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TORNADO INTEGRATED AVIONICS RESEARCH AIRCRAFT (TIARA)

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SUMMARY

The paper describes the rôle, major features and flight trials programme of the Tornado Integrated Avionics Research Aircraft - TIARA. This significantly modified F2A(T) Tornado , ZD902, is the flagship of the trials fleet currently operated by the Defence Evaluation and Research Agency (DERA), an Executive Agency of the UK Ministry of Defence.

TIARA is a multi-sensor, multi-rôle trials facility intended to demonstrate a "total systems integration" concept. It not only directly supports military customer programmes but also has sufficient capacity for collaborative programmes with other research organisations.

Following a major conversion programme, ZD902 is now currently being used for the evaluation of IR sensors and helmet mounted displays. The future installation of the Blue Vixen AI radar will complete TIARA as a research facility and allow trials on sensor data fusion to begin.

1 INTRODUCTION

The Defence Evaluation and Research Agency (DERA) is an Executive Agency of the UK Ministry of Defence. Various parts of the organisation have links with aviation going back many years. In fact it was at the Farnborough site that Colonel Sam Cody made the first manned flight in the UK in 1908. This tradition has been maintained and today the operation of trials aircraft in support of military and civil customer programmes is an important activity. DERA currently owns a fleet of 14 aircraft covering helicopters, laboratory and fast-jet types (Table 1).

These aircraft are operated by DERA's Air Fleet Department (AFD) from an airfield at Boscombe Down, Wiltshire and are flown by military pilots including test pilots. All the aircraft have been modified to varying degrees for the incorporation of experimental equipment. Relevant design, manufacture and installation activities are generally carried out using AFD's own personnel and facilities, although tasks may be sub-contracted if appropriate.

AIRCRAFT	Tail No.
Laboratory:	
Andover C Mk1	XS 646
Andover CC Mk2	XS 790
BAC 1-11 (200)	XX 105
BAC 1-11 (400)	XX 919
BAC 1-11 (500)	ZH 763
HS 748 Series 1	XW 750
Fast-jet:	
Harrier DB T2/4	XW 175
Hunter T7	WV 383
Tornado GR1	ZA 326
Tornado F2A(T)	**ZD 902**
Rotary-wing:	
Lynx AH7	ZD 285
Lynx AH7	ZD 559
Sea King HC4	ZB 506
Wessex HC2	XR 503

Table 1 DERA Trials Fleet

Paper presented at the AGARD FVP Symposium on "Advances in Flight Testing", held in Lisbon, Portugal, 23-26 September 1996, and published in CP-593.

This paper is concerned with one particular aircraft, namely Tornado ZD902, which is now the flagship of the DERA trials fleet.

ZD902, a Tornado F2A(T) trainer version of the Air Defence Variant (ADV), (Fig.1) has undergone a major conversion to an advanced flight trials facility designated TIARA - Tornado Integrated Avionics Research Aircraft.

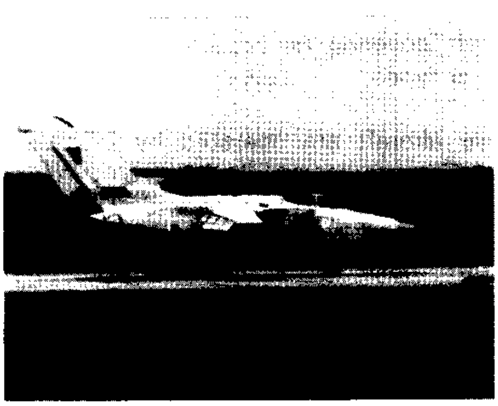

Figure 1 F2A(T) Tornado ZD902

This paper describes the rôle and capability of the aircraft and then outlines some current and future flight trials programmes.

2 ROLE OF TIARA

The primary rôle of TIARA is to support the military customers' programmes with particular, but by no means exclusive, emphasis on the air defence aspects. The location and recognition of targets through the development of all-weather sensor systems, and the reduction of aircrew workload are of particular interest. Consequently, the intention is that TIARA should demonstrate the operational benefits of "total systems integration" encompassing all aspects from the sensors through to the man-machine interface (MMI).

Because of the apparent emphasis placed on single pilot military fighters, the front cockpit has been significantly modified to provide a single seat fighter environment.

The rear crew member acts as a safety pilot and carries out such tasks as controlling and monitoring the experimental systems and data recording.

A major objective of the "integration" programme is to evaluate and demonstrate the principle of multi-sensor data fusion.

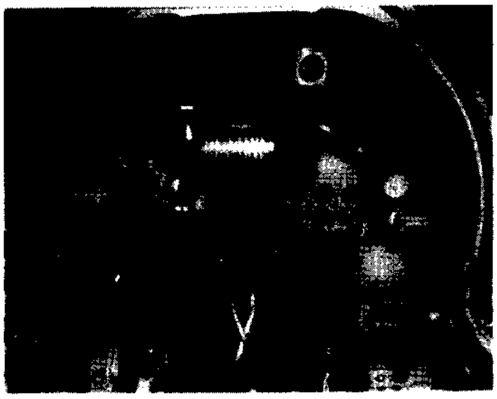

Figure 2 Original front cockpit of ZD902

3 TIARA FEATURES

3.1 Front cockpit

The original front cockpit of ZD902 with its vast array of electro-mechanical instruments, shown in Fig. 2, was completely removed and replaced by a more advanced diffractive head-up display (HUD), CRT full-colour head-down displays (HDDs) and a "hands on throttle and stick" (HOTAS) capability (Fig. 3).

An experimental wide field of view, diffractive HUD is being used, providing the pilot with a 30° x 20° field of view. It has a raster/cursive capability and potential enhancements to this device include improvements to the pilot's up-front control panel (UCP) and increased output luminance. If required for trials reasons, however, a HUD with a more conventional field of view may be fitted as an alternative.

Figure 3 TIARA's "glass" cockpit

Three 6 ins. square, full colour, raster/cursive shadowmask CRTs with integrated control panels are mounted in-line across the cockpit and provide the primary head-down displays (HDDs). This technology was chosen because of the immature state of flat-panel displays existing in 1992 when such decisions were made.

The 20 buttons around each display are soft keys allowing rapid multi-moding of the displayed information. In addition to standard flight information the displays can also present specialised experimental formats.

For flight safety reasons a set of electro-mechanical (EM) standby flight instruments have been retained together with the main engine temperature and RPM parameters.To provide space for these instruments, the existing central warning panel (CWP) has been moved to a position just below the middle HDD, although this has required the physical separation of the display and electronics sections.

The standard displays for both the radar homing & warning receiver (RHWR) and missile management system (MMS) have been removed from the front cockpit due to the limited panel space available, although equivalent information will be presented on the HDDs. The RHWR and MMS displays have, however, still been retained in the rear cockpit, the latter being necessary to preserve the emergency stores jettison capability.

The cockpit also has provision for a range of helmet mounted devices including simple sights and integrated helmets incorporating CRTs and image intensifiers. Both AC and DC electro-magnetic head position sensor systems (HPSS) can be fitted for use with the helmet mounted displays (HMDs). This aspect is discussed further in section 5.4.

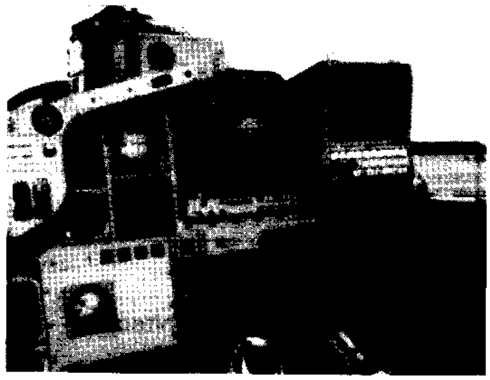

Figure 4 TIARA's rear cockpit

In due course, attention will be given to upgrading other aspects of the cockpit e.g replacement of the standard UHF/VHF radio frequency selection box by a flat panel display to allow for possible voice or "touch screen" operation.

For general cockpit monitoring purposes, up to 5 miniature CCD colour video cameras can be installed. Currently, one camera views forward over the aircraft nose and others may view the HDDs or the pilot's actions as dictated by the trials requirement.

3.2 Rear cockpit

The rear cockpit has deliberately been left relatively unchanged in the short-term,

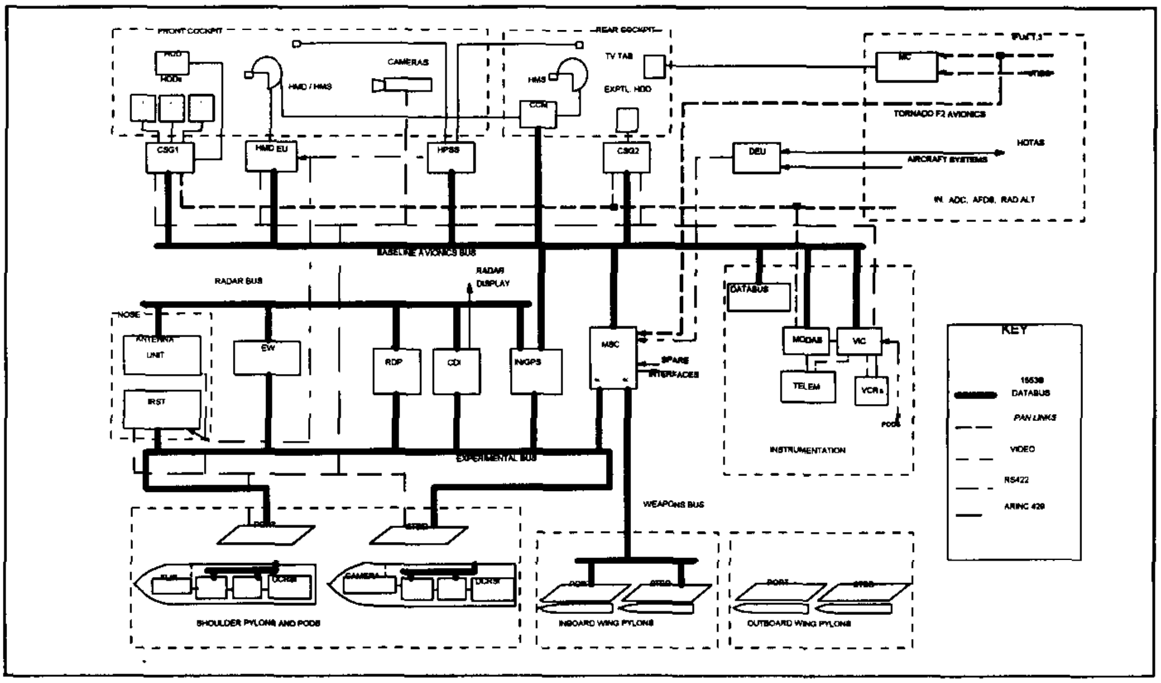

Figure 5 TIARA avionics architecture

especially as far as the electro-mechanical instruments are concerned, thus preserving the overall Tornado systems integrity. However, one of the TV TAB displays has been removed thus making it possible to install an alternative display. Currently, a shadowmask display of the same type as used in the front cockpit is fitted, although it could readily have been some alternative *technology such as a flat panel liquid crystal* display (LCD). Should side-by-side display comparisons be required e.g shadowmask CRT and LCD, then such provision can also readily be made.

Control panels are installed in the rear cockpit side consoles for the recording system, video cameras, telemetry and *experimental power distribution.* These include a data loading system which by means of a small data card can be used to initialise the experimental systems for the mission in question rather than having a number of different control panels, one per equipment.

Needless to say, an important requirement is for both cockpits to be fully night-vision *goggle compatible and this process is nearly* complete.

3.3 Avionic systems architecture

To provide the necessary experimental flexibility a new avionics architecture has been installed based on a multiple 1553B databus system. These have been designated *as the baseline avionics, radar, experimental* sensors and weapons buses. However, the use of the existing Panavia point-to-point data links has been retained and for specific applications RS422 and ARINC 429 communications introduced.

The current configuration is shown schematically in Fig. 5. It comprises a *number of distinct functional areas :-*

(a) standard Tornado avionics

(b) front cockpit

(c) rear cockpit

(d) experimental interfaces, bus controllers and electronic units

(e) instrumentation

(f) airborne sensors including IRST, EW and the AI radar with its associated units e.g radar data processor (RDP) & controls and displays interface (CDI)

(g) pylon mounted equipment (shoulder, inner & outer pylons)

At the present time no main computer (MC) outputs are used by the experimental system. Instead, information is taken directly from the standard Tornado avionics e.g inertial navigation system, air data computer and radio altimeter, via the serial Panavia datalinks. Approved Pan Link tee-modules provide the necessary degree of isolation and signal buffering in order to preserve the integrity of the basic aircraft avionic systems. Thereafter, the signals can either be used directly or else accessed via the 1553B baseline avionics bus. The conversion is made within one of the computer symbol generators (CSG) to ensure minimum latency.

A dedicated laser gyro based inertial navigation (IN) system provides accurate time tagged attitude and navigation data for the experimental system. It also feeds the radar bus thus ensuring accurate stabilisation information is available at a high (240 Hz) data rate. It also incorporates a global positioning system (GPS) capability which fulfils a number of functions both experimental and operational.

The so-called mission computer (MSC) performs a multi-function rôle including bus controller for the baseline avionics bus, experimental sensors bus and the weapons bus. It can also provide non-standard analogue, synchro and discrete interfaces and receive digital information from HOTAS and other aircraft systems via the data encoder unit (DEU).

Since there are many requirements for high speed processing on the aircraft e.g to emulate the in-flight trajectory of a missile such as AMRAAM, the MSC will encompass such functions. To achieve this degree of flexibility the MSC comprises a ruggedised VME system with multiple 68040 processors and is primarily programmed in Ada.

Display symbol generation (cursive, raster and cursive in raster flyback) is provided by means of two computer symbol generators (CSGs) capable of receiving data from 1553B and Pan Links as well as analogue and discrete signal sources. One CSG drives all four electronic displays in the front cockpit; the second provides a reversionary source for the HUD, serves experimental displays such as the HDD in the rear cockpit and also provides an output for video recording purposes. These units are modular in design, currently based on the 68020 processor and with expansion capability built in.

Provision has been made in TIARA for the incorporation of EFABUS (Mil.Std. 3910) which provides fibre-optic transmission and has a theoretical 20 Mbit/sec capability. However, until the appropriate interfaces are readily available for the avionic equipment and sensors, the commissioning of this system will be postponed.

A cockpit computer module (CCM) has been incorporated as a means of reducing the number of separate equipment control panels needed in the aircraft. It allows a general purpose panel to be reconfigured using software, provides a data read-out capability and also allows rapid data entry via a "data card".

3.4 Air Interception radar

Instead of the AI 24 Foxhunter radar normally fitted in F3 Tornados, a GEC-Marconi Avionics Blue Vixen multi-mode AI radar will be installed of the type currently fitted to UK Sea Harriers. This option was selected because the radar incorporates more modern technology and, because it has been specifically designed for single crew operation, provides a more appropriate man-

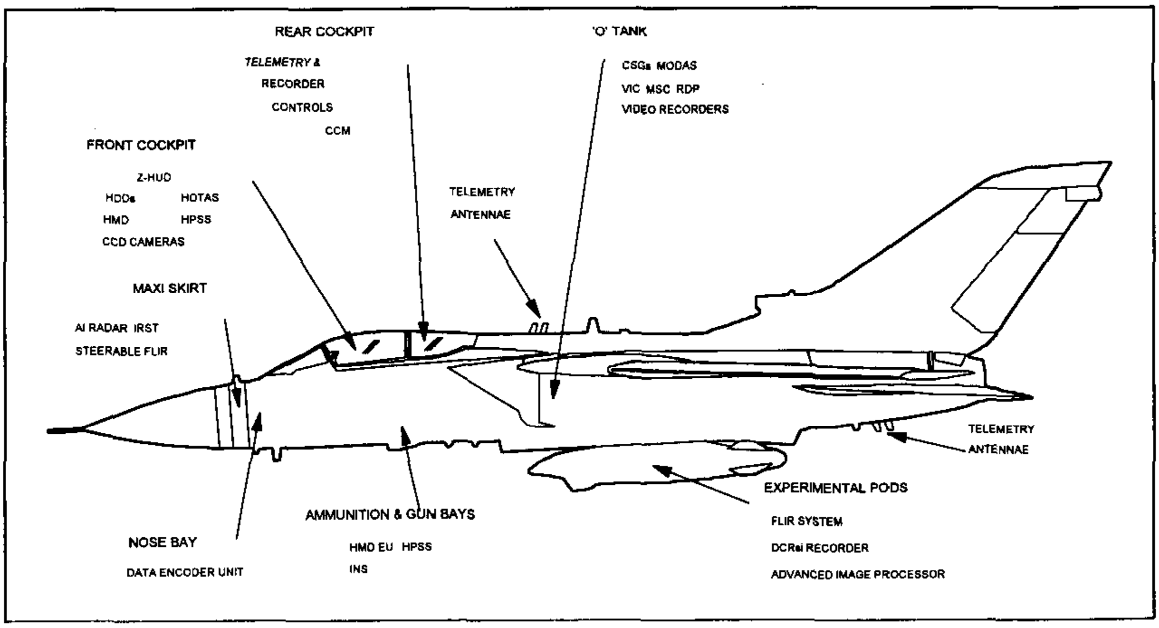

Figure 6 TIARA equipment locations

machine interface for the front crew-member. Another significant benefit arises from its relatively small physical size which will enable an infra-red search & track (IRST) sensor to be co-located in the nose, providing the initial basis of the sensor data fusion programme.

Although there will probably be a reduction in performance of some parameters such as maximum detection range, the research is primarily concerned with concepts and hence this is not considered to be a major problem.

The intention is to integrate the radar into the system as part of the experimental avionics and in Fig. 5 the radar data processor (RDP) is shown connected to the experimental sensors bus as well as its own radar bus. (A dedicated fibre-optic link connects the RDP to the antenna assembly.) The optimum manner to integrate the radar is still being studied. However, design work on the physical installation is well advanced using representative space models and the actual radar will be delivered in 1997.

3.5 Recording system

As shown in Fig. 5, the basic recording system comprises 5 video cassette recorders (VCRs), a general purpose modular data acquisition system - (MODAS) and two dedicated Heim databus recorders.

An onboard telemetry system allows a limited range of parameters and a video channel to be transmitted to a ground station. This will provide trials personnel with on-line information concerning the progress of the trial, supported by TV pictures from one of the cockpit cameras.

In addition, for certain trials, it is proposed to use a high bandwidth digital recorder which will be flown in one of two environmentally conditioned pods capable of being fitted to shoulder pylons beneath the aircraft.

3.6 Equipment locations

Fig. 6 shows the approximate locations of the various equipment on the aircraft. The three major areas are the nose bay, the

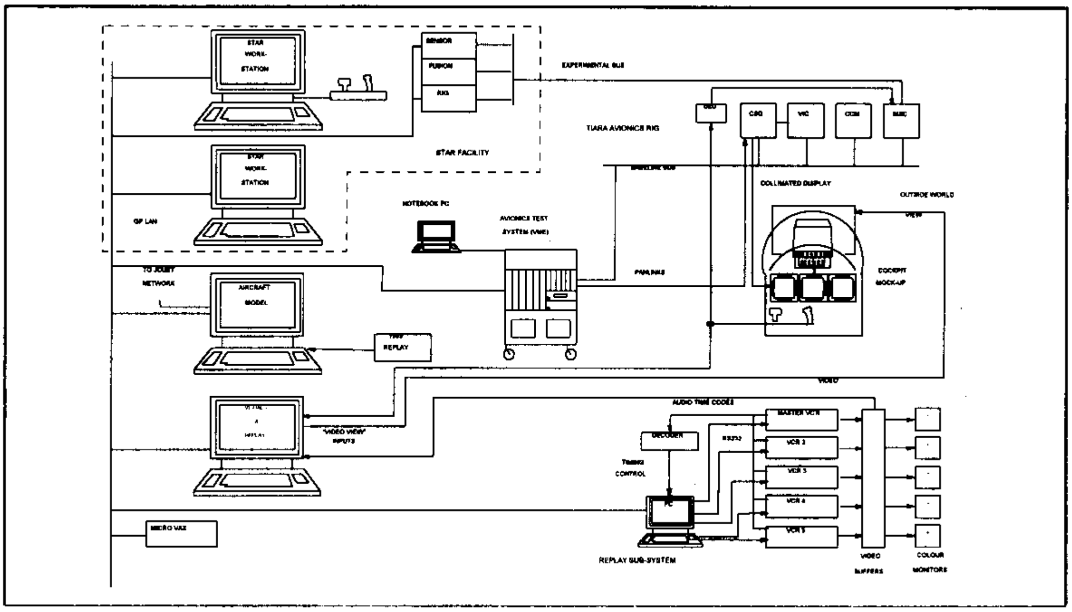

Figure 7 TIARA avionics ground rig

ammunition bay and 'O' Tank, the latter having been converted from a fuel tank to an avionics bay. Despite the removal of 'O' Tank, sorties well in excess of one hour are possible and this extends to two hours with wing tanks. However, the flight refuelling probe has also been retained as another means of enabling longer duration sorties to be flown if required.

The capability will also exist to carry experimental equipment in the pods referred to above e.g FLIR sensors, recorders or additional computers. Conventional stores can be carried on the in-board wing pylons e.g fuel tanks, AIM9L Sidewinders and ASRAAMs. The reinstatement of the out-board wing pylons, as fitted to Tornado GR1s, is being considered since it would provide a valuable additional trials capability.

4 TIARA AVIONICS GROUND RIG

To support the aircraft, a comprehensive avionics ground rig has been built, housed in mobile trailer. It is now currently based at Boscombe Down along with the aircraft although it could be brought back to Farnborough if necessary. The rig is used for a range of tasks including systems integration, software development, and the functional testing of experimental units.

In addition, the rig may be connected to a self-standing representative TIARA cockpit and a collimated outside world display providing the forward (48°x 36°) scene for the pilot if required. This allows some of the experimental display formats to be fully stimulated and assessed by the aircrew and, in due course, will provide a mission rehearsal/debrief capability.

The major hardware elements are shown in Fig. 7. Two Silicon Graphics (SG) computers provide the processing power for the Tornado aerodynamic model and the outside world display. A VME based system converts the ethernet LAN data into equivalent 1553B and Pan Link form for use by the aircraft experimental equipment under test. An important feature of the rig is that it can be linked via ethernet with the adjacent Sensor fusion & Tracking Applications Rig (STAR). This will allow sensor fusion algorithms to be subjected to man-in-the-loop assessment using the representative TIARA cockpit prior to actual flight trials.

The rig can also be networked with the JOUST™ beyond visual range (BVR) combat simulator. This facility allows multi-player operational assessments of weapon/avionics/platform combinations in realistic air combat scenarios. The TIARA cockpit will be used as a JOUST station both to assess the man-machine interface (MMI) aspects and validate simulator results prior to flight trials.

5 TIARA TRIALS PROGRAMME

TIARA is a pan-DERA facility and supports a wide range of military applied research programmes, technology demonstrators and projects. The flight trials programme underway covers the following general research areas :-

(i) Infra-red sensors

(ii) Helmet mounted displays (HMD)

(iii) Sensor data fusion (SDF)

(iv) Off-boresight weapon aiming

(v) Man-machine interface (MMI)

(vi) Systems integration

Brief descriptions of these trials programmes are given in the following sections.

5.1 IR sensors

The evaluation of IR sensors represents a major trials activity on TIARA and is concerned with long range passive detection and identification of targets, for both air-to-air and air-to-ground operations. An infra-red search and track (IRST) system is installed in the nose of the aircraft, collocated with the radar (Fig 6). Both sensors are physically mounted in the Tornado maxi-skirt for ease of access and installation.

By interchanging some of the IRST modules it is possible to convert the system to a head steered FLIR (HSF). This can be used in conjunction with an integrated aircrew helmet as discussed later.

In addition to the above, TIARA can fly with dual podded FLIR sensors and it is intended to carry out advanced processing on the IR sensor data to enhance the image detection, recognition and tracking capability.

The above IR programmes are supported by a strong sensor modelling activity.

5.2 Helmet mounted displays

The HMD will undoubtedly have a major impact on future cockpits since it adds significantly to the flexibility of the MMI. To gain early experience of such a system a technology demonstrator programme has produced a binocular HMD, Viper 2, designed for fast-jet usage and incorporating CRTs. The numerous flight safety issues associated with head mounted equipment have been addressed and the device has been installed in TIARA ready for flight trials. Its evaluation will provide a valuable insight into all the human factor and integration issues involved. Of particular interest will be the use of the HMD to slave the AI radar, IRST or steerable FLIR, or alternatively, the radar to reverse cue the pilot. In addition, research will be required into the specific HMD symbology to be used and the relative rôles of the HMD and the HUD.

Because of the complexity of the problem it is likely to take a number of iterations before a totally acceptable HMD solution is achieved. Many of the underlying technologies are, however, being actively pursued by DERA in collaboration with Industry.

5.3 Sensor data fusion

This programme will be aimed at establishing the operational effectiveness of multi-sensor data fusion for long range target detection, identification and interception, by day and by night, in all weather conditions. The intention is to provide the capability to assess a range of fusion techniques and algorithms. Both track and measurement level fusion will be evaluated and scenarios flown will draw extensively on experience gained from the JOUST simulator trials. Research is continuing on the algorithm development using STAR to provide the initial means of assessment with TIARA providing the means of validation.

The AI radar and the IRST will be the first sensors considered for the fusion process. Both exhibit different temporal and spatial characteristics and accuracies but their collocation should remove one of the major sources of difficulty involved in the harmonisation process.

An essential element of the programme will concern the development of display formats that can effectively present tactical information to the pilot in order to maintain his level of situation awareness under high workload conditions.

Incorporated within STAR is a dedicated SDF rig which comprises a multiple processor configuration using Motorola 68020s and 68040s. SDF software is in Ada and the system architecture includes a fibre-optic EFABUS. The modular construction of this rig allows it to be configured in a manner representative of a number of possible airborne configurations. The intention is therefore to link the SDF rig with the TIARA rig cockpit via ethernet thus effectively emulating the aircraft architecture prior to the start of flight trials.

5.4 Off-boresight weapon aiming

Helmet Mounted Sights (HMS) are far simpler devices than HMDs and yet can still provide significant operational benefits. TIARA will capitalise on the considerable experience gained within DERA from previous HMS flight trials. Both the radar and the IRST will be capable of slewing via the HMS.

The head position sensing system (HPSS) is a critical element when using any helmet mounted device as part of an aircraft system e.g for off-boresight weapon aiming, and considerable effort has been given to identifying the most effective technique.

Based on recent trials experience, particular emphasis has been given to achieving the maximum possible size of head motion box for the pilot. Although a number of potential techniques exist, making them work in a fast-jet cockpit environment can be very difficult. To date, the main experience has been with the AC electro-magnetic system but a DC system will be used with the Viper 2 helmet. The TIARA cockpits are capable of being equipped with either system.

The initial flight trials are attempting to study the operational issues and any problems experienced by the pilot when attempting large off-boresight weapon aiming. Captive missile seeker heads will be used for the evaluation and a digital Mil Std 1760 interface will be available.

5.5 Man-machine interface

Containing pilot workload is an important element of the research programme and essential to maintain the operational effectiveness of the single seat fighter. Appropriate expertise already exists within DERA on the measurement of workload and these techniques will be used on TIARA to study aircrew behaviour in a range of scenarios. The miniature video cameras will be used to record pilot activity from which a time-line mission analysis can be implemented. Cognitive processes will be deduced by careful debriefing of the pilot during mission replays on the ground.

The level of workrate is influenced strongly by the man-machine interface (MMI). As already mentioned earlier, TIARA has a "glass" front cockpit with HOTAS and a number of discrete control panels. Work on cockpit moding and display formats has been underway using the TIARA rig to establish a baseline system. The use of a speech recognition interface is a feasible option and allowance has been made for the installation of such equipment.

The MMI research covers a range of aspects including basic data measurement and advanced display technology. Of particular relevance is the use of flat panel displays e.g LCDs and the intention is to evaluate such technology as it becomes available.

5.6 Systems integration

The aircraft is already fitted with a standard radar homing and warning receiver (RHWR) system and has provision for the installation of a Joint Tactical Information Distribution System (JTIDS). The intention is to integrate these with the radar and other onboard sensors as part of a collaborative programme with Industry to confirm the expected operational benefits. The resulting combination should significantly assist in the rapid generation of an accurate tactical air picture for the pilot, including prioritised threats.

6 CONCLUSIONS

This paper has briefly described the proposed rôle, major features and flight trials programme of DERA's Tornado ZD902, designated TIARA (Tornado Integrated Avionics Research Aircraft). The aircraft is a multi-sensor, multi-rôle trials facility intended to demonstrate a "total systems integration" concept. It will directly support a number of Applied Research Programmes, Technology Demonstrators and Projects.

Following a major conversion programme, ZD902 is now undertaking experimental trials flying. The procurement and integration of the experimental equipment necessary to attain the TIARA concept is virtually complete, apart from the AI radar which will be delivered in 1997.

Among TIARA's prime features are a modern avionics architecture, a multi-sensor capability and the creation of a modern single-seat fighter environment in the front cockpit.

The first major flight trials are concerned with infra-red sensors and helmet mounted displays. Following installation of the Blue Vixen radar, the prime objective will be to evaluate and demonstrate the application of multi-sensor data fusion in a multiple threat environment.

TIARA (Fig. 8) will provide a unique fast-jet trials facility for the Defence Evaluation and Research Agency during the next decade. It will also have sufficient capacity to support a number of collaborative programmes with Industry.

Figure 8 TIARA on trials