BAC100 & AUSTRALIA (REVISED 2015)

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SUMMARY

In 2010 Bristol celebrated 100 years of aircraft design and manufacture, a unique achievement. In the period after World War 2 these achievements extended into Guided Weapons, Space and Manned Space, which continued the company's close relationship with Australia.

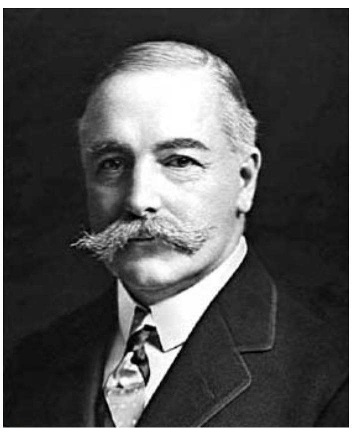
At the time of aircraft industry rationalisation the aircraft company was on the verge of bankruptcy. The way in which this was avoided, which has been kept secret for 50 years, is now revealed.

Many problems were met and overcome in this history, and there are lessons for today and the future.

Introduction

When I joined the Bristol Aeroplane Company (BAC) the factory and the city had suffered German bombing, with hundreds killed and injured. Nevertheless a high rate of Bristol aircraft and engine production continued there and elsewhere in UK, in Canada, and in Australia as John Burleigh's lecture[1] on the first fifty years has reminded us. The many strong and abiding links between the Company and Australia included not only operation of most of the Bristol aeroplanes but also large scale manufacture of some of them, as well as the setting up of the Bristol teams at Woomera and Salisbury.

Bristol was a city of enterprise, where square rigged trading ships formerly anchored in the city centre. Their owners were known as Merchant Venturers.



The founder of the company in 1910[2], was Sir George White, The company remained in family hands until the aircraft industry was reorganised into fewer and larger companies, but the founders' approach at Bristol was to persist there for many years.

A visit to the Bristol website reveals a very wide scope of 2010 activities in celebration of the aircraft company which has survived on the site for 100 years. No other prime site from 1910 in the world can claim to have continued in aeroplane manufacture for that period, and no other British prime site from 1949 can in 2010 claim 61 years of Guided Weapon engineering.

Bristol achieved both.

I have taken the list of Bristol achievements from the website[2] http://www.bac2010.co.uk to which I have contributed memories.

Bristol Aeroplane Company Board Policies

The White family policy throughout had been to move into new technologies which could benefit each other. Accordingly, the Filton airfield site became a big terminus for the family owned tram network, where aircraft and aero engine factories grew side by side.[3] The continuation of this policy was to be of key importance in the survival of Bristol over 100 years.

After the war two projects were introduced:

Sycamore Helicopter 1947 First British designed, built and certificated helicopter.

The Sycamore saw service with the Australian Navy and at Woomera.

Housing1945 - The first of 11,250 Airoh prefabricated houses manufactured at Weston-super-Mare as the last Beaufighter left the production line.

Notably, 80% production learning was achieved throughout Airoh manufacture.

There was an urgent need for revenue from aircraft sales. The Board therefore authorised [3] , as a private venture, the development of a simple twin-engined freight aircraft, the Bristol Freighter powered by two Bristol Hercules engines. The intended first customer was the Army, but they kept increasing the size and weight of their armoured vehicles.

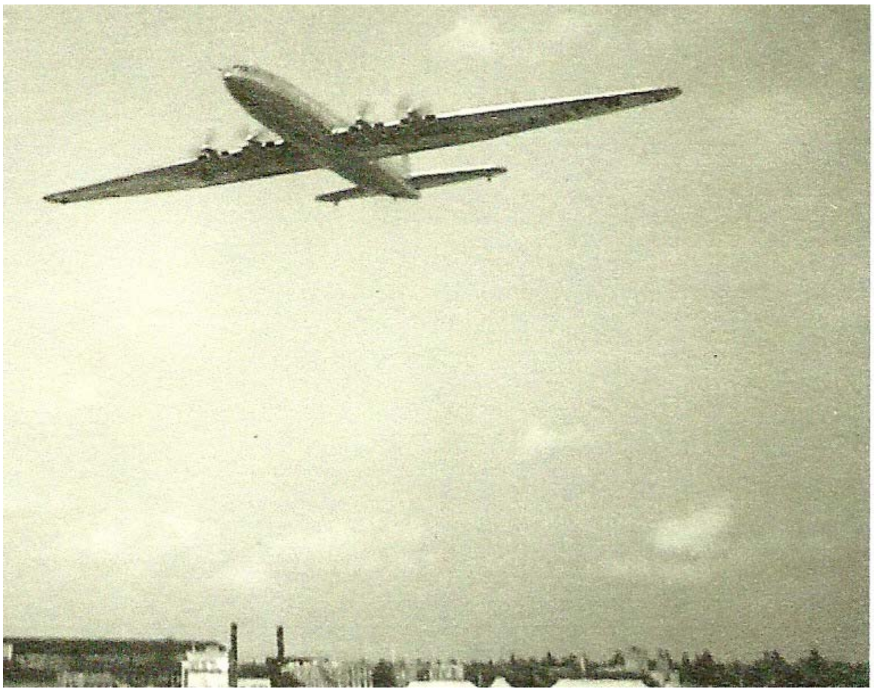
Alec Symon, the designer, was inspired to devise three variants, one to carry passengers (the Wayfarer), one to lift heavy goods, and one to carry cars and their passengers on holidays abroad. The Freighter's payload was 34% of takeoff weight: it could carry heavy vehicles.

Seven Australian airlines bought and operated the Freighter, and it was flown at WRE by the RAAF and two Air Trials units. Its manufacture continued for a long time.

The Post-War Brabazon Aircraft

Brabazon 1949 - World's largest civil transport aircraft introducing 3000psi hydraulic system, all-powered flying controls, AC electrical generation, electric engine controls and Gust Load Alleviation. Powered by eight Bristol Centaurus engines driving contra-rotating propellers.

The Brabazon was designed to be the first passenger aircraft able to cross the Atlantic non-stop. It was only just possible with eight of Bristol's most powerful engines, the Centaurus. The project cost the Government 12 million pounds [3], of which 6.5 million was for the long runway and the Assembly Hall (big enough to handle three A380s at once). These were to play an important part in Bristol survival.



The Brabazon D.Farrar

I was one of three engineers who did the initial design; we all later became Chief Designers.

Bristol's relation with Australia took a new turn[2] in the late 1940s when the work load at Commonwealth Aircraft Factory ran down and some Australians left the Armed services. By then I was in charge of the structural design of the Brabazon aircraft, and ten Australian engineers joined us - regrettably one short of a cricket team.

In return, one of the three initial designers (Bill Strang) left to get a Ph.D. and went to Australia as the head of the Wind Tunnels at Fishermen's Bend. He was later to return as Chief Designer, Aircraft.

The Brabazon's payload was only 50 passengers as BOAC wanted the same degree of comfort as on the flying boats which had flown between England and Australia before the war. Thus the payload was only 3.5% of takeoff weight! This is an example of-, a failure to note the clear 20 year trend of rapid decline of fuel per seat mile [5] of competitors' aircraft.

I devised a Vibration Model of the Brabazon, made of steel plate with lead weights, to confirm the calculated modes of vibration. George Schairer saw it, went back to Boeing and did better by cladding it in aircraft shapes and testing them in the wind tunnel. The shapes he chose included thin swept back wings with external jet engines, which he had seen in Germany immediately after the war, but many showed aero elastic problems of wing twist and flutter. The outcome was the swept thin wing, with low drag forward-podded engines which we see on all airlines today.

The Beginning of Guided Weapons at Bristol and of the Weapons Range in Australia

When I joined the Company in 1941 the Battle of Britain had just been won by the Royal Air Force, despite the bombing of its radars and airfields. Bristol continued having to endure night raids, against which the defence was 3.7 inch guns and rockets operated by the Army. I was one of the volunteers who ran the system at night to give them some sleep.

It started with searchlights, a simple computer, one man slewing the gun, one elevating it, one setting fuze times and one firing (which cost me the hearing in my right ear.)

Soon we had radars, a better computer, automatic slewing and proximity fuzes. The system was easily moved to the East Coast and was marvellously successful against the horde of V1 weapons arriving every day, which the R.A.F found difficult and dangerous to cope with.

After the war the Ministry of Defence studied guided weapons[4] for defence against air attack. The Air Force needed a belt of static weapons along the coast, with good range to minimise cost. The Army wanted shorter range weapons as transportable as the guns had been.

Thus were born the English Electric Thunderbird guided weapon for the Army, and later the Bristol - Ferranti Bloodhound for the Royal Air Force.

At Bristol the head of Flight Test, John Radcliffe, was named as leader of a new guided weapons team. Tragically he was killed [3] in an aircraft accident when in a Bristol Freighter, doing engine-cut-during-climb, the fin and rudder came off.

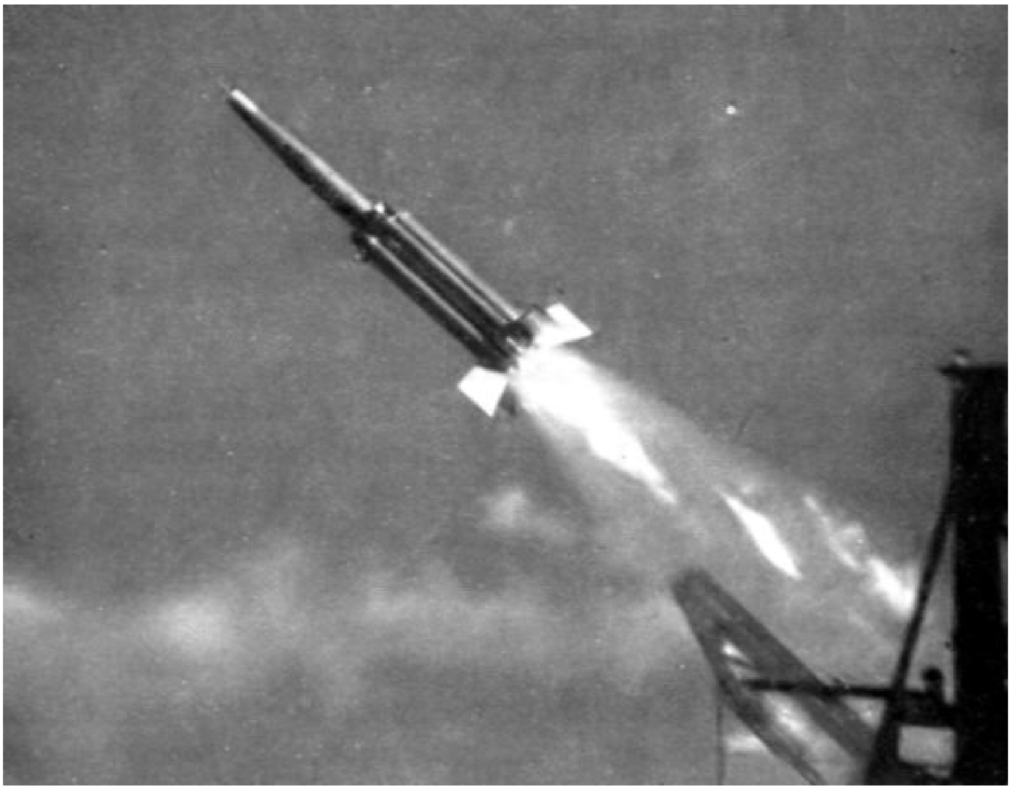
Bristol Aero Collection

The rudder had a setback hinge and was beautifully balanced, but under heavy yaw conditions the rudder centre of pressure was forward of the hinge, causing it to run away to full travel, breaking the fin off.

Shortly before that I had been in the same aircraft doing the same test: it took me years to realise that I had 50% chance of dying at the age of 27……

Instead of that, in my thirties I was to be appointed to the Board of Bristol Aircraft Ltd, responsible for designing and developing (in collaboration with Ferranti) what became the Bloodhound anti aircraft guided weapon.

The JTV-1 was a Farnborough designed test vehicle for 6" ramjets which we made. It would never have worked. We redesigned it and it did.



JTV-2 1951 xplanes

JTV-2 1951 - First British ramjet powered test vehicle to achieve transonic ignition in free flight with sustained combustion and acceleration in supersonic flight.

I went on a team visit to America, led by Stanley Hooker, to look at the ramjet state of the art. Boeing had developed a ramjet for its monoplane beam riding missile, and with George Schairer's goodwill that provided the basis for a joint team to be set up there to design the first Bristol ramjet.

Thor Ramjet - 1958 First British ramjet to achieve Mach 2+ capability.

The Bloodhound system was needed to defend the British Nuclear Deterrent(6), so the Ministry had to make regular reports on its progress to the British Cabinet.

But most Board discussion was of aircraft because GW work was secret. While the Board structure generally implied that functional aeroplane directors had responsibility for the same GW functions, it bore little resemblance to reality. In response the GW people bonded tightly together as a dedicated team, a *de facto* rather than a *de jure* organisation.

At Bristol this tight bonding was to have a major influence on the team's future in the restructuring of the industry

The Bristol Britannia

The Britannia[3] was the result of several strokes of genius by A.E.Russell ("Russ" to us). He won the contract for a mediocre piston-engined medium range Empire route aircraft, whose characteristics were determined by available wartime airfields and the seating on BOAC coaches. He successfully negotiated the big changes to enlarge the aircraft, increasing its speed and range using the Proteus turbo-prop, leading to the famous long range version of which El Al, a notable user, said "No Goose, no Gander."

The Britannia is widely regarded as the summit achievement of turboprop transport aircraft, and it had a very long service life.

Airlife Publishing

Britannia 1957 First passenger aircraft capable of a non-stop London to New York service and first aircraft to have electronic engine controls: powered by four Bristol Proteus engines.

Sadly, the early sales and entry into production were delayed [3] by two accidents. One was due to an obscure autopilot fault, with the loss of the full crew. The other was due to an engine fire which led to a forced landing on the mudflats of the River Severn estuary, with potential airline customers on board. Wading to the shore they became covered in mud, but the Company sent them all home with new clothes that afternoon.

For maximum recovery of ram pressure the Bristol Proteus engine of the Britannia inherited the folded air intake of the Bristol Buckingham, which I had seen on my first day with BAC. Flying home in a Britannia from a visit to Woomera, over Pakistan we experienced a serious intake icing problem, and the resulting compressor blade damage meant that we had to wait at Karachi for replacement engines. This problem prevented sales and wasted eighteen months of the Britannia production programme. We had no idea how close to bankruptcy that problem would bring the Company.

Bloodhound is Last and First

Guided Weapons 1949 - Guided Weapons activity established at Bristol.

In May 1949,over sixty years ago, a few of us studied the state of the art (many unknowns, few facilities) at Farnborough before returning to Bristol to build staff for a secret project known later as "Bloodhound". We learned (and in some cases initiated) one new technology [(6)] each year, and developed new ways of project evaluation [(7),] staff acquisition and development [(7)], and project management.[(7).]

We studied and evaluated many configurations.[(6).] The tenth one, an unconventional moving wing monoplane, was the simplest and avoided many problems found in the others. For the long range we used simple ram air turbines for hydraulic and electrical power rather than fireworks. For the launcher we used proven technology in the 3.7 inch anti aircraft gun base with its running gear and servos. (That gave us transportability; we had replaced the gun by the guided weapon.)

These decisions enabled Bloodhound to survive five changes in the operational requirement (it was never deployed as originally intended.)

Bloodhound 1 at Adelaide Aero Museum

"Bloodhound missile - Parafield" by Peripitus - Own work. Licensed under CC BY-SA 3

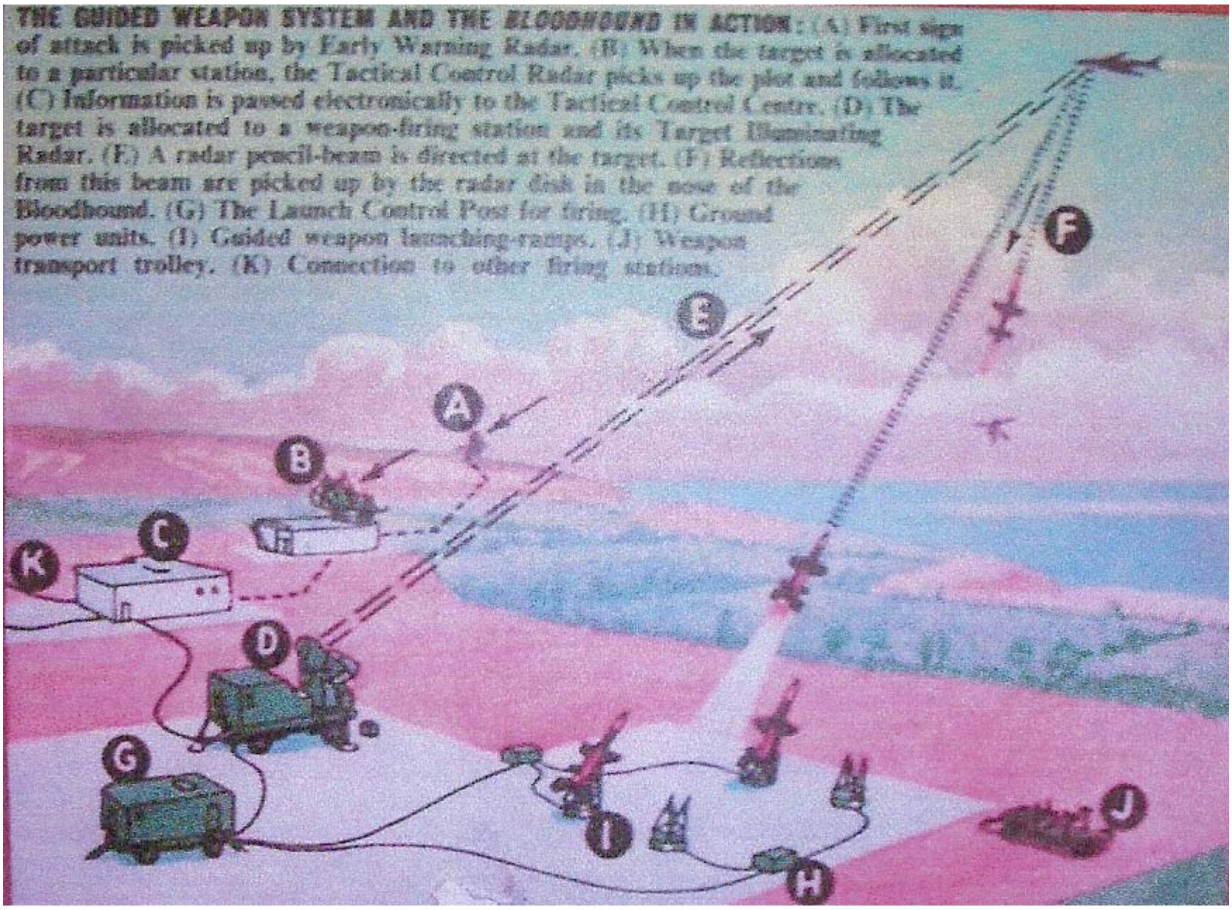
Bristol Aero Engines developed the reliable and powerful Thor ramjet motors for Bloodhound 1.With no moving parts they delivered about 35,000 horsepower[1] to Bloodhound after launch. (If your car's engine had this power/weight ratio, it would weigh about as much as a cup of tea.)

We had observed the two cardinal principles of Design for Economic Manufacture: reduce variety, reduce diversity. They are important: engineers should always remember them, now and in future.

Weapon Systems Engineering

It is too easy to forget that a guided weapon is only the front end of that which is needed to generate an operational capability.

The threat has to be detected and assessed: the means of dealing with it decided: targets allocated and tracked: launch and interception controlled and assessed, and launchers rapidly reloaded.



RAF Museum Hendon

We collaborated with many other contractors to produce a complete weapon system with acquisition,(B), tactical control,(C), target tracking,(D), launch control,(G), missiles,(I), and reloading.

We thus came to have a great and unique understanding of Weapons system engineering -the art of knowing how all the elements interacted.

This art was to be called on by the Ministry of Defence several times over the ensuing fifty years. In particular they asked the Bristol Team to rescue [7] the Polaris submarine and its nuclear missile warhead from serious system problems. It continues today at Bristol, in our successors MBDA, who in 2010 were studying and demonstrating the feasibility of an integrated command and tactical control system for all NATO's surface to air guided weapons.

There were many problems in development. Aerodynamics had to be determined by flight test. Complex interactions were experienced and had to be solved. Booster rockets were unreliable. Telemetry needed calibration and suffered switch-on failures.

To minimise these I insisted on extra standard cabling which the telemetry team had to use, rather than working all over the missile putting in their own wiring, testing it and having repeated sub miniature valve failures as a result (another example of t*unnel vision*.). Together with the prohibition of excessive testing, this halved the factory and firing range preparation time, and thus had much to do with our being ready for the Swedes.

We had a proven working weapon, just in time.

Bloodhound in Service

The RAF could not fly the Bloodhounds, so instead they kept switching them on. Therefore, when deployed in East Anglia the Bloodhounds had problems.

The excessive frequency of being switched on and off caused failures of sub miniature valves and hydraulics, another example of t*unnel vision*. It was necessary to change the operational procedures. Alf Gale, our resident engineer, sorted out many other teething problems and thus retained the confidence of the R.A.F. in the system.

R.Park

A DESIGN ICON OF THE 1950s

Bloodhound 1 at the Science Museum, London 2008

Saunton Sands

Before Bloodhound aircraft sales had been lagging and Peter Masefield became the new Aircraft Managing Director. He held a memorable planning conference at the Saunton Sands Hotel[3], when ambitious sales for aeroplanes, cars, helicopters and plastics were forecast.

I proposed that we might sell hundreds of guided weapons to neutral countries. I was laughed at, but they were included in the Company plan, and F.W. Higginson became GW Sales Manager.

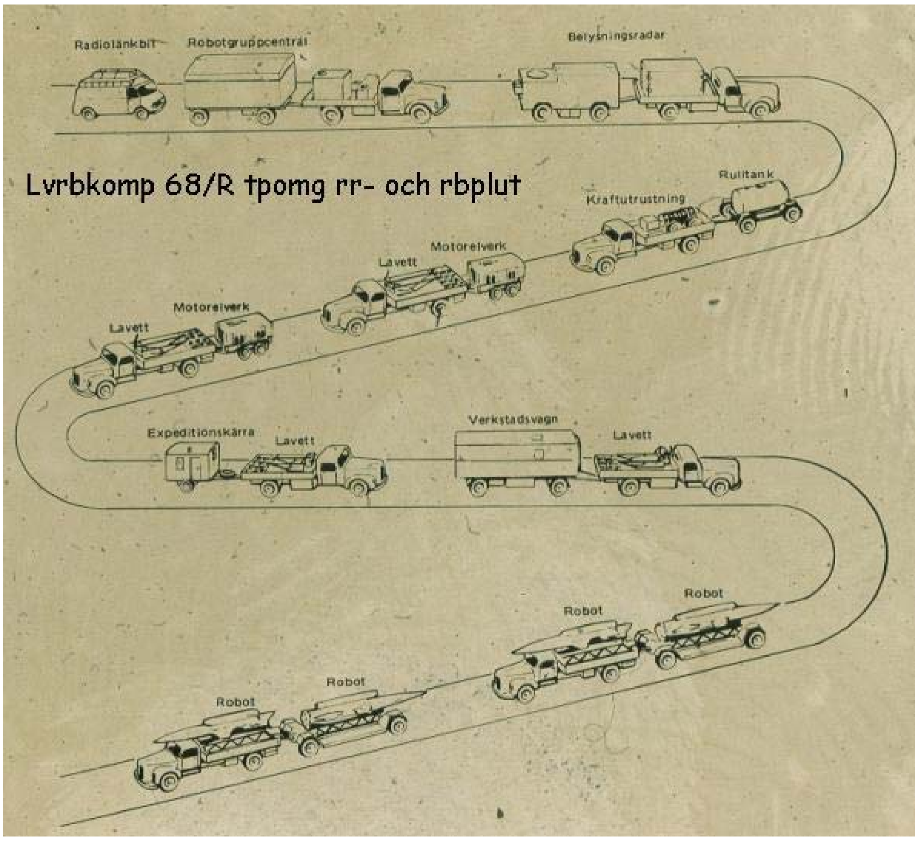
In the end we had the only product to achieve volume sales.

The Swedish Sale

Bloodhound 1 - 1958 - First British missile system to achieve export sales, this was to Sweden.

The sale of Bloodhound to Sweden was not achieved without difficulty. We had tough competition, especially on price, from the Americans. Our English Electric competitors with the Corporation's backing made big promises, but we had achieved real results in those fields.[6]

The Swedish Royal Air Force said "Bristol tells the truth," and the team kept that reputation; it was repeated by a senior Swedish Air Force officer at his retirement party. We had Export Packing Services' help in improving transportability, and it took Greville Beale only a short time to make the rest of the system road transportable to their requirements.



Swedish Air Force

Depicted above is a Swedish Bloodhound fire unit
on the move between secret prepared sites spread around Sweden.

Bloodhound in Sweden with Bristol and Swedish Air Force teams

Big Money

The Swedes had tried unsuccessfully to develop their own GW system, and had set aside the money for its production.

With that money in the bank, the Swedish Air Force negotiated with us and ordered a complete system including radars and first and second line support equipment and workshops, for which they paid a large deposit.

Bristol Aircraft Virtually in Liquidation

A year later the main Bristol Board and the Aircraft Board had to give urgent consideration to the British Government's intention to reduce the number of companies in the aircraft industry.

Research by Professor Keith Hayward has shown that the official record of the Bristol situation at that time [(8)] ignored Guided Weapons; this is published in ‘British Aircraft Corporation: A History ‘By Stephen Skinner:

"In October 1959 Sir Matthew Slattery, chairman of Bristol, admitted that the aircraft group was virtually in liquidation. Production of the Bristol Britannia turboprop airliner was almost at an end with just one remaining unsold, and the poor sales performance of the Britannia had brought about losses to the firm of £7-8 m. There was progress on the SST studies and the Bristol 188 research aircraft, and some hope of producing a competitor to the projected Vickers VC11 and DH121 (Trident), but that would need at least 50 per cent funding from the Government which was very unlikely. The threat of bankruptcy for Bristol was only averted by the sale of the Bloodhound 1 surface-to-air missile system to Sweden, which brought in a substantial down payment."

How Bankruptcy Was Prevented

This statement shows that bankruptcy, and the likely end of the Aircraft Company, had in fact been avoided the previous year because of the large Swedish down payment for the Bloodhound 1 transportable weapon system.

The person who achieved this sale and payment now deserves honour [(2)]. His name was F.W. Higginson**.**

BAC GW Division

Bloodhound 1 - Trials at Woomera

Two British air to air missiles had preceded Bloodhound at Woomera, and they had shown a problem unique to missiles. While aircraft can be flown in mock battle, missiles have to be evaluated theoretically. The British had set up Evaluation Simulation, and staff at W.R.E. did the same. Thus from 1957 under Alex Biggs Australia developed the model for Bloodhound [(9)].

The modelling was complex. It had to include target radar characteristics, radome aberration, tracking errors, and the full dynamic characteristics of the missile and its control systems. First analogue, and later digital computers were barely able to cope with the complexity and needs for accuracy. Yet without it the Air Force would not know how effective its missiles would be as the threat evolved. Comparison with the missile trials would evaluate the model.

Bristol staff joined in on the modelling, and they stayed in Australia. We found the modelling of great value in improving weapon performance, and it was essential for potential customers for the weapon.

Sale to R.A.A.F

Australia purchased Bloodhound 1 for the RAAF, for a dual role. Sited for air defence of the Southern cities and airfields, it had to be capable of rapid transportation to the Northern Territory for defence against possible invasion there. Australian deployments started with No. 30 Squadron at RAAF Base Williamtown in January 1961, under W/Cdr. E.W. Tonkin.

Present at the commissioning ceremony, with David Fairbairn (Minister for Air) and G/Capt. R.N. Dalkin (O.C. Willamstown), were F.W. Higginson with Basil de Ferranti.

Bristol Aero Collection

A detachment formed in Darwin in 1965. The WRE modelling kept the R.A.A.F. up to date on its effectiveness.

Bloodhound 1 1961 - First British Missile System to Achieve Export Sale to Australia

Origins of Bloodhound 2

In a previous attempt to handicap the team we had been ordered by Lord Caldecote to make the Bloodhound static, an order which I had disobeyed (a disobedience essential to the Swedish sale).

Following the sudden cancellation of Blue Envoy (a longer range successor to Bloodhound 1), the Bristol GW team had no new project and was again vulnerable. So we, with Ferranti who had developed a CW ground radar, rapidly modified a Bloodhound 1 missile to second generation continuous wave radar (CW) guidance.

When launched it achieved a direct hit which destroyed the target aircraft.

R.A.E. Aberporth

The other contractors had not reached this stage, so the longer range road and air transportable Bloodhound 2 was developed[6] for the Royal Air Force, and bought by Sweden and Switzerland. Its advanced features were to give it a very long service life in Britain, Germany, Sweden, Switzerland, Singapore and Cyprus.(I visited the system in Cyprus, and was treated royally…)

From then on we took care to keep abreast of research , assigned staff to New Project studies and won contracts.

Bloodhound 2 had a range of 150 km., so we developed a ramjet test vehicle at Woomera with supersonic and subsonic parachute recovery. It had an Aboriginal name, "Bobbin", appropriately meaning "Place of Fire".[10]

Bristol also took over the Jindivik jet target which had been designed and developed in Australia.

Bristol with Ferranti became the largest and most successful guided weapons team in the country.

Bloodhound 2 1964 - In service with the Royal Air Force, Sweden and Switzerland; it remained in service with Swiss Air Force (the final user) until 1999.

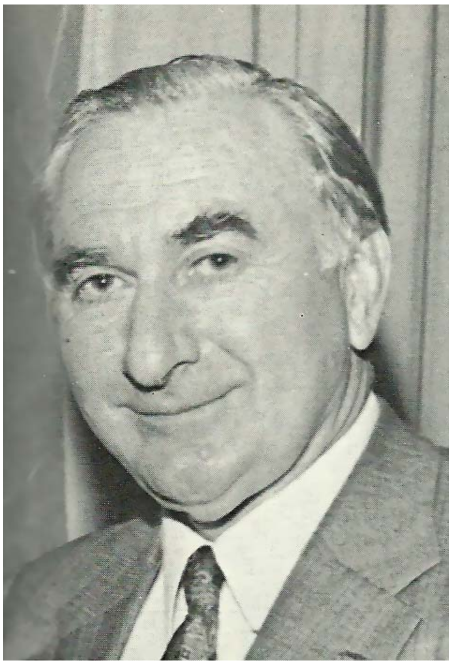
Bloodhound in Switzerland

Swiss Army

In Switzerland the Bloodhound 2 was deployed for many years at a very secret mountain top site, with a larger target illuminating radar which gave it enough range to defend virtually the whole of Switzerland. The missiles were housed in bomb-proof shelters. They are still there: the site is open to the public as a museum, and you can view it all on the Internet.[11]

How Bristol Was Able to Join the British Aircraft Corporation

Bristol could not have joined British Aircraft Corporation without more money in the bank. Where it came from was another deeply kept secret. It did not come from aeroplane sales or Government contracts.



J. T. Jefferies BAC GW Division

During Bloodhound development Jack Jefferies, the Production Manager G.W., caused the missile's cost to fall dramatically below the price allowed by the British Government. He influenced design, achieved continued production learning in manufacture, and advised Ferranti on cost reduction.

Exceptionally, therefore, Bloodhounds made in their hundreds were able to undercut the price of American missiles made in thousands as well as increasing the profit above that allowed by the Ministry of Defence.

We should honour the late J.T. Jefferies (2) , who achieved this: not only because his achievement was kept secret at the time, but (to his intense disappointment) because it has been secret ever since. Even his family knew nothing of his key contribution until 2010.

British Aircraft Corporation Politics

Sir Reginald Verdon Smith arranged for the Bloodhound profits at Bristol not to be visible in the accounts, and kept them outside the British Aircraft Corporation. His bargaining power was unfortunately not great enough to protect his goose which had laid the golden eggs. On the formation of the Corporation, Bristol Aircraft joined as a junior partner. The three aircraft teams, engaged in self preservation, allowed all guided weapon work to be assigned to English Electric.

Corporation policy was then for the Bristol GW engineering team to be closed down (4), with only limited possibilities of employment for its large staff elsewhere in the Corporation. I learned recently that a Government Working Party on rationalisation had previously recommended that the Bristol GW team should continue; but it seems that power had gone to English Electric's head.

The Bristol GW team fiercely opposed Corporation policy; I and leading engineers refused to be moved.

After several months James Harper, the Bristol Managing Director (who was terminally ill at the time) won the support of Sir George Edwards for creating a Guided Weapons Division(4) comprising the Stevenage and Bristol sites. The Division would have some Bristol based Directors, initially James Harper and myself. Taffy Higginson and Jack Jefferies later joined the Board.

B.A.C. Aero Collection

James Harper (left) presenting a silver Bloodhound to the Swedish Air Force.

James Harper's initiative ensured [(2]) that the Bristol GW team was to survive, for which his memory deserves honour.

There was much distrust at the GW Board, and as a result within the first year I suffered a brief nervous breakdown, which had to be kept secret. After James Harper died the long knives came out. The three Bristol Directors were out within a year or two.

When I left the Corporation, Sir George Edwards apologised to me for the way we had been treated.

Dr. Don Rowley, who had joined the Bristol GW team in 1949 and became my deputy, took over at Bristol. He told English Electric that their proposal for Bristol GW was not enough to make him stay, and he progressively negotiated work areas within which he enjoyed much profitable success. I will mention some, but on the whole that is another story which is recorded in two books. [(7),(13]

Concorde: Predictable, Predicted [(12)] Financial failure

When I became Engineering Director, Concorde, at Bristol, some of the GW staff followed me over. During this period Bristol became dominant on the aeroplane front, and the Weybridge site undertook subcontract work on Concorde.

Concorde 1969 - First flight of the world's only successful supersonic passenger aeroplane developed from the Bristol Types 198 & 223.

First aircraft to have digital computers for Master Warning and Air Intake Control systems designed and manufactured by the Guided Weapons Division.

Many airlines, including Qantas, had already placed provisional orders for the Concorde, which promised New York to London in four hours, London to Australia in twelve. The prediction was that 200 Concordes would be purchased by the airlines

Concorde 01 taking off on an early test flight BAC Aero Collection

The British Government was concerned about cost escalation and programme-slip on the project and part of my brief was to correct these [12] if possible.

I found the main cause was repeated redesign for unrealistically low takeoff weights. I talked to Rolls Royce, who agreed and planned increased engine thrust for the final weight.

Bill Strang and Lucien Servanty had done a great job in fixing the basic configuration, but neither prototype nor preproduction Concordes had enough fuel to fly a load of passengers across the Atlantic with normal fuel reserves, which were large because of the aircraft's inferior subsonic performance..

Servanty, obsessed with weight reduction (*tunnel vision*?), would not agree on action even though I had the support of the Bristol Aircraft Board and the British officials. (Like other people who are right about things at an inconvenient time, I became *persona non grata* in France and my career suffered.)

Sir Archibald Russell - after several years - persuaded him to design for extra fuel in the rear fuselage of the second preproduction aircraft. However, the third production aircraft was the first one to be designed as I had proposed.

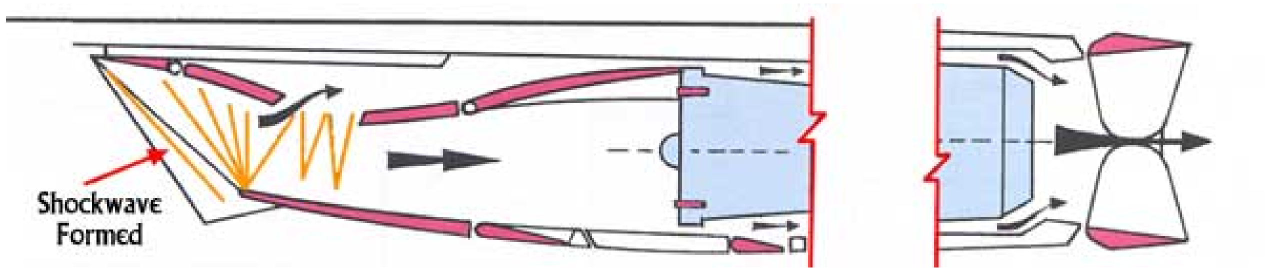
We had also found, using evidence which had been available years earlier [12] , that the aircraft's manufacturing cost would be more than twice that predicted. This, together with our weight predictions, was analysed by Sales at Bristol who concluded that airline orders for more than 12 aircraft were unlikely. Russ said to me "David, if you are right the project should be cancelled."

In response to the aircraft cost problem which I had uncovered, Bristol and Rolls Royce set up very successful value engineering activities primarily to reduce aircraft cost. Reduction of aircraft empty weight was a valuable by product but the French refused to join in.[12]. In contrast, the French-led weight reduction campaign increased aircraft cost, particularly in the front fuselage.

In the end no Concordes were sold. While the fuel price crisis of the 1970s played a part, a subsequent analysis[5] at 1988 economic conditions, after recovery from that fuel crisis, assuming full aircraft utilisation, showed Concorde's cost per seat scheduled mile to be 250% that of a Boeing 747-200, which Russ had seen in the 1950s as the real competitor. (In this situation with skilled marketing British Airways was to be able for some years to make small contributions to the seven hundred million pounds spent on development and manufacture of the aircraft.) Flight testing soon showed that poor function of the air intake analogue control system threatened the project.

The Bristol GW team had already engineered the digital telemetry system for Concorde, and had fixed the Master Warning System in four weeks[7] . As a private venture they had already modelled the Olympus engine, placing them in a unique position for the intake control system. Despite this there was delay in Ministry agreement (due to the electronics industry lobby) but eventually they were given a contract for intake control system development.

Supersonic Speeds (supersonic cruise)



At the supersonic cruise speed of mach 2.0 the ramps have moved over half their amount (Rolls Royce Bristol)

The new intake control system had to be very accurate, speedy and reliable, and involved a new software language needing CAA approval. It was successfully engineered and delivered on time [7], giving Concorde reliable and efficient propulsion.

This example alone shows the value of the " Diverse Complementary Products" policy at Bristol over the years.

When Concorde design work ran down, many of the staff were able to transfer to GW.

A Very Poor Reward

The GW team's reward for doing this was not to be one they would have liked.

Their continued success was a thorn in English Electric's side, so the Main Board endorsed a secret proposal that the Bristol GW design team be integrated with the aircraft team once their immediate design commitments had been completed. This failed because Concorde work ran down soon after. (The electronic industry's lobby would have killed it anyway.)

The preproduction aircraft proved the London to Sydney route, but much of it had to be flown at subsonic speed because of sonic boom prohibition over land.With this restriction, and ever rising seat mile costs, the route was never to happen.

Concorde 2003 - Last flight on November 26th of the last Concorde G-BOAF returning to its birthplace, Filton, Bristol.

The Concorde was the last complete aircraft to be made at Bristol. It was followed by B.A.C. 111 tail assemblies.

From then on, aircraft manufacture at Bristol was to be of major parts, not complete aircraft.

In the ensuing years, Bristol achievements in GW and Space were to outnumber those in aircraft(2).

The BAC 111 Bristol Aero Collection

Australian airlines had by this time abandoned Bristol and were buying American. (Boeing would later set up an Australian company for component manufacture.)

However, the R.A.A.F. purchased two 111s as VIP transports.

The BAC 111 development was funded by Bloodhound 2 profits. (6)

Aerospace Reorganisation Would Later Bring Naval Guided Weapons and Airbus to Bristol

The next stage of mergers resulted in the formation of British Aerospace. Bristol had learned on Concorde to move large aircraft components between countries, and the Brabazon Assembly Hall and runway were facilities ideally matched to Airbus component manufacture.

The Bristol GW team's expertise on weapons system engineering resulted in Bristol becoming first the centre for all naval weapons, and later as M.B.D.A. for weapons system engineering. Bristol GW staff rose to Board level in several Divisions, and the Main Board.

The 100 Year Survival

It is an interesting paradox that the unique 100 year survival of aerospace at Bristol was due to the *original owners' policy* of co-locating different activities which would support each other.

This policy was *in conflict* with government rationalization policy for large units to be set up, each in a specialized field.

While the mutual support was the key to survival, some individuals suffered a personal price from that conflict, while systems engineering knowledge greatly benefited the careers of others.

Thoughts on Predictable Failures

A memorable phrase on the value of experience arose during guided weapon development:

"Experience is what tells you - that you have made the same mistake again."

It is too true to be funny, and previous cures for mistakes are too commonly not followed. A major example in failing to manage complexity is the delay of nearly a year in A380 deliveries because of electrical loom problems.

Bristol designed the Concorde looms with additional identified cables, which initially eased the introduction of modifications and later permitted airline special requirements to be easily incorporated.

If Aerospatiale had followed this practice of Bristol on the Concorde the A380 delays would probably not have happened**.**

There have been other recurring problems - and some previous cures.

***On time, on budget**

Starting with Bloodhound 2, the Bristol GW team was usually on time, on budget. My successor, Dr. Don Rowley, used documented methods which repeatedly gave him these on time on budget outcomes on very complex projects. The successful methods [(7)] used by Don Rowley remain unknown to most engineers and are apparently not included in education or training.

Common experience today continues to be of failure to complete development on time, on budget. I will examine some causes.

***Tunnel vision**

There are numerous causes [(12)] of t*unnel vision*. Historical examples were when Britain failed to spot winners, such as Whittle's 1930s fanjet, and backed many losers, such as most of the Brabazon projects. Lack of environmental thinking on air intakes turned the Britannia from a success to a partial failure.

We need engineers with all round vision; we must develop them. I found that guided weapons engineering forced us to be like that.

At Bristol the aircraft organization took nearly all the available engineering graduates, so we recruited physicists and mathematicians and trained them in the new GW technologies. In our environment they readily became all round adaptable engineers, many enjoying brilliant subsequent careers in aerospace and elsewhere.

***Ignoring evidence**

The SST Committee failed (12) to look at evidence available to it on aircraft cost trends; it only took me a few months to find and use it.

The Concorde accident was predictable (14)..

The two Space Shuttle accidents were predictable (12),.(15).

Today the JSF started with excellent cost credentials but, to the RAAF's embarrassment, is overdue and over cost. Many years ago we at Bristol predicted that this would happen, and why; the project has excessive diversity and variety.

Today the Internet could enable the Society to make relevant evidence available to Government and industry,

***Product ignorance**

In ignorance of the needs of GW engineering after George Jefferson resigned, and thus with t*unnel vision*, the Board of British Aircraft Corporation failed (7) to appoint competent replacement G.W. Managing Directors at both Bristol and Stevenage, resulting in loss of business.

When British Aerospace was formed, people who understood the business (some from the Bristol G.W. team) replaced them and took key jobs at both Divisional and Corporate levels, and work was reallocated on the basis of capability.

Recommendations

***1. Tunnel vision**

It could be argued that the cases of t*unnel vision* in this history are unlikely to recur today. This is not the case: there are basic institutional and psychological factors which promote it. These factors apply equally to industry and Government establishments.

In his book Mistakes (12) Nick Gardner identifies and gives examples of the many causes of error which apply to both procurement and engineering; most are deeply embedded in human nature, and many retired engineers and administrators will readily recognise them. They are summarised below. *Those in italics are recorded in this history as causes of error in the Brabazon, Britannia, Concorde and Space Shuttle.* Those in bold script were overcome to achieve cost reduction in Bloodhound and Concorde.

*Cognition
Inattentional blindness, cognitive dissonance, **cognitive bias**, availability heuristic, simulation heuristic, *anchoring adjustment*, *probability blindness, peer pressure, "not invented here", conflict of interest.*

*Psychological
Sub-optimisation, availability bias, *role bias*, loss aversion, risk aversion, **framing**, *decision avoidance*, accountability bias.

*Organisational
Agency capture, "*we/they*", "**not invented here", short termism**, *scapegoating*, alliances, **failure to examine alternatives, inattention to cost and risk**, *neglect of failures, repressing unwelcome information, respect for authority*.

I recommend that these factors be studied and proposals be developed for minimizing their effect. The book recommends peer review, group forecasting, encouraging scepticism, examination of motives, T-group discussion and review of organizational barriers.

At present (referring to 2010) Governments seem to do none of these.

***2. Procurement**

The establishment of D.P.T.C.An M.O.D. was a major step forward, but the combination of increased system complexity and new technologies has become a major problem which threatens function, timescales and costs.

While Universities can and should develop deeper understanding of the nature of the problem, and teach solutions, the Aeronautical Society could take a lead by organizing a conference on the Management of Complexity. It could well include past successful methods, such as used(9) for the Polaris submarines and missiles by a much appreciated Bristol team, and the use of creative design methods for system simplification such as those which Airbus failed to use on its A380 looming problems. Today these methods have relevance to complex software.

Before requirements and proposals are made firm an adequate study of alternatives should be conducted, covering risk, cost and effectiveness. Had this been done by NASA a smaller Space Shuttle might still be in service.

I suggest that with reduced budgets senior people in Government and Industry should know the benefits, principles and methods of cost reduction through design for economic manufacture, value engineering and production learning. Their practice should be included in engineering education and continued learning, and should be understood by both civil servants and engineers. The contractual interface should be renegotiated to permit these methods to be widely used to mutual benefit.

***3. Avoiding repetition of past mistakes**

The time to look for and avoid earlier mistakes is at Project and Design Reviews.

The Society could work with other interested organizations to ensure that a website is created to remind engineers of the most important of these, and how to avoid them.

***4. Leadership**

Several of the Society's Groups have an interest in these fields, as well as other organizations such as the Ministry of Defence.

It is suggested that initially the leadership of any response should lie with the Society's Management Studies group, should it wish to do so.

Space Begins at Bristol

At Bristol in the 1950s I set up a small private venture budget to start Bristol in Space, and it enabled the engineering by Bob Chisholm of a University space experiment. By 1960-62 a team led by Tom Walters had engineered and built some of the scientific experiments for British universities flown on the American built UK1 and UK2 scientific satellites.

W.R.E. Woomera

At Woomera, from about 1961, Bristol was assembling and testing payloads for the Skylark space sounding rocket and in 1963 Bristol took over management of that project.

Ted Chambers, our former Chief Aerodynamicist, was in charge. He wrote an amusing book[(2)] about it. His degree thesis had been on the spun cricket ball- Australian eyes only!

W.R.E. prepared rocket motors and provided launcher services until 1968, after which BAC Australia took those over. By 1979 a total of 266 Skylarks had been launched, some in five other countries.

Skylark1963 Prime Contractor for payload assembly, overall vehicle procurement, assembly and launch in continuation of the

UK's first space programme started by RAE in 1957 - 441st and final Skylark launched in 2005.

In 1967 my successor at Bristol, Dr. Don Rowley, obtained Divisional agreement that Space activities would be concentrated at Bristol.

From this beginning, scientific, exploration and communication satellite projects [11] were won and successfully executed.

Intelsat 4

Hughes Corporation

An Intelsat 4 at Bristol, with engineers, in the Space Clean Building.

Intelsat 4 was the first commercial communications satellite assembled outside the U.S.A. by BAC for Hughes Aircraft, and it was launched in time to send back live television pictures of President Nixon in China.

It was followed by seven others and ten orders for subsystems.

Space Exploration

Giotto 1985 Bristol built satellite for the European Space Agency launched by Ariane rocket from Kourou, French Guiana.

First to provide pictures of a comet's nucleus.

First to perform a close fly-by of two comets (Halley & Grigg-Skjellerup).

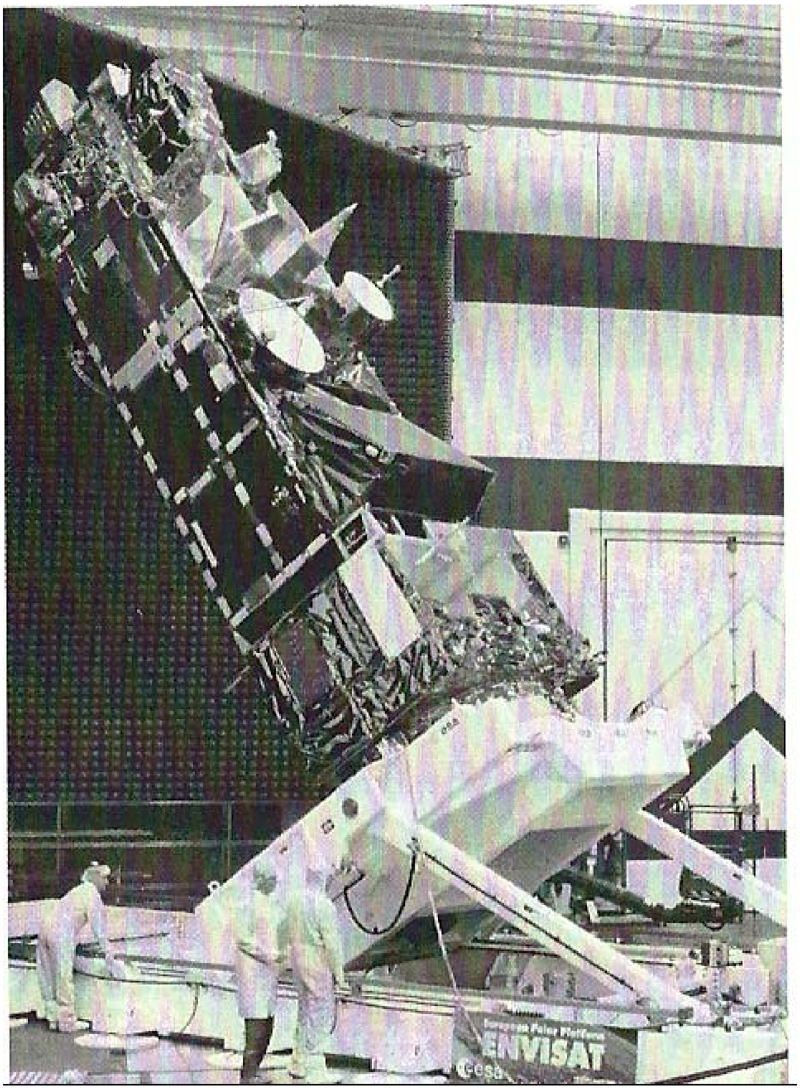
First to return from interplanetary space and perform Earth fly-by.

First spacecraft to be reactivated from hibernation mode. E.S.A.

Close up view of the comet nucleus. Among other things, Giotto showed that Earth's water could not have come from comets.

Envisat

Envisat 2002 - Bristol prime contractor for the European Polar Platform and Satellite Prime Contractor from 1990 to launch in 2002.



E.S.A.

Envisat was Bristol's biggest satellite,
25 metres long in orbit and with a mass of over 6,000 kilograms.

After more than seven years it continues to contribute to man's knowledge of climate change and global warming.

Space Tracking and Data Capture

The Parkes telescope *John Sarkissian, CSIRO*

In Australia the Parkes Observatory, which you see above enveloped in a rainbow, is a 64-metre Telescope used for Radio Astronomy. It is located approximately 380 kilometres west of Sydney. Nobody will forget its role in bringing the first Moon Landing pictures to the world.

It was able to observe all the Bristol space vehicles except the geostationary ones, which served the other side of the World.

Manned Space

When international collaboration commenced on the Space Shuttle design, I was the only Board member in the Company with suitable aircraft and missile experience and became [(4)] the Director responsible for choosing which American firm we would work with. The choice was easy; Rockwell were just like us, a cooperative team with supportive management.

We had a Weybridge team designing the vertical stabilizer, and two Bristol teams designing the payload bay doors and instrumentation in Rockwell's design study which won the development contract. The teams did well and their work was appreciated. Early in the design phase NASA's review group killed the idea of a hypersonic aeroplane mounted on a supersonic aeroplane. However, they and ESA had difficulty in conceiving a Space Tug for geostationary orbit, which was to lead to the loss of many missions[(13)].

I had two unforgettable experiences there. I was able to do a lunar landing in the Apollo Lunar Module Simulator, and beside a skilled NASA astronaut I also experienced reentry in the Space Shuttle Simulator.

Rockwell took heed of my account of the mistakes in Concorde weight targeting, and while setting optimistic mass targets for components they added a mass contingency which designed the rocket thrust and propellant mass. The first Shuttle came out very close to the payload target.

The Space Shuttle programme has come to an end. Or has it?

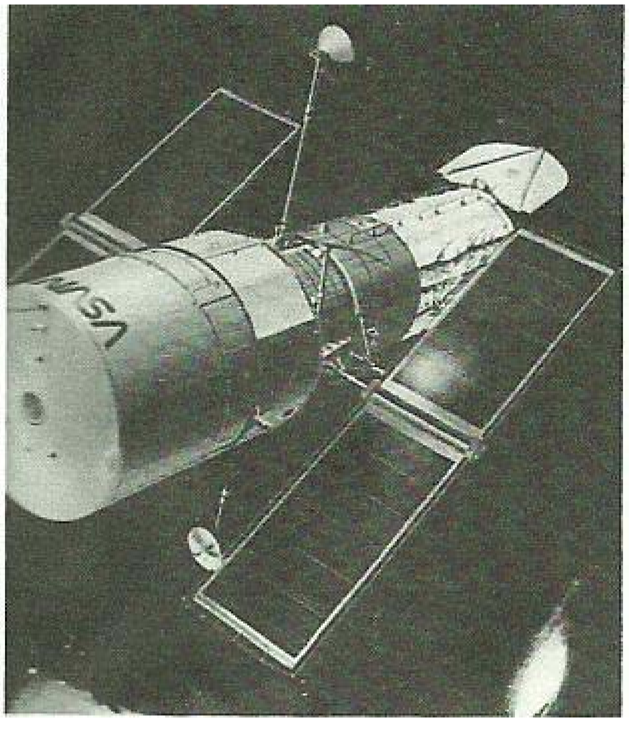
Secretive: The X-37B spacecraft (US Air Force: AFP)

Launched in April 2010 by the reliable Atlas rocket, this smaller Space Shuttle can do the return sidestep required by the USAF for re-entry. It is a pity it was not studied years ago, as it avoids both the ice debris and cryogenic tank seal problems of the NASA shuttle. Its history is on the Internet [16].

In 32 years I had seen speed going from 250 m.p.h. to 20,000 m.p.h.

Hubble Space Telescope

On 25 April 1990 the Space Shuttle launched the Hubble Space Telescope, for which Bristol had supplied the solar arrays, checked in Bristol by visiting astronauts.



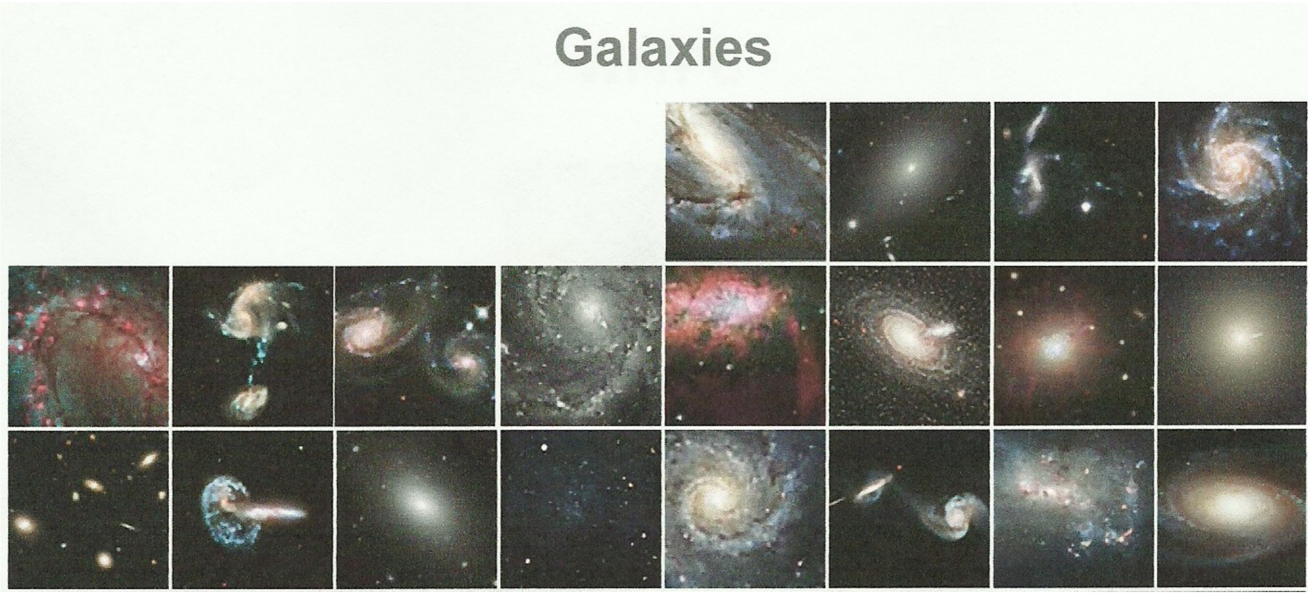
Hubble leaving the Space Shuttle after a NASA service mission. NASA

After launch and deployment it immediately became clear the something was wrong. The main mirror had a fault and there was a small occasional attitude disturbance due to thermal shock on the arrays. Astronauts participated in the Bristol plan for redesigned arrays, which were fitted in space on the Servicing Mission in 1973.

Thirty five Bristol engineers were proud to have participated in the programme, which has since given mankind a new perspective on our place in the Universe. I am privileged to have been the founder of a Bristol G.W. team which has subsequently achieved this.

Hubble Views the Visible Universe

The Universe has hundreds of millions of galaxies. Hubble has photographed [17] many within about 1000 light years from Earth. Here are a few of them.



Individual galaxies have hundreds of millions of stars, most with several planets.. In our galaxy, among hundreds of millions of stars, Planet Earth circles a small sun which lies near the outer edge.

A galaxy rather like ours, 67 light years away.

Mankind can now have a different understanding of the universe as a whole, and of our place in it.

Two Recent Milestones:

Guided Weapons 2009 The 60th anniversary of the establishment of the Bristol Guided Weapons Department which is now represented by MBDA on the Filton site.

- Bristol Aeroplane 2010 The centenary of the Bristol Company celebrated.

- The world's first aircraft design and manufacturing facility to be in continuous operation for 100 years, the site now occupied by Airbus, Rolls-Royce, BAE Systems, MBDA .

My thanks to Bill Ainsley, Charles Halton and Shona Olson for their help in creating this lecture, and to the RAeS Australian Division for encouraging its publication.

Abbreviations:

BAC	Bristol Aeroplane Company (later British Aircraft Corporation.)
BOAC	British Overseas Airways Corporation
CW	Continuous wave
DPTCAn	Directorate of project time and cost analysis
ESA	European Space Agency
GW	Guided weapons
HMG	Her Majesty's Government
HSG	Hawker Siddeley Group
JSF	Joint Strike Fighter
BOAC	British Overseas Airways Corporation
JSF	Joint strike fighter
JTV	Jet test vehicle
MOD	Ministry of Defence.
NASA	National Aeronautics and Space Agency
RAAF	Royal Australian Air Force
RAE	Royal Aircraft Establishment
RAeS	Royal Aeronautical Society
RAF	Royal Air Force
SST	Supersonic transport aircraft
WRE	Weapons Research Establishment

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