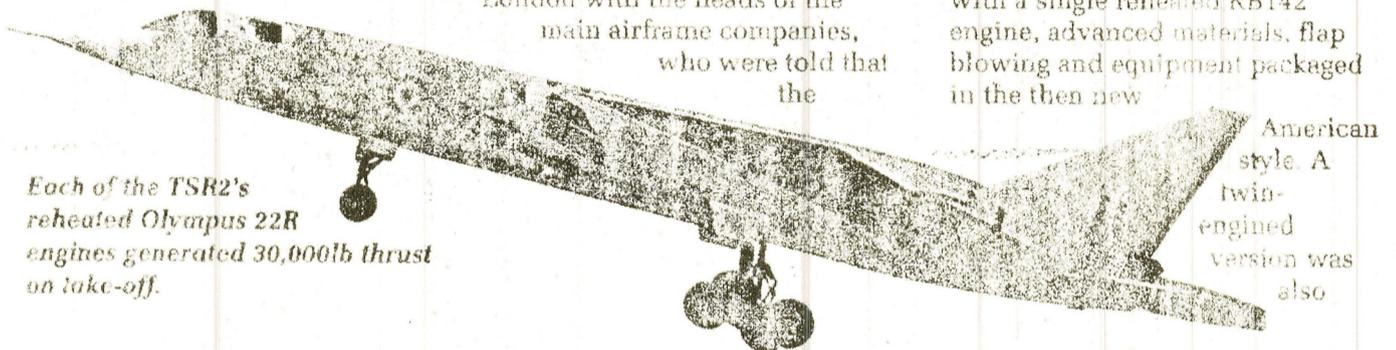
A radius of action of 1,000 miles was demanded and the ability to operate from dispersed short-runway sites. Highly accurate navigation and weapons systems would be required and the avionics industry was called upon to undertake studies.

In September 1957 there was a further bolt from the blue. The Government called a meeting in London with the heads of the main airframe companies, who were told that the

wing aircraft powered by twin Rolls-Royce RB142/3 reheated engines. In layout, the P17A closely resembled the TSR2 as it eventually emerged.

To give a vertical take-off capability, Shorts of Belfast was to provide a delta-wing lifting platform with 44 Rolls-Royce lift engines, 16 tilting lift engines and ten propulsion engines. In operation, the P17A was to be hoisted on to the platform and lifted into the air for take-off.

Vickers-Supermarine also attracted the attention of the RAF with a design called Type 571. This was a thin-winged aircraft with a single reheated RB142 engine, advanced materials, flap blowing and equipment packaged in the then new



Each of the TSR2's reheated Olympus 22R engines generated 30,000lb thrust on take-off.

American style. A twin-engined version was also

In February 1957, however, the industry was dealt a body-blow by the then Conservative administration. Duncan Sandys, the defence minister, issued the annual White Paper which that year decreed the cancellation of nearly all military aircraft programmes in favour of guided weapons, even though the latter were still at an early stage of development. Many would, in their turn, be cancelled.

Only the Canberra replacement and the Lightning

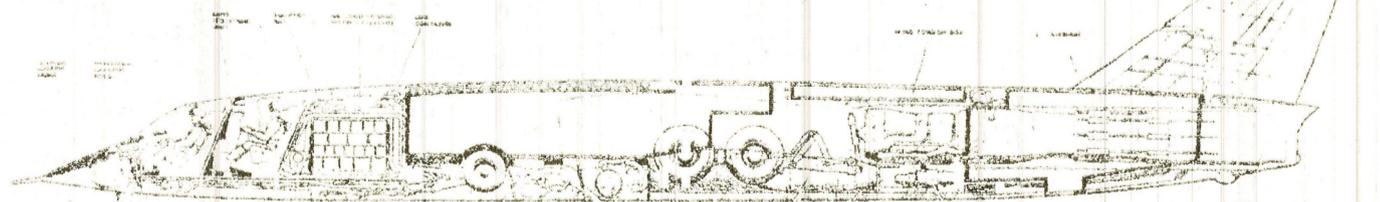
GOR339 contract would be placed only with a group of companies or with two or three in collaboration. One firm had to be project leader. This meant a move to larger units and, ultimately, a sharp reduction in the number of individual firms.

Companies were asked to submit their ideas as to how GOR339 could be fulfilled, with a deadline set at the end of January 1958.

English Electric at Warton offered the P17A two-seat, delta-

offered, and short take-off was to be achieved with blown flaps.

Several other companies offered designs, but by late summer 1957 the Air Staff had made a preliminary decision behind closed doors. What they wanted was the P17A layout, combined with the systems approach of the Type 571. They



... was written out of the programme by replacing GOR339 with an ultimate requirement, OR343, which was, in effect, an amalgam of the English Electric and Vickers designs. OR343 was daunting by any yardstick but, by 1958 standards, it definitely came into the category of the 'wide blue yonder'.

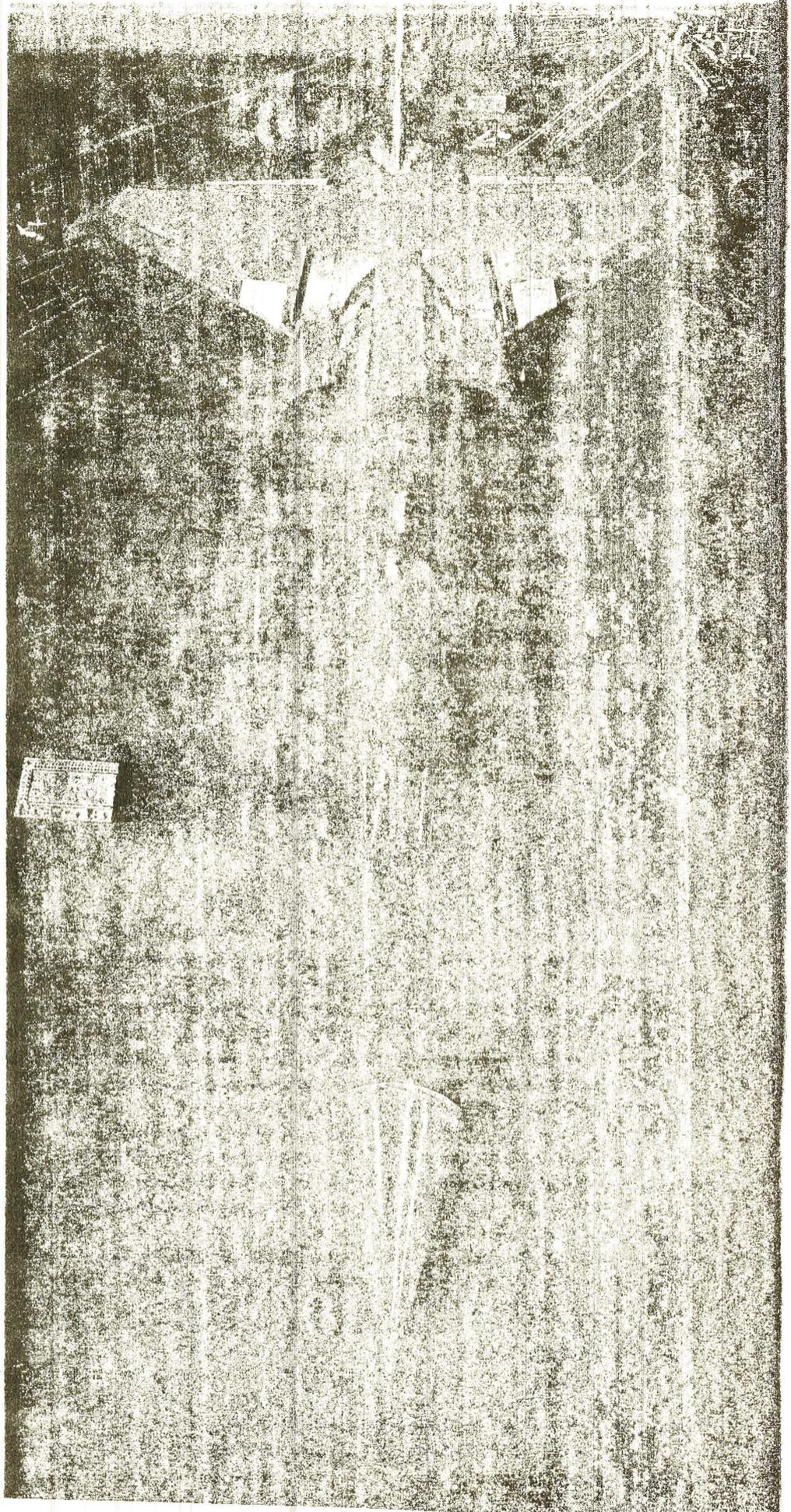
The aircraft was to be capable of Mach 1.1 supersonic dash at 200ft altitude and more than Mach 2 at medium to high altitudes. A radius of action, without external tanks, of 1,000 nautical miles was called for, of which 200nm had to be at Mach 0.9 at low level. For short, rough airstrips a maximum take-off ground roll of 1,800ft was required.

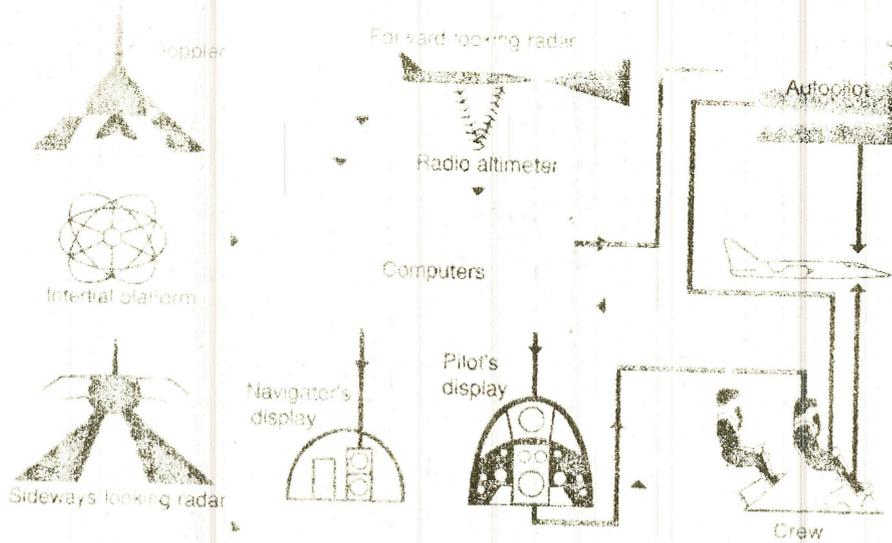
The navigation system was to be automatic, with sideways-looking radar updating the computer, and clearance over ground fulfilled by automatic terrain following. The radar was to be totally new, as was active linescan and the reconnaissance pack. It was a do-it-all machine combining battlefield attack, nuclear strike and reconnaissance.

Despite strong resistance from the Royal Navy (which was developing the Buccaneer low-level subsonic strike aircraft), the Treasury and some Government scientific advisers, a contract was awarded to Vickers-Armstrongs and English Electric for a new bomber to be designated TSR2.

The announcement of the contract was made on 1 January 1959. Vickers was to be the main contractor, specialising in systems, and English Electric was to provide the basic design, based on an enlarged P17A. The companies joined to form British Aircraft Corporation, the forerunner of British Aerospace. The joint TSR2 design team was formed at Weybridge in Surrey.

New construction methods included considerable systems integration and a requirement that prototypes were built in production jigs.

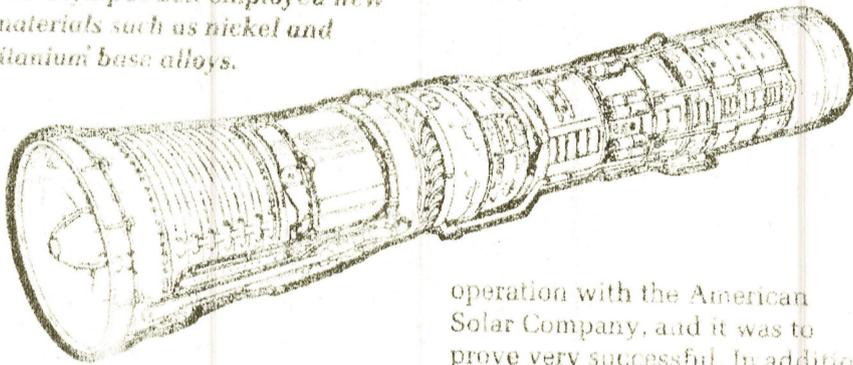




The TSR2 concept was years ahead of its time.

The choice of engine was a bitterly fought contest between Rolls-Royce and Bristol Aero-Engines (later Bristol Siddeley engines and now part of Rolls-Royce)

The Olympus 22R employed new materials such as nickel and titanium base alloys.



Bristol Siddeley won the contract with a version of the Olympus engine known as the 22R. The Olympus was already installed in the Vulcan bomber and was later to be the powerplant for the Concorde supersonic airliner.

Design of the engine was no less daunting than that of the airframe. It was to produce 19,600lb of thrust with water injection and 30,000lb plus with reheat, which made it one of the most powerful turbojets in the world.

The 22R was a two-spool engine with 15 compressor stages and eight canular combustion chambers with twin fuel burners. The low-pressure spool had eight stages, and the high-pressure,

seven. It differed markedly from the engine employed on the Vulcan, particularly in the use of materials such as nickel and titanium base alloys to cope with the high temperatures at speeds up to and exceeding Mach 2.

The variable-nozzle reheat was evolved by Bristol, in co-

operation with the American Solar Company, and it was to prove very successful. In addition to these provisions for high performance, the 22R had to have good fuel consumption to achieve the ranges required at varying altitudes.

While Bristol Siddeley worked to develop the engines, the two aircraft design teams at Weybridge were welded, painfully, into one. The TSR2 was to be built using the American 'weapons system concept', where there was systems integration throughout and prototypes had to be built in production jigs.

This whole process was new and, to add to the problems it caused, there was no overall chief designer to push the programme along. Instead, numerous panels and committees evolved, of ever-

increasing size, with officials sitting on many of them!

After the project was outlined, the design was split into two, one half at Weybridge on systems and weapons and the other half at Warton involved in aerodynamics. Beyond all this, but closely involved in the committees, were the subcontractors, large and small.

Government cost analysis at the time was very weak and the recommendations of the design panels were allowed to run wild. At the same time there was no flexibility on the operational requirement: everything had to be exactly as ordered, which led to continuous cost rises. The Air Staff even refused to defer some of the advanced electronics which would have cut initial costs.

Even in the face of these headwinds, the basic design was finalised. It emerged as a 37ft-span delta with 30 degrees of anhedral at the tips, a large fin, low-set tailplane and intake ducts under the wings. Full-span blown flaps were fitted. Fuselage length, overall, was 89ft.

The two-man crew was seated in tandem with a massive equipment bay behind and the main undercarriage bogies retracting into the fuselage sides under the wing. The weapons bay was in the fuselage underside, while additional tanks or weapons could be carried under the wings. Take-off weight for a 1,000nm sortie was 95,900lb.

The systems companies, meanwhile, were deep into producing the equipment. Ferranti was responsible for the nav/attack/terrain-following radar, while Elliott Automation evolved the automatic flight control system and the licence-produced Verdan computers. EMI was scheduled to provide the instrument landing system.

The committees went on meeting, the programme began to get later and later and the costs soared. By the beginning of 1963 the estimate for research and development had risen to nearly £200 million.

...as experienced a number of problems, the most notable of which was a vibration of the low-pressure shaft in the compressor. In extreme circumstances this condition could lead to a shaft failure and, indeed, such a failure occurred on the Vulcan flying testbed, although fortunately the aircraft was on the ground at the time and no one was injured. The aircraft was destroyed and so, too, was the new fire engine that was dispatched to extinguish the fire!

The problem was overcome by changing the shaft's vibrating frequency by the addition of damping rings, and by removing the risk of air cavity oscillation. So the problem was identified, remedies were engineered and modifications designed to eliminate the risk of failure, but inevitably such a process caused delays.

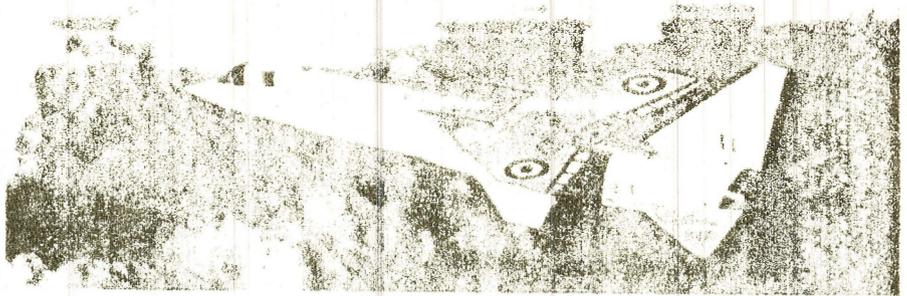
Efforts were made to sell the TSR2 to Australia, which had a suitable requirement, but half-hearted Government backing and the intervention of Lord Mountbatten, who was anti-TSR2, meant that the Royal Australian Air Force turned to the rival aircraft, the American variable-geometry wing F-111. In the event, technical problems meant that the RAAF had to wait nearly ten years for delivery of F-111s, by which time the price had more than doubled.

On 27 September 1964 the TSR2 flew for the first time at Boscombe Down in the hands of Wing Commander Roland Beamont. Against a background of darkening political skies the test programme continued.

Three weeks after the first flight, a Labour government was elected and appeared to have no great affection for the British aircraft industry or its products.

In addition, as a condition for an International Monetary Fund loan to help save sterling, the

One of the two remaining TSR2 aircraft – a museum curiosity at Duxford in Cambridgeshire.



A series of successful test flights failed to persuade politicians of the project's potential.

United States put strong pressure on Whitehall to cancel major military aircraft projects.

The Government abandoned the P1154 supersonic VSTOL fighter and the HS681 transport aircraft in February, while an evaluation took place on TSR2 versus F-111. It had been hoped to cancel the Concorde airliner, but the contract, written with France by the previous Tory administration, was watertight.

In April came the knock-out blow with cancellation of the whole TSR2 programme. To ensure that it could never be revived in any form, the mock-up was buried, jigs and tools broken up and a whole line of development and pre-production aircraft destroyed. All this, despite the fact that the aircraft had gone supersonic and all major targets of the initial flight-test programme had been met.

A Government figure of £750 million was cited as the final cost of developing and producing 150 TSR2s, although this has always been disputed. The RAF was to have the F-111 instead, with an assumed saving of £300 million. Eventually, considerably embarrassed, the Secretary of State

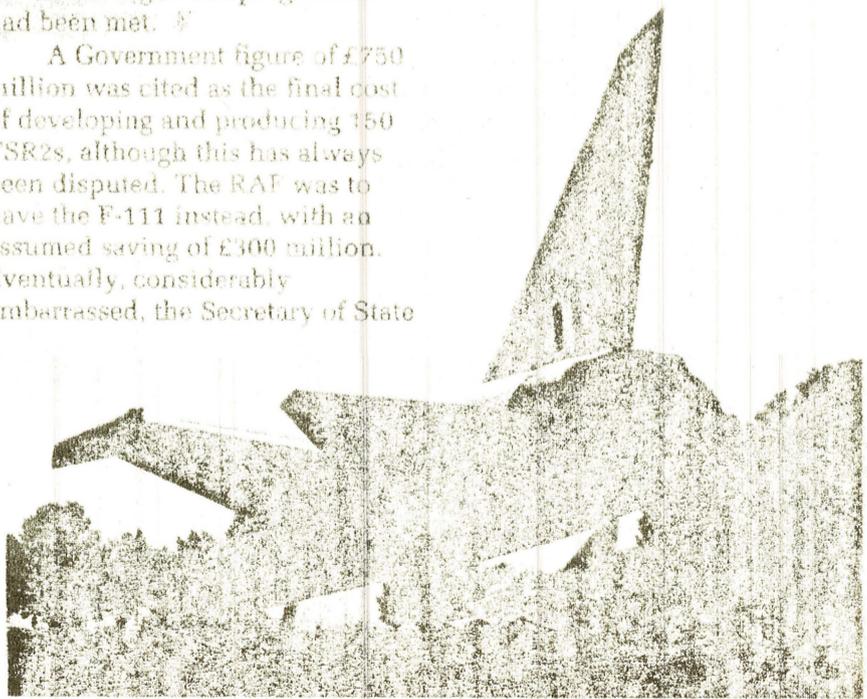
for Defence had to announce the cancellation of that, too.

If the requirement had been eased a little, if there had been a strong chief designer instead of interminable committees, and if there had been the political will, the story would have been very different.

With its large capacity, the TSR2 could have taken advantage of electronic miniaturisation to fulfil a wide variety of tasks – probably to the present day.

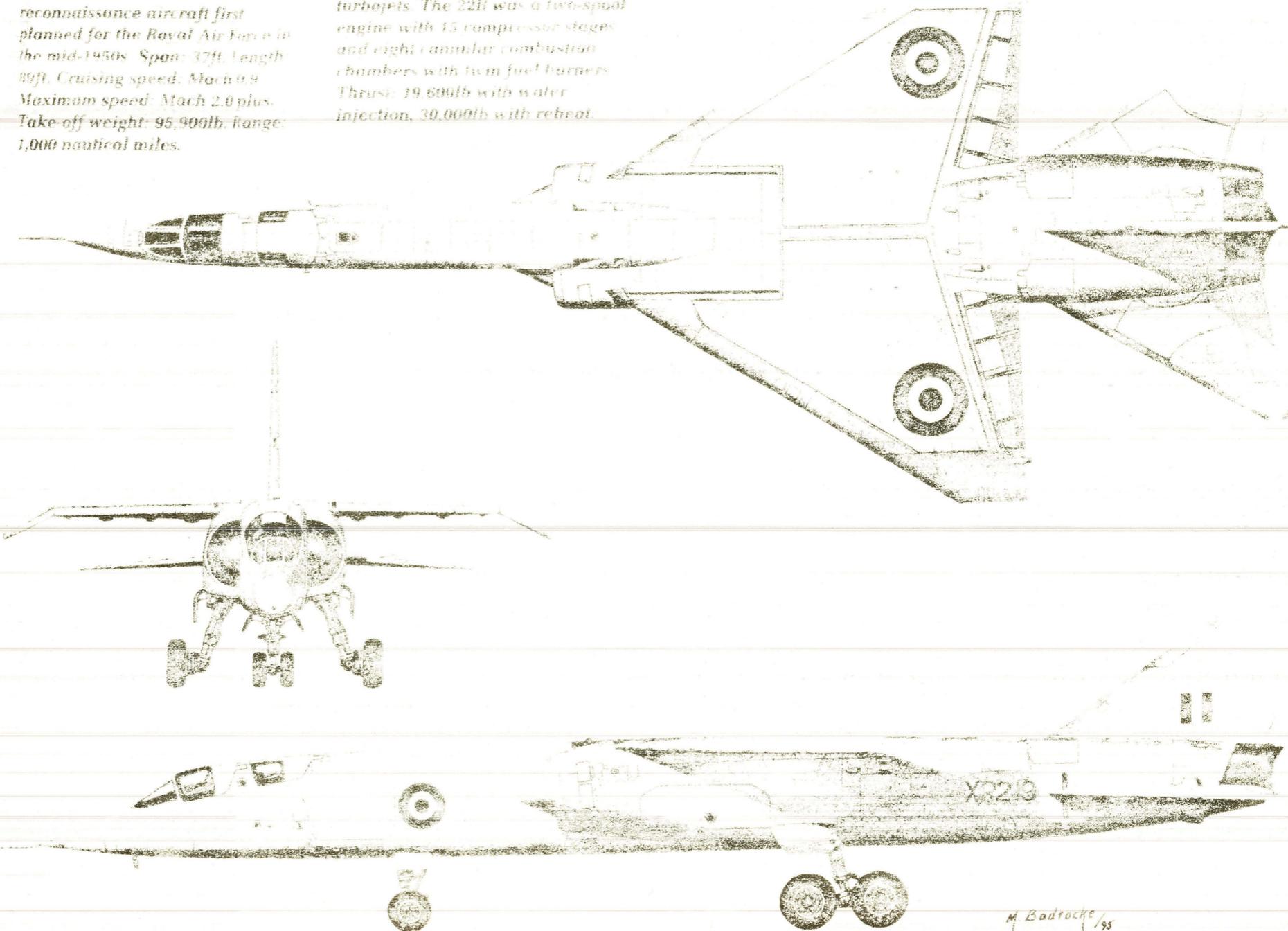
Instead, there are just two TSR2 aircraft in existence – both in museums. One is at Duxford and the other at Cosford. They are still very impressive indeed to see.

Derek Wood was founder editor/publisher of Jane's Defence Weekly. He has been an aviation and defence writer for 45 years. He was London editor of the interavia group of publications from 1953 to 1983 and air correspondent of the Liverpool Post, Westminster Newspapers and then of the Sunday Telegraph from 1981 to 1986. His books include The Narrow Margin (co-author and co-author), Project Cancelled Target England, Attack Warning Red and the Jane's World Aircraft Recognition Handbook. He is currently UK correspondent of Interavia.



TSR2: the two-man tactical strike reconnaissance aircraft first planned for the Royal Air Force in the mid-1950s. Span: 37ft. Length: 89ft. Cruising speed: Mach 0.9. Maximum speed: Mach 2.0 plus. Take-off weight: 95,900lb. Range: 1,000 nautical miles.

Powerplant: two Olympus 22B turbojets. The 22B was a two-spool engine with 15 compressor stages and eight annular combustion chambers with twin fuel burners. Thrust: 19,600lb with water injection, 30,000lb with reheat.



M. Badrocke/95

TSR-2: The Assassination of an Aircraft

In May 1951, when the English Electric Canberra first entered squadron service, it was beyond doubt the world's finest jet light bomber. With some justification, the Air Staff felt that Bomber Command possessed a tactical aircraft capable of delivering a wide variety of weapons to targets in Eastern Europe with a high probability of survival for the best part of a decade.

Only a year later, the picture had changed. MiG-15s in large numbers were equipping the fighter squadrons of Russia and her allies, and there was an unvoiced but growing feeling that, if the Canberra had to go to war — especially in daylight — the tragedy of May 1940, when the RAF's Fairey Battle light bombers were shot out of the sky over France by the Luftwaffe's fighters, might be repeated.

In 1952, therefore, the Ministry of Supply issued Specification B.126T, calling for design studies of a bomber capable of carrying a six-ton nuclear store over a combat radius of 1,500 nautical miles at very low level and a high subsonic speed — not less than 0.85M. Several firms submitted proposals, but the requirement was well in advance of existing technological developments and it was shelved. However, the contest remained open for a low-level naval strike aircraft capable of operating from existing aircraft carriers and delivering a kiloton-range nuclear weapon against land or sea targets by the toss-bombing method. This requirement was covered by Specification M.148T, which was written around Naval Air Staff Target NAST.39, and in 1955 the design competition was won by Blackburn Aircraft with their B.103. A development batch of twenty aircraft was ordered in July that year, and the robust B.103 went on to enter service with the Royal Navy as the Buccaneer.

On the face of it, the Buccaneer might have seemed the ideal aircraft to meet the RAF's requirement for a Canberra replacement. In fact, although its airframe was quite adequate for the kind of low-level precision strike work envisaged by the RAF, its systems as they existed at the time were not. Admittedly, there was plenty of room for further development, but the Buccaneer was not fast enough; by 1956, the Air Staff had modified B.126T, which had been resurrected, to include an over-the-target speed at low level of 1.3M and the incorporation of an inertial nav/attack system that would enable the aircraft to deliver conventional weapons with pinpoint accuracy.

A year later, in the wake of the 1957 White Paper, the RAF's requirement was formalised as General Operational Requirement 339. Eight firms were invited to submit tenders by the end of January 1958; the eight did not include the Hawker Siddeley Group, which had already submitted preliminary drawings of the P.1125 project and which was well in the running with its P.1129 variant. The other firms were left in no doubt that they would have to get together and submit joint proposals if they were to seriously contest Hawker Siddeley; GOR.339 was likely to be the only major British military aircraft project for the foreseeable future, and it was too complex to be tackled by the resources of any single company. For the traditional structure of Britain's aircraft industry, GOR.339 spelt the beginning of the end.

English Electric, who had already done a lot of research into a Canberra replacement, had a head start with the design of a two-seat delta-wing project known as the P.17A, which was to be powered by two RB.142

engines. In collaboration with Short Brothers, English Electric's proposal was for a vertical take-off assembly in which the P.17A would be mounted on a Short-designed VTO platform designated P.17D; this was to be powered by forty-four RB.108 fixed lift engines, sixteen RB.108 swivelling lift engines and ten RB.108 engines for forward propulsion. Together, the P.17A/17D combination would weigh somewhere in the region of 150,000 lb. In addition to its primary role of getting the P.17A into the air and so dispensing with vulnerable runways, the P.17D could be used to transport freight and fuel to forward combat areas. The idea was by no means as far-fetched as one might think; Shorts were at that time heavily involved with pioneer VTOL techniques and their prototype SC.1 VTOL aircraft had already flown in conventional flight. Apart from technical considerations, the main drawback to the P.17D was that its development costs were likely to prove prohibitive. In addition to the low-level strike version of the P.17A, English Electric also proposed a long-range interceptor variant, the P.22.

Bristol Aircraft and Vickers-Armstrong also submitted their proposals for OR.339. The Vickers entry, the Type 571, was an advanced twin-engined design incorporating an integrated terrain-following nav/attack system; the aircraft was, in fact, a complete weapons system, and although the Air Staff were coming down heavily in favour of English Electric's P.17A they were sufficiently impressed by the Vickers design to want to incorporate certain features of it in the finalised OR.339 requirement. As a result of this a new Operational Requirement, OR.343, was issued in the spring of 1958; it dispensed with the vertical take-off concept, which brought about the end of Short Brothers' participation, and virtually demanded the amalgamation of Vickers and English Electric to bring the required aircraft to fruition. Together with the Bristol Aeroplane Company, they were eventually to form the British Aircraft Corporation in February 1960.

Meanwhile, on 1 January 1959, it was announced that Vickers-Armstrong and English Electric had been awarded the contract to develop a new tactical strike and reconnaissance aircraft, known as TSR-2, to replace the Canberra. Its airframe was to be developed from that of the P.17, and it was to be powered by two afterburning Bristol Siddeley Olympus 22R engines. The choice of powerplant was pushed through in the face of severe criticism from the Vickers and English Electric design teams, who wanted a Rolls-Royce engine, and as events were to prove it was an unfortunate one. Nevertheless, *at the time* the Olympus 22R was the only engine available for immediate development as a massive reheat unit to provide up to 33,000 lb.s.t. with an acceptable specific fuel consumption, with a configuration suitable for twin rear-fuselage installation.

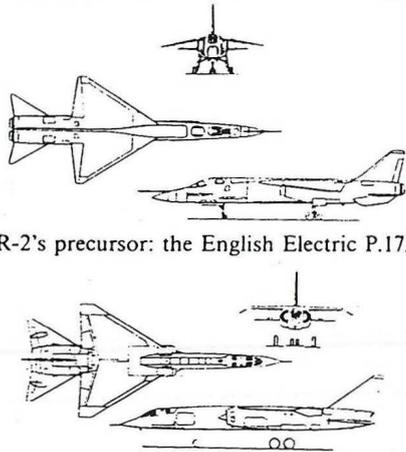
Development work proceeded at Weybridge and Warton, and a Management Board comprising representatives of the RAF, the Ministry of Aviation and BAC was set up to control the entire project and sort out any problems. In fact, the very reverse was to prove true: throughout its development, TSR-2 was to be bedevilled by the Board's decisions and compromises. In effect, it was the first time in the history of British aviation that decisions affecting the design of an aircraft were taken away from the design team involved and placed in the hands of a committee.

While the TSR-2 airframe gradually took shape, various sub-contractors were given the responsibility for

developing the necessary systems. The contract for the automatic flight system went to Elliott Automation, who had amassed an enormous amount of experience in developing the inertial navigation for the V-Force's Blue Steel stand-off missile; Ferranti were given the task of developing the TFR and nav/attack system, and EMI the sideways-looking radar, while Marconi were made responsible for avionics such as the ILS. By the spring of 1960, it was apparent that the cost of developing the aircraft's advanced electronic systems was going to greatly exceed the estimated figures; this was the first of a series of cost escalations which were to contribute to the project's eventual downfall. Funds were diverted from other cancelled projects to keep TSR-2 going, but there was little slowing in the overall upward trend.

By the autumn of 1962 the design of TSR-2 had been finalised and BAC were able to provide the Ministry of Aviation with realistic estimated performance figures. These included a cruising speed of 0.9M—1.1M at sea level and 2.05M at altitude. Combat radius with external fuel would be 1,500 nautical miles, or 1,000 nautical miles with a 2,000-lb internal bomb load on internal fuel only. Initial rate of climb at sea level would be 50,000 feet per minute. A variety of flight profiles was envisaged, most involving lo-lo sorties at heights of not more than 200 feet at 0.9M. The aircraft could carry a formidable range of weapons, both in the nuclear and conventional strike roles.

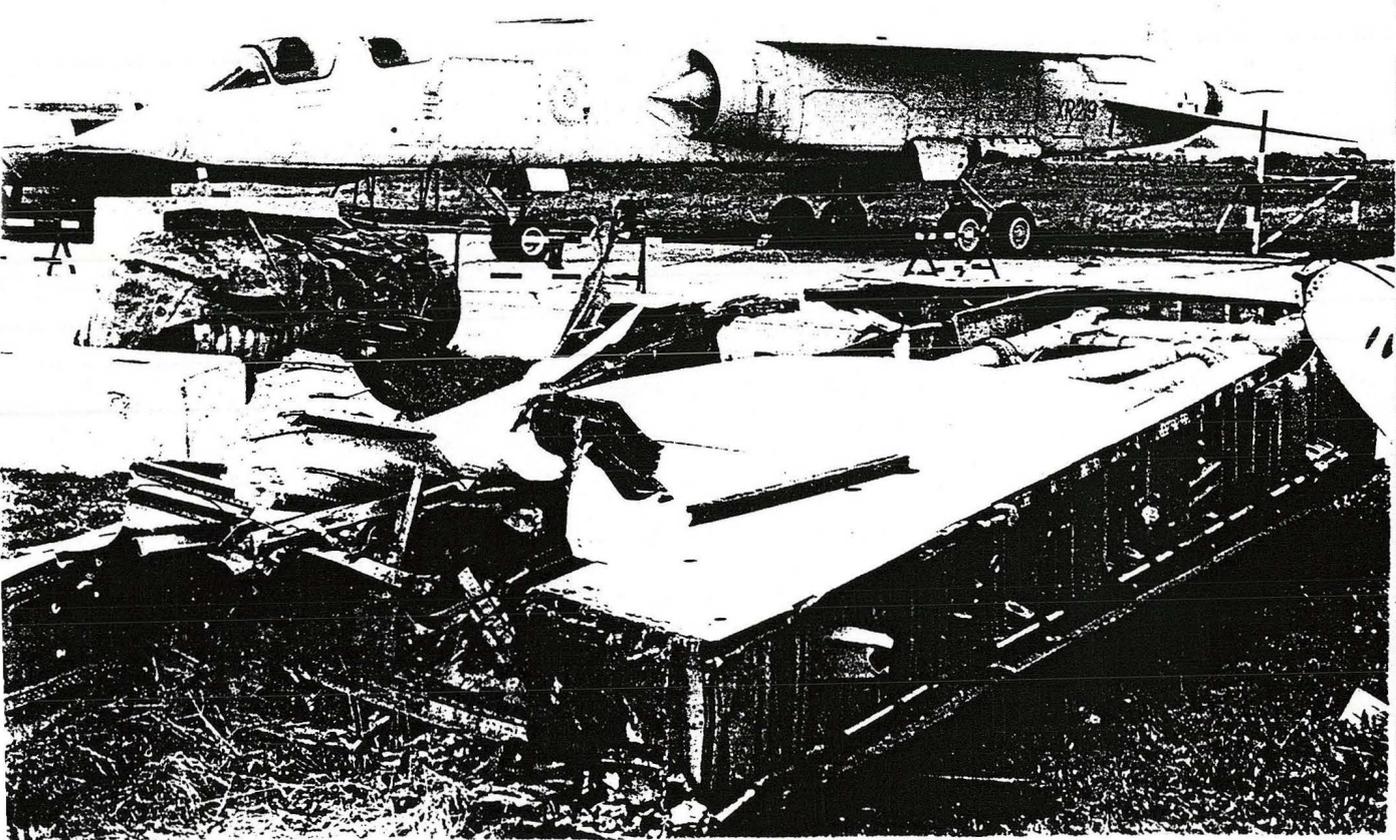
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Crew: 2.
Service ceiling: 60,000 ft +.
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TRS-2. TRS-2 XR.219 on the gunnery range at Foulness after the programme was abandoned.



attack missions against targets that required deep penetration of enemy territory, such as large bridges, airfields, missile and radar sites, marshalling yards, communication centres and concentrations of vehicles and armour. As a deep penetration system, TSR-2 was years ahead of its time; it was also the only strike aircraft in the world capable of a true short-field performance, which would have enabled it to operate in areas of the globe where large stretches of concrete did not exist, as well as increasing its own chances of survival in the event of an enemy attack on its bases. The use of an all-moving tailplane, replacing conventional elevator and aileron control, allowed maximum use to be made of full-span blown flaps as a high-lift device for short take-off and landing and permitted the aircraft to operate from semi-prepared or low-grade surfaces only 3,000 feet long. Another feature was TSR-2's long-stroke undercarriage with low-pressure tyres, specifically designed for operation from rough surfaces. The nosewheel strut could be extended during take-off to position the aircraft in take-off attitude and so shorten its run.

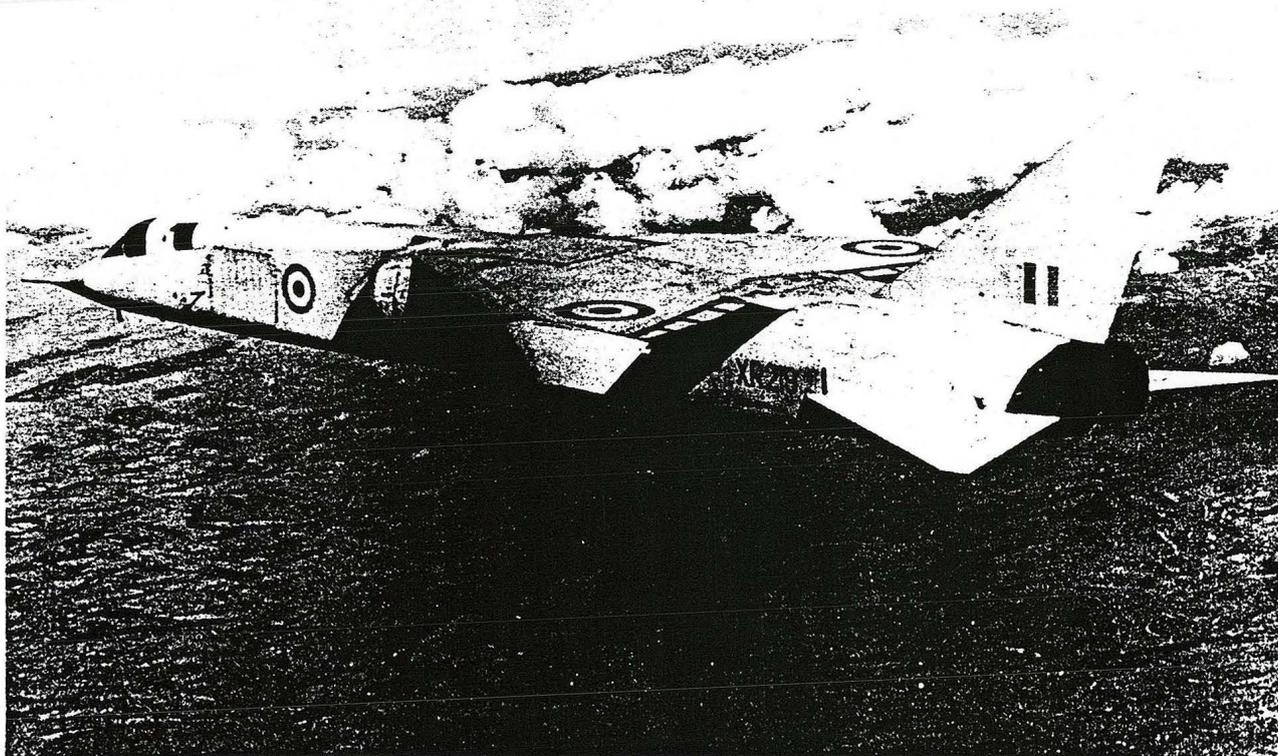
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regardless of weather at a pre-selected height above the ground. Data from the navigation and TFR systems was fed by a complex of digital and analogue computers into an automatic pilot which was capable of flying the aircraft to and from a predetermined target, the flight plan being fed into the digital computer on punched tape. Throughout the flight, the ground position of the aircraft was displayed to the crew on a moving map. The particular attack mode required could be pre-selected and carried out automatically, without visual reference to the target.

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BLACKBURN BUCCANEER MK. 2. With the demise of the TSR-2 and the American F-111, the RAF adopted the Buccaneer Mk. 2 as its primary low-level strike aircraft. The Buccaneer did the job remarkably well and could have been in RAF service several years earlier, saving enormous expenditure.

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A lot of thought was given to crew comfort and safety in TSR-2's design. The windscreen, for example, which was made of alumino silicate, was designed to stand a 1-lb bird strike at speeds in excess of 1.0M, and the cockpit incorporated a first-class air conditioning system, including refrigeration for high-speed flight. Both crew members had rocket-powered Martin-Baker ejection seats, capable of safe operation through every phase of the flight envelope from the take-off roll.

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technical problems, mainly involving the Olympus 22R engine. The fifth Vulcan B.1, XA894, had been allocated to Olympus development work; the engine, fuelled from two tanks in the bomb bay, was mounted in a nacelle beneath the Vulcan's fuselage. First flight with the 22R was made on 23 February, 1962, and later in the year XA894 was fitted with the more powerful Olympus 22R-1, featuring a high performance reheat system. All went well until 3 December 1962, when, during a full reheat ground run, the LP shaft of the 22R-1 failed and the engine disintegrated, spewing out metal fragments which ruptured both the bomb bay and main fuel tanks. Such was the force of the break-up that the LP turbine disc was hurled for half a mile in bounds of 150 yards, narrowly missing the Bristol 188 research aircraft. There were no casualties, but the Vulcan was completely burned out. The cause was resonance, which led to the break-up of the LP shaft at a certain RPM, but it was a long time before Bristol Siddeley established what had gone wrong, and in the meantime other Olympus 22R test engines failed, fortunately on the ground. Modifications were made, but these, together with other engine design changes, caused severe problems in marrying the Olympus to the TSR-2 airframe. The LP shaft problem had not been completely cured when the aircraft made its first flight, and failures were still occurring when the engine was run up to high RPM from a cold start — a procedure that was very necessary in a military aircraft, especially one whose whole effectiveness relied on getting airborne in the minimum time.

By the end of 1963, the writing was already on the wall for TSR-2, although neither the government nor BAC would admit it. Escalating R and D costs had made the project the subject of heated political controversy; the

Labour opposition, influenced by 'advisors' who had a minimal knowledge of military aviation, and even less of the RAF's operational requirements, made political capital out of the funds that were being diverted to keep TSR-2 alive, and left the electorate in no doubt about what they would do to the project if they got into power. But there were sinister forces at work within the Ministry of Defence, too: the Chief of the Defence Staff, Lord Louis Mountbatten, made no secret of the fact that he favoured a land-based version of the Buccaneer to meet the RAF's requirement, while the Ministry's Chief Scientific Advisor, Sir Solly Zuckermann, told everyone concerned that he thought TSR-2 a waste of public money and that better value could be obtained by buying equipment from the United States.

Predictably, in-fighting such as this had an adverse effect on government attempts to promote the TSR-2 overseas. The Australians, in particular, had shown an active interest in the aircraft since 1960, and two years later were favouring the British machine as a Canberra replacement. Yet there was no sales drive aimed at convincing the Australian Government that TSR-2 was the aircraft the RAAF needed, so it was hardly surprising that Australian interest began to wane after Lord Mountbatten, during a tour of South-East Asia, expressed the opinion that mounting costs and complexity would prevent the aircraft ever coming into service. It was not until the end of 1963 that a British Government delegation led by Hugh Fraser, the Secretary of State for Air, went to Australia to mount a sales drive, but by that time it was too late. Soon afterwards, the Australians decided to meet the RAAF requirement by ordering twenty-four General Dynamics F-111As — at a cost that was eventually to outstrip anything they might have spent had they opted for TSR-2.

The prototype TSR-2, XR219, flew from Boscombe Down on 27 September 1964 with Roland Beamont at the controls, after carrying out twelve taxi runs. Some undercarriage problems delayed the next flight until the

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The Labour Government, which had taken office under Prime Minister Harold Wilson shortly after TSR-2's first flight, had kept the project going so that the aircraft could be evaluated against its American rival, the F-111. At that time, Wilson — acting on faulty advice — seriously believed that some £300 million might be saved by buying the American aircraft; his Cabinet thought so too, and the final nail in TSR-2's coffin was hammered home on 6 April 1965, when Chancellor James Callaghan, during his Budget speech, announced that the project was to be cancelled forthwith. The assassination was to be complete; no trace of the project was to survive. Orders were issued for the destruction of the two completed prototypes and those on the assembly line, and of all the jigs and tools used by the manufacturing companies.

It is fair to say that the decision to cancel TSR-2, at its stage of development, was probably the most ill-advised ever made by a British Government involving the aircraft industry. Admittedly, there were still snags to be overcome: but fewer snags than those that afflicted the F-111, for which the Government opted. Soaring costs and technical problems in the F-111 development programme eventually led to the cancellation of the British order, at considerable cost.

The gap was filled, in 1969, by the Buccaneer Mk.2, which Blackburn had wanted the RAF to have ten years earlier, and an admirable job it has done ever since. But it was not until 1982, with the debut of the Tornado, that the strike squadrons of the Royal Air Force at last possessed an aircraft capable of carrying out all the tasks for which the ill-fated TSR-2 had been intended.

TSR-2: The Assassination of an Aircraft

In May 1951, when the English Electric Canberra first entered squadron service, it was beyond doubt the world's finest jet light bomber. With some justification, the Air Staff felt that Bomber Command possessed a tactical aircraft capable of delivering a wide variety of weapons to targets in Eastern Europe with a high probability of survival for the best part of a decade.

Only a year later, the picture had changed. MiG-15s in large numbers were equipping the fighter squadrons of Russia and her allies, and there was an unvoiced but growing feeling that, if the Canberra had to go to war — especially in daylight — the tragedy of May 1940, when the RAF's Fairey Battle light bombers were shot out of the sky over France by the Luftwaffe's fighters, might be repeated.

In 1952, therefore, the Ministry of Supply issued Specification B.126T, calling for design studies of a bomber capable of carrying a six-ton nuclear store over a combat radius of 1,500 nautical miles at very low level and a high subsonic speed — not less than 0.85M. Several firms submitted proposals, but the requirement was well in advance of existing technological developments and it was shelved. However, the contest remained open for a low-level naval strike aircraft capable of operating from existing aircraft carriers and delivering a kiloton-range nuclear weapon against land or sea targets by the toss-bombing method. This requirement was covered by Specification M.148T, which was written around Naval Air Staff Target NAST.39, and in 1955 the design competition was won by Blackburn Aircraft with their B.103. A development batch of twenty aircraft was ordered in July that year, and the robust B.103 went on to enter service with the Royal Navy as the Buccaneer.

On the face of it, the Buccaneer might have seemed the ideal aircraft to meet the RAF's requirement for a Canberra replacement. In fact, although its airframe was quite adequate for the kind of low-level precision strike work envisaged by the RAF, its systems as they existed at the time were not. Admittedly, there was plenty of room for further development, but the Buccaneer was not fast enough; by 1956, the Air Staff had modified B.126T, which had been resurrected, to include an over-the-target speed at low level of 1.3M and the incorporation of an inertial nav/attack system that would enable the aircraft to deliver conventional weapons with pinpoint accuracy.

A year later, in the wake of the 1957 White Paper, the RAF's requirement was formalised as General Operational Requirement 339. Eight firms were invited to submit tenders by the end of January 1958; the eight did not include the Hawker Siddeley Group, which had already submitted preliminary drawings of the P.1125 project and which was well in the running with its P.1129 variant. The other firms were left in no doubt that they would have to get together and submit joint proposals if they were to seriously contest Hawker Siddeley; GOR.339 was likely to be the only major British military aircraft project for the foreseeable future, and it was too complex to be tackled by the resources of any single company. For the traditional structure of Britain's aircraft industry, GOR.339 spelt the beginning of the end.

English Electric, who had already done a lot of research into a Canberra replacement, had a head start with the design of a two-seat delta-wing project known as the P.17A, which was to be powered by two RB.142

engines. In collaboration with Short Brothers, English Electric's proposal was for a vertical take-off assembly in which the P.17A would be mounted on a Short-designed VTO platform designated P.17D; this was to be powered by forty-four RB.108 fixed lift engines, sixteen RB.108 swivelling lift engines and ten RB.108 engines for forward propulsion. Together, the P.17A/17D combination would weigh somewhere in the region of 150,000 lb. In addition to its primary role of getting the P.17A into the air and so dispensing with vulnerable runways, the P.17D could be used to transport freight and fuel to forward combat areas. The idea was by no means as far-fetched as one might think; Shorts were at that time heavily involved with pioneer VTOL techniques and their prototype SC.1 VTOL aircraft had already flown in conventional flight. Apart from technical considerations, the main drawback to the P.17D was that its development costs were likely to prove prohibitive. In addition to the low-level strike version of the P.17A, English Electric also proposed a long-range interceptor variant, the P.22.

Bristol Aircraft and Vickers-Armstrong also submitted their proposals for OR.339. The Vickers entry, the Type 571, was an advanced twin-engined design incorporating an integrated terrain-following nav/attack system; the aircraft was, in fact, a complete weapons system, and although the Air Staff were coming down heavily in favour of English Electric's P.17A they were sufficiently impressed by the Vickers design to want to incorporate certain features of it in the finalised OR.339 requirement. As a result of this a new Operational Requirement, OR.343, was issued in the spring of 1958; it dispensed with the vertical take-off concept, which brought about the end of Short Brothers' participation, and virtually demanded the amalgamation of Vickers and English Electric to bring the required aircraft to fruition. Together with the Bristol Aeroplane Company, they were eventually to form the British Aircraft Corporation in February 1960.

Meanwhile, on 1 January 1959, it was announced that Vickers-Armstrong and English Electric had been awarded the contract to develop a new tactical strike and reconnaissance aircraft, known as TSR-2, to replace the Canberra. Its airframe was to be developed from that of the P.17, and it was to be powered by two afterburning Bristol Siddeley Olympus 22R engines. The choice of powerplant was pushed through in the face of severe criticism from the Vickers and English Electric design teams, who wanted a Rolls-Royce engine, and as events were to prove it was an unfortunate one. Nevertheless, *at the time* the Olympus 22R was the only engine available for immediate development as a massive reheat unit to provide up to 33,000 lb.s.t. with an acceptable specific fuel consumption, with a configuration suitable for twin rear-fuselage installation.

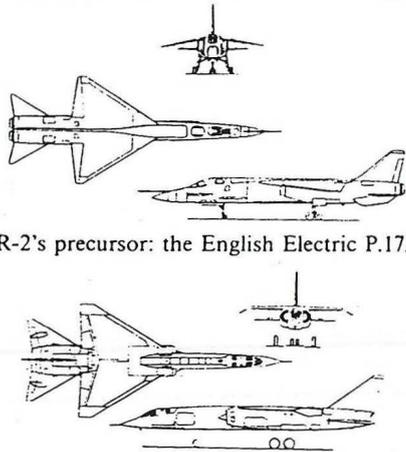
Development work proceeded at Weybridge and Warton, and a Management Board comprising representatives of the RAF, the Ministry of Aviation and BAC was set up to control the entire project and sort out any problems. In fact, the very reverse was to prove true: throughout its development, TSR-2 was to be bedevilled by the Board's decisions and compromises. In effect, it was the first time in the history of British aviation that decisions affecting the design of an aircraft were taken away from the design team involved and placed in the hands of a committee.

While the TSR-2 airframe gradually took shape, various sub-contractors were given the responsibility for

developing the necessary systems. The contract for the automatic flight system went to Elliott Automation, who had amassed an enormous amount of experience in developing the inertial navigation for the V-Force's Blue Steel stand-off missile; Ferranti were given the task of developing the TFR and nav/attack system, and EMI the sideways-looking radar, while Marconi were made responsible for avionics such as the ILS. By the spring of 1960, it was apparent that the cost of developing the aircraft's advanced electronic systems was going to greatly exceed the estimated figures; this was the first of a series of cost escalations which were to contribute to the project's eventual downfall. Funds were diverted from other cancelled projects to keep TSR-2 going, but there was little slowing in the overall upward trend.

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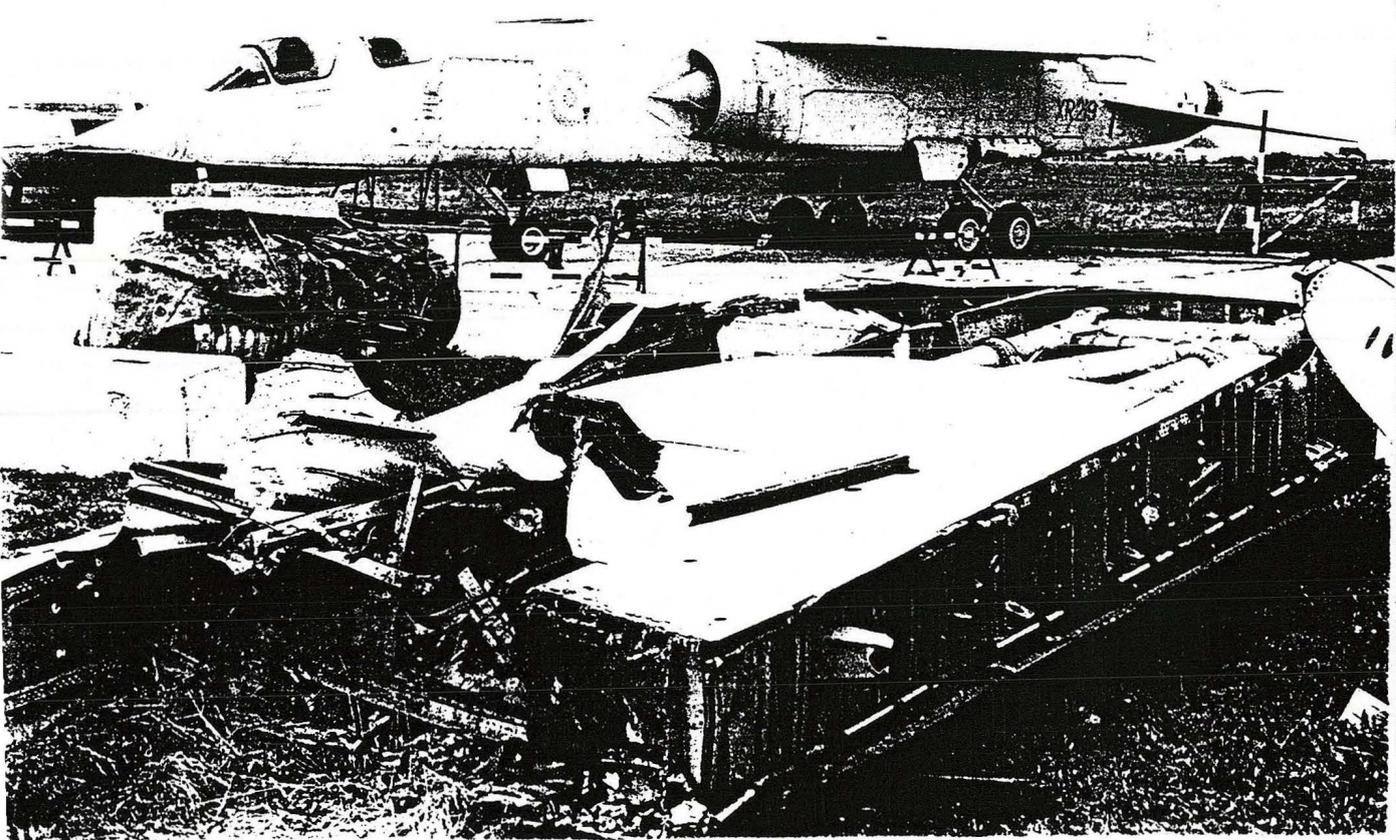
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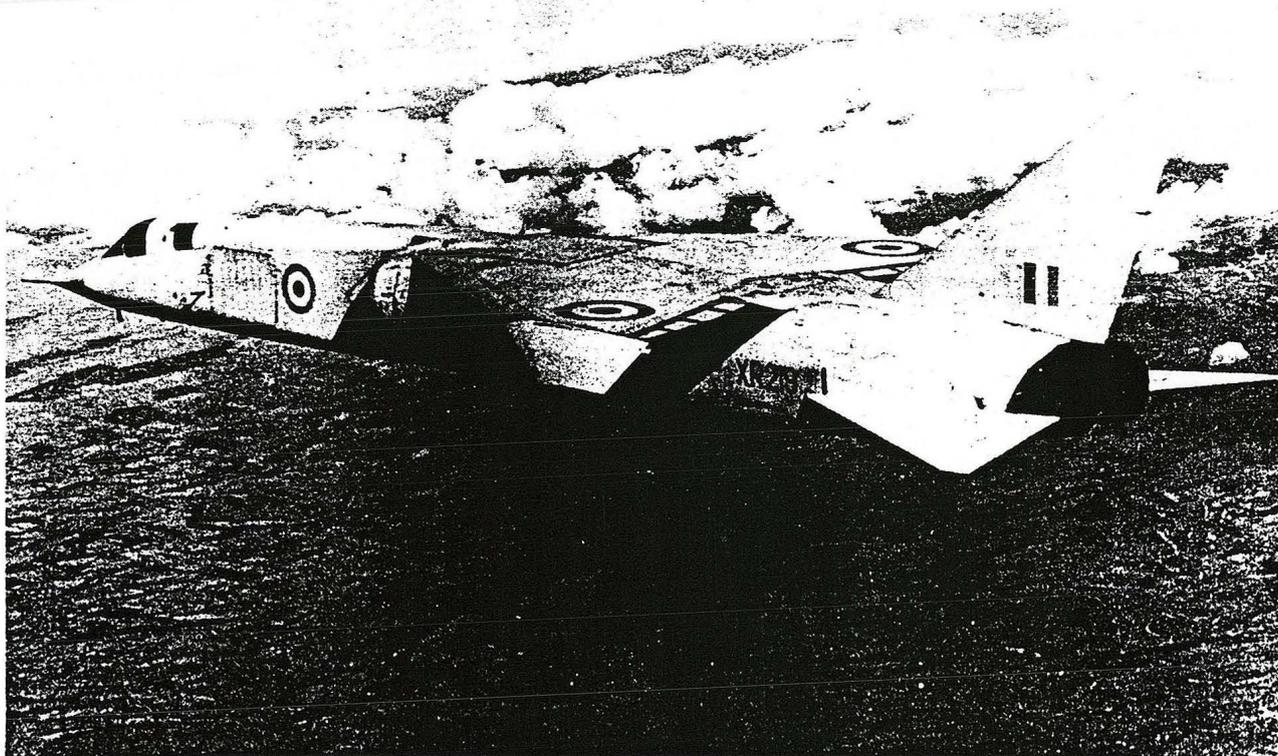
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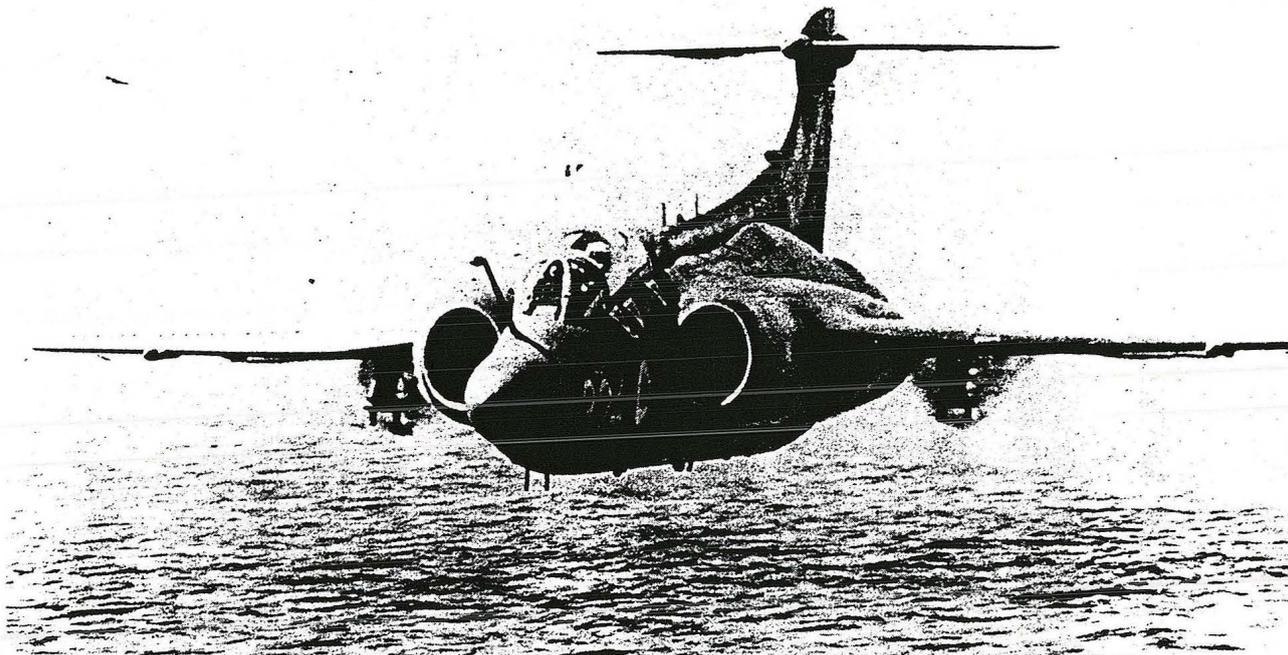
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It is fair to say that the decision to cancel TSR-2, at its stage of development, was probably the most ill-advised ever made by a British Government involving the aircraft industry. Admittedly, there were still snags to be overcome: but fewer snags than those that afflicted the F-111, for which the Government opted. Soaring costs and technical problems in the F-111 development programme eventually led to the cancellation of the British order, at considerable cost.

The gap was filled, in 1969, by the Buccaneer Mk.2, which Blackburn had wanted the RAF to have ten years earlier, and an admirable job it has done ever since. But it was not until 1982, with the debut of the Tornado, that the strike squadrons of the Royal Air Force at last possessed an aircraft capable of carrying out all the tasks for which the ill-fated TSR-2 had been intended.

In the course of his Budget speech in the House of Commons on 6 April 1965, Chancellor of the Exchequer James (now Lord) Callaghan announced the cancellation of the TSR2 military aircraft project.

The tragedy of the TSR2

Derek Wood

The Chancellor in his 1965 Budget speech brought the demise of the most advanced long-range supersonic strike aircraft of its time. TSR2 had a performance envelope and equipment that would be considered modern even now – thirty years on.

The letters TSR stood for Tactical Strike Reconnaissance, and the aircraft had its origins in the RAF's need to replace the Avon-powered Canberra light bomber. Initial ideas on the aircraft the RAF wanted for this and other roles began to filter through to design teams in 1956.

were still to go ahead, and the following month the RAF issued General Operational Requirement 339 for a tactical strike reconnaissance aircraft. The primary mission was low-altitude subsonic attack.

A radius of action of 1,000 miles was demanded and the ability to operate from dispersed short-runway sites. Highly accurate navigation and weapons systems would be required and the avionics industry was called upon to undertake studies.

In September 1957 there was a further bolt from the blue. The Government called a meeting in London with the heads of the main airframe companies, who were told that the

wing aircraft powered by twin Rolls-Royce RB142/3 reheated engines. In layout, the P17A closely resembled the TSR2 as it eventually emerged.

To give a vertical take-off capability, Shorts of Belfast was to provide a delta-wing lifting platform with 44 Rolls-Royce lift engines, 16 tilting lift engines and ten propulsion engines. In operation, the P17A was to be hoisted on to the platform and lifted into the air for take-off.

Vickers-Supermarine also attracted the attention of the RAF with a design called Type 571. This was a thin-winged aircraft with a single reheated RB142 engine, advanced materials, flap blowing and equipment packaged in the then new

American style. A twin-engined version was also

Each of the TSR2's reheated Olympus 22R engines generated 30,000lb thrust on take-off.

In February 1957, however, the industry was dealt a body-blow by the then Conservative administration. Duncan Sandys, the defence minister, issued the annual White Paper which that year decreed the cancellation of nearly all military aircraft programmes in favour of guided weapons, even though the latter were still at an early stage of development. Many would, in their turn, be cancelled.

Only the Canberra replacement and the Lightning

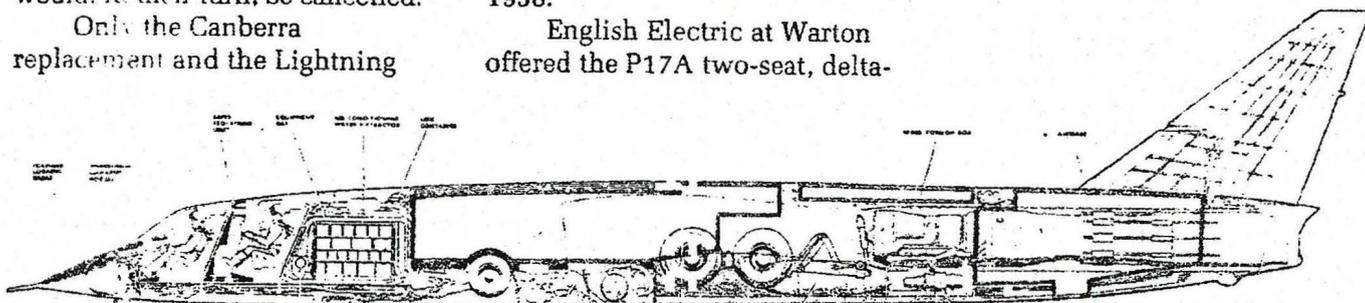
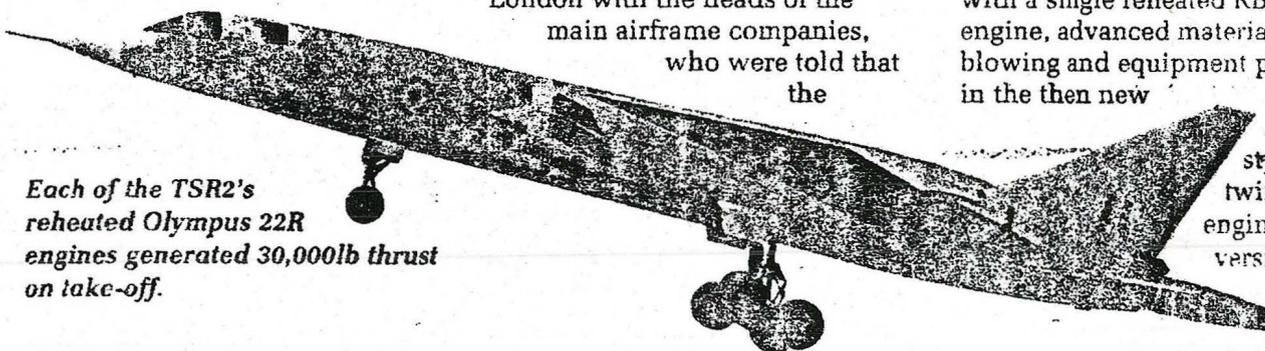
GOR339 contract would be placed only with a group of companies or with two or three in collaboration. One firm had to be project leader. This meant a move to larger units and, ultimately, a sharp reduction in the number of individual firms.

Companies were asked to submit their ideas as to how GOR339 could be fulfilled, with a deadline set at the end of January 1958.

English Electric at Warton offered the P17A two-seat, delta-

offered, and short take-off was to be achieved with blown flaps.

Several other companies offered designs, but by late summer 1957 the Air Staff had made a preliminary decision behind closed doors. What they wanted was the P17A layout, combined with the systems approach of the Type 571. They



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the existing size of the aircraft and officials sitting on a committee.

After the project was outlined, the design was split into two, one half at Weybridge on systems and weapons and the other half at Warton involved in aerodynamics. Beyond all this, but closely involved in the committees, were the subcontractors, large and small.

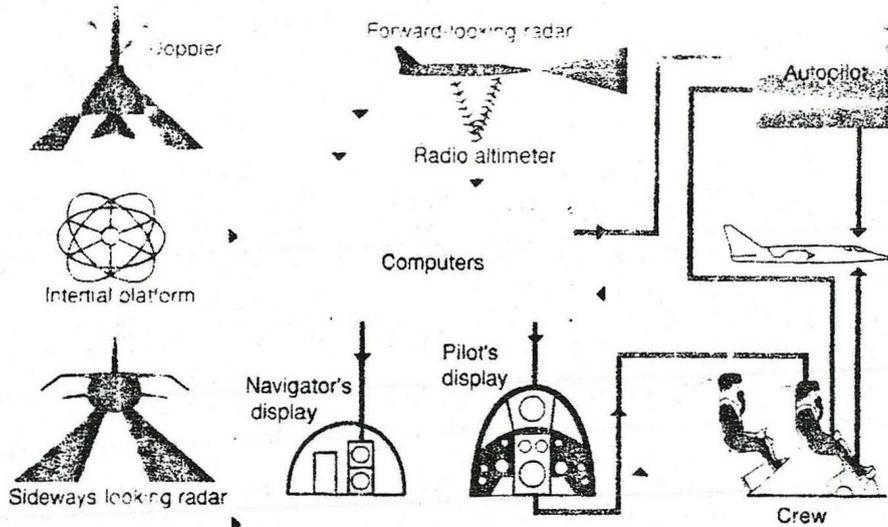
Government cost analysis at the time was very weak and the recommendations of the design panels were allowed to run wild. At the same time there was no flexibility on the operational requirement: everything had to be exactly as ordered, which led to continuous cost rises. The Air Staff even refused to defer some of the advanced electronics which would have cut initial costs.

Even in the face of these headwinds, the basic design was finalised. It emerged as a 37ft-span delta with 30 degrees of anhedral at the tips, a large fin, low-set tailplane and intake ducts under the wings. Full-span blown flaps were fitted. Fuselage length, overall, was 89ft.

The two-man crew was seated in tandem with a massive equipment bay behind and the main undercarriage bogies retracting into the fuselage sides under the wing. The weapons bay was in the fuselage underside, while additional tanks or weapons could be carried under the wings. Take-off weight for a 1,000nm sortie was 95,900lb.

The systems companies, meanwhile, were deep into producing the equipment. Ferranti was responsible for the nav/attack/terrain-following radar, while Elliott Automation evolved the automatic flight control system and the licence-produced Verdan computers. EMI was scheduled to provide the instrument landing system.

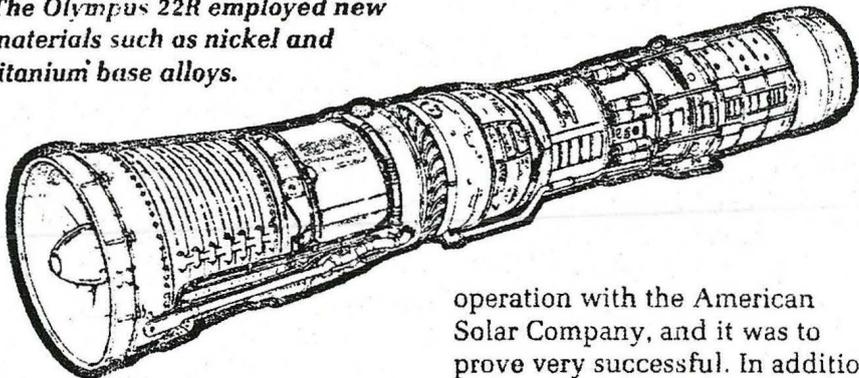
The committees went on meeting, the programme began to get later and later and the costs soared. By the beginning of 1963 the estimate for research and development had risen to nearly £200 million.



The TSR2 concept was years ahead of its time.

The choice of engine was a bitterly fought contest between Rolls-Royce and Bristol Aero-Engines (later Bristol Siddeley engines and now part of Rolls-Royce).

The Olympus 22R employed new materials such as nickel and titanium base alloys.



Bristol Siddeley won the contract with a version of the Olympus engine known as the 22R. The Olympus was already installed in the Vulcan bomber and was later to be the powerplant for the Concorde supersonic airliner.

Design of the engine was no less daunting than that of the airframe. It was to produce 19,600lb of thrust with water injection and 30,000lb plus with reheat, which made it one of the most powerful turbojets in the world.

The 22R was a two-spool engine with 15 compressor stages and eight cannular combustion chambers with twin fuel burners. The low-pressure spool had eight stages, and the high-pressure,

seven. It differed markedly from the engine employed on the Vulcan, particularly in the use of materials such as nickel and titanium base alloys to cope with the high temperatures at speeds up to and exceeding Mach 2.

The variable-nozzle reheat was evolved by Bristol, in co-

operation with the American Solar Company, and it was to prove very successful. In addition to these provisions for high performance, the 22R had to have good fuel consumption to achieve the ranges required at varying altitudes.

While Bristol Siddeley worked to develop the engines, the two aircraft design teams at Weybridge were welded, painfully, into one. The TSR2 was to be built using the American 'weapons system concept', where there was systems integration throughout and prototypes had to be built in production jigs.

This whole process was new and, to add to the problems it caused, there was no overall chief designer to push the programme along. Instead, numerous panels and committees evolved, of ever-

Olympus 593 was experiencing a number of problems, the most notable of which was a vibration of the low-pressure shaft in the compressor. In extreme circumstances this condition could lead to a shaft failure and, indeed, such a failure occurred on the Vulcan flying testbed, although fortunately the aircraft was on the ground at the time and no one was injured. The aircraft was destroyed and so, too, was the new fire engine that was dispatched to extinguish the fire!

The problem was overcome by changing the shaft's vibrating frequency, by the addition of damping rings, and by removing the risk of air cavity oscillation. So the problem was identified, remedies were engineered and modifications designed to eliminate the risk of failure, but inevitably such a process caused delays.

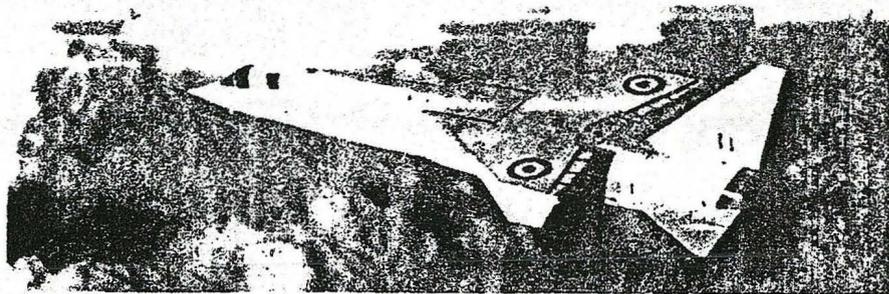
Efforts were made to sell the TSR2 to Australia, which had a suitable requirement, but half-hearted Government backing and the intervention of Lord Mountbatten, who was anti-TSR2, meant that the Royal Australian Air Force turned to the rival aircraft, the American variable-geometry wing F-111. In the event, technical problems meant that the RAAF had to wait nearly ten years for delivery of F-111s, by which time the price had more than doubled.

On 27 September 1964 the TSR2 flew for the first time at Boscombe Down in the hands of Wing Commander Roland Beamont. Against a background of darkening political skies the test programme continued.

Three weeks after the first flight, a Labour government was elected and appeared to have no great affection for the British aircraft industry or its products.

In addition, as a condition for an International Monetary Fund loan to help save sterling, the

One of the two remaining TSR2 aircraft - a museum curiosity at Duxford in Cambridgeshire.



A series of successful test flights failed to persuade politicians of the project's potential.

United States put strong pressure on Whitehall to cancel major military aircraft projects.

The Government abandoned the P1154 supersonic VSTOL fighter and the HS681 transport aircraft in February, while an evaluation took place on TSR2 versus F-111. It had been hoped to cancel the Concorde airliner, but the contract, written with France by the previous Tory administration, was watertight.

In April came the knock-out blow with cancellation of the whole TSR2 programme. To ensure that it could never be revived in any form, the mock-up was burned, jigs and tools broken up and a whole line of development and pre-production aircraft destroyed. All this, despite the fact that the aircraft had gone supersonic and all major targets of the initial flight-test programme had been met.

A Government figure of £750 million was cited as the final cost of developing and producing 150 TSR2s, although this has always been disputed. The RAF was to have the F-111 instead, with an assumed saving of £300 million. Eventually, considerably embarrassed, the Secretary of State

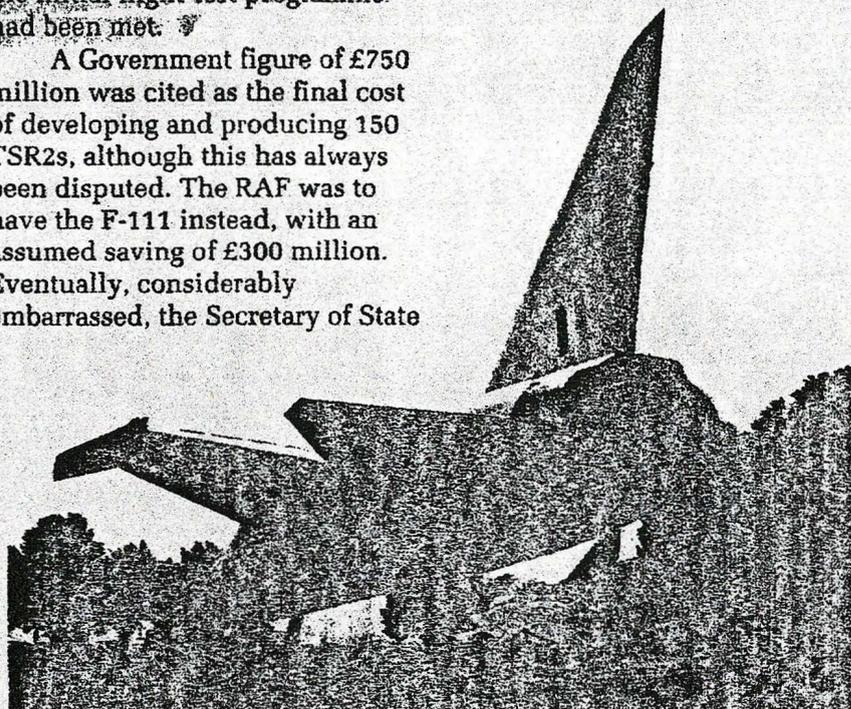
for Defence had to announce the cancellation of that, too.

If the requirement had been eased a little, if there had been a strong chief designer instead of interminable committees, and if there had been the political will, the story would have been very different.

With its large capacity, the TSR2 could have taken advantage of electronic miniaturisation to fulfil a wide variety of tasks - probably to the present day.

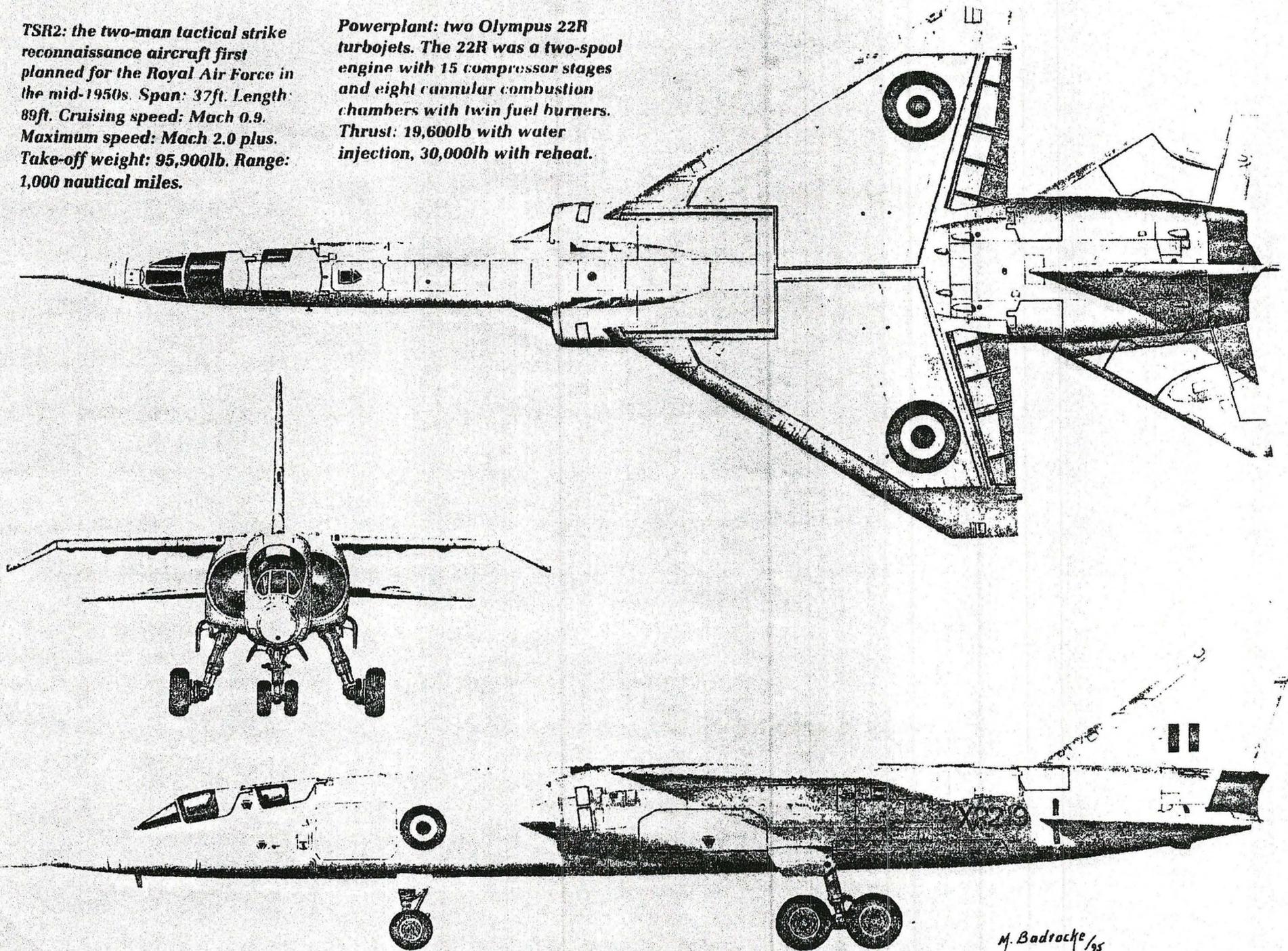
Instead, there are just two TSR2 aircraft in existence - both in museums. One is at Duxford and the other at Cosford. They are still very impressive indeed to see.

Derek Wood was founder editor/publisher of *Jane's Defence Weekly*. He has been an aviation and defence writer for 45 years. He was London editor of the *Interavia* group of publications from 1953 to 1983 and air correspondent of the *Liverpool Post*, *Westminster Newspapers* and then of the *Sunday Telegraph* from 1961 to 1986. His books include *The Narrow Margin* (originator and co-author), *Project Cancelled*, *Target England*, *Attack Warning Red* and the *Jane's World Aircraft Recognition Handbook*. He is currently UK correspondent of *Interavia*.



TSR2: the two-man tactical strike reconnaissance aircraft first planned for the Royal Air Force in the mid-1950s. Span: 37ft. Length: 89ft. Cruising speed: Mach 0.9. Maximum speed: Mach 2.0 plus. Take-off weight: 95,900lb. Range: 1,000 nautical miles.

Powerplant: two Olympus 22R turbojets. The 22R was a two-spool engine with 15 compressor stages and eight annular combustion chambers with twin fuel burners. Thrust: 19,600lb with water injection, 30,000lb with reheat.



M. Badrocke /95