Control Loading System Developments related to Mission Training Systems

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Abstract

This paper discusses the distinctive requirements and development of a light-weight reconfigurable compact control loading system and the future prospects of such a training module. The paper includes some specific information about the AVCATT (Aviation Combined Arms Tactical Trainer) developed by L3 Communications, and used by the US Army and its control loading system.

The AVCATT system is a trailer mounted deployable system that called for a new approach to the control loading system. The system has to be rapidly reconfigurable so that it can represent different helicopter types depending on the requirements of the training exercise. The low profile of the mounting frame and desirability for low weight and power to enhance deployability also drove the design.

The solution developed was based on modified industrial precision brushless actuators networked using an industrial field bus to a control module based on an industrial PC. The actuators include integrated control electronics for the inner loop control in a manner that reduces cables to simplify integration.

The fixed location of the actuators and pivot points across the different aircraft representations required some optimisation of the stick designs. Linkages were removed by making modular loading assemblies that were directly connected to the sticks, thereby reducing weight.

Pilot and co-pilot seats have separate loading modules and are linked via software using techniques transferred from the Company's development of aircraft active sticks. Thus no inter pilot linkages are required further simplifying installation and reducing costs. The software also includes special features to rapidly change over from one aircraft type to another.

The paper presents all these features to demonstrate the unique system design for a mission trainer application that has found applications in other systems since its development. The flexible installation and rapid set up of force feel requirements brings a new cost effective solution to the market. Further examples and applications are discussed in the paper.

1 Introduction

In the early days of flight simulators people recognised the need for control loaders that reproduced control feel that changed with flight condition. Precision low friction hydraulic systems with analogue computers were developed – exemplified by those of the McFadden Company. Models of the aircraft control surface dynamics and aerodynamic forces together with compliant mechanical control runs were included in the systems to reproduce the feel precisely.

The architecture of control loading systems remained relatively stable from these early systems until the advent of the compact systems discussed in this paper. Control loading system actuators were connected to actual aircraft hardware using control rods or cables. Early actuators were hydraulic systems controlled by electric servo valves, which provided a reliable and effective solution. In the '80's the hydraulic systems were replaced by industrial electric servo systems, in the form of brushed pancake motors with smooth belt drives to provide gearing for the high torques required. These were also highly reliable but were still large and required mounting at the back of the simulator or within a large frame below and attaching to rods and mechanical linkages like their hydraulic predecessors.

In the 90's interest began to develop in active sticks for aircraft. Active sticks are control sticks driven directly by full authority electromechanical actuators. These systems had to be smooth, compact and light weight. Nevertheless these systems reproduced a control feel and were therefore transferable to the control loading market. Their compact size made them particularly suitable for the mission trainer market where transportable systems were required.

2 Distributed Mission Training

2.1 Overview

In the last 10 years networking technologies have made it possible for Distributed Mission Training Systems to be developed. Such simulations can involve many participants in different environments using different equipment. Military flight simulation systems have been developed to integrate with the distributed environment. Moreover, the differing nature of global conflicts and the need to bring mission training and rehearsal to front line operators has driven the demand for such systems to be flexible, reconfigurable and deployable. Such systems can help ensure that missions are completed in as efficient and effective a way as possible. This increased preparedness can be accomplished by providing the means for experienced pilots to rehearse their missions prior to actually flying them. Training in the mission and different aspects and possible changes to the mission allows pilots to be ready for all eventualities and so are able to act quickly and with the best judgment during the actual mission.

The US armed forces are always searching for new ways to train its operational aircrews. Distributed Mission Training (DMT) or Distributed Mission Operations (DMO) is an area that has seen growth recently due to the success of this type of training. Using state-of-the-art simulation technology, DMT permits aircrews to train in synthetic battle-space environments, connected electronically to other aircrews at distant air bases. DMT can also deliver this enhanced training from the home station, helping the air force limit the amount of time airmen spend deployed and facilitating the training of USAF air-expeditionary forces as they prepare for deployment to global crisis zones.

The valuable ability to include all those involved in the mission together in one training exercise was conceived so that all personnel would react in the same way and be ready for the changes in the mission. As a result distributed training systems and distributed mission operations are being developed for armed forces across the world.

An added element to the distributed mission training for the military market was taken from the civil market. The recent trend in the civil market has been to sell hours of training rather than the simulators themselves. The idea of leasing time rather than selling trainers is the most cost effective solution and drives the industry to ever higher reliability requirements.

2.2 System Requirements

Distributed mission training is best fulfilled in the field in different locations throughout the world with the ability to be there in a short period of time. With the need for rapid deployability often using air transport, size and weight become crucial issues. In addition, the pilots required the training environment to be as realistic to the actual aircraft as possible. One example of this is the pilot controls, which must accurately represent the complex mission functionality implemented using Hands On Throttle And Stick (HOTAS) controls.

From the standpoint of the control loading system, reliability, compact size, minimum weight, high accuracy and smooth feel are key requirements. A software system that allowed users easy access to set up and manage their models and tune the system response was also highly desirable.

This required high power density actuators to ensure accurate high forces and optimal compactness.

2.3 Actuator Technology

The WITTENSTEIN name represents a full service of motion support that grew from very humble beginnings. Formed in 1949 as DEWITTA a privately owned gear and mechanical machine manufacturer. The present owner, Manfred Wittenstein, revolutionized the servo world in 1983 by rolling out the first high precision planetary gearbox for industrial application from the newly formed alpha getriebebau company.

WITTENSTEIN was the first manufacturer to produce servo planetary gearboxes and over 20 years later, is still known as the standards and performance setter in servo component technology. Specializing in the alpha range of servo mechanical components ensured the development of highly reliable components that have low friction, high torsional rigiditiy and low backlash. These components have been optimized for highly dynamic applications.

This technology was ideal to be extended into creating a control loader which was much more compact and capable of being used with direct pilot input (i.e. no linkages). The problems which needed to be overcome were firstly the smoothness of the actuator and secondly, the actuator electronic control unit that can be mounted on the rear of the actuator to complete the compact package. The resulting WITTENSTEIN developed control loader can be seen in the Figure 2-1 below.

This package is revolutionary for its low weight, compact design. This design has been accomplished by tightly integrating the motor to the gearbox and then also housing the electronics in the same assembly. A further advantage of this concept is the reduced cabling.

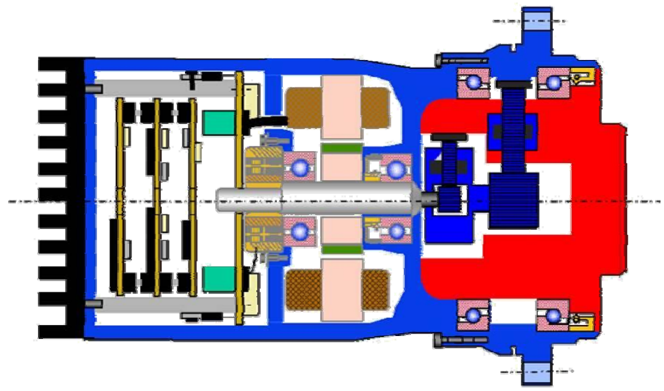

Figure 2-1 Compact Integrated Actuator Assembly

One of WITTENSTEIN's core competencies is an expertise in gear tooth technology. The company was able to develop a gear reducer with minimal backlash whilst feeling smooth. The smooth gearbox was possible through a combination of helical gears and the smoothness of the gear teeth. Additionally some proprietary techniques were developed to optimize the solution for the smooth feel.

Traditional brushed pancake motors have well established smooth characteristics enhanced by the damping effect of the belt drive. Standard brushless permanent magnet motors are known to have cogging torque ripple effects from factors including the movement of the magnets past the stator slots. Skewing the stator slots within the motor improves this characteristic; however it is necessary to further improve the motor cogging torque with advanced magnetic circuit design of the motor.

It was also determined that by utilizing advanced control methodology final optimization of the smoothness could be achieved.

This technology has been backed up by research and development to determine the manufacturing methods and best practices to measure the smoothness of all actuators during production. Prior to WITTENSTEIN's research quantification and acceptance criteria for smoothness has always been largely subjective. As a result, over the past few years WITTENSTEIN has dramatically improved the smoothness and consistency of brushless permanent magnet electric actuators available to the control loading industry. Today it is possible to achieve the same smoothness as the old pancake motors with a WITTENSTEIN actuator.

2.4 Power Requirements

Power requirements are also an important factor for mission training applications. Since the distributed mission trainers are often portable and, in the case of AVCATT, are mounted and installed in the back of a trailer. The infrastructure to supply the power, including the cabling, and the amount of power is a crucial consideration. The actuation systems and power supply requirements for a typical system were developed to use only 2000W total and can be operated from standard mains voltages of 115 or 230 Vac.

This begins to have even more relevance in today's world of environmentally conscious companies and governments along with higher energy costs.

2.5 System Architecture

WITTENSTEIN Control Loading Systems are made up of a set of electromechanical control loading devices with actuators controlled by a System Control Module (SCM). The SCM is an industrial PC that controls the device actuators to provide an accurate representation of the force-feel characteristics of the controls of a particular aircraft or vehicle.

The SCM communicates with the actuators using a CAN bus. Force signals are received by the SCM either over the CAN bus or via analogue inputs. This communication depends on the type of motor controller electronics and force sensors used. The SCM can also transmit grip switch or other input device data to the host when integrated with the CAN bus using a WITTENSTEIN CAN I/O module. For enhanced security the SCM can be fitted with removable solid state hard disk containing all data and software. Alternatively, it is also possible to have a network bootable SCM.

The SCM is connected to the host using an Ethernet connection using simple ASCII protocol supported by WITTENSTEIN. Host interface development support is provided by the Communication Protocol Manual which includes typical source code listings.

Figure 2-2 shows a generic example of a WITTENSTEIN control loading system.

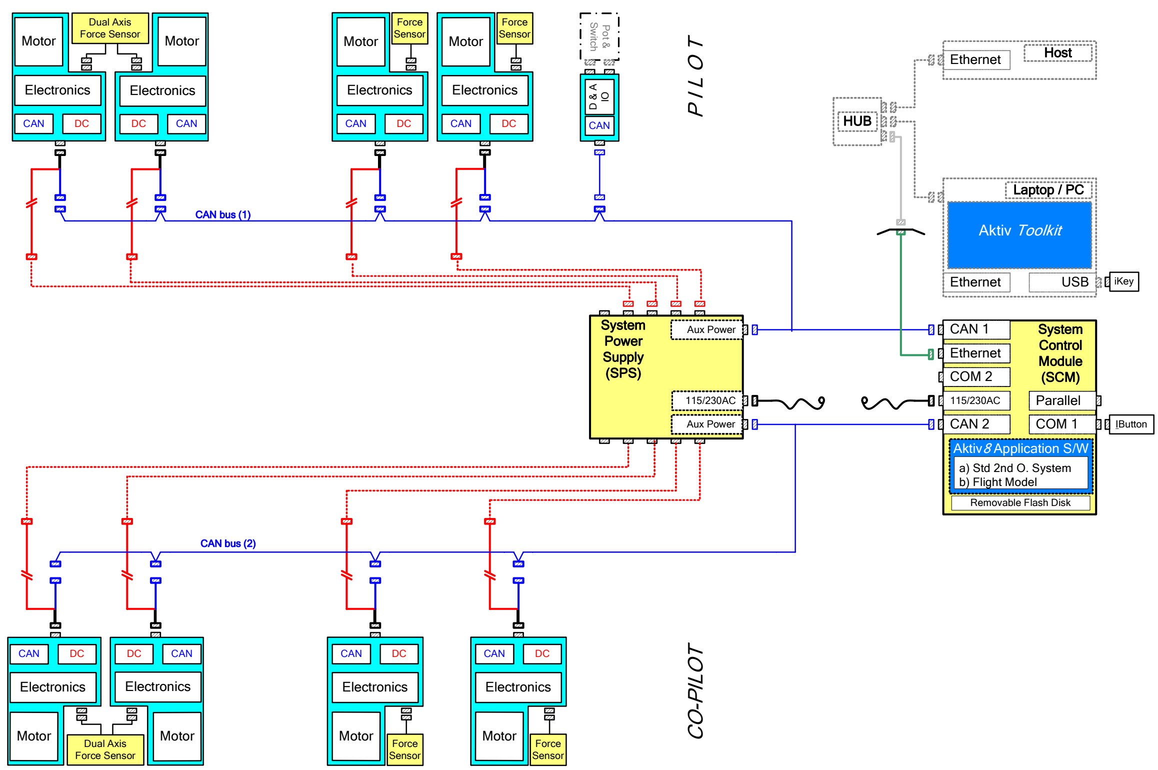

Figure 2-2 Concept of Operation Diagram

Every system is delivered with a set of configuration files that have been set up with standard preset force-feel characteristics. The user can refine the configuration to provide the required force-feel characteristics by using the Aktiv Toolkit graphical user interface. Consultation can also be provided to set up a system to meet defined feel and performance goals.

A WITTENSTEIN control loading system contains the following major components for distributed mission training applications:

- **Device assemblies** (e.g. cyclic, collective and pedal assemblies as used on AVCATT-A)

- **System Control Module** (Industrial PC which contains COTS hardware and runs the WITTENSTEIN proprietary software as well as the software aircraft models for the application)

- **System Power Supply** (WITTENSTEIN designed industrial power supply using COTS hardware to supply power to the actuators)

- **Cabling** (Actuator power, control and force sensor cables as required)

3 The AVCATT System

The Aviation Combined Arms Tactical Training is produced by L-3 Communications for the US Army. Each suite of the system contains 6 reconfigurable 2 pilot cockpits located in 2 deployable trailers. Each cockpit is capable of being rapidly reconfigured to represent one of 5 aircraft types without restriction on the mix of aircraft within one suite. This reduces the number of training systems required, increasing the capability of deployment.

These requirements for ease of deployment and reconfigurability led to the development of more compact and modular systems. For the AVCATT system it was necessary to simulate up to 5 different aircraft types with the same cockpit location.

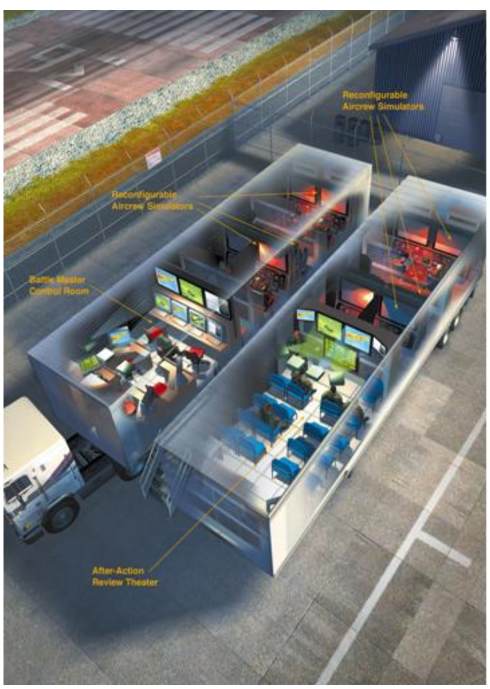

Figure 3-1 AVCATT Images

3.1 Sticks and Grips

From the control loading perspective, this posed somewhat of a problem in that the sticks and grips for each aircraft type are different as well as the pivot locations. However since this was for mission training it was deemed not necessary to provide exact replication of the pivot point locations for the differing aircraft being simulated, however different sticks and grips were designed for each aircraft type to ensure the correct grip shape and mission related switches were provided. Careful optimization of the stick designs ensured that the grips are positioned in the correct place relative to the pilot even if the pivot point is not exactly correct. The sticks and grips were also designed such that they could be replaced quickly and easily when reconfiguring from one aircraft to another.

This feature was then further developed by integrating the switches from the sticks and grips onto the CAN bus and with the sticks for each aircraft type having a different CAN ID.

The software was adapted so that with one command the system can reconfigure itself to the correct aircraft type with the correct feel characteristic. The CAN ID of the sticks can also be used to cue the correct aircraft type.

3.2 Mechanical Design

Fixing the pivot point meant that with optimization of the actuators all aircraft types can be represented with one hardware set configured with the different software loads.

The decision to have the control loading hardware the same for each aircraft type required a mechanical design that was in keeping with the compact design of the actuators. Therefore the design of the AVCATT system utilized the system architecture and the patented gimbal concept of the company's simulator active sidestick developed for a number of handling qualities and engineering simulators. The sidestick mechanical design was robust enough to be evolved into the electromechanical sub-system for the flightworthy active sidestick which WITTENSTEIN has developed for the Korean Aerospace Industries T-50 aircraft.

The sidestick and AVCATT cyclic gimbal assemblies use a bracket which allows the the pitch and roll actuators to be co-located in one simple assembly [See Reference 1].

The design of the pilot station is illustrated in Figure 3-2. This together with a simple design for the collective stick and grip mechanism and a common mechanical assembly for the pedal created a compact and modular control loading system which is exactly what was required for the AVCATT system. The individual pilot controls are pictured in Figure 3-3

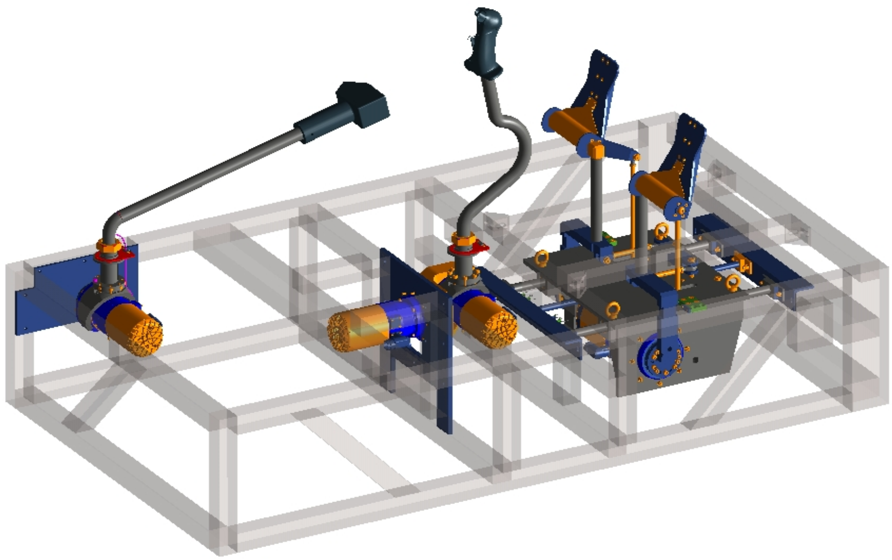

Figure 3-2 Example AVCATT Pilot Station Assembly

3.3 Pilot/Co-Pilot Linking

On other systems, as well as with AVCATT, it is necessary to provide linking of the pilot and co-pilot controls. This has typically been achieved through complex mechanical linkages. Although this saves the cost of the control loading actuators one control loading actuator per axis, it requires additional linkages that require set-up rigging and maintenance. These factors can add to weight, volume and life cycle cost. Moreover in the AVCATT some aircraft types use different pilot and co-pilot sticks with different lengths to establish the correct pilot grip relationship. This can be allowed for in the software linking in a way that could not be accomplished with simple linkages. Therefore, in the AVCATT system two mechanically separate cyclic, collective and pedal assemblies were linked together electronically.

Start-up synchronization and re-linking of the pilot controls following a controlled breakaway, such as may occur in the event of a high pilot/co-pilot force fight, are provided by the software in a manner that provides completely safe transient free operation.

In the AVCATT the pilots are located side by side. However, in some applications the pilot and co-pilot may be located some distance apart to allow the use of separate optimized visual systems. The pilot and co-pilot cockpits may even be used for separate training tasks without the cockpit controls linked.

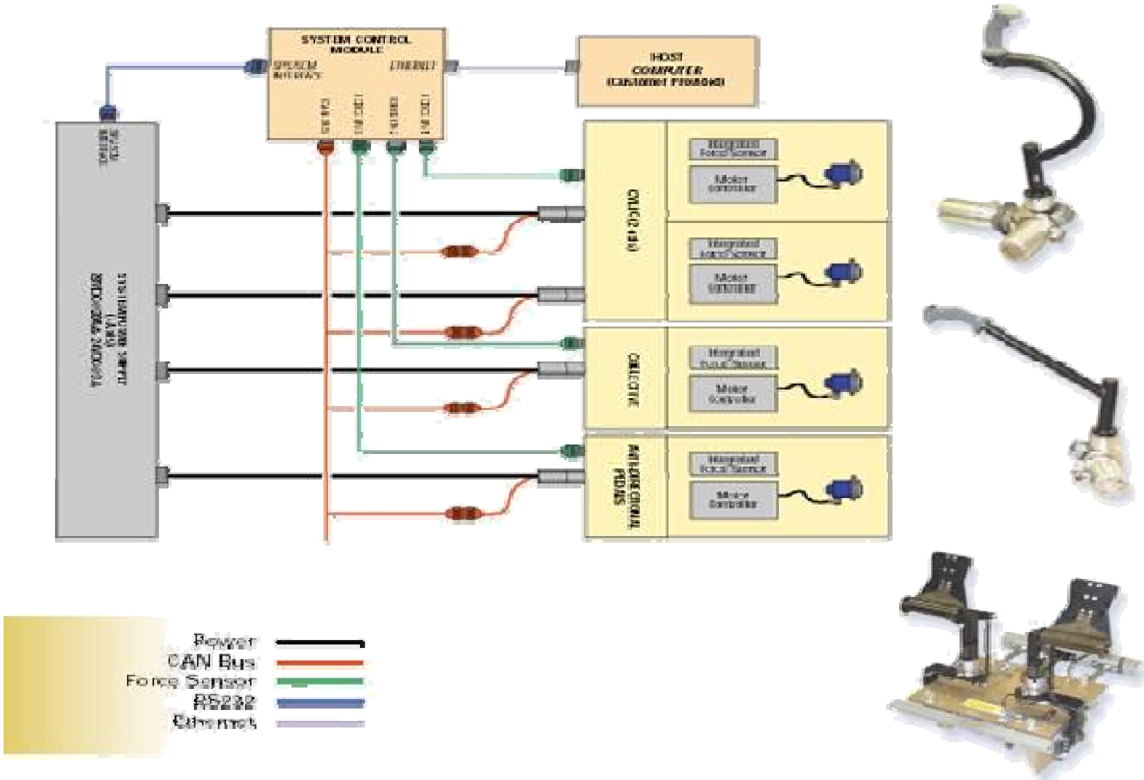

Figure 3-3 AVCATT Specific System Diagram

4 Other Applications

The technology developed used in AVCATT system has also been adapted by WITTENSTEIN for a number of other distributed mission training developments over the past few years.

The original sidestick simulation system has been refined and matured and supplemented by throttle assemblies which provide drop in modules to be used for the simulation of F-16, F22 and F-35 aircraft types. These are also modular and reconfigurable. Examples of these systems are shown in Figure 4-1 below.

Integrated compact control loading assemblies for an F-15E cockpit have been developed that allow for two different training concepts of operation. These assemblies are designed to be fitted directly into (or “dropped-in”) the cockpit to reduce assembly and integration time.

The F-15E development required complex mechanical solutions to ensure the correct fidelity of application was developed. These systems are now integral to the current US air Force’s distributed mission training operations for this aircraft.

Figure 4-1 DMT Examples

5 Possible Future Developments

The future of mission trainers seems to be positive with more and more mission training being developed in the military markets and concepts being developed for the civil markets.

In terms of the future for control loading systems, it is clear that compact and light are increasingly important factors and with more and more of these control loading actuators, it is important the industry develops a standard for smoothness of these controls. As described earlier, due to the extensive research in the smoothness of actuators by WITTENSTEIN there is a basis for this work to proceed although it is obviously important that the industry as a whole be involved in this. Also with the continued involvement of WITTENSTEIN in the flight worthy sidestick business, it is clear that this will quickly become an area of importance to the wider aircraft industry as well.

In some applications for mission trainers the flexibility to allow the electronic linking of two single cockpit trainers to become a dual cockpit trainer has been developed by WITTENSTEIN. This allows the flexibility to move from a two pilot training scenario to a linked pilot and trainer scenario which enhances the training so that the trainer or more experienced pilot can feel the pilot in training’s inputs and relay any suggestions to them more easily. Alternatively the second seat becomes the navigator or weapon systems officer of the aircraft.

Other possibilities are to enhance the network capabilities and features of the control loading system. However, this requires a greater degree of integration into the customer’s system than hitherto has been discussed.

It is also possible for the control loading system to become even more compact and integrated, examples being the further integration of the motor, gearbox and electronics to include all the control loading system functionality and also perhaps an integrated force sensor.

6 Conclusion

Distributed mission trainers are becoming more and more important and useful in military training. As a result, the key requirements for these systems of being distributed whilst providing high fidelity training means that control loading systems are needed that are compact, integrated and modular.

Technology development across the simulation industry and from the commercial markets will continue to drive the control loading system development in the right direction for Distributed Mission Training, ensuring that our armed forces are in the best position for each important mission.

Reference

1. *THE DEVELOPMENT OF A NEW RANGE OF CONTROL LOADING SYSTEMS. Cowling D.A., The Royal Aeronautical Society, Flight Simulation Group Meeting on the Simulation of On-Board Systems, 3-4 November 2004 in London*