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SPIE—The International Society for Optical Engineering

Helmet- and Head-Mounted Displays VI

Ronald J. Lewandowski
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Volume 4361

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John S. Crowley, U.S. Army Aeromedical Research Laboratory
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Panel on
Helmet-Mounted Display (HMD) Biodynamic Issues and Concerns

Panel Moderators

Clarence E. Rash and John S. Crowley
U.S. Army Aeromedical Research Laboratory, Fort Rucker, Alabama

OBJECTIVE

To present a forum for government, military, industrial, and academic researchers and program managers to exchange information on biodynamic issues of concern in the design of helmet-mounted display (HMD) systems.

Keywords: Helmet-mounted display (HMD), biodynamics, weight, center of mass, protection, impact

1. INTRODUCTION

The role of the basic helmet historically has been to provide protection. The dictionary defines a helmet as an armored device designed to protect the head. The use of helmets can be traced to the ancient Egyptians and Assyrians. These first helmets, made of fabric or leather, were used to protect against clubs and lances. Many helmet styles were introduced and used through the 17th century. Helmets and other personal armor items fell into disuse when firearms were introduced. It was not until World War I, with the development of fragmentation armament, that helmets again were recognized as necessary protective equipment. In the decades to follow, improvements in manufacturing processes, discovery of newer and better protective and energy-absorbing materials, and extensive ballistic research have led to the modern military helmet.[1]

The use of helmets in aviation, and more especially in U.S. Army aviation, covers a shorter time span. Army aviation was conceived in September 1861 when the Union Army sent hot air balloons aloft to observe Confederate troop movements. The first "heavier than air" flight machines were delivered to the Army in August 1909. Based on records and preserved examples from early Army aviators, the first helmets were made of leather and fabric. However, some aviators wore industrial-style, hard-shelled helmets. Since that time, the U.S. has developed multiple aviation branches within the military community; therefore, multiple helmet designs have been developed and fielded. While the design of the basic helmet changed throughout history, its primary purpose has remained that of protection.[1]

With the development of helmet-mounted displays (HMDs), this role has been expanded. In addition to providing impact, vision, and hearing protection, the helmet now is expected to serve as a platform for mounting a display. However, this new function must not compromise the helmet's primary requirement to provide protection. To design an integrated HMD that can meet all of these requirements, numerous biodynamic factors and issues must be considered. These factors include head supported mass, center of mass (CM), fitting systems and methods, impact attenuation, retention, frangibility, hearing protection, communication, and eye protection. In addition to the factors themselves, there are the issues associated with the development of system and component specifications and the test methodologies to ensure compliance.[2]

Paramount in importance is the potential of increased injury associated with the use of HMDs. To date, few studies are available to assess this concern. An investigation of the U.S. Army accident database for the period 1985-1995 found only four injuries (four aviators in three accidents) which were directly attributable to the use of the Integrated Helmet and Display Sight System (IHADSS) HMD used in the AH-64 Apache. However, serious injury remains a troublesome possibility due to the proximity of HMDs to the face.[3]

In the following sections, panelists representing government, military, industrial, and academic organizations present specific aspects of their various roles in HMD programs and the issues and concerns they must address in the design, development, manufacture, and fielding of successful HMDs.

2. HELMET DESIGN

Gerald L. Johnson
Life Support Technical Specialist, Gentex Corporation

Originally, helmets were designed for the personal protection of the wearer. Before long, designers were hanging goggles and oxygen masks on them. By the late 1970s, we had added chemical protection, night vision goggles and helmet sight systems. In the early 1980s, the U.S. Army's Apache helicopter was produced, and the new Integrated Helmet and Sight Display System (IHADSS) was introduced. In this early development, there was not a requirement for chemical or laser protection. Night vision goggles (NVGs) were being used on other helmets but were not going to be required for the IHADSS. The requirements changed rapidly. A chemical mask was developed to fit the IHADSS system. Laser protection and spectacles were being developed. All of these new requirements were add-on systems. The weight and center of gravity of the IHADSS were right on the edge of the maximum allowable requirement curve but were accomplished by a combined effort of all involved, and the system has performed in an acceptable manner for 20 years.

Early in the 1980s, the Army decided to develop a new Aircrew Integrated Helmet System (AIHS) to replace all helmets except the IHADSS. The AIHS was to be compatible with all existing aviation head mounted equipment, to include NVGs, laser protection, spectacles, oxygen masks, chemical protection, flash blindness goggles and a maxillofacial shield for fragmentation protection. The noise protection was to be equal to or better than the existing helmets, and the crash/impact and retention requirements were to be greatly increased.

Gentex, the provider of the AIHS, met all the requirements, and the helmet was type-classified (HGU-56P) in the early 1990s. In the mid 1990s, the program manager (PM) decided to look at adapting the IHADSS system for the Apache helicopter to the HGU-56P. Honeywell, Inc. and Gentex, together, took the IHADSS system out of the old helmet and made it a bolt-on addition for the HGU-56P. It was tested and validated but was never put into the system. At about the same time, it was decided that a magnetic tracker system developed by Honeywell, Inc. might work. Again, it was tested but never was fielded.

Recently, the RAH-66 Comanche helicopter has been under development, and a new HMD with the same compatibility requirements with Army aircraft is being developed by Kaiser Electronics. All safety requirements would have to be better than or equal to the HGU-56P, and the weight and center of gravity must stay below the acceptable curve. After the HGU-56P was fielded in the mid 1990s, the Army decided that the Comanche should use the HGU-56P with few, if any, minor modifications. Kaiser Electronics, with Gentex assistance, seems to be on the right track. However, numerous problems have surfaced regarding compatibility with existing equipment and aircrew comfort. Cockpit compatibility is always a problem, and the Comanche is no exception. Space in the cockpit is very limited, and there is no place to store extra equipment that is not immediately needed on the helmet or when the aircraft is not in use.

In the mid 1990s, a compatibility study was sponsored by the PM-Aircrew Integrated Systems, U.S. Army, to see if there was other technology available for the Comanche system. Three manufacturers participated: Kaiser Electronics, Honeywell, Inc., and Microvision. Each manufacturer submitted their version, all of which were subjected to a compatibility evaluation. Each version used the HGU-56P as the baseline helmet, and Gentex assisted in the helmet interface requirements. All versions had good points as well as deficiencies. Some of these systems are still being evaluated.

One solution to help with these problems is to use newer technologies in manufacturing of systems to be mounted on the aircrew member's head. Lighter, stronger materials to cut down weight and maintain strength must be used. There must be more direct interface and communication between the HMD manufacturer and all the other manufacturers that build the helmet system. Greater use must be made of user input and prior experience early in the development program. More adjustments on the HMD to compensate for helmet slippage and pilot-induced helmet position changes must be made available. The use of modular helmet design must be employed so the pilot can have an individual fit on the inner part and switch to the outer module(s) when flying a specific mission requirement.

HELMET DESIGN, INDIVIDUAL PROTECTION

- Impact/Retention/Fragmentation
- Hearing protection
- Sight protection
- Comfort
- Must meet the Aircraft Mission Requirement

02/23/2001

How it was prior to the 1980s

COMPATIBILITY

- HMD
- NVG
- LASER PROTECTION
- CHEMICAL MASK
- OXYGEN MASK
- MAXILLIOFACIAL SHIELD
- LIP LIGHTS
- CEPs or other type communication
- FLASH BLINDNESS PROTECTION
- HEAD BLOWN AIR

PROBLEMS

- WEIGHT
- CENTER OF MASS
- HELMET PERFORMANCE
- FIT AND FUNCTION
- HMD ADJUSTMENTS
- CARE AND MAINTENANCE

SOLUTIONS

- NEW TECHNOLIGIES IN MANUFACTURING
- NEWER LIGHTER MATERIALS IN ALL COMPONANTS THAT ARE TO BE WORN ON THE HEAD
- MORE DIRECT COMMUNICATION BETWEEN MANUFACTURERS
- MORE USER INPUT EARLY IN DEVELOPMENT

SOLUTIONS CONTINUED

- USE MODULAR HELMETS WITH INDIVIDUAL FIT INNER SYSTEMS THAT ARE FIT TO THE INDIVIDUAL AND STAY WITH HIM.
- MODULAR OUTER SHELLS THAT MEET AIRCRAFT MISSION NEEDS.

3. DEVELOPMENT OF RISK INJURY CURVES

B. Joseph McEntire
Mechanical Engineer, U.S. Army Aeromedical Research Laboratory

Rotary-wing aircrew helmets have become more sophisticated with increased mission requirements and their use as platforms for helmet-mounted displays (HMDs). This increase has resulted in additional mass being supported on the head, often with an asymmetrical center of mass (CM). The functional requirements of the modern aircrew helmet have grown considerably. Traditional helmet functions include head impact protection and utility as a mounting platform for communication systems, hearing protection, eye protection, and, occasionally, oxygen systems. Helmets also must interface with night vision imaging systems, chemical and biological protective masks, and nuclear flashblindness protection. As a result of these requirements, helmets have increased head supported weight and potentially less than optimal CM location.

Historically, helmet mass and CM requirements have been vague or nonexistent.[2] The rationale for defining aviator helmet mass requirements can be based on three factors: Aircrew health, operational effectiveness and user acceptance. Aircrew health can be affected by both short- and long-term exposures of head and neck loadings. Long-term exposures are the result of helmet mass and its CM location in normal flight conditions (vibration and 1 to 2G flight environment). These effects include discomfort from a sore or stiff neck after normal missions. Short-term exposures may cause neck injuries resulting from inertial loadings. Inertial neck loadings are created in high acceleration, short duration, dynamic crash environments. At high accelerations, neck loads are compounded by helmet mass and improper CM locations. These neck injuries can be low severity, such as strains and muscle tears, or high severity, such as cervical transections. Operational effectiveness is degraded by increased aircrew fatigue, which is affected by the amount of head supported weight and an asymmetrical CM. User acceptance is also a critical factor. Failure of a helmet system to receive user acceptance will result in misuse and abuse of the system, resulting in less than optimal performance.

Seven parameters are required to define mass properties of helmet systems. These are mass, CM location along three orthogonal axes, and the mass moment of inertia about the three respective axes. The Army uses a head anatomical coordinate system. The x-axis is defined by the intersection of the mid sagittal and Frankfurt planes with the positive direction anterior of the tragion notch. The y-axis is defined by the intersection of the Frankfurt and the frontal planes with the positive y-axis exiting through the left tragion notch. The z-axis is oriented perpendicular to both the x- and y-axes following the right hand rule.

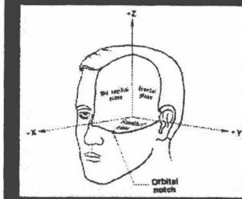
In an initial attempt to define a safe limit for flight helmet mass for Army aviation, USAARL, in 1982, proposed a maximum limit of 1.8 kilogram (kg), or 3.96 pounds, during the development of the AH-64 Apache IHADSS helmet. Further work in developing mass property limits has been performed in support of the Army's proposed RAH-66 Comanche HMD, the Helmet Integrated Display Sight System (HIDSS). The development of the Comanche HIDSS has prompted a continuing effort to develop new head-supported weight and CM requirements. As a result, new recommendations have been developed for allowable mass and the x- and z-axes CM locations.

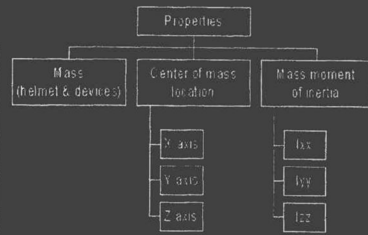
Why do we need mass requirements for head supported devices?

- User acceptability
  - Poorly defined
  - Subjective
- Mission execution
  - Performance decrements
  - Fatigue
- Aviator health
  - Acute injuries (short term or repeated exposure to dynamic events)
  - Chronic injuries (repeated exposure to normal operations)

Aircrew Protection Division
US Army Aeromedical Research Laboratory

Mass properties





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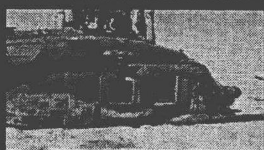
Vertical head-borne mass requirement



Impact event dynamics → Acute neck injury ← Head-borne devices

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Factors influencing inertia induced neck injury

- Impact dynamics
- Seat & restraint performance
- Selected neck injury threshold
- Head and head-borne mass
- Head and head-borne CM location

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Mass requirement determination

- Newton's 2nd Law: F = ma
  - F: select neck injury threshold
  - m: effective mass acting on neck
  - a: acceleration acting on head
- Where: F = 4050 N
  m = head + helmet + neck
  a = (seat accel) (dynamic overshoot) (gravity)
- Thus:
  - 4050 = (4.32 + helmet + 1.05) (35) (1.5) (9.81)
  - maximum helmet mass = 2.5 kg

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US Army Aeromedical Research Laboratory

Vertical CM requirement determination

- Vertical CM location is based on constant mass moment concept
- Hold the mass moment constant about C7/T1 with a 95% female neck link (11.94 cm)
- Worst case is SPH-4 in AH-1 configuration (1.74 kg @ 5.2 cm)

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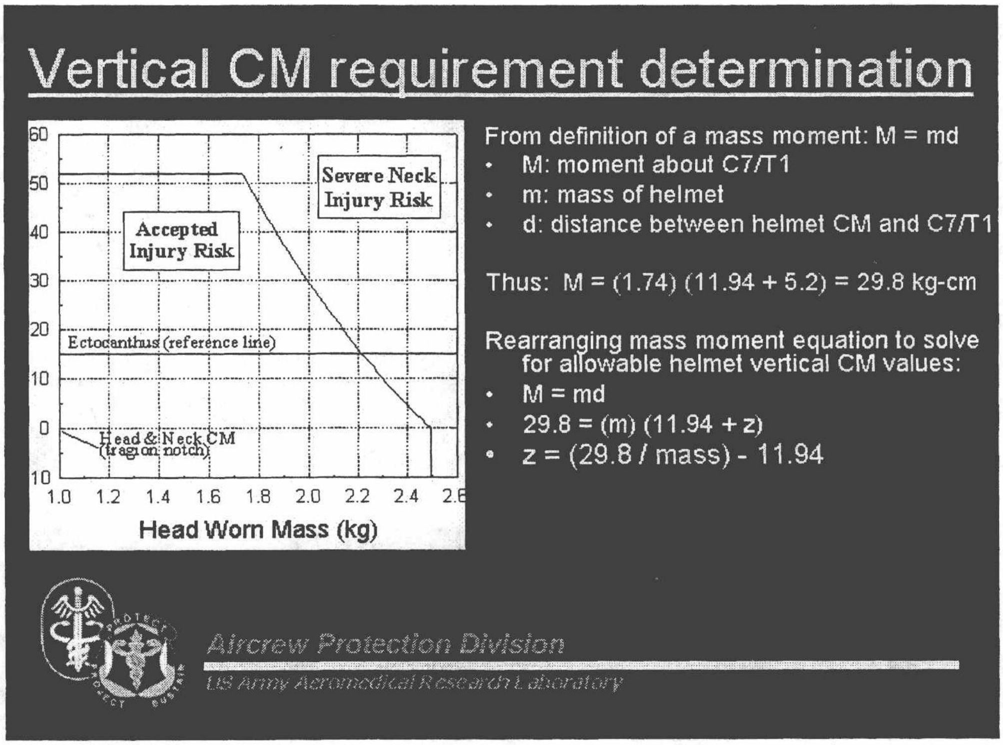

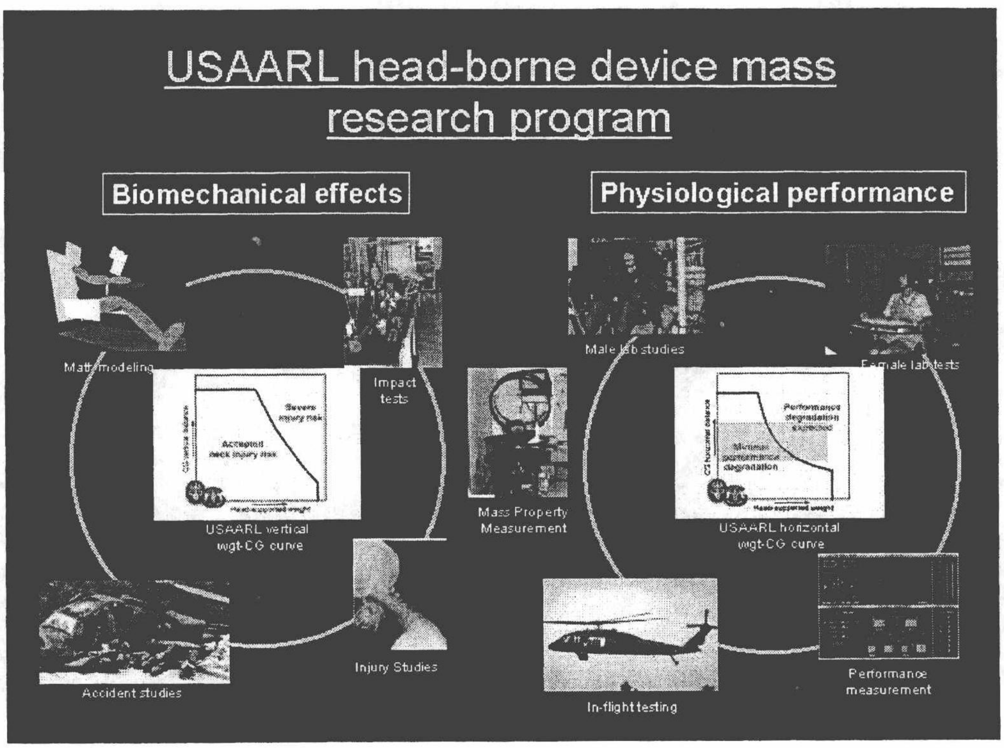

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4. NOVEL VISOR DESIGN FOR HMDS

Bahman Taheri
Vice President of Research and Development, AlphaMicron, Inc.

With advances in helmet-mounted displays (HMDs), the role of the visor has evolved significantly. Visors of the future are expected to perform several functions in addition to their current role of providing mechanical protection and static shielding from sunlight. A new class of visors, Variable Transmittance Visors (VTV), is emerging, in which the tint can be either set by the pilot or automatically controlled. They can fulfill a variety of functions: in addition to providing fast dynamic shielding from the sun, they can provide ambient light control for HMD systems, local blocking of the image of the sun, and background light/image elimination. In HMDs, VTV reduces image washout and enhances performance in situations where lighting conditions are rapidly changing. Several technologies for this purpose have been investigated by the Air Force. Thus far, only a liquid crystal technology (VALiD) has been successfully implemented on large area polycarbonate visors.

Visor functions

Conventional:
- impact protection for pilot
- sun shield

New generations:
- impact protection for pilot
- sun shield
  - variable tint
  - sun tracking
- background elimination
- projection screen for HMDs
  - last surface (optical quality)
  - reduction of multiple reflections
  - image contrast maintenance
- laser protection

AlphaMicron

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Conventional:
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- laser protection

AlphaMicron

Candidate Technologies

Electrochromics:
Current induced electrochemistry

Suspended particles (SPD):
Field induced alignment of suspended dichroic particles

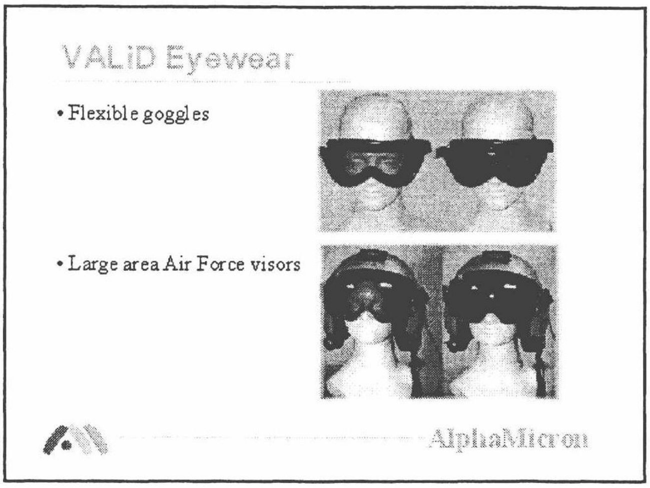
Liquid Crystals (VALiD):
Field induced alignment of LC and dye molecules

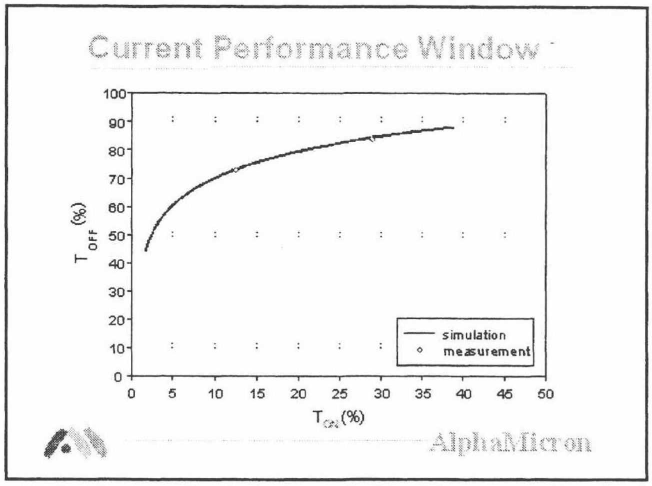
AlphaMicron

Technology Characteristics

Features	VALiD	Electrochromic	SPD
Normal State	Clear	Clear or Dark	Dark
Fail-Safe	Yes	No	No
Polarization	Yes	No	No
Window	50%	50%	40%
Haze	0%	0%	15%
Switching	Voltage	Current	Voltage
Speed	ms to seconds	seconds	ms to seconds
Color	Any	Grey & Blue	Black & Blue
Plastic	Yes	Yes	Yes
Curved	Yes	Yes	Yes
Flexible	Yes	No	No

AlphaMicron





5. CHALLENGES OF HMD EJECTION QUALIFICATION DUE TO NECK INJURY RISKS

James M. Barnaba
Human Factors and Crew Station Technical Expert, Aeronautical Systems Center

Before a helmet-mounted display (HMD) can be utilized operationally in a U.S. fighter aircraft, its design must be certified as safe and compatible with ejection seat operations. The U.S. Air Force (USAF) and U.S. Navy (USN) crew systems communities have utilized similar qualification procedures that first expose the device to simulated portions of an ejection event and then to actual ejections from sleds or an in-flight platform. The lesser developmental and qualification tests can vary in expense but are typically significantly less expensive than a full up ejection test. Successes with these lesser tests establish confidence that the ejection tests will be successful and that the financial expenditure for that testing will be made with lower risk. These lesser tests vary in coverage and fidelity, some address only helmet structural properties, but a few address potential neck loading (i.e.; windblast testing, computational fluid dynamics modeling and ejection tower tests.)

Challenges arise with respect to fidelity. Non-ejection tests don't have realistic windblast loads and flow patterns or realistic body positions. They utilize manikins whose necks do not truly represent human necks and body movements that are not the same as those of a human. Furthermore, no two ejections are the same and vary with crewmember size, life support equipment ensemble, body position and airspeed. These challenges then exacerbate other challenges in assets and resources. System acquisition programs of today are always limited in money, time, and personnel. Performing too few tests ultimately limits statistical confidence in the findings. With new aircraft and systems acquisitions emphasizing larger population dimensions and more women, it is extremely difficult to quantify individual risk across all ejection speeds. As a result, safety qualification is accomplished with insufficient statistical confidence.

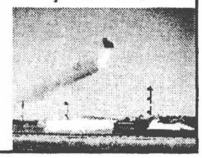
Some suggestions on dealing with this reality are given as an aid to those facing such system qualifications. They include sharing of resources, facilities and personnel with other programs that need similar testing; determining worst case situations to focus testing on; applying repeated measures for statistical confidence when conducting the lesser tests; learning from every test be it successful or not; and controlling variables in test configurations for the unit under test.

How we qualify

- Look at the ejection event piece by piece
  - Canopy separates/seat fires - Debris in air
  - Moving up the rails - Acceleration of body
  - Entering the air stream - Head slams back
  - Drogue chute opens - Body/head decelerate
  - Pilot's chute opens - Risers pass by helmet
    - Substantial opening shock - Deceleration
  - Descent - Check chute function and controls
  - Landing fall - Helmet protects head
- Then put it all together - Ejection Test

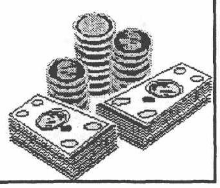
Qualification Testing

- Impact and Penetration
  - Helmet with HMD and Visor
- Mass Properties
- Hanging Harness
- Windblast / Computational Fluid Dynamics
- Ejection Tower
- Wiring Tests
- Sled/Ejection Testing



Challenges

- Fidelity
  - Ejection event is very dynamic
  - Inexpensive preliminary tests always fall short
  - Manikin Neck vs. Human Neck
  - Facility Limitations
  - Data Loss
- Assets
  - Enough test configurations
- Resources



Acquisition Reality Check

- Warfighter wants capability for all users
  - Sometimes at the expense of safety
- Designers/Contractors want absolute criteria for pass/fail
- Acquisition funds are always limited, especially by time for testing
- Laboratory demonstrations have even less resources than acquisition program

Solutions?

- Look for opportunities to "piggy-back" tests with other programs
- Test for worst case, try to eliminate variables
- Support lack of statistical power for sled test data with repeated measurements from less expensive tests
- Learn from every test (pass or fail)
- Control variables in testing

6. RETINAL SCANNING DISPLAY HELMET: BIODYNAMIC ISSUES

Mircea Bayer
Section Manager, Microvision, Inc.

Traditionally, the main function of the aviator helmet was to protect the pilot from mechanical impact and noise hazard. With the introduction of the helmet-mounted display (HMD), the helmet became the link between the human and the display and sight elements. Becoming part of the optical system imposes new and stringent requirements on the helmet in terms of stability, fit and retention all for maintaining the display in front of the pilot's eyes. Whether used as an add-on to existing shells or in a custom-made integral design, HMDs are adding to helmet system weight and size and lead to potentially less than optimal center of mass location. Nevertheless, despite the difficulties in integrating the helmet in a Visual Coupled System (VCS), HMDs' benefits are now recognized, and they are expected to become an integral component of next-generation aircraft.

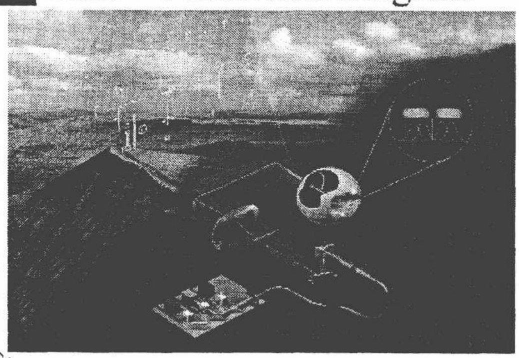
However, all the additional functions to the helmet should not compromise its primary requirement that was, and still remains, providing user protection. This presentation addresses some of the key biodynamic factors in a helmet and the impact the Retinal Scanning Display (RSD) technology may have in future military HMDs.

Retinal Scanning Display

- Retinal Scanning Display (RSD) - Uses retina as projection screen. Most display technologies generate an image plane.
- Creating an image - similar to CRT:
  - CRT - Electron beam scans raster pattern on a phosphor screen
  - RSD - Photon beam scans raster pattern on the retina
- RSD Advantages
  - High brightness & High resolution
  - Wide color gamut - spectrally pure light sources
  - Cost: does not require large up front investment as the AMLCD
  - Minimize head supported weight: photonics module remotely located
  - Decouples light generation from image presentation
  - Same resolution in Color & Monochrome mode:
    - Temporal separation vs. Spatial separation in matrix displays

MICROVISION 2 RSD Biodynamics

RSD - Functional Diagram



MICROVISION 3 RSD Biodynamics

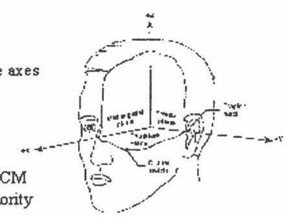
Helmet System: Functional Requirements

- Head protection: impact & tear
- Minimum head supported weight
- Minimum CM offset
- Minimum bulk
- Maximum safety - including ejection
- Maximum crash worthiness
- Laser eye protection
- Maximum comfort and freedom of movement
- Minimum obscuration in visual field
- Controls and display interface
- Primary display for pilotage imagery and symbology
- Provide heads up eyes out pilotage capability
- Image Intensifier (I^2) provisions
- All weather, 24-hour operation
- Minimum training requirement
- Communication: microphone & earphones, speech intelligibility
- Acoustical protection (maximum noise attenuation)
- Helmet tracking for turret control
- Gas and Oxygen mask

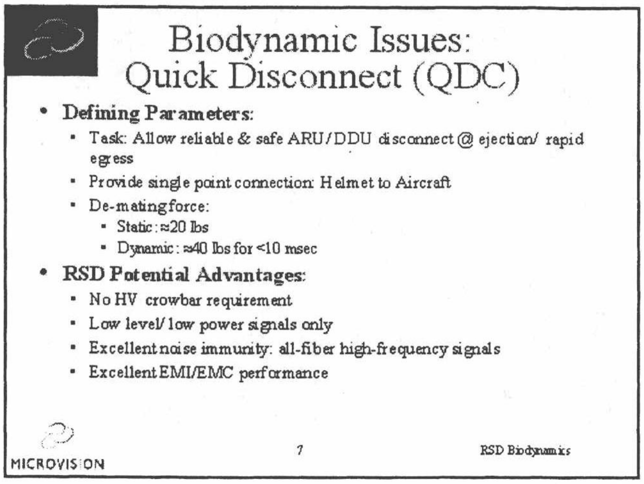
MICROVISION 4 RSD Biodynamics

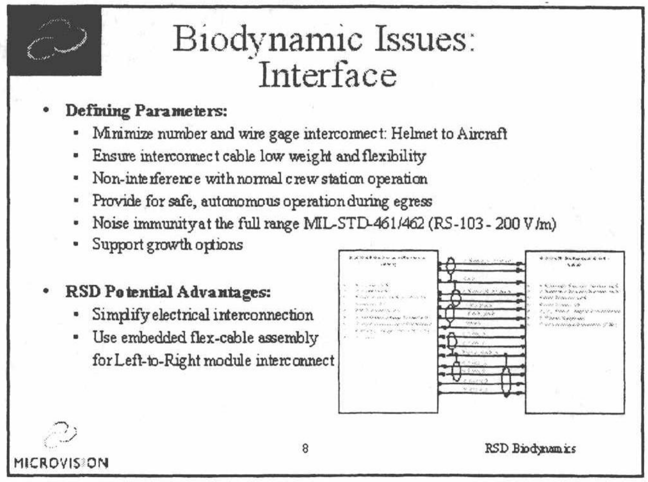
Biodynamic Issues: Mass & CM

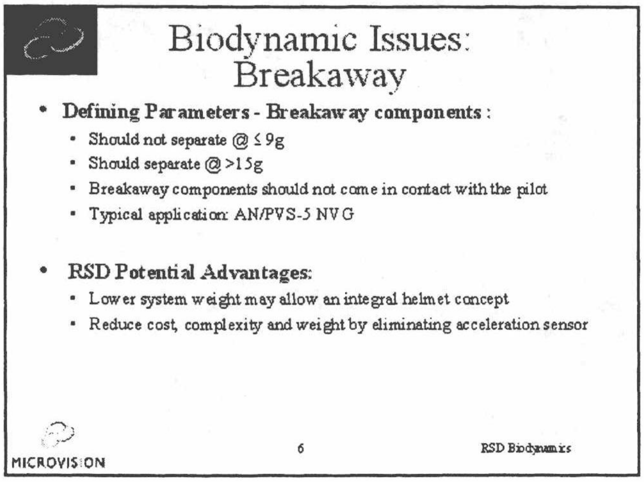
- Defining Parameters:
  - Mass: NTE 2.5 kg(≅5.5lbs)
  - CM in three orthogonal axes
  - Moment of inertia along respective axes
- RSD Potential Advantages:
  - First system (1998): ≅2.2 kg
    - Added lead (≅ 0.2 kg) to improve CM
    - Weight optimization was not a priority
  - Potential for further improvement:
    - New ARU architecture: diffractive optics, asphemics
    - Alternative materials: Beryllium, glass-filled plastics (Ultem)

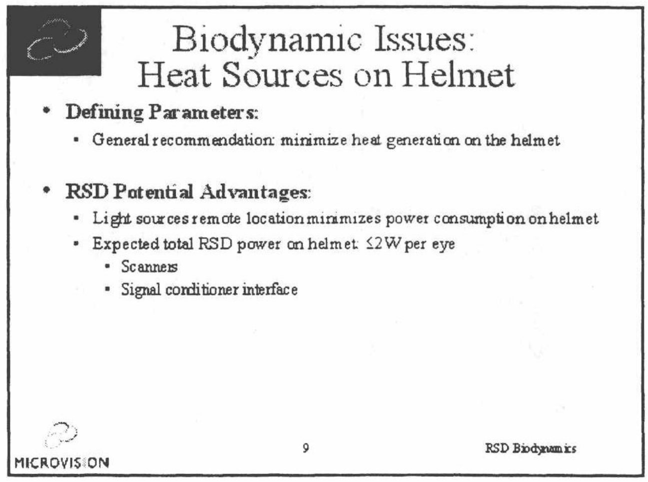


MICROVISION 5 RSD Biodynamics









7. BIODYNAMIC INJURY PREDICTIVE TECHNIQUES FOR MILITARY APPLICATIONS

William Tiu
Senior Lecturer, University of Hertfordshire

Current prediction of injury levels relies on empirical method and standard legislative requirements. Therefore, the design envelope of helmets and helmet-mounted displays (HMDs) would tend to be on the conservative side. The work carried out at the University of Hertfordshire involves the use of a crash simulation package used widely in the automotive Industry and is called MADYMO (MAthematics DYnamic MOdeller) developed by TNO, Delft, Holland. A typical helicopter crash situation was modeled and the injury levels - Head 'g', Neck Moment and Force - were predicted for a baseline configuration. Solutions for reducing the initial injury values also were obtained by carrying out a series of optimisation runs. The results from these runs show that there is scope for extending the design boundaries of military headgear.

HMD Biodynamic Issues and Concerns Panel Presentation - 17th April 2001, Orlando

University of Hertfordshire

Introduction

- **Mass and CG of HMD are liable to cause severe neck injuries during a crash**
- **Current predictions based on empirical results and standard legislative requirement**
- **Require numerical simulation of occupant loads for validation of current HMD mass requirement**
- **MADYMO (a Mathematical Dynamic Modeller) was used for the simulation**

06/03.01 2

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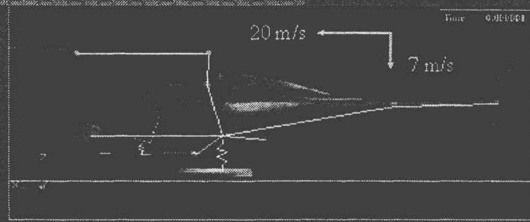
Modelling Techniques - Structure



- Lumped Mass Idealisation
- Rigid body connections
- Sprung Support for seat and 'undercarriage

06/03.01 4

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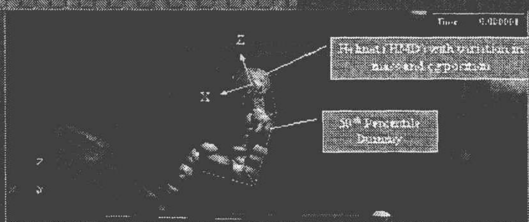
Modelling Techniques - Occupant



06/03.01 5

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Parameters Considered

- **Stiffness of undercarriage and seat**
- **Stiffness of Head Strap**
- **Mass of HMD**
- **CG Position of HMD**

06/03.01 6

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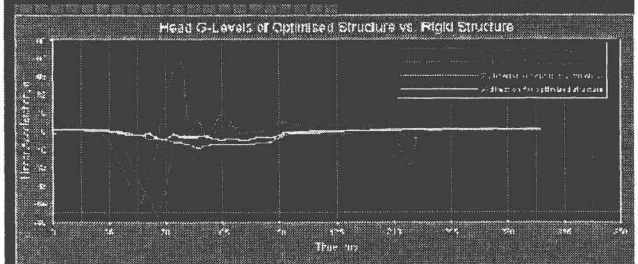
Stiffness of undercarriage and seat



06/03.01 7

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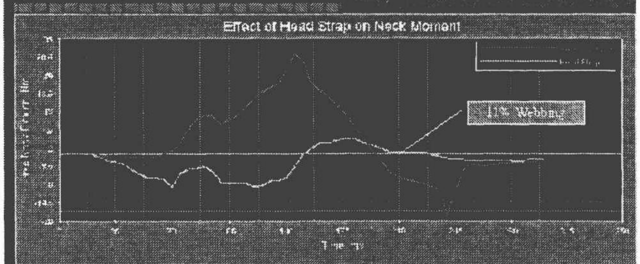
Stiffness of Head Strap



06/03.01 8

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