MILITARY AIRCREW HEAD SUPPORT SYSTEM

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Abstract

This paper describes research work undertaken in order to determine a suitable method of supporting the military pilot's head during high 'g' manoeuvres, enabling him to maintain his head in an upright position, thereby enhancing his ability to monitor Head-Up Displays, and increasing his awareness of the situation outside the cockpit. The paper also describes how the Military Aircrew Head Support System can serve as an effective head restraint system during an ejection from the aircraft. A description is given of the work carried out to date and proposals for further work are also discussed.

Nomenclature

BAe.	— British Aerospace.
Gz	— Line of force acting vertically down through aircraft.
Gx	— Line of force acting parallel to aircraft longitudinal axis.
IAM	— Institute of Aviation Medicine.
MAHSS	— Military Aircrew Head Support System.
NBC	— Nuclear, Biological and Chemical.
PEC	— Personal Equipment Connector.
RAE	— Royal Aerospace Establishment.
RAF	— Royal Air Force.
Φ	— Head angle, measured from vertical in Gx plane.
θ	— Body angle measured from vertical in Gx plane.

Subscripts

i	— Initial.

Introduction

The idea of a head restraint system for military aircrew is not new. The idea was first considered by Sir James Martin for use by aircrew during high speed escape, in the early 1960s, but as far as it is possible to ascertain, the idea has never been seriously considered as an aid to the pilot during high 'g' manoeuvres.

When manoeuvring violently, modern combat aircraft can frequently subject a pilot to centrifugal forces up to eight times the force of gravity (8 'g'). Under these conditions a pilot's head, complete with flying helmet and attached equipment can have an apparent weight of up to 85kg, as much as his entire body under normal 1 'g' conditions. These loads place a great strain on the pilot's neck muscles and severely reduce his ability to look around during typical combat manoeuvres.

After discussing these problems with fast jet pilots and having evaluated a number of well documented accidents attributed to the effective incapacitation of aircrew during high 'g' manoeuvres, it became evident that there was a clear requirement for a suitable aircrew head support system.

Initial work on the concept of the Military Aircrew Head Support System (MAHSS) commenced in 1986 whilst the author was studying for an honours degree in Aeronautical Engineering at Kingston Polytechnic. After taking up a permanent position with the company in 1987, development of a prototype system was undertaken and trials using the human centrifuge at the Royal Air Force Institute of Aviation Medicine were used to evaluate the concept.

Whilst the main aim of the MAHSS is to provide an active head support system for the pilot (or aircrew member), the design also has an application in acting as a head restraint during ejection from the aircraft.

Outline of the Project Aims

The modern military aviator is now faced with an array of devices such as Night Vision Goggles and Helmet Mounted Sights which can be attached to the helmet to assist the pilot in his mission. However, whilst these devices are of assistance in acquiring and designating targets, their additional weight under high 'g' forces can present the pilot with significantly increased physiological loads. These loads place a great strain on the pilot's neck muscles and severely limit head movement.

If the pilot is forced to eject from the aircraft even higher forces of up to 16 'g' can be experienced, giving the pilot's head and helmet an apparent combined weight of 151 kg, thereby creating a risk of serious neck injury.

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The aim of this research work was to investigate a suitable method of supporting the pilot's head during high 'g' manoeuvres, permitting a full range of head movement under virtually any 'g' load, and also providing restraint for the head and torso during an ejection from the aircraft in order to prevent spinal injury.

The advantages to aircrew when provided with a suitable head support system can be divided into the following areas:—

(a) *Head Support* — This enables the pilot to maintain a greatly improved level of awareness of his surroundings, and additionally helps to prevent fracture injuries of the cervical vertebral column associated with high values of dg/dt.

The head support system also provides significant advantages when used in conjunction with a helmet mounted sight or display, where the mobility of the pilot would otherwise be severely restricted under increasing 'g' levels. This will help the pilot to exploit the full potential of the system especially when the aircraft is engaged in high 'g' manoeuvres and the pilot requires to use the helmet mounted sight or display for target acquisition or designation.

The head support also offers significant benefits for navigators and other aircrew members.

Often crew members of a military aircraft will be unaware of impending high 'g' manoeuvres, which as well as imposing sudden loads on the body may also result in a situation where the safety of the aircraft and its occupants is placed in jeopardy [1]. During such sudden manoeuvres, the MAHSS will be able to provide a high degree of support thereby enabling other aircrew members to fully assist the pilot both by carrying out their duties efficiently under any 'g' loads, and also in observation duties required during combat.

(b) *Head Restraint* — By providing a means of aligning the pilot's head and cervical vertebral column at the start of an ejection sequence, the risk of cranial and vertebral injury can be reduced.

In ejections severe and sometimes fatal injury to the cervical vertebral column is not uncommon [2]. By ensuring that the ejection loads on the vertebral column are kept evenly distributed across the faces of the vertebrae, the risk of injury by shear fractures in the cervical vertebral column can be reduced.

The tendency for the head to flail as a result of wind blast in high speed ejections is also reduced.

During an ejection, the pilot will be protected by the restraint system up to the point of man/seat separation.

(c) *Reduction in Aircrew Fatigue* — By reducing the tiring effects associated with high 'g' manoeuvres, physical fatigue will be reduced, thereby increasing aircrew effectiveness during prolonged combat sorties.

The design requirements for the MAHSS can therefore be summarised as follows:—

- To provide support to the pilot's head in order to relieve the additional bending moment caused by an increase in the apparent weight of the pilot's head due to the effects of 'g' forces.
- To provide an effective method of head restraint during ejection from the aircraft.

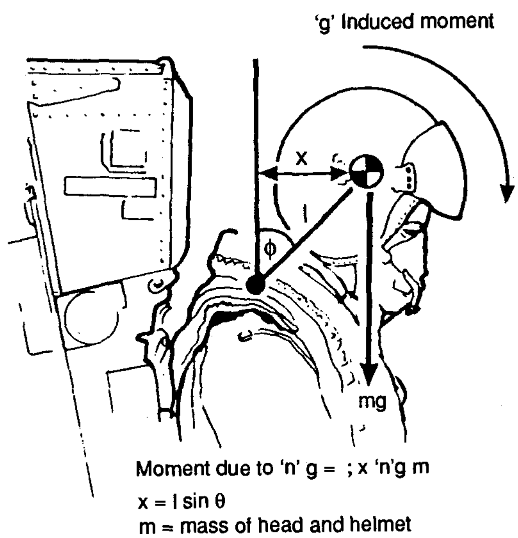
At the same time however, the design must also satisfy the following criteria:—

- Fail-safe man/system separation at the required point in the ejection sequence.
- Unhindered movement within the cockpit for the pilot.
- Small size and low weight of MAHSS connections to the pilot.
- Ease of connection and disconnection from the system.
- Comfort and safety of use.
- NBC clothing compatibility.

Principle of Operation during Normal Flight

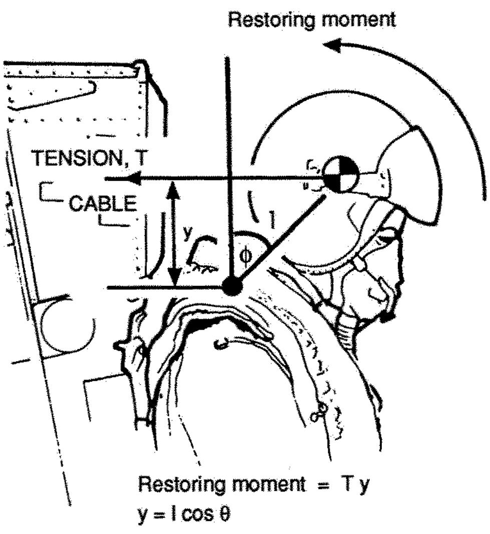
The MAHSS aims to provide support to the pilot's head by providing relief of the induced bending moment rather than by alleviating the apparent increase of weight associated with increasing 'g' forces. This principle of operation is shown in Figs. 1a and 1b where the "'g' induced moment" is countered by a 'restoring moment'.

The system itself consists of a microprocessor controlling two support cables which are mounted on drums and fixed to the aircraft's ejection seat. One of the cables runs to a horseshoe shaped attachment on the pilot's helmet, the other to the life preserver or torso harness.



'g' Induced moment

Fig. 1a



Restoring moment

Fig. 1b

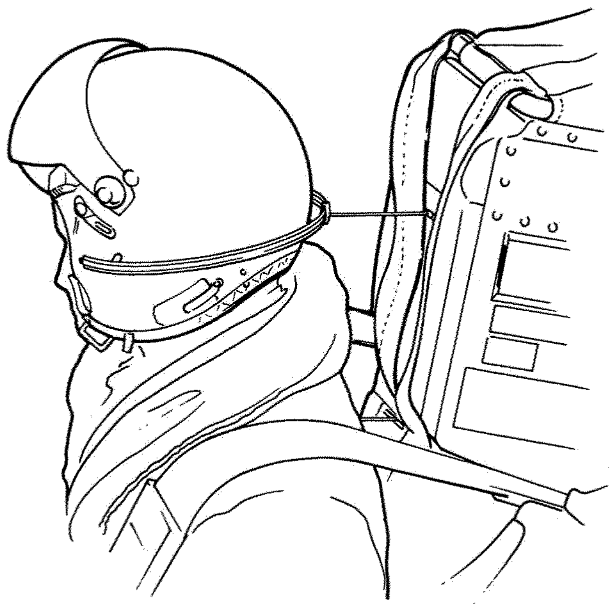


Fig. 2

The helmet mounted horseshoe pivots at its attachment points and the cable slides freely along its length, thereby ensuring that the line of force from the head support cable passes through the centre of mass of the pilot's head and helmet irrespective of his head position (Fig. 2).

When the pilot experiences 'g' forces greater than 1 'g', the microprocessor uses an algorithm based on the biomechanical model described later in the paper to calculate the cable tension required to maintain the pilot's head and torso position. These cable tensions are determined by the posture of the pilot and by the 'g' forces being experienced, and therefore continuously change during flight.

From load cells mounted at the end of each cable it is possible to determine the existing cable tensions. These values are used to determine whether the existing cable tension is greater or less than the expected value calculated by the microprocessor. If the tension is greater than expected, the system assumes that the pilot is trying to lean forward and the servo motors will unwind the cables at a rate proportional to the difference in the two values. Similarly if the tension in the cables is less than expected, the system assumes that the pilot is trying to sit up and the cables will be wound in. If the measured cable tension is within the predetermined limits, the motor torque is adjusted to keep the pilot's head and body in the same position. This method of operation is shown in Fig. 3.

When the head and torso cables are retracted, they are wound onto two interconnected drums. The head support cable drum is of a larger diameter than the torso support drum; both interlocking with each other to ensure that head support cable movement is proportional to torso support cable movement. This acts as a safety feature should one of the two servo motors fail. The drum, motor, and cable arrangement is shown in Fig. 4.

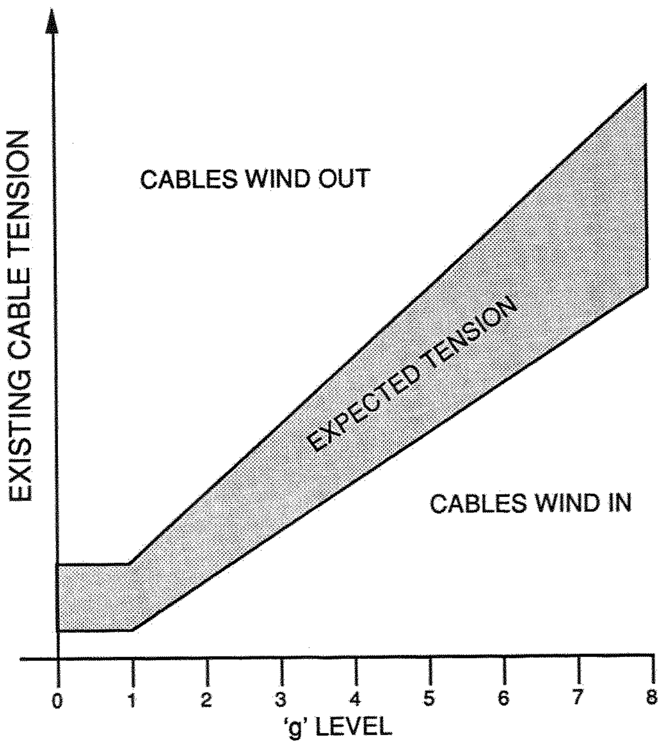


Fig. 3

Structural and Ergonomic Considerations

Recent centrifuge trials have shown that the system confers minimal restriction upon the pilot's movement, allowing him to look freely over his shoulder during air combat or when flying in close formation with other aircraft.

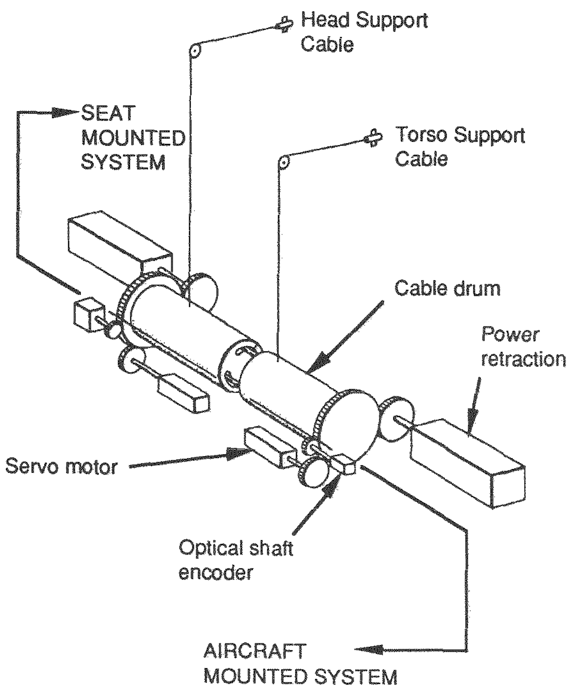


Fig. 4

In order to eliminate the possibility of the supporting force twisting the pilot's head, it is important to have the line of force passing through the centre of mass of the head and helmet irrespective of the head position. This is achieved as described earlier by attaching the support cable to the pilot's helmet via a semi-circular 'horseshoe' and slider arrangement.

This arrangement ensures that the line of force created by the tension in the head support cable will pass through the centre of mass of the pilot's head and helmet under even the most extreme postures. If the pilot wishes to look to his left or right by an angle greater than 90°, small extension arms recessed into each end of the horseshoe are extended as the slider moves around in the track to the extremes of the horseshoe. These arms extend by several inches in order to give the pilot greater support when looking at objects in the rear hemisphere.

In order to provide a sufficient degree of lateral movement for the pilot it is important to direct the forces from the support cables in a direction parallel to that of the aircraft longitudinal axis, and not just back to the centre of the head box. By directing the forces in this manner, the pilot's head will not be pulled back to the centre of the head box, but will remain supported at the required lateral position. This lateral support, required for both the head and torso, can be achieved by the use of two semi-circular tracks built into the head box and back rest. Both tracks are of a constant radius, and because the path of each support cable passes through the centre of the respective track, the cable length required to support the pilot remains constant irrespective of the lateral head and body position.

If the pilot wishes to move the centre of his head past the edge of the head box, a similar sliding arm arrangement to that used on the horseshoe is used to facilitate lateral head movement.

The location of the two constant radius tracks and the sliding arm are shown in Fig. 5.

The design of the mechanical aspects of the MAHSS has resulted in a system capable of providing head support to the pilot under virtually any 'g' loads likely to be experienced during the most violent manoeuvres. By careful attention to the design of the mechanical aspects of the system, it has been possible to achieve this level of support without conferring any significant limits to the movement of the pilot.

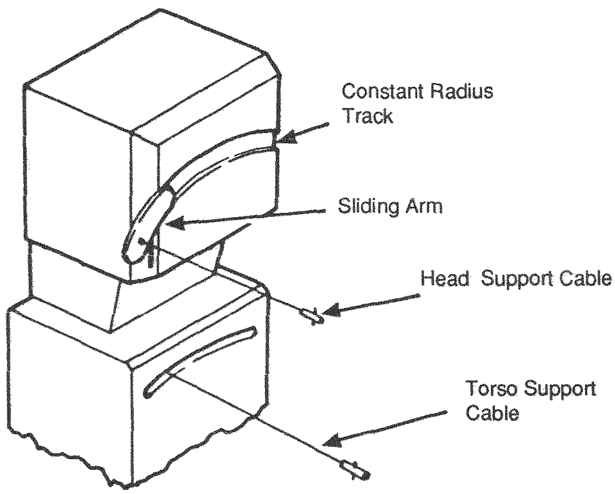


Fig. 5

Ingress and Egress

The two MAHSS cables are connected to the pilot via two small scissor shackle connectors. The operation of the scissor shackles is controlled by a small solenoid located at the end of each cable as shown in Fig. 6. During normal operation when power is applied to the solenoids, the inner cable is kept slack and the coil spring mounted at the scissor shackle pivot point ensures that the jaws are kept closed.

When cable disconnection is required, power to each of the two solenoids is cut, resulting in the inner cables being pulled tight, and the subsequent opening of the scissor shackle jaws.

The solenoid power supply is controlled by a microswitch mounted on the PEC seat-portion. When the PEC man-portion is disconnected i.e. during egress from the aircraft, power is cut and the cables disconnect from the pilot.

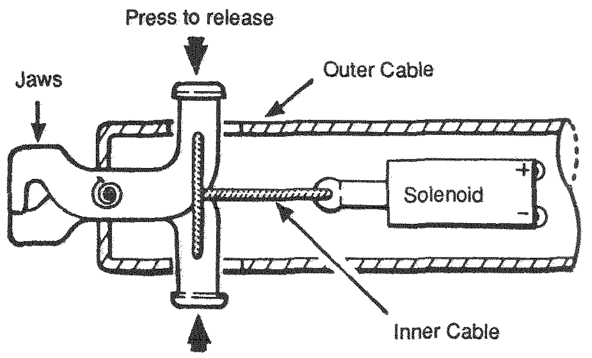


Fig. 6

Forces experienced by pilots during ejections have already been studied by many researchers interested in limiting vertebral damage during very rapid +Gz acceleration. Whilst similar to existing ejection seat biomechanical models, the model developed for this project (Fig. 6) assumes that for the rates of rise of 'g' likely to be experienced during combat flying, the dynamic effects can be ignored. This assumption is based on the observation by a number of authors that during an ejection, peak transient loads are some 25% more than the equivalent steady state loads [3]. These transient responses however were associated with rates of rise of 'g' between 200-1000 g/s whilst in combat these values are likely to be in the region of 10 g/s. The subsequent second order effects have therefore been assumed to be negligible.

The final version of the biomechanical model will be used as the core of the microprocessor control software.

Principle of Operation during Ejection

During an ejection the two support cables bring the pilot into an upright position and restrain the pilot's head and torso until man-seat separation occurs. At this point the scissor shackles connecting the cables to the pilot are opened as the power supply to the solenoids is cut. Fractions of a second later the cables are also guillotined at their seat end thus ensuring that even if normal scissor shackle release has failed, clean separation will still occur.

System Control

The magnitude of the restoring moment and subsequent cable tensions are determined by the head and torso position and the +Gz forces being experienced. These parameters, together with the existing cable tension are used as inputs to the microprocessor to determine the control signals for the two servo motors.

All microprocessor inputs are triplexed to ensure safe operation of the control system, and a number of signal conditioning arrangements are used to prepare the signals for the A-D converters.

The calculations to determine the expected tensions and subsequent motor control signals are performed at a rate of about 50Hz to ensure smooth operation of the system.

During an ejection from the aircraft an interrupt routine is used to command the servo motors to bring the pilot into an upright position and to operate a ratchet type latch which locks the cable drums in position as they rewind.

Biomechanical Modelling Aspects

A biomechanical model of the seated human has been used as a design tool to predict the head support, torso support and cervical vertebral forces under varying +Gz levels.

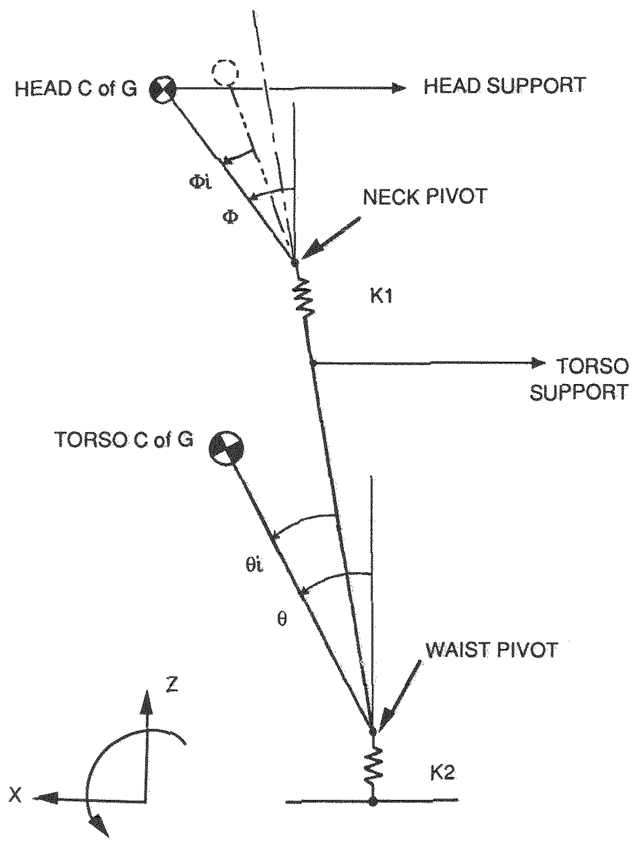


Fig. 7

Results of Centrifuge Trials

Trials of a prototype system at the Royal Air Force Institute of Aviation Medicine have been highly successful. Volunteer subjects have demonstrated the effectiveness of the system at loads of up to 6 'g' using the Institute's human centrifuge. During these trials, the subject using the head support system was able to control the servo motor torque by means of a manual slider arrangement mounted on the seat's armrest enabling rapid changes in position to be performed even under high 'g' levels.

Significant increases in the degree of mobility under high 'g' levels have been achieved, and data gathered during these trials has been used to further develop the biomechanical model.

Future Plans

Further trials using the human centrifuge are planned for late 1990. During these trials a more representative mechanical arrangement of the MAHSS system will be evaluated, and an assessment made of the automatic motor control system.

Following development on the centrifuge it is planned to commence flight trials of the system to assess its potential in a fully representative environment.

Other developments may include the use of the system to support a pilot incapacitated by 'G' Induced Loss of Consciousness (G-LOC), and the use of the horseshoe and slider system as a helmet position monitor for use with Helmet Mounted Sights.

Conclusion

Work to date suggests that the system described above will be capable of providing an effective head support system for fast jet aircrew.

Perhaps the potential benefits are best summed up by Mr J.F. Farley (Ex-Chief Test Pilot, BAe. Dunsfold) who in a recent article on Fast Jet Aircrew Safety [4] stated:—

> *"The prize for a reliable head restraint system is not just safer high speed escape. It could be the only real way to exploit the high sustained 'g' levels fully. It could be that the first aircraft so equipped will have a tremendous tactical advantage over the opposition."*

References

[1] "Tornado Navigator Ejected Pilot", *Flight International Magazine*, 8th January 1986, p13.

[2] "Report of the Working Group on The Clinical and Biomedical Evaluation of Trauma and Facilities Associated with Aircrew Ejection and Crash" *AGARD Advisory Report No.194.*

[3] A.P. Vulcan, A.I. King, "Forces and Momentums Sustained by the Lower Vertebral Column of a Seated Human during Seat to Head Acceleration", *The American Society of Mechanical Engineers, Conference proceedings*, Dec 1970, p84-100.

[4] J.F. Farley, "Fast Jet Aircrew Safety", *Flight International Magazine*, p25-29. 31st August 1985.