

UNCLASSIFIED

Defense Technical Information Center  
Compilation Part Notice

ADP010303

TITLE: The Tornado GR4 Programme - A New Approach

DISTRIBUTION: Approved for public release, distribution unlimited

This paper is part of the following report:

TITLE: Advances in Vehicle Systems Concepts and  
Integration. [les Avancees en concepts systemes  
pour vehicules et en integration]

To order the complete compilation report, use: ADA381871

The component part is provided here to allow users access to individually authored sections of proceedings, annals, symposia, ect. However, the component should be considered within the context of the overall compilation report and not as a stand-alone technical report.

The following component part numbers comprise the compilation report:

ADP010300 thru ADP010339

UNCLASSIFIED

## The Tornado GR4 Programme - A New Approach

T Watkins

British Aerospace, Military Aircraft and Aerostructures  
Warton Aerodrome  
Preston PR4 1AX  
United Kingdom

### Summary

The growing costs of new weapon systems will encourage potential customers to consider upgrading their existing fleets. Today's aircraft will therefore be expected to remain longer in service and counter the threats of the future. Industry will need to adapt from developing and manufacturing new weapon systems to finding ways to improve the capability of an existing asset to maintain a deterrent in a higher technological environment. According to the 1997 British Aerospace Military Aircraft Value Plan 'The upgrade and re-life of existing aircraft is a valuable market opportunity – over the past five years the upgrade of existing assets has accounted for 16 per cent of the total value of combat orders world-wide'.

The RAF's IDS (Interdictor Strike) Tornado aircraft are expected to have a service life-span of up to 40 years and to ensure their combat effectiveness are currently undergoing a Mid Life Update (MLU) - the largest of its kind in Europe. The Mid Life Update programme returns 142 IDS Tornado aircraft to industry and upgrades them to a new variant, designated Tornado GR4/4A, which will become the new common standard for the RAF IDS aircraft.

The £1bn programme is split into three contractual elements – development, production embodiment and support. Panavia, the industrial partnership consisting of Alenia, DASA and British Aerospace brought together originally to design, develop and manufacture Tornado aircraft, is the prime contractor for the Development contract but British Aerospace lead for the Production Embodiment and Support contracts.

The Tornado MLU programme had a difficult start as the world socio-political environment changed but has emerged as one of the success stories of British industry.

The aircraft will receive during the embodiment programme system enhancements including a forward looking infra red system, an improved defensive aids system, improved and full Night Vision Goggles compatible cockpit displays, and the ability to carry a wide range of new weapons. This will provide a baseline standard for further upgrade improvements grouped into packages. Each new package will be introduced to the aircraft approximately every 18 months. Due to the flexibility of the approach taken by the team working on

the programme it has been possible to encompass some additional operational requirements onto the aircraft as they pass through the MLU embodiment process.

This paper will provide an introductory overview of the programme looking at the historical backcloth, the three contract elements, and how we are tackling the future requirements of our customer. Specifically the experiences encountered by British Aerospace and its partners, and how the Mid Life Update programme has stimulated innovative approaches to improve the responsiveness to customer demands. There has been a direct correlation between performance on the Programme and the level of team working that takes place. This is very encouraging to the programme with the continuing series of package upgrades planned over the next few years.

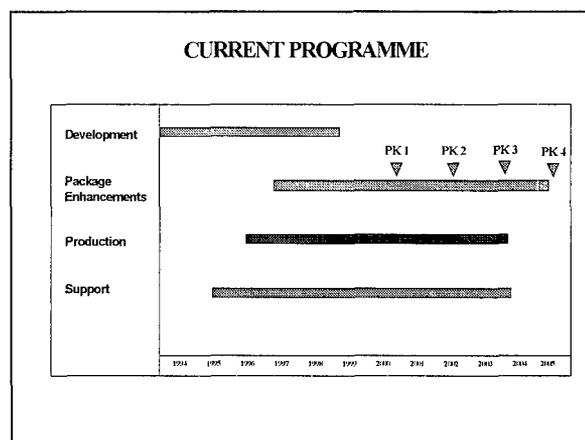


Figure 1 Tornado GR4 Programme

Finally the paper considers why an update for the Tornado was the right approach for the RAF in its quest to maintain an effective capability to match the defence needs of the United Kingdom in the early 21st century.

### Historical Overview

The first discussions of a Multi-Role Combat Aircraft, the project from which Tornado emerged, took place in 1969 and involved a number of European countries. Many of these countries dropped out but three remained to design, develop and manufacture the swing-wing aircraft. The first Tornado GR1 aircraft entered service

with the Royal Air Force in 1981. The last Tornado aircraft built was delivered to the Royal Saudi Air Force in September 1998. Within the UK, the RAF use the aircraft primarily for Air Interdiction, Offensive Counter Air and Tactical Air Reconnaissance roles, and SEAD (Suppression of Enemy Air Defences) following the introduction of ALARM in 1990.

The Tornado aircraft is in-service with the Air Forces of Germany, Italy, Saudi Arabia and the United Kingdom. Panavia have built nearly one thousand Tornado aircraft. In the United Kingdom there are two main variants - the IDS (Interdictor Strike) and the Air Defence Variant (ADV). The UK IDS has three versions:

- GR1 - IDS
- GR1A - Reconnaissance
- GR1B - Maritime Attack

In addition to this the Royal Air Force have fitted specific equipment and carried out special order only modifications to certain aircraft to meet an immediate operational requirement which has resulted in a situation where there are very few aircraft to the same standard.

The Tornado GR1 is a proven performer, with successful operations in the Gulf War, has automatic navigation and weapon aiming, a very comprehensive passive and active Electronic Warfare capability, and can carry a wide range of weapons. The aircraft is optimised for all weather, day or night low level operations, and is heavily dependent on its automatic terrain following radar.

However, already by the mid 1980's studies were underway involving Germany, Italy and the UK on how to improve the aircraft's capability in view of the technology advances since the aircraft had been designed and developed in the early seventies. After some delay eventually the UK decided to go ahead alone with a requirement 'To enhance the capability of the Tornado GR1 aircraft to find and successfully attack its targets in all weather and reduce its vulnerability to attack'. This was Staff Requirement (Air) 417.

Specific areas of improvement highlighted were:

- To achieve improved covert night operations. The Tornado GR1 is very good at keeping low and out of sight behind hills but in bad weather has to use its Terrain Following Radar and hence potentially leaving itself vulnerable to being tracked by opposing forces.
- To improve the aircraft's capability to fix positions and target locations for navigation and weapons aiming.

- To provide additional growth capability. The on-board computing capability is limited by modern standards.

- To improve supportability of the aircraft. As the Tornado's went through their original build programme the aircraft was consistently improved leaving a legacy of the three versions - trainer, strike, and reconnaissance aircraft - each with a range of different build standards. Additionally the RAF has incorporated numerous Special Trial Fits (STFs) and Special Technical Instructions (STIs) on specific aircraft. Consequently the logistic support and fleet management of the aircraft in service is very management intensive, which has also proved a major management challenge in the MLU Return-To-Works programme; this is discussed later.

The initial studies led to the development stage of the Mid Life Update programme starting in 1989. To meet the stated requirement the development work on the upgrade programme can be split into a number of areas:

- Introduction of a new avionics architecture built around a 1553 databus.

- New sensors & Displays consisting of a Forward Looking Infra-red sensor, a Pilot's Multi-Function Display with digital map, Wider angle HUD, Computer Symbol Generator, Video recording System and a Computer loading System.

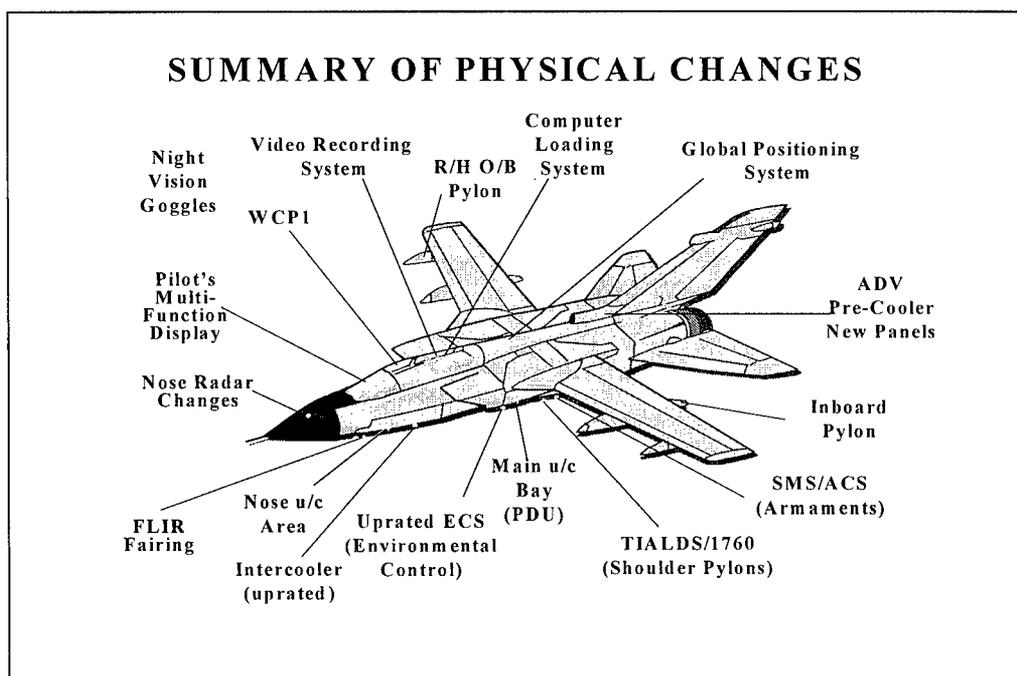
- New Armament Control System consisting of a Stores Management System, a Weapon Interface Unit linked to a 1553 databus within a 1760 interface.

- A Night Vision Goggle compatible cockpit.

- Terrain Reference Navigation / Terrain Following Display / Terrain Following Switching & Logic Unit / Covert RadAlt.

Development work started in earnest but in the world some momentous events were taking place with the ending of the cold war. The original plan to embody the MLU standard onto the Tornado aircraft was to incorporate it into the last batch of aircraft to be built and retro-fit the earlier builds. However, this plan was thrown into disarray by the cancellation of the last batch buy from the UK. This left a hiatus over how to embody the MLU standard into the Tornado fleet.

The IDS Tornado's first operational use came with the



**Figure 2 – Summary of Physical Changes**

Gulf war where the aircraft carried out some of the toughest missions during the conflict - low-level attacks at night against heavily defended targets. The lessons learnt from the Gulf War emphasised that the sensors were optimised for low level operations. At night the crew were blind to other aircraft resulting in tactics having a heavy reliance on timing that gave little flexibility to evade and safely avoid air and ground threats. Once operations were moved to medium level there was a greater reliance on precision weapons and illuminators

On the domestic political front two government reviews took place – ‘Options for Change’, and ‘Front Line First’. These resulted in MLU being under severe financial pressure not least because the politicians were looking for savings from the Defence budget, the so-called peace dividend, as a result of the collapse of the Warsaw Pact, but also the embodiment strategy was still not clear. In addition it was desirable to incorporate the Gulf War lessons. This led to a reassessment of the requirement to take the Tornado through to 2018. The solution resulted in what was to become MLU '93 and Production Embodiment would take place through a return-to-works upgrade package for 142 aircraft at Warton.

Despite the medium level lessons learnt in the Gulf the RAF decided that covert low level penetration remained the core requirement. The main deletion from the original MLU in hardware terms was the Terrain Reference Navigation System and its associated equipment. In its place a Global Positioning System was introduced to ensure the required capability was met.

The main additions to the programme were a TIALD (Thermal Imaging Airborne Laser Designator) system and a MEGTF (MLU Enhanced Ground Test Facility).

Whilst development activities were ongoing the Tornado GR1 had a number of software enhancements which were outside the scope of the original MLU development contract. These software additions had now to be somehow taken into account and incorporated.

The most important aspect of MLU '93 is that in addition to the basic enhancements of MLU, the flexible design created the foundation to incorporate future developments to the aircraft's capability. This is particularly relevant to the introduction of new smart weapons such as Brimstone and Storm Shadow scheduled for early in the 21st century.

### Development

At the time of the initial negotiations for the development contract on MLU the MoD were in the process of moving away from cost plus contracting. The MoD and industry were learning about fixed price contracting when the Development contract was negotiated. The impact meant that the work content had to be fixed to provide a fixed price. Therefore certain actions were placed so that the Tornado GR1 aircraft was updated from as common a standard as possible. Remember each aircraft had been built to a slightly different standard and the RAF had also made some changes of their own to meet specific operational requirements. A baseline standard was agreed together

with a 'Minimum Modifications List', which lists all the modifications that had to be on the aircraft when the RAF returned them to industry was included in the contract documentation. This solution meant that some modifications would have to be removed before the aircraft entered the MLU programme, an approach that suited the contractor since it provided a firm baseline for the development work. However, as development work progressed, any change, which is inevitable at this stage of a project, could only be carried out by an amendment to the contract.

The RAF found this one of the most frustrating areas since development on the Tornado GR1 aircraft continued to take place providing capability enhancements in isolation to the GR4 development programme. One such example is the carriage of Sea Eagle where some of the Maritime Tornado's had been upgraded to carry the weapon via the STF route. Under the terms of the contract this capability had to be removed before the aircraft entered the MLU programme, and would not be part of the MLU upgrade programme. Hence in this particular area the aircraft would be returned to the RAF at a lower capability than at which it left the Service. The RAF was not amused! This has been resolved by Package 1 that introduces Sea Eagle onto Tornado GR4.

Industry preferred to have no change since it distracted the engineers away from the task. The exception to this is where there is a need to undertake some additional work, for instance testing, to ensure compliance to the contract specification. For example the engineers identified the need to do more testing on the cockpit lighting mock-up as a result of making some minor equipment changes to the cockpit panels.

Although availability of hardware is important the speed of the development programme is driven by how quickly software development cycles can be achieved. A software load and two correction cycles have traditionally taken approximately three years to undertake. Therefore any change involving the integration of new avionics equipment, according to the working processes at the time, could only be introduced at three yearly intervals without disrupting and hence potentially risking the completion of the original software load.

As one would expect once the development programme had been stabilised with MLU '93 there were a number of issues that were identified as potential risks to the time scales of the contract. One of the continuing challenges to the update programme has been the difficulty encountered with TIALD development. The time scales available for its introduction onto Tornado GR4 had been continually shortening. TIALD was in development with a different contractor and the customer was committed to delivering a fully functional

TIALD pod to the programme. Further there had been a number of observations from the RAF when the first cycle of software was released - in the terms 'well I know I specified it like that but now that I've seen it and tried it I want something slightly different'. Consequently a decision was taken to change the development programme radically again with the introduction of Package '0'.

The introduction of Package '0' occurred in early 1996 when the customer formally redirected the programme. It took a year to finally agree all the changes to the contract amendment. Package '0' encompassed the required changes from the customer observations to the software generated controls and displays, and accommodated the delay in the availability of a working standard TIALD pod. Furthermore the customer was keen to incorporate as many other software changes that were a direct result of enhancements in the Tornado GR1 aircraft since the scope of MLU '93 had been defined. All the hardware development would now be completed by October 1997 as originally planned, with the exception of TIALD. However, a new software load was introduced to cover off the customer observations and incorporate the Tornado GR1 enhancements. This meant that the full MLU standard software would not be released until September 1998, thereby taking up the planned six months contingency on the programme.

The key driver behind the revised programme was to ensure no impact upon the production embodiment contract. The net result was that the aircraft would be delivered on time, October 1997, to the customer but initially only with an interim standard of software. This would only effect the first few aircraft.

In hindsight, such an approach was risky because on the first aircraft delivered, the RAF crew, including the ground crew, would only see the 'work-arounds' undoubtedly leading to some frustrations because certain functionality was missing. Consequently all the parties involved with the decision, including the various elements of the MoD and the RAF, visited the main operating bases and explained to the RAF personnel who were receiving the aircraft what was happening on the project, what to expect and their role in the process. This proved a very useful exercise and in the process many of the urban myths and unfounded opinions were dispelled. The end user now knew what to expect when the aircraft arrived.

Additionally, once the aircraft arrived at the main operating bases a member of the development team was located with the RAF crews to assist in resolving any issues that may arise.

This paper has been written around the presentations given.

Not only were there concerns over the perception likely to be received from delivering the aircraft at an interim standard, but BAe and DASA did have a severe challenge in achieving the September 1998 deadline using the traditional software development process. The revised schedule required three years work to be completed in just over two years together with some additional effort to give a formal release at an interim standard.

It was at this point that the 'team', composing of the various organisations including MoD, RAF, BAe and DASA began to work much closer together and found ways to shorten the time scales and get a better standard of software at an earlier stage.

BAe had developed the 'GHOST' development process that allowed modelling and rapid prototyping of systems design algorithms and also cockpit displays. This provided an early assessment opportunity that greatly reduces the possibility of the final design not satisfying the customer's requirement. The new process enabled the RAF project personnel to perform dynamic assessments of the proposed system design and agree what the cockpit displays should look like rather than attempting to specify their requirement on a piece of paper.

The MLU programme involved changing the software, with DASA doing the main computer, BAe the Missile Computer Unit and writing completely new software for the introduction of a Computer Symbol Generator. The traditional method of proving software on Tornado is to undertake sub-system testing, and then to provide a formal release to the full integration rig, which is a representative example of the aircraft on the ground. Once integration testing has completed stringent schedules for flight satisfactorily a formal clearance for flight test is issued. The paperwork formalities took time, and like many other programmes, once the software was released from one stage to the next required improvements would be quickly identified. To overcome this it was agreed to make software-engineering releases available to the integration rig early before the formal paperwork to enable a quick look to enable any obvious improvement requirements to be identified, which could be incorporated before formal release. The process has moved further to allow a number of engineering loads to be progressively released to the next stage so that a higher standard of formal release is achieved. To assist in this process on the integration rig the BAe aircrew would participate in the fitness for flight assessments with the engineering loads so that anything that may compromise a successful flight test could be corrected earlier.

Similarly engineering loads were flight tested where there was no safety critical implications. This shortened the time scales for software development and assisted in

achieving an earlier clearance than might otherwise have been achieved. This meant a higher standard of software was available earlier leaving more time to fix any problems and analyse the testing results. Effectively what we did was have a large number of small iterations to the software, 'rolling development' rather than three big loads. The net effect meant that when errors did occur it was easier to identify where they were and hence more easily corrected. All this is an obvious thing to do but changing the attitudes and working practises is always a challenge.

A knock on benefit of using engineering loads is that this method reduces the number of times clearance paperwork was raised. Previously the time consuming paperwork process raised to fly a software load had to be repeated often as the software proved to of limited airborne value. This work was removed, as the software will have been rejected at an earlier point. The downside was additional effort on configuration control.

The process encouraged better teaming and shortened the time from when the software engineers wrote the software to it being tested on a rig. This meant that the software engineers were taking a closer attachment to 'their' work and were disappointed when their work did not work as planned. Hence more pride in their work developed and the association with the aircrew demonstrated how important their input was to the final outcome of the project.

These efforts enabled the development contract to be completed as planned at the end of October 1998. Hence the Production Embodiment programme was not disrupted and the development team was in a position to move forward on the follow-on enhancements to the aircraft.

### **Production Embodiment**

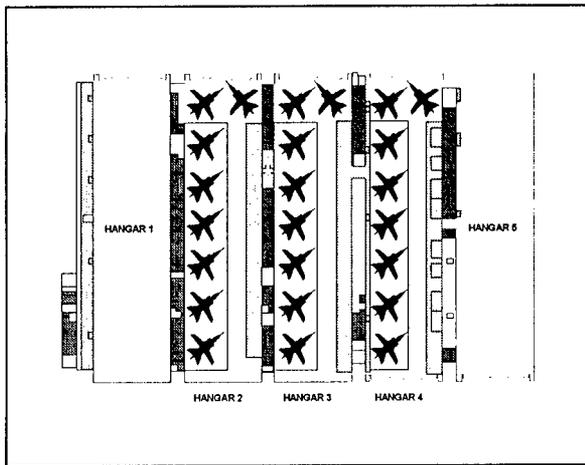
The enormity of the production embodiment task cannot be underestimated. There are over 30 miles of cables in the Tornado aircraft and the MLU programme demanded that most of it be removed with 20% being replaced completely.

Less than two years were available for planning and preparing for the first aircraft on the return-to-works production embodiment programme. The embodiment would take place at the British Aerospace facility at Warton, North West England where the aircraft had originally been assembled. In mid 1995 a 'strategy formulation team' comprising of all the key stakeholders was established to move the planning process forward for the embodiment activities. The team highlighted some of the issues facing the programme as:

- The Logistics system would be the key to the success of the RTW programme. Over 3000 parts

and equipment's would be removed from the aircraft and then scrapped, stored for refit or sent away for modification. Further to this over 500 new parts or equipment's had to be fitted to the aircraft. The number of suppliers involved in the supply chain was huge and the management of this process would be critical for the project's success.

- The 'flow' line manufacturing process amplified any problems in the logistics process. Removing parts from multiple aircraft, storing and distributing them centrally, and then trying to control them back to the correct individual aircraft once they had been moved on added further complexity to an already complex system.
- The information technology used by the majority of manufacturing programmes at Warton would not support effectively the complexity which was envisaged on the Tornado MLU programme.
- The manufacturing environment once set up had to be flexible to respond to programme changes and potential future business but it needed to be robust enough to support a seven year activity intensive programme.



**Figure 3 – Aircraft Layout in Hangars**

The strategy team developed a network of people from the stakeholders and worked with them to formulate a sub-strategy for each area. Initially the organisation resisted this approach, however over time some key people were able to influence the group and a framework for developing a co-operative working environment ensued.

The strategy team identified five areas of success:

- Process
- Logistics
- Engineering
- People
- Quality

The key decision on the manufacturing process concerned the build philosophy. The team concluded that there should be a complete break from the traditional 'flow' line process and instead each aircraft would remain in a dedicated position, or bay, during its modification and testing. This eradicated the need to move the aircraft during its build and meant that the modification phase, the Production Flight Acceptance Tests and final handover to the customer could be cleared from the same hangar.

The layout of the three hangars allocated two bays at the south end for acceptance of the aircraft on arrival and for engine ground runs / flight preparation at the end of the modification process.

Each dedicated bay has a single parts control area, termed regulators, which act as the focal point for control of all parts taken off the aircraft, stored or transported to a vendor and then replaced on the aircraft. This means it is not possible to mix up parts from different aircraft and secondly parts being 'robbed' from aircraft to satisfy shortages elsewhere can be strictly controlled.

The movement of parts to/from the regulators is achieved by purpose built transportation media. These meet the 'everything has a place' philosophy ensuring full visibility of complete sets of panels and boxes, and allow the easy identification of missing parts. Alternatively the parts are transported to a dedicated repair and refurbishing area, and then returned to the regulator. Similarly vendor equipment are delivered into the regulator on a strict time scale similar to a 'just-in-time' process.

The normal supply of kit sets of parts to an assembly line is a bag with all the parts tagged to ease their identification by the fitter. On Tornado GR4 the original plan was to adopt best practise in British Aerospace which was on the T45 trainer aircraft assemblies where the parts are delivered nested into foam shadow boards in purpose built suitcases with Perspex tops. However, with a return-to-works build line the required parts for each suitcase would not necessarily be the same, as each aircraft is potentially slightly different. To overcome this a simplified approach has been taken and each kit set is mounted on standard size boards and then vacuum packed, and stored in the regulator.

Once a decision had been made to dedicate bays for each aircraft a number of knock on considerations have to be resolved. In a flow line environment the fitters tend to specialise in one or two phases of a ten phase build process. This leads to some demarcation across individuals, for example, a structure person is prevented from carrying out a mechanical systems test. A team concept is the alternative adopted allowing each operator within the team the opportunity to use his skills in the most beneficial area to the team at any particular time.

One team would manage three aircraft from acceptance to delivery. The main advantage perceived being that ownership would be developed to eradicate some of the problems associated with an aircraft moving down the line often before the work has been completed.

From a purely people point of view it was argued that giving people more options, and more flexibility in the way they worked would create and sustain interest in their working day. If managed properly it would mean that individual skills were being utilised more efficiently for the benefit of the business. By adopting a number of individual teams an element of healthy competition could be evolved between them, for the benefit of the project.

The principle structural changes to the aircraft are restricted to three areas. The most obvious change is on the port underside of the front fuselage where a fairing has been added which houses the new Forward Looking Infra-Red (FLIR) sensor. To accommodate this in the existing structure the left hand gun has been removed and some additional structural strengthening has been undertaken. Another main area is on the lower fin where the Environmental Control System has been modified by using the Tornado ADV primary heat exchanger. The final area are structural changes to the pylons to allow the use of the 1760 weapons databus.

To exacerbate the challenge each aircraft would arrive at Warton at a different standard depending when originally built and whether it was a strike, recce or trainer aircraft. It was recognised at an early stage that the standard of the Tornado's in service varied dramatically and BAe work very closely with the RAF to relieve the situation. The Tornado aircraft come from the operating bases to RAF St Athan for a Pre Input Maintenance Programme, or PIMP. At this point the RAF carry out a major or minor star service, remove any service installed STFs (Special Trial Fits) and check the required modifications on the Minimum Modifications List are fitted. Should any modifications require fitting, or alternatively removing this work is undertaken before the aircraft is flown to Warton to enter the Return-to-Works programme.

The testing of the electrical modifications on the aircraft to identify any wiring anomalies is done before any aircraft equipment is loaded into the structure. This is undertaken by two mobile DITMCo electrical test rigs, which move to each bay when the testing stage is reached in the modification process.

The first aircraft arrived at Warton in April 1996 and was completed twelve months later. The make span is reduced to 8 months by the 17th aircraft delivery. From the end of 1998 onwards 20 aircraft will be in the process of being upgraded until early 2003 when 142 Tornado GR1s will have been upgraded to the Tornado

GR4 standard. During this period one aircraft will be returned to the RAF every 8 working days.

The challenge has been met through a combination which started with the extensive forward planning done by the strategy formulation team and moved on with the development of new working methodologies, new equipment, exceptional co-operation with the customer, and tremendous team working arrangements.

The success of meeting the challenge has been achieved by the MLU team questioning our traditional working practices and, where possible, replacing them with innovative ways of carrying out routine tasks and ensuring we continue to improve our methods of working in the most effective manner.

The concepts developed by employee involvement teams prior to the first aircraft arriving at Warton has not stopped. Since the first hangar was completed in early 1996, more than thirty further improvements have been introduced in advance of the two other hangars being completed. Improvement plans and, Customer and employee involvement continue to be a way of life, throughout the GR4 programme, in the drive to reduce costs and meet the Customer's future delivery requirements.

Once work is started on each aircraft some form of emergent work is inevitably found when the aircraft is 'opened up'. This has to be dealt with very quickly, otherwise the delay will have an impact on the planned delivery date which in turn will result in no hangar space being available for the next incoming aircraft. Previously this would have generated a mass of paperwork between BAe and the Ministry of Defence Procurement Executive as the customer, the RAF as the operator, and the relevant design authority for the part of the aircraft affected - Alenia, DASA or BAe. Uniquely representatives from the MoD (PE) and the RAF who between them have the authority to authorise any additional work, and Alenia and DASA personnel are available on site. When problems do arise it is very easy to visit the aircraft and see exactly what is needed, so decisions can be made in a fraction of the previous time. This cuts down on much of the paperwork and reduces delays to a minimum.

Teamwork has been the cornerstone to the Mid Life Update's early successes on the programme and this is not just the customer involvement. Within BAe Integrated Product Teams for development, production embodiment and support have provided the organisational structure in which the total team has focused on the task. On the shop floor, a full support team of planning, design, finance, logistics, and other experts are co-located next to the bays where the aircraft is being worked. This allows the Fitters or Electricians who come across a problem on an aircraft can get an

expert opinion straight away. Similarly they can buttonhole the person responsible for giving them an unreasonably difficult task to perform and take them to the aircraft to show them exactly what's what!

Reams of paperwork have also been eliminated by the installation of electronic dedicated Manufacturing and drawing storage and retrieval systems. Terminals are located next to the aircraft so that all those working on them can call up the latest information they need to get on with the job.

Once the aircraft has completed its upgrade to a Tornado GR4 it is delivered to RAF St Athan where a Post Output Maintenance Programme, or POMP, is undertaken. At this point the RAF have the option to embody any Service Embodied Modifications or Special Trial Fits if required. The aircraft are then transferred to their front line operating bases at RAF Bruggen, RAF Marham or RAF Lossiemouth.

The MLU programme is a baseline for further capability growth. These capability enhancements will be introduced progressively as the hardware and software development is completed. The enhancements will be embodied on the Return to Works programme and retro fitted on those aircraft that have already gone through the MLU programme. Hence the planned work content of the RTW programme increases over time, with very little relief on time scales.

## Support

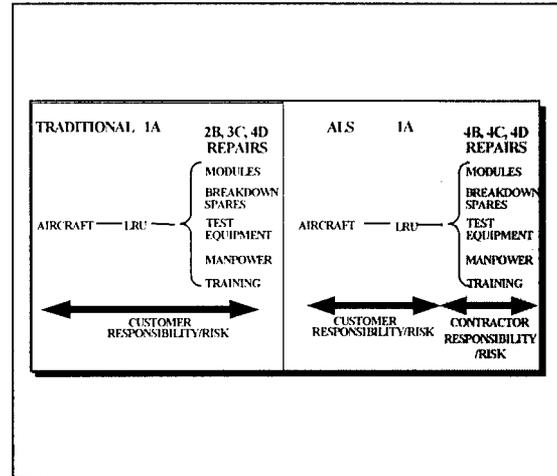
Throughout the MLU programme there are a number of innovations that improve processes and on the support aspects of the programme this continues. One of the most important requirements that the RAF desire is the availability of their aircraft when required. The lessons learnt from the experiences gained to date supporting in-service aircraft have been incorporated into the support activities of GR4.

Like the production embodiment contract the support contract with BAe is directly with the Ministry of Defence (Procurement Executive), and is fixed price against a fixed time scale related to the in service requirements. The task covers:

- Initial provisioning
- Aircraft Ground Equipment
- The supply of an avionics ground training rig
- Technical publications
- Training
- Data requirements
- Augmented Logistic Support (ALS)

The most notable innovation is 'Augmented Logistic

Support' where the new, high cost, high risk avionics equipment are supported by industry at the aircraft's main operating bases – RAF Bruggen, Lossiemouth and Marham. When an ALS LRU goes defective the RAF collect a replacement from the industry managed ALS store located on the base. The performance requirements are very stringent - 85% of all demands need to be achieved within one hour, 95% within 24 hours and 100% within 28 days.



**Figure 4 ALS - Change in Philosophy**

This support concept provides maintenance on a basis such that industry is responsible for all repairs apart from non-attributable damage. This puts the emphasis on industry to supply reliable equipment in the first place and therefore negates the need for repairs or associated spares. Failure to meet the service level target gives rise to retention penalties so a compromise based upon equipment reliability is determined by industry and not the RAF as previously managed. A slightly different system operates in time of war, when the RAF takes over control.

To date the new process has worked well with minimal difficulties encountered during the introduction into service period.

## The Future of the Tornado GR4

The Tornado GR4 MLU programme provides an upgrade in aircraft effectiveness and a baseline for future continuous technology insertion. A parallel life extension programme is on-going to enable the structure and existing equipment in the Tornado GR1 to be qualified to its out of service date around 2020.

As previously stated the MLU programme provides a step change in baseline capability for the Tornado IDS aircraft in the UK. This will make it easier for new more advanced equipment, sensors and weapons to be integrated onto the weapon platform. The speed at which

these can be introduced will be determined by our ability to develop new software loads in line with the time scales required to qualify any new hardware.

The RAF wants the most capable aircraft they can get but are restrained by affordability. It would be nice to have a new aircraft but the time scales from inception to in-service are now in the order of 20 years and the funding required is enormous, notwithstanding the political challenge and will. Therefore in the short to medium term the only option to improving the aircraft's capability is an upgrade, and that only happens if the funds can be justified against other competing demands. The RAF has four requirements:

- 1 Mission success. - There is no point sending highly trained men on a mission if it is unlikely to be successful.
2. Effectiveness. There is no point sending highly trained men on a mission using equipment that is no longer effective for its planned task.
- 3 A consistent standard of aircraft. With the same standard of aircraft fleet management is minimal. Availability of specific aircraft due to their 'special' equipment fitted and the subsequent specific support add significantly to the fleet management task.
- 4 Avoid red line entries. It is no good having highly capable aircraft if they are grounded due to a shortage of spare parts.

So, what can and cannot be done economically to an aircraft? Our experience on Tornado tells us that as long as the aircraft can remain effective and successful in its missions then it will generally make economic sense to upgrade. There are likely to be fewer advances in airframe design compared to the advances possible in systems over the coming years. Within BAe we view the aircraft as the platform for the weapon systems and therefore it is important to get the system flexible enough to integrate updated and improved systems onto the existing airframe. It is only when the fatigue life of the airframe makes it too costly to upgrade to be safe to fly that a new aircraft is justified. During this period undoubtedly new ways and methods of doing things may not be economically feasible on an existing airframe, for instance smart skins. Progressively the aircraft will lose capability in comparison to newer aircraft available on the world stage, and at some point its effectiveness and ability to achieve mission success will be sufficiently compromised to justify the development of a new weapon platform.

This view is sound in an environment where there is no longer a serious threat. The situation may be different in an arms race where a greater proportion of the nation's

GDP would be directed towards the Defence budget. Once a decision is made to go for a new aircraft the new air platform should provide a step change in performance.

The limitations to extending the useful life of the aircraft will heavily depend on the RAF's four requirements. Clearly if any of these are compromised it would not be in the UK's interest to continue extending the life of the aircraft. From a Design Authority's viewpoint maintaining the safety of the aircraft is of paramount importance. As the aircraft ages overcoming obsolescent equipment and ensuring the structure has clearance qualifications for the platform's extended life are serious considerations. Similarly from an operator's view the cost of maintaining an ageing aircraft will eventually become unacceptable.

The approach taken for Tornado GR4 to integrate new technology advances has been to provide a versatile design. The MLU programme restructured the original design to make the aircraft's avionics systems more versatile and capable of upgrading. Significant upgrades will come with the introduction of the various Packages planned. There must be a limit on what can be integrated onto the GR4 system but as yet that limit has not been reached.

#### Current Programme Status

The initial phase of the MLU Development programme was successfully completed in September 1998, and the Production Embodiment programme is now at full speed. The follow on packages are now defined. Package 1 will be embodied next year; Package 2 development activities are underway and the contents of Package 3 and 4 are now defined. There is no doubt that the Tornado GR4 has given the Royal Air Force a significant improvement in capability and the currently planned Package improvements will ensure the Tornado remains an effective strike aircraft well into the 21st century.