"This paper was presented at the "Engine as a weapon III" Symposium, Organised by the Institute of Marine Engineering, Science and Technology"

ELECTRICAL ACTUATION OF SUBMARINE HYDRODYNAMIC CONTROL SURFACES (2)

BY

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ABSTRACT

The United Kingdom's Defence Equipment and Support (DE&S) organisation has been developing electric actuation since the late 1990s as part of the All Electric Ship (AES) concept. In 2004 the Electrical Actuation of Hydrodynamic Control Surfaces (ELAHCS) project fitted an electromechanical actuator to the stabilisers of a Type 23 frigate. Now complete, this trial developed the technology to Technology Readiness Level 7 (TRL 7) for non-safety critical applications in the surface ship environment. As a result the technology is considered sufficiently mature for selection by future platforms without further MoD investment.

The technology is now being extended to the submarine environment with the associated demands for increased safety, reliability and environmental performance. A technology demonstrator is being built to replace the aft hydroplane hydraulic actuator on a TRAFALGAR class SSN with the aim being to develop the technology to TRL 7 in order to make the technology exploitable by SSBN-F. The project has the additional benefits of being a test case for software assurance in safety-critical applications within the Marine Engineering field and also developing linear electro-mechanical technology for a wider range of (less demanding) linear-motion applications.

The project has particular relevance to the EAAW3 conference in the area of digital systems integration. Extensive use is made of COTS components. To meet reliability and safety targets we have introduced redundancy and diversity into the electrical control system and avoided single point failures. The architecture takes the form of a duplex digital system with analogue "wrap-around" circuits to reduce the software requirements to Safety Integrity Level (SIL) 2. The project passed the Critical Design Review in September 2008 with Factory Testing due to commence in 2010 followed by extended durability shore testing for 12 months. Delivery to the trial SSN will follow enabling a 12 month Fleet Equipment Trial.

This paper will discuss how the MoD is extending its experience with digital systems, the key features of the system architecture and how the required reliability and safety targets are being achieved.

AUTHORS' BIOGRAPHIES

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GLOSSARY

ACMU	Analogue Control and Maintenance Unit	FSC	Future Surface Combatant
ACU	Analogue Control Unit	MCU	Motor Control Unit
AES	All Electric Ship	OCP	Operators Control Panel
ASU	Analogue Safety Unit	SCRAM	Reactor shut-down condition
CDR	Critical Design Review	SHM	Simple Harmonic Motion
CDU	Control and Drive Units	SIL	Safety Integrity Level
COTS	Commercial Off The Shelf	SSBN-F	VANGUARD Class Successor
DISM	Directorate In-Service Submarines	TLC	Through Life Cost
ECU	Electronic Control Unit	TRL	Technology Readiness Levels
ELAHCS	Electrically Actuated Hydrodynamic Control Surfaces	UPC	Unit Procurement Cost
ELAHCS(SM)	Submarine ELAHC(SM)	WLC	Whole Life Cost
EPM	Emergency Propulsion Motor		

INTRODUCTION

DE&S has previously embarked upon a number of technology demonstration projects which were designed to de-risk those technologies identified as enablers for the AES Concept. In addition to the main motor and prime mover technologies there are also a considerable number of auxiliary systems that need to be considered. This includes the actuators for surface ship rudders and stabilisers, as well as submarine control surfaces. Since 1997 DE&S's Fleet Wide Equipment Team has been investigating the replacement of the current hydraulic technology used for these applications and within this decade this search has focused on electromechanical actuation systems. This investigation is being conducted through the ELAHCS Programme which in 2004 fitted an electromechanical actuator to the stabilisers of the Type 23 frigate, HMS ST ALBANS (see Figure 1). Now complete, this trial developed the technology to TRL 7 for non-safety critical applications in the surface ship environment. As a result the technology is considered sufficiently mature for selection by future platforms without further MoD investment and is now being actively considered for the Future Surface Combatant (FSC).

FIG.1 – ELAHCS GENERAL SURFACE VARIANT DRIVING A TYPE 23 FRIGATE'S PORT STABILISER

In 2005 a parallel project, ELAHCS(SM) was set up to extend the technology to the submarine environment with the associated demands for increased safety, reliability and environmental performance. This paper follows on from similar ELAHCS(SM) papers given at the IMarEST's Engine As A Weapon II [1] and 2007 All Electric Ship [2] conferences that presented the lessons learnt from the ST ALBANS trial and described the concept work and safety justification carried out to adapt the technology to the submarine application. The project having completed the Design Phase this paper provides design details, explains the benefits of electromechanical actuation for the application at a system level and describes the project's approach taken to software safety assurance.

AIM

The aim of the project is to develop cost effective electrically actuated submarine control surfaces from TRL 3 to TRL 7 in order to make the technology exploitable by SSBN-F (the Successor to the VANGUARD Class SSBNs).

Whilst the project is concentrating on control surface actuators the technology will also be available for a wider range of (less demanding) linear-motion applications such as weapon handling equipment, mast and periscope raising gear and powered door actuators. Finally, the project is one of a number of test cases for software assurance for safety-critical applications within the Marine Engineering field.

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[1] B.R.Stafford, N.P.Osborne; "Technology Development for Steering and Stabilisers"; Proceedings of Engine As A Weapon II Conference.

[2] B.R.Stafford; N.P.Osborne; "Electrical actuation of submarine hydrodynamic control surfaces"; Proceedings of All Electric Ship Conference 2007

ELAHCS(SM) SYSTEM

The ELAHCS(SM) system comprises of the following:

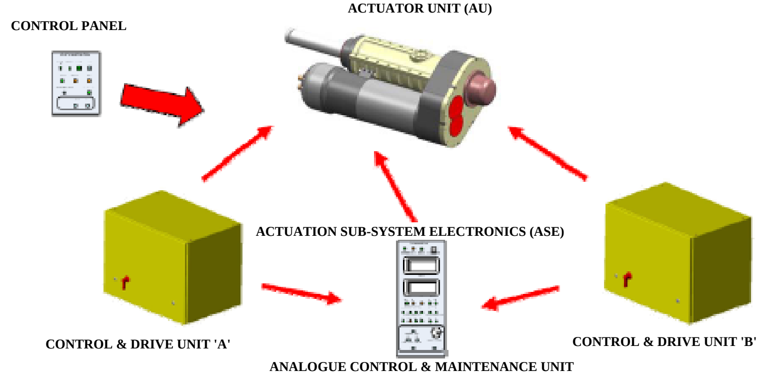

FIG.2 - ELAHCS(SM) SYSTEM.

a. Actuator Unit. Two 610V COTS brushless-DC motors drive a planetary roller screw via an integral gearbox. The roller screw drives a roller nut connected to the output rod, which is thus driven in and out of the support tube. The unit is sealed so that it can be positioned internal or external to the pressure hull.

b. Control and Drive Units (CDU). Each CDU contains a COTS motor control unit and a specially designed Electronic Control Unit (ECU) both containing software.

c. Analogue Control and Maintenance Unit (ACMU). The ACMU is positioned near the actuator and comprises the Analogue Control Unit (ACU) and Analogue Safety Unit (ASU) and provides both a “wraparound” safety capability and maintainer facilities.

d. Operators Control Panel (OCP). The OCP is positioned in the Control Room adjacent to the planesman and provides system status indication and basic operator actions. In the SSBN-F application this functionality could be subsumed into the Platform Management System.

TABLE 1 – *ELAHCS(SM) Specifications*

Max dynamic load	590 kN	
Max static load	2360 kN	
Rate (normal/quiet)	5.0/0.5°/s	
Swept arc	± 25°	
Accuracy	<0.5°	
Electrical supplies:		
Power	250V DC	Converted to 610V DC
Control	24V DC	Grade 1 and 2
ACH	115V AC	
Electrical load:	Starting current	Running current
25° SHM full speed	200A	40A
15° SHM EPM drive	30A	<5A

System Architecture

In normal operation one ECU is used to drive both MCUs. Each MCU is dedicated to drive one of the two motors. Should any one MCU or motor fail the system will be in single motor drive and will be capable of operation at full load (constant operation at submarine full speed) for up to 90 minutes. Should the online ECU fail the operator will be alerted to that fact and can switch over to the stand-by ECU which will be operational within 1.5 seconds. Should both ECUs fail the operator can select the ACU. Should the ASU activate (such as for an over speed condition, actuator run away or if end of stroke limits are exceeded) the ACU will automatically take over from the online ECU. The ACU will enable the operator to bring the actuator back into range before re-starting the ECU.

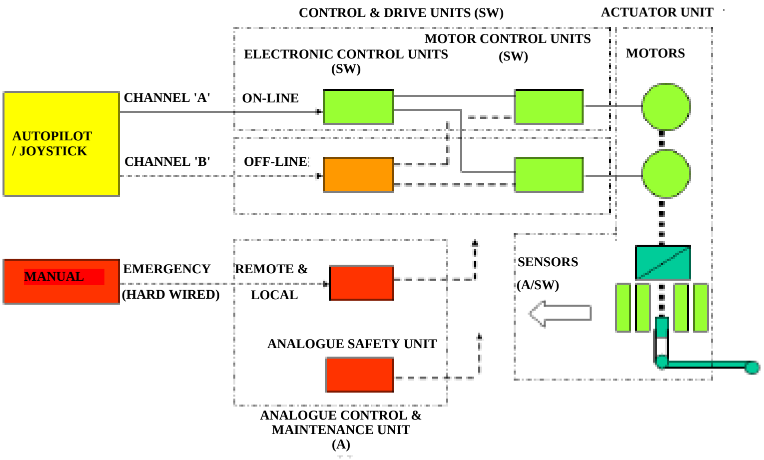

FIG.3 – ELAHCS(SM) CONTROL SCHEMATIC

The legacy hydroplane and rudder actuation system onboard RN submarines is predominantly hydraulic based. That fitted to the SWIFTSURE, TRAFALGAR and VANGUARD classes uses internal hydraulic rams with the aft hydroplanes backed up with an emergency pneumatic ram. The ASTUTE class has external hydraulic rams and achieves redundancy by splitting the aft hydroplane port and starboard, thus negating the requirement for an emergency pneumatic ram. In all classes a dedicated hydraulic plant is required with cross-connections to separate main or external hydraulic plants.

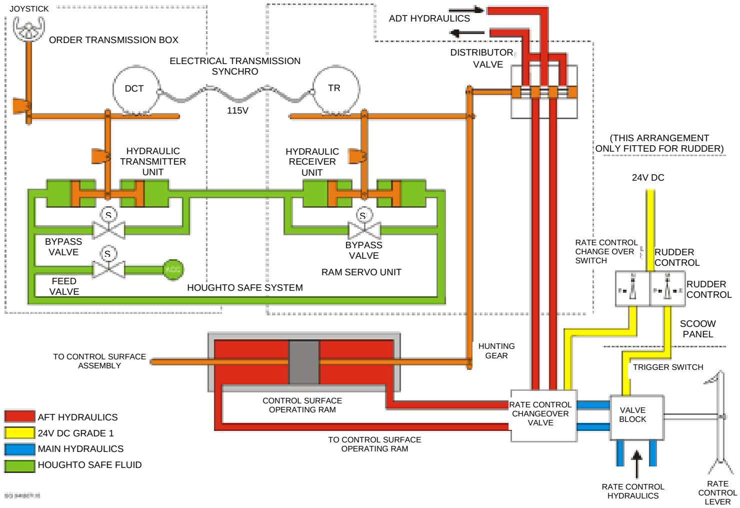

FIG.4 - TRAFALGAR CLASS AFT HYDROPLANE OR RUDDER CONTROL SYSTEM.

The legacy control system comprises an electric (and back-up hydraulic) control signal transmission system driving the position of a distributor valve via mechanical hunting gear. The distributor valve directs pressurised hydraulic fluid to the actuator to achieve the desired hydroplane or rudder angle.

ELAHCS(SM) BENEFITS

ELAHCS(SM) offers several benefits to SSBN-F, some of which are unique to the submarine application and some of which are shared with the surface ship version. Whilst ELAHCS(SM) is clearly a Marine Engineering system it is also a complex system and as such may have lessons for the combat system community. Particular benefits that are of relevance to this audience include the ease of system integration, advanced software control, reduced signatures, increased efficiency and lower wild heat production. Further areas of benefit include lower mass and through life costs, increased safety and environmental performance.

System Integration

Unlike the legacy system ELAHCS(SM) lends itself to a modular build approach. By removing the hydraulic power transmission system ELAHCS(SM) only requires electrical supplies to be run. This substantially simplifies the build and acceptance process. This also facilitates future in-service upgrades with a “plug-and-play” functionality being a real aspiration.

The issue of whether to provide a local energy store for the actuator has yet to be resolved. Whilst there is currently a local hydraulic accumulator sufficient to power one full hydroplane cycle the different characteristics of hydraulic and electrical power transmission systems may mean that the submarine’s main battery can be considered as a suitable power back-up for ELAHCS(SM). This negates the requirement for a heavy local battery or other uninterruptible power supply. Were a platform to be fitted with Zonal Power Supply Units, each with localised energy storage, the requirement for dedicated energy storage becomes even weaker. Such an architecture fits within the wider requirements of marine and combat systems onboard an All Electric Ship.

Advanced Software Control

As already outlined the system has a parallel control architecture with advanced software used for higher levels of functionality (as detailed below) and an analogue "wraparound" for safety assurance. However, owing to the use of COTS motor controllers it has so far been impossible to entirely remove software reliance for the safety function and as a result software certification to the SIL2 standard is required (details below). This is a considerable cost and risk issue that is likely to apply across both the marine and combat communities. The lesson being that a full analogue "wraparound" system for safety-critical systems can significantly drive down programme cost and risk.

<u>Soft Start/Stop</u>.

The bespoke software control system provides several advantages compared with the legacy system. The soft start/stop functionality allows the hydroplane slewing speed to ramp up and down at the beginning and end of every movement thus reducing the risk of cavitation and operating linkage "knock". Such an approach could be applied to a hydraulic actuation system but is more easily integrated with ELAHCS(SM)'s advanced DC motors and their associated control units.

<u>Quiet Mode</u>.

The hydroplane slew rate can be easily reduced from the 5o/sec maximum to any value required. It is proposed that a 0.5o/sec value is used as a "quiet" mode for sensitive operations although this value can be easily changed to whatever is required. Such a mode reduces the chance of cavitation at the hydroplanes, reduces system noise due to the low speed operation and also reduces the chance of a depth excursion and possible submarine broaching at periscope depth. The ability to restrain the tendency of inexperienced planesmen from overcorrecting would also be attractive to Commanding Officers.

<u>Runaway Detection</u>.

Software control can detect an undemanded actuator movement and so prevent hydroplane runaway. This reduces the risk of both noisy end stop clashes and submarine depth excursions.

Signature

The signature benefits of ELAHCS(SM) are split into 2 areas: noise benefits associated with smoother hydrodynamic flow over the hydroplanes and rudder and reduced machinery and hydraulic flow noise.

<u>Hydrodynamic Flow</u>.

The advanced software control described above reduces the chance of cavitation through soft start/stop and a "quiet" mode.

Machinery and Hydraulic Flow Noise.

ELAHCS(SM) only produces noise when actually moving the hydroplanes and rudder. Noise produced is also in proportion to the speed and duration of that movement; thus at slow speeds and steady attitudes (such as during stealthy patrols) the system will be produce very little noise. On the other hand, the legacy system requires a constantly running hydraulic pump with associated machinery and hydraulic flow noise, even when the system is stationary. Furthermore, runaway detection helps prevent end stop clashes causing mechanical noise and soft start/stop reduces operating linkage knock.

Efficiency

At full operating load (i.e. high speeds and high hydroplane and rudder angles) ELAHCS(SM) is predicted to have an approximately 20% lower power requirement than the legacy system. However, at more typical patrol and periscope speeds this value increases to 80%. This can largely be attributed to the constantly running hydraulic pump with pressure, flow resistance and bearing losses leading to inefficiencies; conversely ELAHCS(SM) draws virtually nothing when not moving the hydroplanes and very little at low speeds. During a reactor scram, when electrical load must be reduced as much as possible an entire ELAHCS(SM) system will draw <10A compared with approximately 50A for the legacy system.

Mass (v Hydraulics)

Whilst the actuators are approximately twice the mass of their hydraulic equivalents, ELAHCS(SM) as a system is less than half the mass of the legacy hydraulic system.

TABLE 2 - *Legacy Hydraulic System and ELAHCS(SM) Mass Comparison*

Description	**Hydraulic (kg)**		**Electromechanical (kg)**	
	Each	Total	Each	Total
Aft hydroplane actuators	800	1600	2000	4000
Rudder actuators	1560	3120	2000	4000
Fwd hydroplane actuator	1175	1175	2000	2000
Hydraulic power plant (inc oil & control panel)	8800	8800		
Reserve hydraulic oil (est aft hydraulics proportion)		4000		
Actuator control manifolds (one for each actuator)	500	2500		
Hydraulic pipework		9250		
Valves & fittings (est)		1000		
ELAHCS(SM) Control & Drive Units (2 per actuator)			165	1650
Analogue Control & Maint. Unit (1 per actuator)			165	825
Electrical cable: CDUs to actuators (300m)				120
Total		**31445**		**12595**

Table 2 compares the mass of the hydraulic hydroplane actuation system for the fore and aft hydroplanes and rudder on ASTUTE with a representative ELAHCS(SM) system also on ASTUTE. ELAHCS(SM) is 40% the mass of the hydraulic system with a large proportion of the difference being tied up in the hydraulic plant, fittings, pipework and oil. You will note that no local power supply has been included in the ELAHCS(SM) system as the issue of whether to provide a local energy store for the actuator has yet to be resolved, see under Integration above. Were this to be required against expectation there is plenty of mass margin to fit a battery or other uninterruptible power supply and still be lighter or at least no heavier than the legacy hydraulic system.

TLC/Maintenance

Hydraulic systems typically require significant maintenance and hence high Through Life Costs (TLCs). In addition to the cost the maintenance burden on ships staff is a significant manpower driver. This is one of the drivers behind DE&S's Marine Systems Development Strategy Objective 4: the reduction of high-energy fluid systems by 50% for SSBN-F and FSC [3]. The only planned maintenance required for ELAHCS(SM) is inspection and dust filter cleaning of the CDUs; the actuator unit itself is designed to be sealed for 16 years, i.e. until mid-life refit.

A Whole Life Cost (WLC) comparison has been carried out and is shown in Table 3 but as with all such comparisons the TLC figures are highly debatable. Many of the ELAHCS(SM) figures have been estimated as equal to the hydraulic configuration; £737k for 100s of metres of hydraulic pipework is reasonable but the same amount for far less cabling is highly pessimistic. However, it is interesting to note that the WLCs for each system are more or less identical despite there being such an imbalance between each configuration's Unit Purchase Cost (UPC) and TLC. Clearly in this situation the actual TLCs and platform life will have a dramatic effect on the WLC comparison.

TABLE 3 - *ASTUTE Hydraulic and ELAHCS(SM) Hydroplane Configuration WLC Comparison*

ASTUTE Hydraulic Configuration		**ELAHCS(SM) ASTUTE Configuration**	
Actuators	£437k	Actuators	£1,250k
Hydraulic power pack	£300k	Base spares	£83k
Valves & manifolds	£333k	Cable	£737k
Pipework	£737k	Installation	£26k
Installation	£26k	Commissioning	£32k
Commissioning	£19k	10 yr software reprogramming	£3k
Hydraulic power pack maintenance	£119k	16 yr survey	£16k
Valve & manifold maintenance	£112k	Routine maintenance	£90k
Actuator overhauls	£112k	Corrective maintenance	£240k
Hydraulic power pack overhaul	£150k		
Valve and manifold overhaul	£100k		
WLCs (£)	**£2,445k**		**£2,477k**

Environmental

Whilst not a large impact the removal of around 6 tonnes of hydraulic fluid from the submarine will have a positive environmental benefit. Whilst ELAHCS(SM) has electrical components the environmental impact of the associated materials are

[3] UK DE&S's Marine Systems Development Strategy; (Dec-Sep 06); Strategic Objective 4; KPT 4.7

considered no worse than the existing plant has within its AC and DC motors, starters, control and monitoring equipment.

Safety

A great deal of time and effort is devoted to training submariners to deal with high pressure hydraulic bursts. Whilst the greatest concern is a subsequent fire, hydraulic bursts can also lead to mechanical impact, slips and toxic injuries. Unlike surface ships submarines still have hydraulic ring mains throughout the submarine and hence there is a considerable driver to localise hydraulics to individual power packs or better still remove them entirely.

ALTERNATIVE APPLICATIONS

Whilst ELAHCS(SM) is concentrating on control surface actuators the electromechanical linear actuator technology can also be used wherever there is a need for linear actuation. Applications of interest to the combat systems community include submarine tactical weapon handling and discharge systems and mast and periscope raising gear. These systems are the main users of hydraulics within submarine command deck modules and weapon stowage compartments. Both of these areas are complex and crowded with other systems; the removal of hydraulics from them would significantly ease construction, commissioning, maintenance, operability and most of all safety. Furthermore, the increased controllability of this equipment through electromechanical actuation would reduce noise transients and allow for finer positional control. With the ELAHCS(SM) trials programme including seal trials (see below) the technology is being de-risked for the external environment and could hence be used both internally for weapon movements and externally for bow caps and shutters; likewise it could be used for masts and periscopes whether they were internally or externally actuated as is increasingly the case.

SOFTWARE ASSURANCE

The required safety reliability targets have been derived from SSCP 73 Submarine Hydrodynamics [4], ASTUTE document DMS 5088016 - SSCP 73 and Hydroplane Jams [5] and DISM's Whole Submarine Safety Case – Safety Policy, Principles and Criteria [6]. Marine Engineering projects have experience with meeting these documents' safety targets for mechanical and electrical systems; however, the increasing use of programmable electronic systems requires an understanding of the associated safety standards. Whilst Def Stan 00-56 Issue 4 is the key document, IEC 61508 (Functional Safety Programmable Systems) is the source document for Safety Integrity Levels (SILs), a specification of safety performance widely used for software systems. Other standards consulted include ISO 17894 (Ship & Marine Technology Computer Applications), ISO/IEC 12207

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[4] SSCP 73 Submarine Hydrodynamics, Issue 1, February 1994

[5] ASTUTE DMS 5088016 'SSCP 73 and Hydroplane Jams – An assessment of the ASTUTE design against safety and reliability requirements with particular reference to hydroplane jams', Issue D dated 20 Oct 2004

[6] Whole Submarine Safety Case – Safety Policy, Principles and Criteria - DLO/SUBIPT/037/1792/004/3 - Issue 3 – October 2005

and BS 'TICK IT' (ISO 9003, 2004 & ISO 9001) which are all being used for the ELAHCS(SM) project.

Table 4 is derived from IEC 61508-Part 1 [7] Tables 2 and 3 and shows the relationship between the required SIL for a continuous/high demand system and the tolerable frequency (per year) of a dangerous failure.

TABLE 4 - *Target Failure Measures for a Safety Function Operating in Continuous or On Demand Modes of Operation ("On Demand" is < 1 Demand / year)*

	Continuous per hour		**Continuous per 90 day mission**		**On demand**	
	Max	Min	Max	Min	Max	Min
SIL 1	1.0E-05	1.0E-06	2.2E-02	2.2E-03	1.0E-01	1.0E-02
SIL 2	1.0E-06	1.0E-07	2.2E-03	2.2E-04	1.0E-02	1.0E-03
SIL 3	1.0E-07	1.0E-08	2.2E-04	2.2E-05	1.0E-03	1.0E-04
SIL 4	1.0E-08	1.0E-09	2.2E-05	2.2E-06	1.0E-04	1.0E-05

As the hydroplanes are in nearly constant use the continuous criteria is of most interest for the ELAHCS(SM) actuators and the standby ECU is also assessed using the continuous rating for conservatism in the analysis. The architectural design uses the upper bound failure probability for determination of each Safety Integrity Level. By comparing the safety targets from Refs v and vi with those specified in Table 4 it is apparent that ELAHCS(SM) should be delivered to the SIL 2 standard.

As already discussed the system architecture is such that the ACMU provides the simple yet very reliable analogue safety "wraparound" capability in parallel with the programmable ECUs which provide the "bells and whistles". However, both the ECUs and ACMU drive the motors through the software driven COTS MCUs. Therefore, to achieve a satisfactory safety case the MCUs are being justified to SIL 2, the selected Moog MCUs already have third party certification for a SIL 2 safety function within them. Whilst there is no safety requirement for the ECUs to be designed to SIL 2 it is sensible to do so to maintain a common approach with the MCUs and to provide an assurance of ECU reliability.

TRIAL STRATEGY

The trial strategy for ELAHCS(SM) consists of 3 discrete areas: extended durability shore testing, sea trials on a TRAFALGAR Class SSN and extended seal testing. Unlike the ASTUTE Class and possibly SSBN-F, TRAFALGAR Class hydroplane actuators are located internal to the submarine and therefore the seal testing is required to de-risk positioning ELAHCS(SM) external to the pressure hull.

Extended Durability Shore Testing

Following Factory Acceptance Testing to ensure achievement of functional requirements the system will commence extended durability testing modelled on

[7] IEC 61508 Functional Safety of Safety Related Electrical / Electronic / Programmable Electronic Systems, Issue 1, 1998

the ASTUTE hydroplane actuator testing regime. In brief, this involves 14 million actuator movements across a broad range of angular position demands over the course of 12 months, all the while submerged in stagnant sea water and acting against a representative load. In both ASTUTE's and ELAHCS(SM)'s situation this regime provides assurance of the actuator mechanical fatigue performance.

Sea Trials

On completion of extended durability trials the system will be fully stripped, inspected and rebuilt with all lifted components renewed. It will then be installed onboard a TRAFALGAR Class SSN in place of the aft hydroplane hydraulic actuator. This actuator has been chosen for safety, access and representative load reasons. The installation process will take place during a scheduled docking period and the subsequent Fleet Equipment Trial is expected to last 12 months. Whilst there will be an option to remove and re-instate the original hydraulic actuation system on completion of the trial the system could be left in-situ until the end of platform life; clearly this continued testing would be beneficial to further de-risk the SSBN-F application.

Considerable effort has been spent integrating ELAHCS(SM) with the TRAFALGAR class SSNs. This effort was partly due to the simple differences between the hydraulic actuation system and ELAHCS(SM) but a large part of it was due to the problems with integrating a 21st Century technology into a 1970s designed platform. The particular areas of integration difficulty were: control, installation/alignment and electrical power.

a. Control. The existing TRAFALGAR hydroplane control signals are transmitted through non-screen twisted paired cables giving a risk of electromagnetic interference. Also there are a limited number of cable cores so system functionality and redundancy has been restricted to essential controls.

b. Installation/Alignment. Owing to the roller screw's tight tolerances ELAHCS(SM) has far more stringent alignment requirements than the existing hydraulic ram. In the ASTUTE and likely SSBN-F configuration this is not a problem as the actuator makes use of a trunnion and spherical bearing arrangement to accommodate some misalignment. However, the TRAFALGAR ram has a fixed linear output rod passing through a hull gland; as a result ELAHCS(SM) has had some minor adjustments to it to allow a high degree of accuracy during installation. Pressure hull compression may also affect alignment but this cannot be confirmed prior to sea trials, as a result the trial test form will include a staged dive process to check actuator alignment and operability across the whole depth range.

c. Electrical. ELAHCS(SM) utilises COTS motors and motor controllers operating at 610V DC. Therefore, an inbuilt DC-DC converter is being used to step up the submarine's 250V (nominal) DC supplies as required. The issue of whether to provide a local energy store for the actuator has yet to be resolved, see under Integration above.

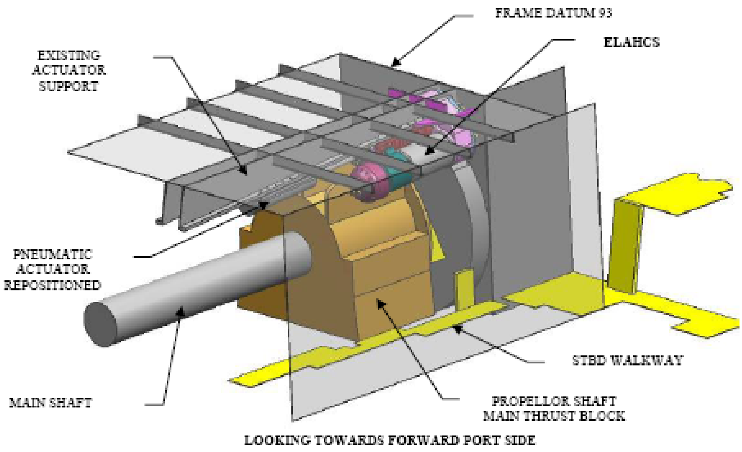

FIG.5 - ELAHCS(SM) SEA TRIAL INSTALLATION.

Extended Seal Testing

The ASTUTE Class aft hydroplane and rudder actuators are located external to the pressure hull, within free-flood spaces. Whilst the final position of SSBN-F's actuators has yet to be fixed it is likely that they will be in a similar location. The intuitive problems associated with positioning electrical equipment external to the pressure hull are confirmed with the poor experience the submarine flotilla has had with secondary propulsion motors. Therefore, with the sea trials taking place within a TRAFALGAR pressure hull it is important to prove the sealing arrangements through a comprehensive testing process.

Two seal packs, output shaft and representative actuator body will be mounted within a test structure and submerged in an estuarine environment for 6 months. At monthly intervals it will be subjected to seal blow out tests, pressure and vacuum tests, operational cycles and thermal tests.

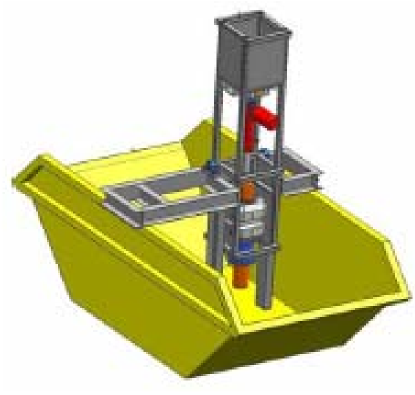

FIG.6 - SEAL TEST RIG (OUT OF ESTUARINE WATERS, MOUNTED IN TEST CONTAINER).

PROGRAMME

The ELAHCS(SM) programme is currently highly fluid owing to commercial considerations: in summary, the original sub-contractor that was developing the technology is now refocusing on core activities due to the global recession. As a result the following programme dates are for indication only.

	Continuous per hour		**Continuous per 90 day mission**		**On demand**	
	Max	Min	Max	Min	Max	Min
SIL 1	1.0E-05	1.0E-06	2.2E-02	2.2E-03	1.0E-01	1.0E-02
SIL 2	1.0E-06	1.0E-07	2.2E-03	2.2E-04	1.0E-02	1.0E-03
SIL 3	1.0E-07	1.0E-08	2.2E-04	2.2E-05	1.0E-03	1.0E-04
SIL 4	1.0E-08	1.0E-09	2.2E-05	2.2E-06	1.0E-04	1.0E-05

TABLE 5 - *ELAHCS(SM) Key Programme Phases*

Programme phases	**Objective for each phase**	**Programme**
Task definition	A review of the options for a Submarine Hydroplane Electromechanical Actuator System Demonstrator and future work proposals.	Complete
Concept design Review	A review of the design concepts, risks and safety issues. This has shaped the future programmes of work	Complete
Sub system design review	More detailed review of the preferred design concepts, risks and safety issues.	Complete
Preliminary design review	Preliminary design culminating in a design review. Successful acceptance of the design review triggered the ordering of long lead items	Complete
Seal testing	Development and testing of the sealing arrangement	Design work commenced 2007, tests due 2009
Critical design review	Detail design and analysis culminating in a design review	Design review complete Sep 2008, currently awaiting final deliverables
Pre-qualification	Manufacture, assembly and integration testing culminating in qualification test readiness review	To follow detail design and complete after 10 months
Qualification of the system	Factory testing of the system leading to customer acceptance	To follow pre-qualification and complete after 2 months
Extended durability shore testing	Achieve confidence in equipment durability	To follow qualification and complete after 12 months
Sea trials	Progress sea trials to demonstrate the system	12 month programme depending upon platform availability (to be fitted during 6 month RAMP)

CONCLUSION

In summary the ELAHCS (SM) programme has successfully demonstrated through design and analysis that an electromechanical system with a digital software control can meet the submarine requirements for safety, reliability and environmental performance and yet provide a cost effective hydroplane and rudder actuation solution for SSBN-F.

A detailed Technology Demonstrator has been designed including the electromechanical actuator, digital and analogue control systems and TRAFALGAR class interfaces. The benefits of electromechanical actuation versus hydraulic actuation on a system level have been presented, in particular the 60% mass reduction, signature reduction through advanced control and TLC reduction. The next phase of the programme will be the manufacture, qualification and trial programme, the last of which has been explained in this paper. This work aims to mature the technology currently at TRL 3 to TRL 7.

The ELAHCS(SM) project is being aimed at SSBN-F's hydroplane and rudder actuation requirement; however, the potential market is substantially larger. Not only could the technology be used for a wider range of less demanding linear-motion applications onboard UK surface and sub-surface platforms but there are also export opportunities. The US Office of Naval Research is currently running a similar development programme to develop electrically actuated control surfaces [8] for their OHIO class replacement and a potential commercial partner has expressed interest in marketing the technology to European SSK manufacturers, a market in which ELAHCS(SM)'s reduced mass and power demand would be very appealing.

ACKNOWLEDGEMENTS

The authors would like to acknowledge the work of the ELAHCS(SM) project team, particularly John Bench, David Atkinson and Kevin Hurst.

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[8] ONR Broad Agency Announcement Number 09-011 (Electrically Actuated Submarine Control Surfaces)