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Lawrence J. Specker and James W. Brinkley

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The performance capability of emergency ejection seats is limited at high speeds by the occurrence of windblast injuries rather than the maximum qualification test speed that is commonly cited. Serious injuries may occur at relatively low airspeeds. For example, the injury rate due to aerodynamic forces exceeds 10% at 193 m/s (375 knots). At 256 m/s (500 knots) the major and fatal injury rate increases to nearly 50%. The injuries range from joint dislocation and long bone fracture to cervical cord transection. If the injuries are survivable, long recovery periods are frequently required and, in cases where there is joint disruption or nerve involvement, return to flight status may not be possible.

Conventional approaches to windblast protection have used extremity restraints, such as leg garters and arm sleeves which must be donned and attached to the seat by encumbering straps. Head and neck protection concepts have restricted head and neck mobility, added bulk, presented actuation problems, and frequently created added injury hazards. Therefore, no acceptable approach has been adopted. The absence of directional stability of the ejection seat has severely compromised the effectiveness of side panels and nets which are intended to prevent extremity flair injuries.

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WINDBLAST PROTECTION: WIND TUNNEL EVALUATION OF CONCEPTS FOR CREWMEMBER PROTECTION

Lawrence J. Specker and James W. Brinkley
Air Force Aerospace Medical Research Laboratory
Aerospace Medical Division, Air Force Systems Command
Wright-Patterson Air Force Base, Ohio

INTRODUCTION. The performance capability of emergency ejection seats is limited at high speeds by the occurrence of windblast injuries rather than the maximum qualification test speed that is commonly cited. Serious injuries may occur at relatively low airspeeds. For example, the injury rate due to aerodynamic forces exceeds 10% at 193 m/s (375 knots). At 256 m/s (500 knots) the major and fatal injury rate increases to nearly 50%. The injuries range from joint dislocation and long bone fracture to cervical cord transection. If the injuries are survivable, long recovery periods are frequently required and, in cases where there is joint disruption or nerve involvement, return to flight status may not be possible.

Conventional approaches to windblast protection have used extremity restraints, such as leg garters and arm sleeves which must be donned and attached to the seat by encumbering straps. Head and neck protection concepts have restricted head and neck mobility, added bulk, presented actuation problems, and frequently created added injury hazards. Therefore, no acceptable approach has been adopted. The absence of directional stability of the ejection seat has severely compromised the effectiveness of side panels and nets which are intended to prevent extremity flail injuries.

BACKGROUND. Physical processes which produce windblast injuries are relatively well understood. There is great disparity between the forces acting on the extremities of an ejectee and those acting on the seat during ejection into a high velocity windstream. The limbs are forced outward and backward due to the direction of the aerodynamic flow and their tendency to decelerate more rapidly than the torso and seat. If the arms and legs are dislodged from the seat by the aerodynamic and inertial forces and if the airspeed is sufficiently high, the extremities are injured when joint strength is exceeded or when the long bones are fractured by contact with the seat structure. Injury of the cervical spine is caused by tension, bending, and/or shear loads resulting from inequalities of the aerodynamic forces and accelerations acting on the head and neck.

The apparent general solutions are to restrain all extremities to the seat or to reduce the disparities between the forces acting on the limbs by altering the aerodynamic flows and inertial loads. However, implementation of these solutions is difficult in the face of numerous design constraints imposed by the seat occupant, the aircraft, and other escape system design requirements. Such constraints effectively eliminate such schemes as total body restraint or heavy mechanisms that protrude in front of the seat to deflect the aerodynamic flow away from the seat occupant.

State-of-the-art ejection seat stabilization is also a major factor that constrains the design of an effective windblast protection system. It is apparent from wind tunnel test data and the results of rocket sled tests that ejection seats have not achieved adequate directional stability at high-speed ejection conditions. However, directional control has been improved in the recent generation of ejection seats and further advancements are anticipated in the next decade. Therefore, protection schemes predicated upon seat stabilization may prove to have merit as longer term solutions.

The Air Force Aerospace Medical Research Laboratory has undertaken a research program to investigate various concepts for windblast protection using devices which partially encapsulate the crewmember to provide flow diversion as well as restraint that is not encumbering during normal flight. These concepts provide protection for most of the crewmember's head, torso and limbs and involve the deployment of relatively lightweight flow diversion and restraint structures.

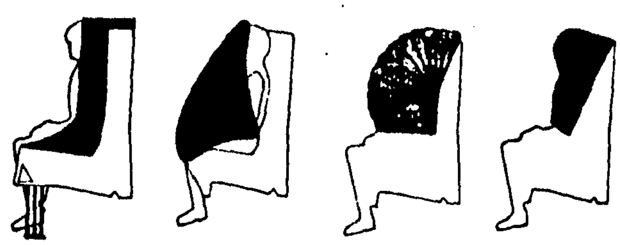

FIGURE 1.

Illustrations of each concept are presented in Figure 1. The first drawing is a composite of two concepts. Concept 1 involves the use of high strength fabric panels. The panels stored on the sides of the seat and over the headrest, would be pulled forward during ejection. They are intended to stagnate the aerodynamic flow impinging on the seat occupant's upper extremities and torso.[1] Concept 2 is a leg protection device which consists of telescoping tubes and heel strap which prevent external rotation of the foot and limits rearward motion of the legs. Concept 3 consists of an inflatable, high pressure bladder with a rigid foam outer layer that would divert the aerodynamic flow and react the aerodynamic loads through the seat structure. Concept 4 also provides these same functions by means of an inflatable structure deployed in a sweeping motion from the upper portion of the seat back. This device would be constructed of a series of tubular-section bladders.[2] Concept 5 is a fabric curtain that is deployed in a manner similar to Concept 4. The curtain is intended to restrain the upper body and eliminate upward loads acting on the crewmember's head and neck by lifting from the surface of the helmet and reacting the loads into the seat structure.[2] Deployment of these protection devices would occur either prior to or during seat motion.

METHODS. The effectiveness of each concept was evaluated by wind tunnel tests. A 1/2 scale model of a crewmember and ejection seat was tested using a low speed wind tunnel at LTV Aerospace Corporation, Vought Aeronautics Division.[3] The steady-state forces and moments acting on the crewman's limbs and neck were measured. Static pressures were measured at seven locations on the crewman/seat model. The models of concepts 1, 2, 3, and 4 were instrumented with as many as 15 additional static pressure ports on the internal and external surfaces of the protection device. Pitch angle was varied from -0.35 rad (-20°) to 0.52 rad (30°). Yaw angle was varied ±0.35 rad (±20°). Freestream incompressible dynamic pressure (Q) was $4.79 \times 10^3 N/m^2$ (100 psf) at a Reynolds number of 1.67×10^6 based on the reference crewman length. The operating tunnel speed was approximately Mach 0.26. Determined from the collected data were the lift, sideward, and drag forces on the helmet; sideward and upward forces acting on the knee; drag and sideward forces at the foot; lift and sideward forces on the hand at the ejection initiation handle; and sideward and drag forces at the shoulder. All collected crewmember data were reduced to force area coefficients (force/Q). Seat stability data were expressed as aerodynamic coefficients (force/(Q X projected area)). In addition to the five protection concepts, the basic crewman/seat was tested to provide baseline data.

RESULTS AND DISCUSSION. Each of the five concepts was evaluated against the baseline seat configuration to determine whether or not the aerodynamic forces acting on the crewmember's limbs were reduced. Changes in the aerodynamic static stability coefficients for each concept were also evaluated. Figure 2 plots helmet lift force area data for the most effective and the least effective concept as well as the baseline seat configuration. It was anticipated that the flexible curtain would react the loads through the fabric as would a sail. However, ram pressure forced the lower portion of the device to press against the torso and chin of the crewmember. This allowed large aerodynamic loads to be reacted through the crewmember's head/neck. Head and neck axial loading was increased by a factor of eight. The stagnation flow fence configuration lowered the helmet lift force area significantly and was the most effective concept in reducing crewmember loading. The concept worked as theorized by eliminating large differential pressures on the fore and aft side of the individual body segments. There was a major reduction of the aerodynamic loads measured on all of the extremities protected by the stagnation fences.

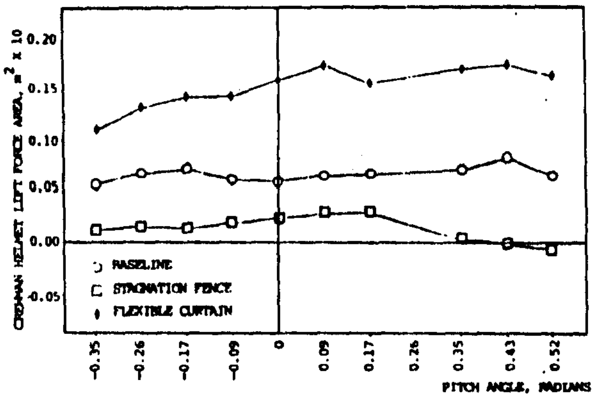

FIGURE 2.

Figure 3 illustrates pitching moment data for Concepts 1 and 2 and the baseline seat. At zero radian pitch angle the pitch moment coefficient was nearly zero for the stagnation flow force configuration. With the addition of the leg protection device, the pitching moment coefficient was doubled at zero degree pitch angle. Therefore, the stagnation flow fences tended to improve seat pitch stability and the leg protection devices degraded pitch stability. The yaw moment coefficient data showed no difference between the baseline and the five concepts over yaw angles ranging to ±0.18 rad (±10°). Overall, the stagnation flow fence protection concept provided the best crewmember protection while not degrading seat performance.

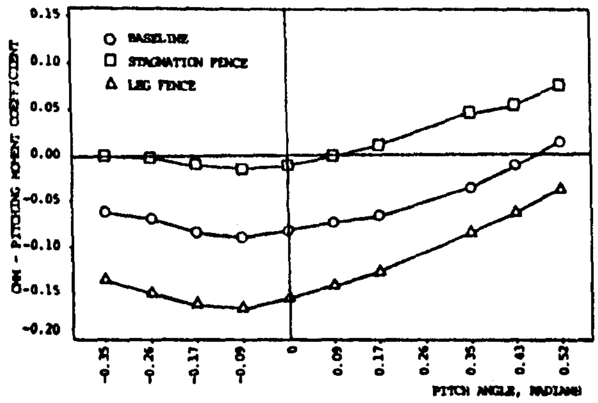

FIGURE 3.

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