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Military Aircrew Head Support System

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This article describes research work undertaken to determine a suitable method of supporting the military pilot's head during high *g* maneuvers, 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 external environment. In addition, the operation of the system also serves to reduce the incidence of incapacitating and nonincapacitating neck and nerve injuries experienced by pilots during air combat maneuvering. The article also describes how the military aircrew head support system (MAHSS) can serve as an effective head restraint system during an ejection from the aircraft, and how its operation differs between normal high *g* flight and ejection. A description is given of the work carried out to date including biomechanical modeling of the human body under high *g* loads and trials on the human centrifuge at Royal Aerospace Establishment (RAE) Farnborough, designed to validate the automatic control system. Plans for future trials are also outlined.

Nomenclature

F = head angle, measured from vertical in Gx plane
Gx = line of force acting parallel to aircraft longitudinal axis
Gz = line of force acting vertically down through aircraft
q = body angle measured from vertical in Gx plane

Subscript
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* maneuvers.

When maneuvering 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 85 kg, as much as his entire body under normal 1 *g* conditions. These loads impose a severe musculoskeletal strain on the neck and severely restricts his ability to look around during typical combat maneuvers.

In addition, during these violent maneuvers, high rates of rise of *g* can cause incapacitating neck injuries leading to permanent physiological damage.

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* maneuvers, 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 while the author was studying for an honors degree in aeronautical engineering at Kingston Polytechnic. After subsequently taking up a permanent position with British Aerospace Military Aircraft Division 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.

Although the main aim of the MAHSS is to provide an active head support system for military aircrew, the design also has an application in acting as a head restraint during ejection from the aircraft.

Throughout the text, the advantages of the MAHSS are generally described from the pilot's viewpoint. It should be noted, however, that the system is equally suitable for other aircrew members who may be even more susceptible to the effects of high *g* maneuvers.

Outline of the Project Aims

The modern military aviator is now faced with an array of devices such as night vision goggles (NVG) and helmet mounted sights (HMS) which can be attached to the helmet to assist the pilot in his mission. However, although 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 an additional risk of serious neck injury.

The addition of NVG or HMS equipment would significantly increase this problem due to both the additional weight and increased moment of the helmet-mounted devices which are typically located some distance from the effective pivot point of the neck.

The aim of this research work was to investigate a suitable method of supporting the pilot's head during high *g* maneuvers, 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:

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 rates of rise of *g*.

The head suport 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

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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 maneuvers and the pilot requires the use of the helmet-mounted sight or display for target acquisition or designation.

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

Often crew members of a military aircraft will be unaware of impending high g maneuvers, 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 are placed in jeopardy.[1] During such sudden maneuvers 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.

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 vertebrae is not uncommon.[2] By ensuring that the ejection loads on the vertebral column are kept evenly distributed across the vertebral faces, the risk of injury by shear fractures in the cervical vertebrae 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.

Although arm and leg restraint on ejection is a common feature of modern escape systems, no head restraint system is yet in operational use.

Reduction in Aircrew Fatigue

By reducing the tiring effects asociated with high g maneuvers, physical fatigue will be reduced, thereby increasing aircrew effectiveness during prolonged combat sorties.

The design requirements for the MAHSS can therefore be summarized as follows: 1) to provide an effective means of head support during high g maneuvers; and 2) to provide an effective method of head restraint during ejection from the aircraft.

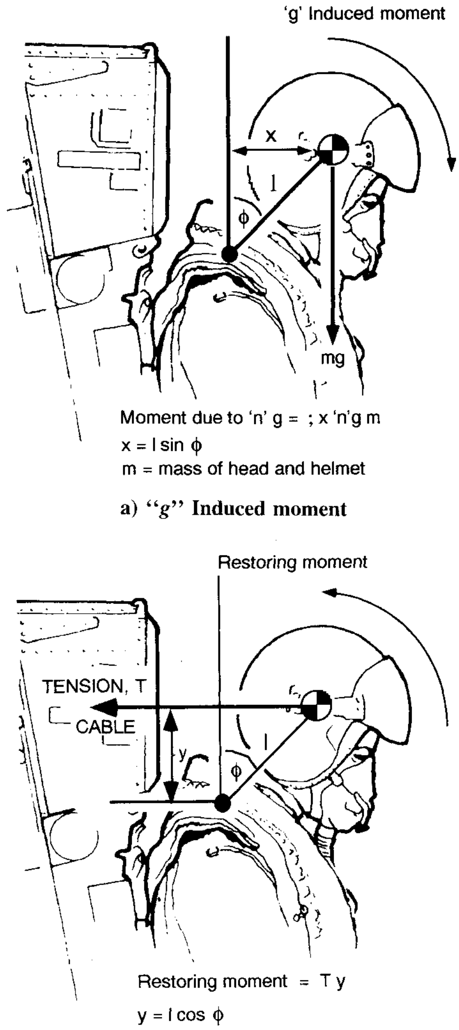
At the same time, however, the design must also satisfy the following criteria: 1) fail-safe man/system separation at the required point in the ejection sequence; 2) unhindered movement within the cockpit for the pilot; 3) small size and low weight of MAHSS connections to the pilot; 4) ease of connection and disconnection from the system; 5) comfort and safety of use; 6) nuclear, biological, and chemical (NBC) clothing compatibility; and 7) simplicity of design for high reliability and minimal maintenance.

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 MAHSS operating system consists of a microprocessor controlling two support cables which are mounted on drums and fixed to the aircraft's ejection seat. One cable runs to a horseshoe-shaped attachment on the pilot's helmet, whereas the other runs to the life preserver or body harness to provide additional support to the pilot's torso.

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 center of mass (c.m.) of the pilot's head and helmet irrespective of his head position (Fig. 2).



a) "g" Induced moment

b) Restoring moment

Fig. 1 Principle of operation to support pilot's head during increasing g forces.

Fig. 2 Artist's impression of MAHSS in use.

When the pilot experiences g forces greater than 1 g, the microprocessor uses an algorithm based on a biomechanical model described later in this article to calculate the cable tension required to maintain the pilot's head and torso position. Cable tensions are determined by the posture of the pilot and by the local $+Gz$ 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 the difference between actual and

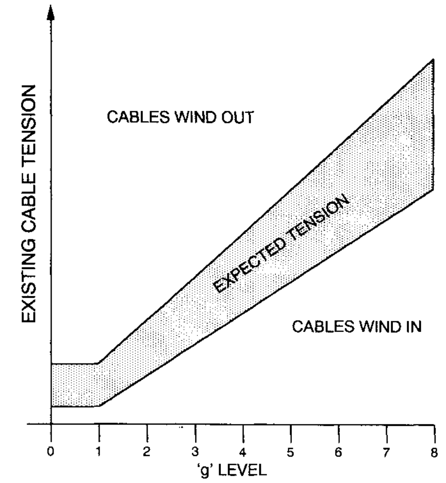


Fig. 3 Method of operation.

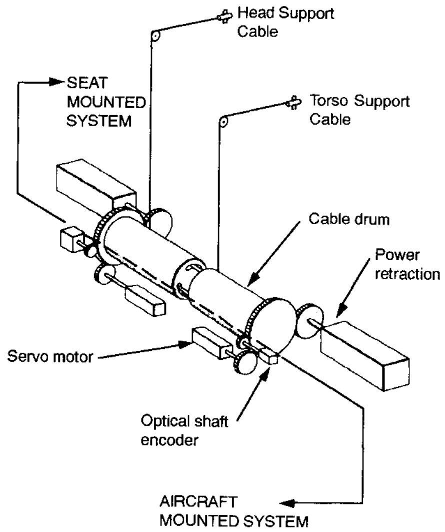


Fig. 4 Cable, cable drum, and motor arrangement.

microprocessor-calculated cable tension. 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. The measurement of cable tensions and the subsequent calculations are performed by the microprocessor at a rate of 50 Hz.

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 in case one of the two servo motors fail. The lightweight cable drums are mounted on the ejection seat, while the servo motors are mounted behind the drums on the cockpit bulkhead. During an ejection, the interconnecting drive gears remain with the servo motors as the cable drums lift away with seat. The drum, motor, and cable arrangement is shown in Fig. 4.

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 as required.

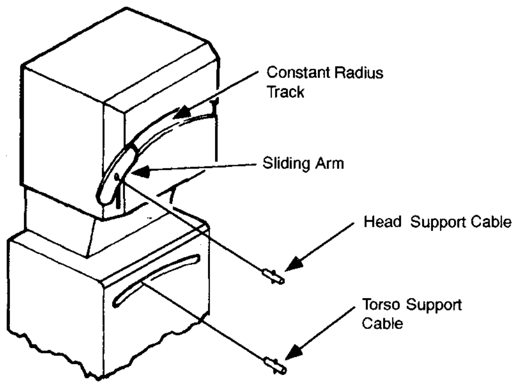


Fig. 5 Ejection seat interface.

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 throught c.m. of the head and helmet irrespective of the head position. This is achieved by attaching the support cable to the pilot's helmet by way of a semicircular "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 c.m. 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 deg, small extension arms recessed into each end of the horseshoe are extended as the slider tracks to its lateral extremes. These arms extend by several centimeters 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 center of the head box. By directing the forces in this manner, the pilot's head will not be retracted to the center 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 semicircular 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 center of the respective track, the cable length required to support the pilot remains constant, irrespective of the lateral head and body position.

Should the pilot wish to move the center 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 maneuvers. By careful attention to the design of mechanical aspects of the system, it has been possible to achieve this level of support without conferring any significant limits on pilot mobility.

Ingress and Egress

Each MAHSS cable is connected to the pilot by means of a small scissor shackle connector. The operation of the scissor shackles is controlled by a small solenoid located at the end of each cable (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 either during egress or during the ejection sequence, power to each of the two solenoids is cut. This results in the inner cables being pulled tight, and the subsequent opening of the scissor shackle jaws.

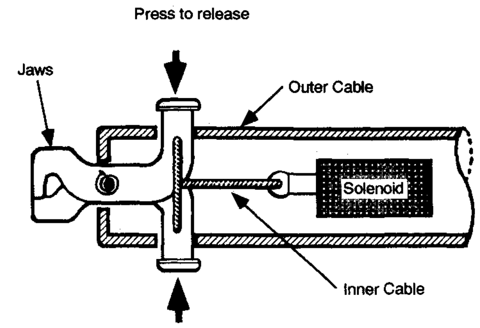


Fig. 6 Scissors shackle at cable end.

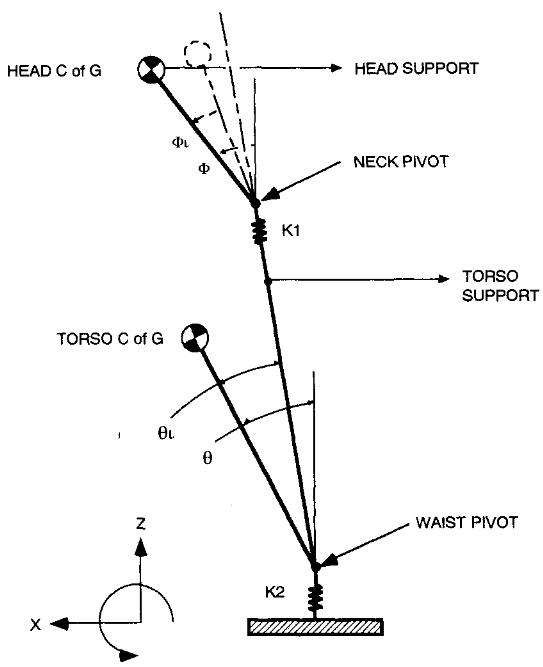


Fig. 7 Biomechanical model.

The solenoid power supply is controlled by a microswitch mounted on the personal equipment connector (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.

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 using pyrotechnic cutters. This ensures 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 local $+Gz$ forces. These parameters, together with the existing cable tension, serve as inputs to the micrprocessor 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 50 Hz 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 Modeling 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.

Forces experienced by aircrew during ejection have already been documented by research aimed at limiting vertebral damage during very rapid $+Gz$ acceleration. Although similar to existing ejection seat biomechanical models, the model developed for this project (Fig. 7) 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, while 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.

Several biomechanical models of varying levels of complexity, including a 4 degree-of-freedom model, have been asessed for their suitability for use with the MAHSS control system. It is intended to compare these theoretical models with the experimental results from the centrifuge trials before the final model is defined.

The final version of the biomechanical model will be used as the basis for the real-time program that will instantaneously predict the head and torso restraint cable tensions as the pilot maneuvers the aircraft and also changes his posture.

Results of Centrifuge Trials

Preliminary trials of a prototype system at the Royal Air Force (RAF) 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 initial biomechanical model. Future centrifuge trials will aim to gather further biomechanical data and to validate the MAHSS control system.

Future Plans

Further trials are planned using the human centrifuge at the RAF Institute of Aviation Medicine. 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 application of the MAHSS as a head position sensor 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 John F. Farley (ex-chief test pilot, British Aerospace 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

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