Whippendell Marine

Bridging The Capability Gap In Embarked Aviation Ground Power Systems Using A Mixed COTS And Bespoke Solution.

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SYNOPSIS

This paper presents the work conducted by Whippendell Marine Ltd to develop a system for the control and distribution of electrical ground power for embarked aircraft in naval platforms. The need for a new system arose from the perceived gap between the requirements of modern aircraft for electrical power, both on the flight deck and in the hangar, and the ability of legacy equipment based on 1950s technology to make the best use of the available generating capacity whilst providing high levels of system and aircraft protection throughout the service cycle. The approach taken was to make use of commercially available off the shelf components and modern industrial control practices to design a system which makes significantly more efficient use of the limited generating capacity available, and provides an intuitive operator interface allowing greater system functionality and flexibility, whilst being capable of withstanding the rigours of the operating environment.

INTRODUCTION

Aircraft have been flown from naval ships for almost as long as they have flown from land. In the early days there were few facilities required on board other than launch and recovery systems. As technology advanced and aircraft became more complex, the introduction of dedicated services for embarked aviation became necessary.

One of the key elements of the embarked aviation facilities is the ground power system, commonly known as the Aircraft Ground Starting & Servicing (AGSS) system. In essence this provides high quality power to the embarked aircraft for servicing and starting functions. Although aircraft are capable of starting using their internal battery supplies or Auxiliary Power Units (APU), this is only generally done when operating away from the ship or an equipped land base.

Early maritime aircraft were little more than weapon carriers or reconnaissance vehicles whereas, today, they are highly complex platforms which fulfil a variety of roles. As such, the complexity of mission systems, avionics, communication suites and environmental control systems all contribute to a dramatic increase in the electrical load, and, if power is to be applied from outside the aircraft, the ship system has to be capable of meeting these demands. In addition, the range of activities for which external electrical power may be required has also increased. Starting, compressor washing, battery charging, servicing or pre flight warm up are all examples of the services required and this results in, on a multi aircraft vessel, more aircraft requiring simultaneous power for longer periods. This leads to the requirement to carefully manage the ship's converted power capacity to ensure that supplies are available where and when required.

There are two primary elements within the AGSS system, firstly the conversion of the ships main 440V 60Hz supply into the required AC and DC supplies[1] and secondly the control and distribution of these services to the required point of use. On some small platforms, with only one point of use, the second element may not be present.

In most platforms the conversion is done by rotating machinery (motor generators) for the AC supply and Transformer Rectifier Units for the DC. More modern systems have started to use static frequency converters for the AC supply. The use of modern static technology within naval platforms has been widely discussed at other conferences.

For the purposes of this paper the control and distribution element of the AC system within the Invincible Class Aircraft Carriers will be considered.

BACKGROUND

The late 1990's saw the introduction of the Merlin EH101 rotary wing aircraft into service with the Royal Navy and the UK Ministry of Defence, through the then Warship Support Agency (WSA), began looking at the aviation facilities to support this aircraft in the fleet's Invincible Class Aircraft Carriers. It soon became clear that the published power requirements for Merlin would necessitate an upgrade to the embarked aviation AC ground power system.

With the financial constraints in place at the time it was not possible to procure an entirely new system, it was therefore assessed that the existing converters, in this case motor generator sets, were adequate, but the distribution system needed to be replaced and upgraded to allow Merlin to be supported in these platforms.

At this time all AGSS systems were tailored to the given platform and, in the main, employed many electro mechanical components specifically designed for naval applications, but which were becoming difficult to source and maintain. This had the effect of reducing equipment availability, increasing mean active repair time (MART) and increasing the maintenance load on an

[1] See BS 2G 219 Specification for General Requirements for Ground Support Electrical Supplies for Aircraft and MIL – STD 704E Department of Defense Interface Standard – Aircraft Electrical Power Characteristics.

already stretched ship's staff. In addition, existing systems could contain up to 250 electro-mechanical relay contacts to enable the system interlocks, all prone to failure, resulting in system unavailability. Overload protection provided by 27 oil filled dashpot devices, each of which could take up to 4 hours of skilled labour to set-up or check.

Capability Gap

A capability gap had also been recognised. With the then fitted system, it was only possible to feed the supply from a converter to one spot at a time as the system provided no means of calculating the load being drawn. As each converter supplied both hangar and flight deck spots, this resulted in a serious shortcoming of system capability and its effect on the operational availability of embarked aircraft.

With a mixture of embarked aircraft, requiring different loads, the legacy system was failing to make best use of the limited supply power available. The fixed wing aircraft required only about one quarter of the power of some of the rotary wing aircraft, yet only one could be connected to each power source at a time.

Not only did this limit the operating capability, it also lead to serious problems in the maintenance procedures for the aircraft. With some aircraft maintenance procedures lasting several hours, a choice had to be made between tying up the power for the maintenance period in the hangar, or stopping the procedure to allow flight deck operations, and then starting again from the beginning. This capability shortfall lead to the platform operating with mobile cart power sources to supplement the fixed system.

Whippendell Marine was contracted by the MoD to design and build a system which would provide enhanced functionality to bridge this capability gap, but where possible using Commercial Off the Shelf (COTS) Components to reduce acquisition costs and improve through life support. Early development work identified that the use of techniques widely used in the commercial controls system industry could bring added functionality, reduced maintenance and increased reliability. At the same time the system was still required to meet the exacting standards[2] of the naval environment, including shock, vibration and EMC.

[2] Def Stan 59-41 Electromagnetic Compatibility, BR8470 Shock Manual , Def Stan 08-123: "Requirements for Design and Testing of Equipments to Meet Environmental Conditions (Category 2)"

TECHNICAL APPROACH

Outline System Requirements

In general terms the AGSS distribution system was based on a zonal model. A number of converters were located around the platform and the power from these was to be distributed to a number of aircraft spots (points of use) on the flight deck and within the hangar. In addition the system had to be able to route the power from one converter distribution board (DB) to another in the event of converter failure; provide over current protection for the converters, distribution system and aircraft; and include safety interlocking between the AGSS system and the attached aircraft.

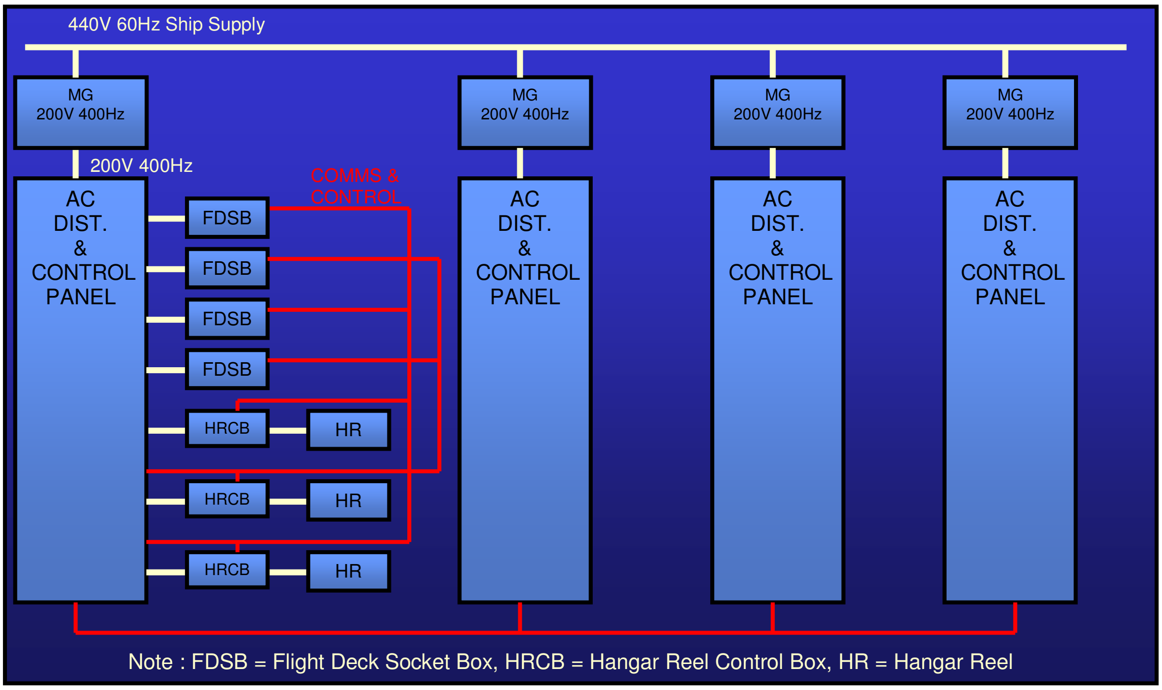

Fig 1 Typical Zonal Configuration for a Multi-Spot Platform.

The Design Solution

At the very early stages it was clear that an intelligent control system was required to make maximum use of the limited power resources. A bespoke electronic system, based on PIC (Programmable Interface Chip) technology, was considered, but this was rejected on the grounds of cost, timescale, inflexibility and the danger of rapid obsolescence. In addition this did not meet with the requirement for the use of COTS equipment where possible.

Looking at commercial industrial control projects, it was obvious that the application leant itself to the use of a PLC based control system. At a stroke this removed the vast majority of control relays and associated internal panel wiring and drastically reduced the ships wiring between each distribution board. It also had the added benefit of reducing the potential points of failure within the system, and it also allowed the use of power management techniques to ensure the maximum operational capability was leveraged from the available converted power.

The initial approach was to place a PLC in each distribution board and these were networked together by use of a dual ring fibre optic Data Highway + network, giving a level of built in redundancy in the event of damage to the network cables.

The selection of the particular PLC was critical to the success of the design. Very few PLC systems had been introduced into UK warships at this stage and there was no available certification to Defence Standards, or MoD wide policy on particular manufacturers. After considerable research, it was decided to use the Allen Bradley SLC500 series. This did have certification for use in commercial marine applications, and had in fact been selected as the backbone for new Machinery Control Systems to be fitted to two Royal Fleet Auxiliary vessels. In addition it had been available for a number of years, had a large fitted base within commercial industry, was well regarded as stable and reliable, spares were also readily available in most parts of the world.

For the interface to the operator controls and the current monitoring at each spot, a Remote I/O system was selected using two Remote I/O controllers each linked to alternate spots, again providing a level of security to the system.

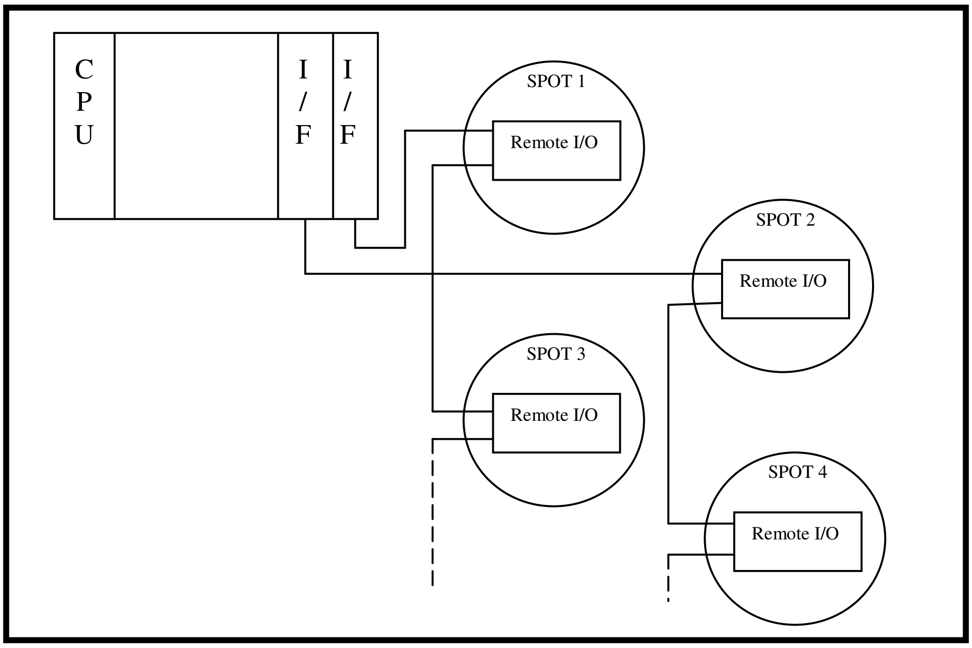

Fig. 2 Typical Remote I/O Connection.

To monitor load current, consideration was given to the use of conventional current transformers (CTs), but these were discounted as they required the use of an additional interface unit between the CT and PLC's analogue input modules. Instead, by employing Hall Effect devices which could be wired directly to the analogue module costs and system complexity was minimised.

The remaining elements of the system comprised Military Off The Shelf (MOTS) components such as shock rated contactors and aircraft cable connecting plugs, and bespoke enclosures, designed to meet the shock requirements for the system.

Battle Override System

With the main components and architecture agreed, the system was then considered for its ability to meet the environmental conditions, and in particular its susceptibility to damage. It was a key requirement for the platform to be able to continue to provide ground service power to aircraft even after sustaining damage. Even with the redundancy and back up designed into the control architecture, it was felt that the AGSS system was still vulnerable to terminal damage, both from direct hit and Electro Magnetic Pulse (EMP).

To overcome these issues it was decided that an emergency "Battle Override" facility should be fitted to allow continued use of the AGSS system in the event of control failure. This function was to be a last resort and as such would simply provide the ability to switch power to the required spots. No over current protection or aircraft interlocking would be required, and thus a simple set of switches would be utilised to directly switch the distribution contactors on and off.

Bridging the Capability Gap

The overwhelming advantage of this approach was the ability to bridge the capability gap identified in legacy systems. The use of a flexible control system architecture allowed the software to monitor and manage the available power to best advantage. Again, using the COTS approach, bespoke software code was developed using a commercially available tool, in this case, RSLogix500.

In order to achieve this the operator interface allowed the ground crew to select both the type of aircraft to be connected and the service it required. From this the control system would use a look up table holding the current profiles for each selection and determine the remaining available power for the rest of the system. Should another aircraft spot call for power, the system could calculate whether sufficient spare capacity was available, and if it was, allow connection.

As many aircraft require a relatively high starting current, which rapidly drops off, the stored profiles were on a time/current basis. Once the system detects the aircraft starting peak, it then make additional spare capacity available progressively for other spots within the system, before waiting for the starting aircraft to be disconnected, again leveraging further capacity from the system.

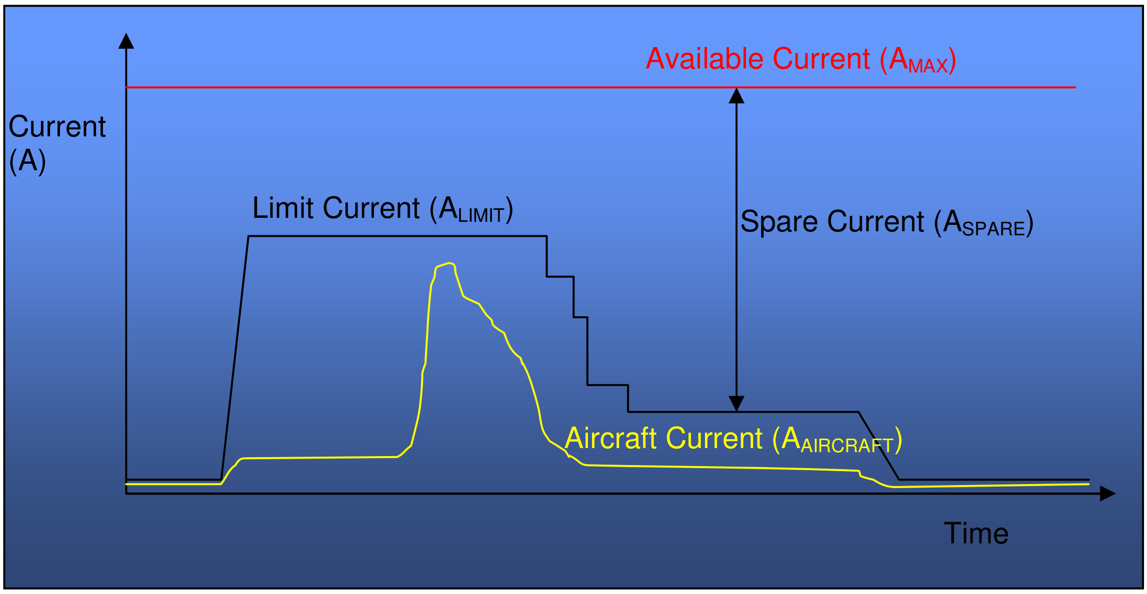

Fig 3

The graph in Fig 3 above demonstrates this principle. The system is pre-programmed with the available current (A_{MAX}) from a given converter. When an aircraft and service is selected the look up table provides the appropriate maximum current profile (A_{LIMIT}) and calculates the remaining available current for other spots (A_{SPARE}).

The system then monitors the current being drawn by the aircraft ($A_{AIRCRAFT}$). When the starting peak is detected the system begins the timed profile for the limit, which can be seen above stepping down to a residual "started" current. The system continually re calculates the remaining available current, so that as soon as the limit current starts to fall off, the available spare current for other spots is increased.

At the same time the system compares ($A_{AIRCRAFT}$) against the programmed (A_{LIMIT}) and should this be exceeded, trips the spot on an over current fault. The system is de-sensitised to cater for transient current spikes, produced by the starting cycle, to prevent spurious tripping.

Employing COTS in the Naval Environment

One of the key issues of using COTS equipment was the consideration of the environment in which it would be placed and the standards which it must meet. As discussed earlier, the system incorporated a last resort "Battle Override" facility in the event of COTS equipment failure, however, consideration had also be given to making the COTS equipment as reliable as possible. A number of options were available, and these are considered below.

One option is to downgrade the standards, particularly the environmental standards, to which the equipment or system is expected to meet. This is a perfectly valid approach when considering non essential systems, although there are still caveats with regard to the consequences on other ships equipments, in particular, with regard to EMC. For essential systems, where high availability is required, this is not a realistic approach, and as noted above, was not an option for this application.

A second option is to modify the COTS equipment to meet the standards. It is not considered that this "Modified COTS" approach, as it has become known, offers a sensible solution. The very fact that the equipment is modified immediately removes many of the advantages to using COTS in the first place. The equipment is no longer available "Off the Shelf", costs increase, and in some cases have been known to exceed the cost of providing a "designed for purpose" piece of equipment, original manufacturers warranties are likely to be invalidated and commercial technical support may not be readily available, depending upon the level of modification. At the same time the perceived and real disadvantages of COTS remain.

The third option is to mitigate any shortcomings in the COTS equipment by other means, and this is the approach taken for this project. This is an approach already widely used in the naval environment, with, for example, the use of shock mounting to reduce the shock withstand criteria for a particular equipment.

For this project the key issues were shock, vibration and EMC. Because of the nature of the COTS equipment used (PLC and Hall Effect Transducers) and their design for commercial environments, it was felt that additional protection from Shock and Vibration would be required. The system was already to be shock mounted and the equipment had a commercial shock rating of 15g. It was not felt that the equipment itself would be damaged or fail under shock or vibration, but that it could come away from fixings, or elements of the PLC rack system would become detached. In order to mitigate against this, additional mounting arrangements were provided and shown to be fit for purpose.

Elements of the system have been subjected to shock testing[3], under operating conditions, at the TNO facility in Delft. This proved highly successful, with the equipment remaining operational before and after the shock event, and sustaining no damage, either internal or external.

Fig. 4 Typical PLC rack with shock securing bar.

Leveraging the COTS Advantage

With the system design completed and the environmental mitigations in place, the flexibility of the control system allowed us to look at leveraging additional functionality from the system at little or no extra cost.

The system was already to be supplied with a simple laptop based SCADA system, again built on a COTS solution[4], providing status indication on various elements of the system for maintenance and fault finding purposes. The addition of an extra SCADA page allowed the system to provide a real time current monitoring facility to assist in the fault finding of embarked aircraft.

[3] Tested to BR8470 Grade D Limits
[4] Rockwell RSView32

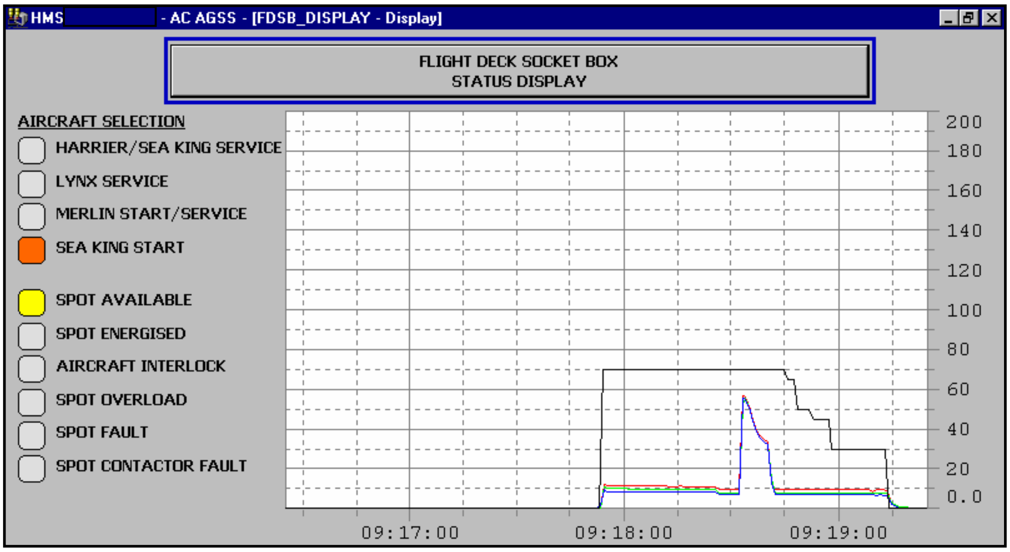

Fig. 5 A real time trace from the start of a Sea King

More interestingly, the combination of the SCADA system and the PLC opened up the possibility of allowing on line re-configuration of elements of the system. Now instead of an AGSS system configured to a limited set of pre-defined aircraft and operations, it required only small software changes to allow any aircraft with known characteristics to be used (within the limits of the power conversion).

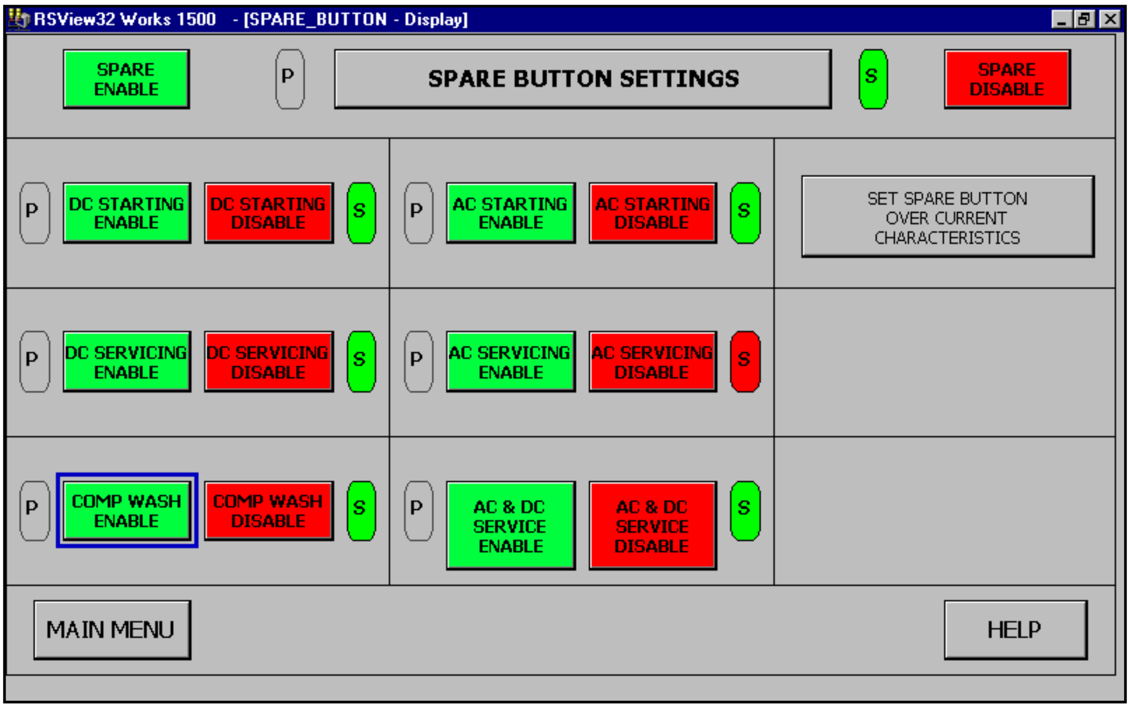

Fig. 6 First Stage of Configuring the System for a Visiting Aircraft.

This small change in the functionality led to a much greater effect on capability. The system was now capable of interoperability with other allied and NATO aircraft, could be configured for special service or maintenance routines and even allowed for new aircraft to be operated, all without any changes required to the core operating software or hardware.

The Bespoke Element

Whilst the COTS solutions discussed above formed the major part of the system design, there emerged a requirement to develop a new and ruggedised operator interface. Previously, control of the system had been by the use of electro mechanical push buttons and selector switches mounted on the system control and socket boxes. As these units were, by necessity, fitted on the flight deck and in the hanger, they were susceptible to failure due to the effects of the salt laden atmosphere despite being rated at IP67. This resulted in excessive maintenance being required to achieve reasonable levels of operational availability, though this in itself, was often a cause of moisture ingress and, therefore, contributed to the problem.

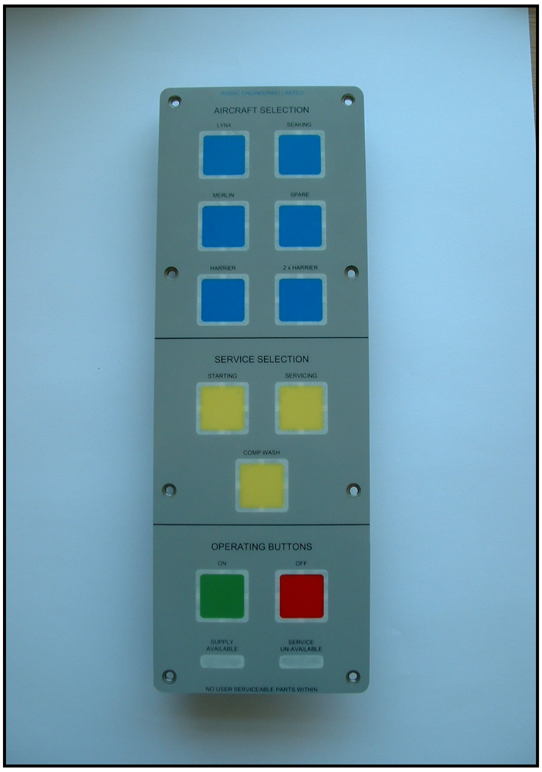

Fig. 7 & 8 Operator Interface Handset

The use of a PLC control system allowed the development of an enclosed and sealed handset which contained the interface electronics to allow communication and indication with the PLC controller. A touchpad membrane allows for the selection of aircraft type, service required and the application of power (AC and DC), with illuminated confirmation of satisfactory selection or illegal / unavailable service. The handset is connected to the system via an RS232 interface which allows the number of cores required to be reduced to a manageable number whilst maintaining and, indeed, increasing functionality. Further development of this unit has introduced additional optical filtering to achieve compatibility with NVG equipments, and a variable illumination levels for improved day / night operation.

The Future

Since completing the work on the Invincible Class Carriers, this COTS based solution has been introduced into a range of further platforms, both through equipment upgrade programs and at new build. This has been achieved because of the scaleable and flexible nature of the COTS solution. Regardless of platform size, the core elements of the system and operating software routines have remained the same. It is simply a matter of how much I/O is added to the PLC.

CONCLUSIONS

A mixed COTS / bespoke solution can be both a realistic and better alternative to a wholly bespoke design.

The use of COTS components reduces project lead times and costs, provides easy availability of spares and technical support and benefits from the reliability associated with a large industrial user base and which is now well understood.

It is possible, as has been shown here, that a COTS solution can also provide greater flexibility and enhanced functionality without a major cost penalty.

COTS solutions will not be the right approach to every project. The limitations of COTS equipment must be well understood and these need to be considered against the declared standards and specifications, but where these are compatible, or can be made so with mitigation strategies, COTS can provide big advantages in terms of acquisition costs, spares provisioning, maintenance effort and the management of obsolescence.

Flexibility and adaptability within systems is critical to the modern naval platform, as vessels built today will be expected to remain in service for many years. The only thing we can be sure about is that their operational roles and capabilities are going to change significantly over that period.

Biography

David Swabey completed his first degree in Electrical and Electronic Engineering at UMIST in 1988, whilst being a sponsored student with Plessey. After his degree he joined Harland Simon Automation Systems as an Application Controls Engineer, being promoted to a Senior Engineer in 1992. During this time he worked on a variety of mechanical handling and process control systems. In 1993 he joined Whippendell Marine as Business Development Manager, being promoted to Director in 1994 and Managing Director in 1996. At Whippendell Marine he managed the acquisition of EAC (UK) Ltd. and RAMAC Engineering Ltd., and was the technical lead in the development of the Invincible Class AGSS system. He is a Member of the Institution of Engineering and Technology and is an Affiliate of the Institute of Marine Engineering Science and Technology.

Chris Lowes joined the Royal Navy in 1974 as an electrical mechanic and served in HM Ships THORNHAM and FIFE before being selected for technician training at HMS Collingwood in 1979. As a Control Artificer, he saw service in HM Ships ROTHESAY, LEDBURY and LIVERPOOL, and spent 2 periods in the Fleet Maintenance Group at Rosyth. Selected for promotion to Sub Lieutenant in 1989, he underwent staff training at RNC Greenwich, further technical training at RNEC Manadon and systems engineering and management training at HMS Collingwood before joining HMS Edinburgh as the Weapons Section Officer. There followed subsequent appointments ashore on the staff of Commodore Mine Warfare and Minor War Vessels and Flag Officer Surface Flotilla before taking up the post of Squadron Engineer to the 1st Mine Countermeasures Squadron. Chris's final appointment in the RN was as the Sales and Marketing Manager, (Warships) on the staff of the UK MoD's Disposal Service Agency where he had the responsibility for Government to Government sales of former naval vessels. Chris joined Whippendell Marine in January 2005.