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# Design, Development, Fabrication, and Safety-of-Flight Testing of a Panoramic Night Vision Goggle

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**ABSTRACT**

A novel approach to significantly increasing the field of view (FOV) of night vision goggles (NVGs) has been developed. This approach uses four image intensifier tubes instead of the usual two to produce a 100 degree wide FOV. A conceptual demonstrator device was fabricated in November 1995 and limited flight evaluations were performed. Further development of this approach continues with eleven advanced technology demonstrators delivered in March 1999 that feature five different design configurations. Some of the units will be earmarked for ejection seat equipped aircraft due to their low profile design allowing the goggle to be retained safely during and after ejection. Other deliverables will be more traditional in design approach and lends itself to transport and helicopter aircraft as well as ground personnel. Extensive safety-of-flight testing has been accomplished as a precursor to the F-15C operational utility evaluation flight testing at Nellis AFB that began in March 1999.

**Keywords:** Night vision goggle, helmet-mounted display, image intensification, field of view, night operations, head-up display, safety-of-flight, flight safety, windblast testing, aircraft ejection

## 1. INTRODUCTION

Delivery of the conceptual demonstrator device, now referred to as the panoramic night vision goggle (PNVG), was quite impressive considering it was developed with very limited funding under a phase I small business innovative research (SBIR) program with Night Vision Corporation. The extremely positive feedback of this demonstrator from the warfighter community propelled the program into a phase II SBIR effort and also received the attention and supplemental funding support of the Air Force Research Laboratory's Helmet-Mounted Sensory Technologies program office. Phase II will further develop the PNVG by first addressing ejection seat aircraft with two configurations of a low profile design (designated PNVG I, Figure 1). This version with its better center of gravity should be less fatiguing during longer flights and will potentially allow for ejection by permitting retention of the system on the head throughout the ejection sequence. Retention of PNVG I may also permit evasion and rescue. Additionally, three configurations of a never-before-seen NVG for transports, helicopters, and ground personnel (designated PNVG II) are being developed. These models will look more like a traditional goggle. PNVG II, while weighing more than a PNVG I, should be more robust and will attach to any existing ANVIS mounting system. Both PNVG I and II, like the phase I conceptual demonstrator, will provide a 100 degree horizontal by 40 degree vertical ($100^o$ H X $40^o$ V) intensified field of view (FOV) (Figure 2a). This represents a 160% increase of the warfighter's intensified image FOV compared to currently fielded $40^o$ circular FOV systems.

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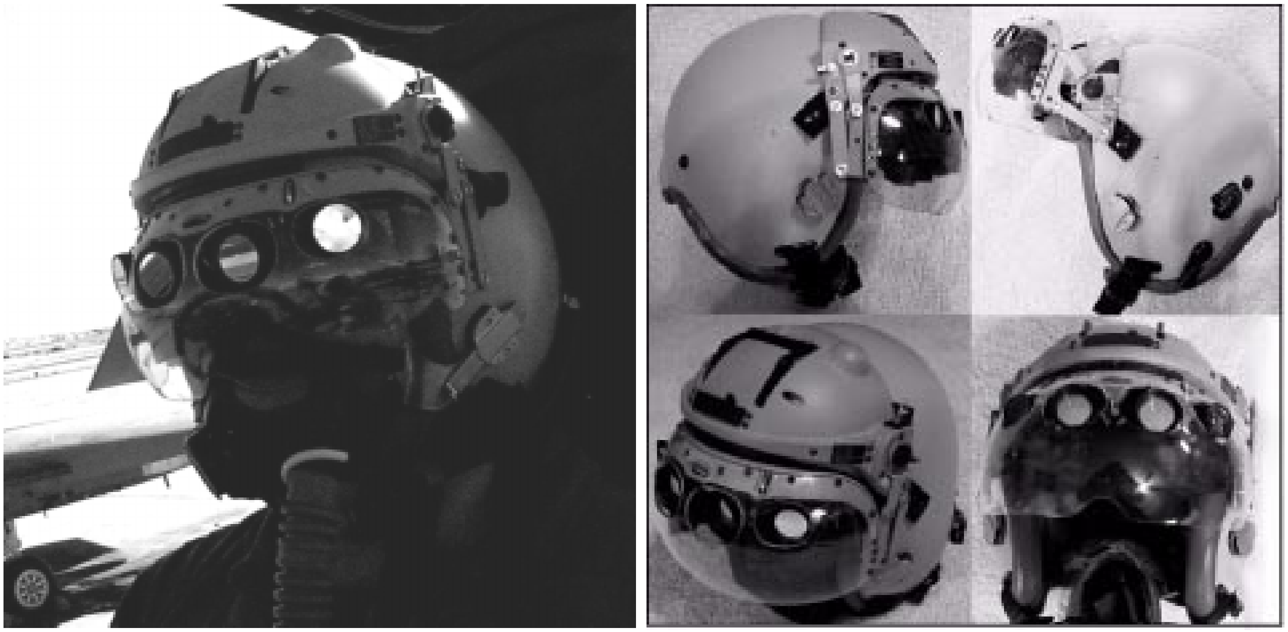


Figure 1. PNVG I, low profile design (Patent # 5,416,315, Other patents pending)

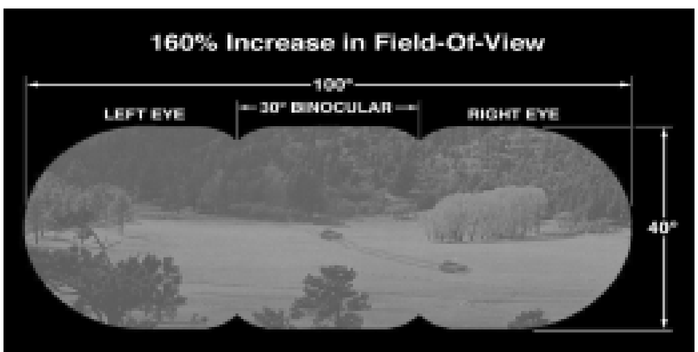



Figure 2a. Simulated PNVG 100°H x 40°V FOV

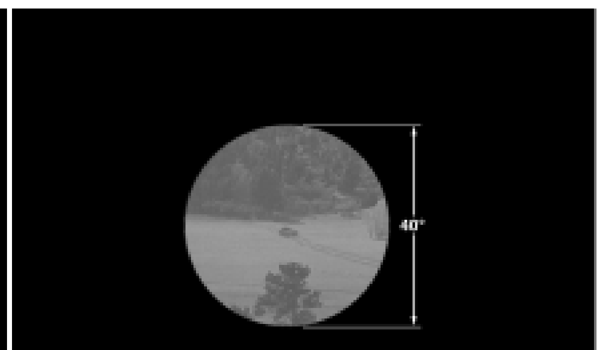



Figure 2b. Simulated 40° AN/AVS-6 and AN/AVS-9 FOV

## 2. BACKGROUND

NVGs with FOVs ranging from 30° (GEC-Marconi Avionics' Cat's Eyes NVGs) to 45° (GEC-Marconi Avionics' NITE-OP and NITE-Bird NVGs) have been used in military aviation for more than 20 years. The vast majority of NVGs (AN/AVS-6 and AN/AVS-9) provide a 40° FOV (Figure 2b). Because each ocular uses only a single image intensifier tube, increased FOV for these NVGs can only be obtained at the expense of resolution.[1,2] The image intensifier tube has a fixed number of pixels (picture elements). Therefore, if the pixels are spread over a larger FOV, the angular subtense per pixel increases proportionally. As a result, resolution is reduced.

An extensive survey of military (U.S. Air Force) NVG users conducted during 1992 and 1993 revealed that increased FOV was the number one enhancement most desired by aircrew members followed closely by resolution.[3] This was a major motivating factor for the development of an enhanced NVG capability.

## 3. PNVG I DESCRIPTION

PNVG I (Figure 1) is similar in design approach to the conceptual demonstrator PNVG. However, PNVG I has optimized the overall design and added several enhancements. PNVG I still features a partial overlap (100$^o$ H X approximately 40$^o$ V) intensified FOV. The central 30$^o$ H X 40$^o$ V FOV remains completely binocular while the right 35$^o$ is visible only to the right eye and the left 35$^o$ is visible only to the left eye. Additionally, a thin demarcation line separates the binocular image from the monocular peripheral image.

PNVG I features a newly developed 16-mm image intensifier tube rather than the currently fielded 18-mm format tube. Along with the goal of offering comparable performance to the recent Omni IV tubes, its weight will be reduced by nearly 50%. Therefore, four 16-mm PNVG tubes weigh about the same as two of the current 18-mm tubes. The 16-mm tubes have longer fiber optics on the outside optical channel than the inner optical channel. The outer and inner channel fiber optics do not require image-inverting fiber optics. Dual fixed eyepieces (tilted and fused) and four objective lenses (the inner two adjustable and the outer two fixed) make up part of the folded optical approach. The inner optical channels include very fast F/1.17 objective lenses as compared with the F/1.25 objective lenses of the currently fielded AN/AVS-6 and AN/AVS-9 goggles. The outboard channels, due to size and weight constraints, incorporate F/1.30 objective lenses. All of the objective lenses will incorporate Class B, leaky green filters for compatibility with color cockpits and aircraft head-up displays. Eyepiece effective focal length is 24 mm while the physical eye clearance has been designed for 20 mm.

A specially designed single left side and single right side power supply is remotely located but allows each side's inner and outer optical channels to be controlled independently. Multiple adjustments (i.e. tilt, independent inter-pupilary distance, up/down, and fore/aft) should permit an optimized optical fitting. Customized visors will also be incorporated cockpit compatibility, mechanical stability, and escape protection. Individualized holes will be cut for the objective lenses to protrude. Also, a unique latching mechanism affords one-handed don/doff capability. A new linkage system enables the PNVG I to easily transition into a stow position (Figure 3).

Figure 3. PNVG I, stow position (Patent # 5,416,315, other patents pending)

Power on certain aircraft test platforms is provided to the PNVG system by the aircraft itself. In the event of an ejection, two "AAA" alkaline batteries located in the remote electronics module (REM) provide power during the escape sequence, evasion, and rescue. These batteries provide up to 16 hours of operation. Due to funding constraints, PNVG I is currently designed to attach with only the Air Force's HGU-55/P helmet.

Two configurations of the PNVG I will be built. PNVG I-Configuration 1, will have four deliverables. The PNVG REM will attach to a unique "universal connector", the same connector used with the Visually Coupled Acquisition and Targeting System (VCATS) daytime helmet module. VCATS is currently being evaluated on F-15C aircraft as part of an advanced technology demonstration (ATD) at the 422$^{nd}$ Test and Evaluation Squadron (422 TES) at Nellis AFB. The universal connector provides aircraft data and power to the PNVG. This configuration also features a 640x480 active matrix electroluminescent display (AMEL) for symbology overlay, a magnetic head-tracker, class B "leaky green" objective lens filter, and an electronics package. PNVG I-Configuration 2, a stripped down version of Configuration 1, will have two

Figure 4. PNVG II (Patent # 5,416,315, other patents pending)

deliverables. Configuration 2 does not include an AMEL display, magnetic head-tracker, or electronics package. Since the majority of the HGU-55/P helmets are not equipped with the VCATS universal connector, a special banana clip mount has been designed that will accept the PNVG module on any HGU-55/P helmet. Because there is no aircraft power being provided through a universal connector for configuration 2, system power will be supplied by the two “AAA” alkaline batteries located in the REM.

## 4. PNVG II DESCRIPTION

An alternative approach to PNVG I has been developed. The partial overlap 100$^o$ H X 40$^o$ V intensified FOV is maintained, but the system resembles the currently fielded aviator NVGs.[4] Whereas PNVG I mates to only the HGU-55/P helmet, PNVG II (figure 4) is compatible with any helmet that incorporates the standard ANVIS mounting bracket. This will allow any warfighter to assess the utility of a panoramic night vision scene given they have the proper bracket. If testing proves that the panoramic scene is required but the PNVG I approach is preferred, a development effort will have to address the specific design issues necessary to mate it with a particular helmet type.

Similar to the PNVG I, the central 30$^o$ H X 40$^o$ V FOV is completely binocular while the right 35$^o$ is visible only to the right eye and the left 35$^o$ is visible only to the left eye. Additionally, like PNVG I, a thin demarcation line separates the binocular image from the outside monocular image. PNVG II utilizes the newly developed 16-mm image intensifier tube but requires image inverting fiber optics (the outer channel fiber optics are the same length as the inner channel). Dual fixed eyepieces, tilted and fused together, and four objective lenses (the inner two adjustable and the outer two fixed) remain part of the optical approach. The non-folded inner optical channels are designed with extremely fast F/1.05 objective lenses. The folded outboard channels use the PNVG I inner channel optics with F/1.17 objective lenses. Eyepiece effective focal length is 24 mm while the physical eye clearance has been significantly increased to 27 mm. All of the mechanical adjustments currently available on the AN/AVS-6 and AN/AVS-9 remain (i.e. tilt, independent inter-pupilary distance adjustment, up/down, fore/aft). Power for the PNVG II will be provided via the batteries that are currently integrated with the AN/AVS-6 and AN/AVS-9 mounting systems. Therefore, no special power provisions are necessary.

Three configurations of PNVG II will be built. PNVG II-Configuration 3 will have only one deliverable but will feature a 640x480 AMEL display. Additionally it will have a Class B, leaky green filter incorporated into the objective lens. PNVG II-Configuration 4 will have three deliverables but will not include the AMEL display. One of the three will use the Class B “leaky green” filter, while the remaining two will use a Class A filter. The final deliverable, PNVG II-Configuration 5, is intended for ground applications and will be integrated to a special hand-held “PIRATE” mounting system including its own batteries and a single infrared diode. This configuration will not include an AMEL display and the objective lens will be unfiltered (i.e. no class A or B filters).

# 5. SAFETY-OF-FLIGHT-TESTING AND ANALYSIS

## 5.1 Overview

Safety-of-flight testing and analysis for advanced fighter helmets involves many different test and analysis areas. The AFRL team investigated seventeen of these areas for PNVG I-configuration 1, which began OUE flight testing on F-15C aircraft in March 1999. See Table 1 for a summarized listing of the areas. The following sections detail the outcome of these test and analysis. A System Safety Executive Board (SSEB) was convened at Wright-Patterson AFB, Ohio on 6 January 1999 to evaluate the results. The SSEB gave its approval for limited flight testing of the PNVG I at Nellis AFB, Nevada on the F-15C fighter. Then, a flight readiness review was convened at Nellis AFB in late January 1999 to brief the details to the flight safety officer, who makes the ultimate decision to fly the new advanced NVG helmet system.

For more detail on safety-of-flight testing, there are several SPIE papers that contain useful information. A paper by MacMillan, Brown, and Wiley describes the process in detail for performing safety-of-flight testing for advanced fighter helmets.[5] Another paper by Wiley, Brown, and MacMillan provides details on safety during ejection.[6] Lastly, a paper by MacMillan discusses the complications behind determining neck loading experienced during ejection, with particular emphasis on the combination of windblast and catapult forces.[7]

Table 1. Summary of PNVG safety-of-flight testing and analysis

| | |
|---|---|
| Inertial Properties Testing | Weight, center of gravity, and static torque effects on neck loading |
| Vertical Impact Testing | Effects of catapult phase of ejection on neck and shoulder loading |
| Helmet Impact Testing | Protection provided by helmet shell and liner against high G impacts |
| Visor Ballistics Testing | Protection provided by helmet visor against small projectiles traveling up to 550 fps |
| Helmet Penetration Testing | Protection provided by helmet shell and liner against penetrations |
| Rapid and Explosive Decompression Testing | Performance of the PNVG in a rapidly changing atmosphere and an explosively changing atmosphere, such as canopy jettison during ejection |
| Ejection Windblast Testing | Effects of windblast phase of ejection on neck loading, contact of the PNVG with the eyes, structural integrity of the PNVG, and proper functioning of ACES II pitot tubes |
| Quick Disconnect Functionality | Effect of cable tether on safe separation from the aircraft during ejection |
| Comfort | General comfort and fit with no hot spots during prolonged wear of PNVG system |
| Communications and Sound Attenuation | Ability to communicate effectively and have external sound attenuated to appropriate safe levels |
| Hanging Harness Testing | Investigates possible interference with risers and pilot's ability to carry out the descent checklist, including landing procedures |
| Cockpit Compatibility Testing | Affect on performing flying mission safely, limits on range of motion, viewing flight instruments, stow position clearance, and canopy clearance of PNVG compared to breaker |
| Electromagnetic Compatibility Testing | Affect of electromagnetic emissions from the PNVG on its own systems and other systems, and the affect of other systems emission on the PNVG, with particular emphasis on flight instrument safety |
| Emergency Ground Egress Testing | Ensure PNVG does not interfere with pilot's ability to quickly exit the aircraft during emergency egress while on the ground with open canopy |
| Electrical Shock Analysis | Ensures the addition of an electrical assembly to the helmet does not impose an excessive risk of electrical shock to the pilot during normal flight operations and even conditions such as ejecting into water |
| Optical Performance Testing | Ensures the pilot can see accurately and without distortion when operating the aircraft and wearing the PNVG; also quantifies performance of PNVG |
| Symbology Analysis | Identifies any symbology issues that my cause disorientation to the pilot |

## 5.2 Inertial Properties Testing

The PNVG helmet system's inertial property data for center of gravity (CG), weight, and static torque meets the AFRL Head and Neck Criteria.[8] This testing was completed in November 1998 by the AFRL Biodynamics and Acceleration Branch (AFRL/HEPA) at Wright-Patterson AFB, Ohio. The PNVG center of gravity data (cgx = 0.23 in., cgy = -0.01 in., cgz = 1.20 in.) is within the AFRL Head and Neck Criteria's Knox box (cgx = -0.8 to 0.25 in., cgy = -0.15 to 0.15 in., cgz = 0.5 to 1.5 in.). This Knox box was developed by Dr. Ted Knox to provide a means for determining the safety of helmets with respect to neck loading during the catapult phase of ejection.[8] In addition to CG effects, the overall head-supported weight (including the helmet system with six inches of signal and power cable and the MBU-20/P oxygen mask with 3 inches of hose) exceeded the 5.0 lb. criteria by 0.31 lb. However, an analysis of vertical impact testing data by Mr. Chris E. Perry of AFRL/HEPA showed this only increased the compressive neck load by less than 5%, which is well under maximum safe limits.[9] Therefore, the overall head-supported weight of PNVG does not seem to cause any safety concerns. In addition, the static torque value of 93 lb-in$^2$ was well under the safe criteria of 120 lb-in$^2$ for maximum static torque.

### 5.3 Vertical Impact Testing

The AFRL/HEPA evaluated effects of inertial property differences of PNVG as compared to a baseline HGU-55/P in October 1998.[9] They performed testing using the AFRL vertical deceleration tower to simulate an 11-12 G catapult shock on an Advanced Dynamic Anthropomorphic Manikin (ADAM) (Figure 5b). Five vertical deceleration tests were performed for both the HGU-55/P helmet as well as the PNVG I system. Testing showed that PNVG does not increase the risk of injury during the catapult phase of ejection with an ACES II seat. PNVG will not induce neck loads greater than established human tolerance (Table 2). Dynamic evaluation also found no structural failures to PNVG mounting points.

Table 2. Vertical impact testing results

| Load Parameter | Baseline HGU-55/P Helmet | PNVG Helmet | Criteria |
|---|---|---|---|
| (-) X-Axis Shoulder Load (lb) | −82.90 ± 13.74 | −93.07 ± 22.65 | N/A |
| (-) X-Axis Neck Load (lb) | −40.07 ± 2.58 | −57.11 ± 1.38 | 80 |
| (+) X-Axis Neck Load (lb) | 27.60 ± 2.85 | 27.87 ± 2.89 | 80 |
| Z-Axis Neck Load (lb) | 165.44 ± 8.68 | 213.04 ± 3.07 | 260 |
| Neck Moment (in-lb) | 130.17 ± 4.76 | 152.12 ± 13.89 | 400 |
| Neck Moment (in-lb) * | 294.37 | 333.79 | 400 |
| * ADAM data was converted to estimated human data for neck moment. Note, for other types of loading, this conversion is not necessary. | | | |

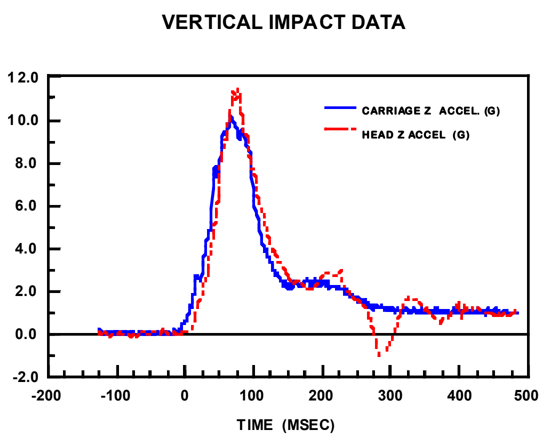



Figure 5b. Vertical impact tower

Figure 5a. Vertical impact acceleration response

### 5.4 Helmet Impact Testing

Helmet impact testing was performed at Gentex East in Carbondale, Pennsylvania in November 1998. The PNVG helmet system provides adequate impact energy attenuation by meeting the HGU-55/P helmet specification MIL-H-87174, showing that the addition of the PNVG components to the baseline helmet do not increase the pilot's risk of injury from impact.[10] The PNVG system allowed the pilot's head to be subjected to a maximum G load of only 134 G's. The military specification requirement is less than 400 G instantaneous, less than 200 G for 3 ms or less, and less than 150 G for 6 ms or less.[10]

### 5.5 Visor Ballistics Testing

Visor ballistics testing was also performed at Gentex East in Carbondale, Pennsylvania in November 1998. The PNVG helmet visor provides adequate projectile fragment protection by meeting the HGU-55/P helmet visor specification MIL-V-43511C, showing that the clear visor does not allow any penetration from the specified 0.22 caliber T37 fragment simulating projectile at 550 fps, nor does the impact cause cracks on the visor.[11] The test was conducted in accordance with MIL-STD-622. The test is formally known as the "impact resistance" test, while Gentex refers to it as the "ballistics" test.

### 5.6 Helmet Penetration Testing

In addition to impact and ballistics, penetration testing was also performed at Gentex East in Carbondale, Pennsylvania in November 1998. The PNVG helmet system meets the HGU-55/P helmet specification MIL-H-87174, showing that the addition of the PNVG components to the baseline helmet do not increase the pilot's risk of injury from penetration.[10] The PNVG system allowed a maximum penetration depth of 1/16$^{th}$ of an inch, while the requirement is less than 1/4$^{th}$ of an inch.

### 5.7 Rapid and Explosive Decompression Testing

National Technical Systems completed rapid decompression testing in December 1998. The PNVG helmet system passed all safety and operational criteria with no exceptions during the rapid decompression testing at NTS in Saugus, CA. These tests were tailored from rapid decompression test procedures in MIL-STD-810E, indicates the goggle is safe up to 50,000 feet, in the event of a rapid (60-seconds) decompression. Two tests were performed: (1) decompression from 8k feet to 22k feet in 44 sec, and (2) decompression from 25k feet to 50k feet in 59 sec. These times and pressures were chosen due to the nature of the flight testing at Nellis. In both tests, the PNVG integrity was maintained. No visible structural damage to the PNVG was evidenced nor was there any internal damage visible by looking through the lenses. Nothing came off the PNVG during either test. The PNVG operated flawlessly both before and after the tests and was left on during the tests. Also, there was no movement of the focus rings or eyepieces. These tests were considered a complete success.

In addition to this rapid decompression testing, an explosive decompression test of 1k feet to 17k feet and 1k feet to 8k feet within 10 ms was successfully performed in March 1999 at Wright-Patterson AFB, Ohio. An explosive decompression can occur when ejecting during canopy jettison or during an mid-air accident.

### 5.8 Ejection Windblast Testing

Windblast testing was completed at Dayton T. Brown in October 1998. Testing was performed at 350, 450, and 600 KEAS at both the 17 and 34.5 degree seatback angles. Compared to the baseline HGU-55/P helmet (with the integrated chin-nape strap (ICNS) and bungee visor), Mertz criteria evaluation indicates that PNVG does not increase the risk of neck injury to the pilot during the windblast phase of ejection up to 600 KEAS. This is for ejection using an ACES II seat for both 17- and 34.5-degrees seatback angle. Overall, PNVG and HGU-55/P (with ICNS and bungee visor) have very similar neck loading, with PNVG actually performing better than HGU-55/P at some speeds, likely due to a more favorable aerodynamic shape.

Considering peak neck loads only (no duration of load consideration), the probability of neck injury during an ejection while wearing PNVG is: 9.91% at 350 KEAS, 21.4% at 450 KEAS, and 41% at 600 KEAS. This is identical to the baseline HGU-55/P (with ICNS and bungee visor). Note the standard breakaway chinstrap helmet has the same probability of injury at 600 KEAS as it does at 450 KEAS (21.4%). This is because the pilot looses the protection of the helmet around 300 pounds of axial neck loading. All of this probability data is for 17-degree seatback angle only. One can factor in the USAF non-combat ejection history, which is a distribution of ejections at various speeds (Figure 6). This gives an overall probability of neck injury, given an ejection occurs when flying with PNVG within a certain flight envelop (Table 2). Note that 90% of all USAF non-combat ejections occur below 400 KEAS. Also note, the table shows results for VCATS Uplook advanced flight helmet as well as the HGU-55/P (with ICNS and standard bungee visor).

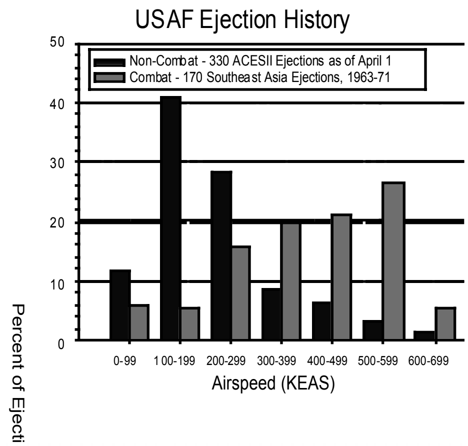
However, at a 17-degrees seatback angle, the PNVG interrupts airflow enough to cause marginal pitot tube compatibility, therefore, warranting the use of deployable pitot tubes (Figure 7). The F-15Cs that will be used for PNVG testing at Nellis are equipped with deployable pitots.

The PNVG helmet system only experienced minor (tiny cracks) structural damage during windblasts up to 600 knots equivalent airspeed (KEAS), which would add no risk of injury to the pilot. Windblast testing did uncover a problem with the universal connector latch handle popping up due to forces during the blast, resulting in a re-design of this handle that fixed the problem. This new handle was re-tested and stayed latched throughout the blast. During the eleven windblast tests at speeds from 350 to 600 KEAS, at no time did any part of the PNVG system come into contact with the pilot's eyes. While the power supplies and eyepieces did contact the forehead, this contact was deemed to be low risk due to the smooth, curved shape of these pieces and the relatively large contact area.

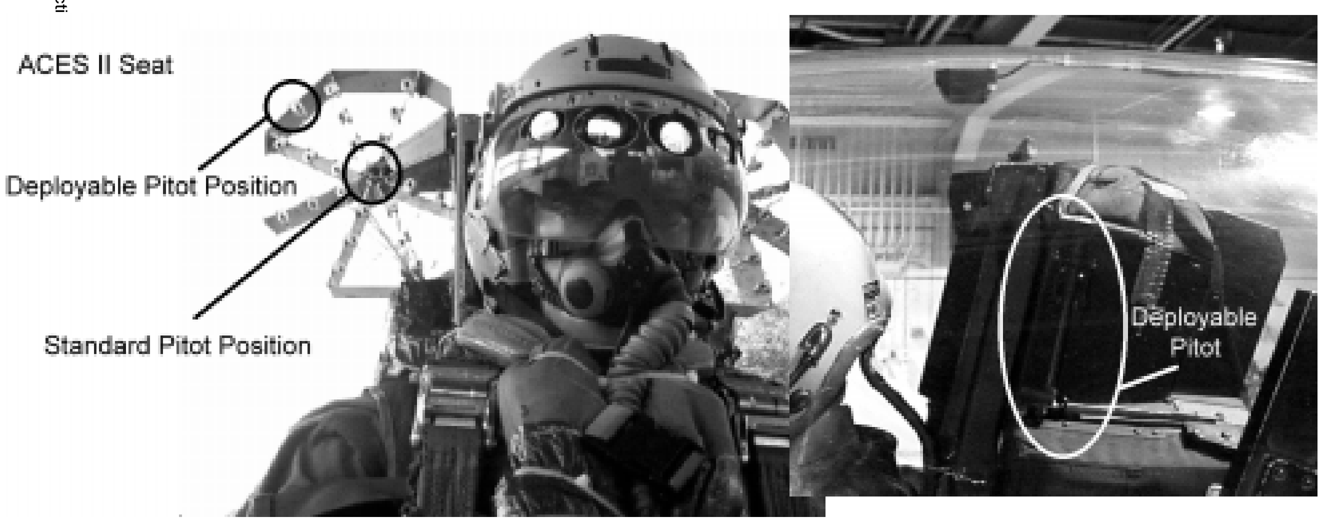
Figure 6. USAF ejection history

Table 2. PNVG windblast testing results using probability of

neck




| Probability of Injury (%) for certain flight envelope | | | |
|---|---|---|---|
| **Flight Envelope (KEAS)** | **PNVG** | **VCATS Uplook** | **HGU-55/P With ICNS** |
| **< 700** | **1.10** | **7.57** | **1.17** |
| **< 600** | 0.69 | 6.53 | 0.92 |
| **< 500** | 0.33 | 4.95 | 0.62 |
| **< 400** | 0.08 | 2.88 | 0.31 |




injury, given pilot ejects within certain flight envelop

(a) (b)

Figure 7. Windblast testing of PNVG I with pitot tube positions noted. Note, the picture on the left (a) is of the windblast test apparatus and manikin, showing the pressure-sensing rake array or “Mickey Mouse” ears. The picture on the right (b) shows an actual F-15C ACES II seat fitted with the deployable pitot tube.

### 5.9 Quick Disconnect Functionality Testing

Quick disconnect connector (QDC) functionality testing was performed at Reynolds Industries, Inc. in October 1996. PNVG test pilots will utilize the same helmet, and hence the same cable connection to the aircraft as the VCATS helmet. The cable connection electrically connects the helmet to the aircraft and has a QDC. The QDC will safely disconnect at speeds up to 240 in/sec without significantly increasing the potential risk of injury to the pilot’s neck or head. The placement of the QDC at the left side, lower torso minimizes the risk of injury to the pilot’s arms and legs. The peak separation force was shown to be less than 54 pounds (typically 30 lb.) in all cases, different pull speeds (quasi-static and 240 in/sec) and angles (straight, 15 degrees forward, and 15 degrees aft). In all cases during emergency egress, there is minimal risk of injury to pilot due to the QDC.

### 5.10 Comfort Analysis

PNVG helmets are not expected to cause hot spots or other discomfort to the pilot after periods of prolonged wear (4 hours). 422 TES pilots will utilize the same helmets currently used for VCATS testing, which is the Gentex Lightweight HGU-55/P. VCATS uses a thermoplastic liner (TPL) fitting scheme with a minimum of 2 layers and custom poured energy absorbing liner (EAL) to ensure a good fit and comfort. The EAL uses a 6-lb/ft$^2$ material rather the standard 4.5-lb/ft$^2$

material. Internal dimensions of VCATS helmets versus the standard operational HGU-55/P helmet are reduced by no more than 0.10 inches, which can be made up by removing one TPL layer.

### 5.11 Communication and Sound Attenuation Analysis

The PNVG helmet system should also meet minimum sound attenuation requirements to ensure pilot communication is not hindered during flying operations. PNVG test pilots will utilize the same helmets currently used for VCATS testing, which have been successfully used for several years. VCATS uses the H154 earcup. Sound attenuation requirements for the Air Force are outlined in the specification for the H154 earcup (MIL-E-83425). However, no “VCATS specific” testing was performed because the H154 earcup is standard issue and meets USAF requirements for sound attenuation. Flight test experience from VCATS and Vista Sabre II HMDs (Kaiser Mark-III and Mark-IV) have revealed no sound attenuation or communication problems with the Kaiser Lightweight HGU-55/A/P helmet shell and H154 earcup.

### 5.12 Hanging Harness Testing

Hanging harness testing was completed at Ohio Air National Guard’s 162nd Fighter Squadron on 5 January 1999 (Figure 8). This test investigated any possible riser interference and the pilot’s ability to carry out the descent checklist, including landing procedures. The test indicated there are no significant concerns for a pilot completing the post ejection procedures checklist while under the canopy during decent and during the parachute landing fall. In addition, PNVG test pilots will utilize the same helmet as VCATS, and hence the same cable connection to the aircraft. Hanging harness testing was previously performed successfully for VCATS on 23 August 1995, revealing no problems. It should be noted that because the pilot would be ejecting at night while wearing the PNVG, he/she would be much safer with this NVG capability retained than without it. The practice for standard NVGs is to remove them prior to ejection, while the PNVG was designed to stay on during ejection. Having the ability to see the ground and your canopy significantly reduces risk during a nighttime ejection.

Figure 8. Hanging harness testing of PNVG I

### 5.13 Cockpit compatibility Testing

The PNVG helmet was tested for F-15C cockpit compatibility at Nellis AFB, 422 TES in January 1999. This test investigated the affect of PNVG on performing the flying mission safely, range of motion, and viewing flight instruments. The test also checked stow position clearance and canopy clearance of PNVG system versus canopy breaker position during ejection. The test was performed in a darkened hangar with a fully operational PNVG. Changes and additions to the baseline helmet system were found to not interfere with the pilot’s ability to perform the flying mission. The pilot’s range of motion in the cockpit is not limited by PNVG’s increased helmet bulk or electrical harness routing in such a way as to cause compatibility problems. This testing was performed with the PNVG down and also flipped up in the stow position. The pilot was able to see all of the flight instruments without obstruction and was able to safely perform all standard procedures in a timely manner. It was noted, however, that the bottom edge of the PNVG visor needs to be custom trimmed for each pilot so that it does not cut through the view of the cockpit instrument panel. An improperly trimmed visor can cause annoying discontinuities that tend to reflect light from the head-up or head-down displays into the pilot’s eyes.

With PNVG in down position, the HMD module does not protrude above the baseline HGU-55/P in such a way that it contacts the canopy before the canopy breaker does even for the maximum sitting height pilots. With PNVG in the stow position, it can contact the canopy before the breaker does for taller pilots. However, the PNVG latching mechanism, which holds the goggles in the up position, is designed to break away due to a 6 G or more catapult force in a controlled manner to allow PNVG to come down and lock into position before the pilot's head enters the wind stream.

In general, the best cockpit compatibility data is taken from actual pilots flying with the PNVG, which is the point of the operational utility evaluation. From a safety standpoint, basic information can be gained by analysis on the ground in a real cockpit inside of hangar, such as was described above. Another tool that can be useful is a physically realistic flight simulator.

### 5.14 Electromagnetic Compatibility Testing

The PNVG helmet was tested for F-15C electromagnetic compatibility both at Boeing in St. Louis and at Nellis AFB at the 422 TES in January 1999. The Boeing testing was performed using an electromagnetic interference chamber, while the Nellis AFB testing was performed in a powered up F-15C cockpit with an operational PNVG. The pilot performed a checklist verifying all cockpit instruments were functioning properly. This testing took into account guidance from MIL-STD-461 (Requirements for the control of electromagnetic interference emissions and susceptibility), MIL-STD-462 (Measurement of electromagnetic interference characteristics), and MIL-STD-464 (Electromagnetic environmental effects, requirements for systems). In all tests, no significant problems were discovered.

### 5.15 Emergency Ground Egress Testing

Emergency ground egress testing was performed at Nellis AFB, Nevada in January 1999 using both a ground egress trainer and an operational F-15C inside of a hangar (Figure 9). The addition of PNVG to the helmet system will add extra cables to the pilot's head that become entangled or snagged as the pilot attempts to perform an emergency egress. This test ensured that PNVG does not interfere with pilot's ability to exit the aircraft during emergency egress while on the ground with open canopy. Additionally, the quick disconnect must also reliably separate during ground egress with the pilot making no manual disconnects. This test was performed with PNVG in the stow position. It was noticed that the PNVG could possibly snag the forward canopy hook unless the pilot carefully maneuvers around it.


Figure 9. Emergency egress testing of PNVG I (note forward canopy hook can snag PNVG)

### 5.16 Electrical Shock Analysis

The addition of an electrical assembly to the helmet must not impose an excessive risk of electrical shock to the pilot during normal flight operations and even conditions such as ejecting into water. A preliminary electrical shock analysis has been performed at Wright-Patterson AFB, Ohio, which has identified some areas that need to be investigated more closely. These areas include the remoted power supply connection and exposed circuit boards and flex circuitry. In Phase III of the program, Night Vision Corporation shall perform a more detailed analysis.

The PNVG uses relatively low voltage (less than 12 volts DC) connections from the aircraft to the pilot through the wiring harness. The VCATS program has proven the safety of this harness through many successful flight hours. In fact, the PNVG should actually be safer than VCATS, because it does not use a high voltage connection from the aircraft power.

Inside of the helmet, Module IV flex cables are routed between the helmet shell and the protective EAL, thus minimizing the risk of electrical shock. The universal connector has several fail-safe mechanisms engineered into it to prevent inadvertent electrical shock. In addition, the display controller is coated with a spray-on non-conducting conformal coating to both protect the electronics and add safety. Also, voltages and power in the controller should be low enough to not cause any significant risk to the pilot.

The Image Intensifier Tube (IIT) power supplies on the PNVG helmet module are separated from the IITs by a few inches, and four insulated wires connect each of the two IITs. However, this power supply is only driven with 3 volts at a maximum of 60 milliamps. This means that the device uses a maximum of 180 milliwatts, which should be of little safety concern. Epoxy potting insulation on both ends of these wires provides protection and keeps out moisture. If aircraft power is not present, only the goggle power supplies receive their 3-volt DC supply from two AAA alkaline batteries.

### 5.17 Optical Performance Testing

The optical performance of the PNVG is extremely important for safety-of-flight certification. Internal laboratory testing of the PNVG unit was performed in early January 1999 at the AFRL Night Vision Operation Laboratory. This analysis revealed the PNVG has similar optical performance when compared to the standard F4949 NVG. Additional testing is necessary to verify these preliminary results, which is why no performance numbers are presented in this paper.

### 5.18 Symbology Analysis

The PNVG displays flight symbology identical to VCATS except the symbology is yellow rather than green. The pilots who use the PNVG symbology should be aware of the possibility of being disoriented by looking at the attitude reference indicator's artificial horizon, which is referenced to the aircraft symbol on the PNVG display. The aircraft symbol is referenced to the pilot's helmet and not the aircraft, as it is with a head-up display (HUD) mounted on top of the instrument panel. Therefore, unless the pilot is looking straight ahead and perfectly level using PNVG, the artificial horizon will not match the outside world horizon, either viewed directly or through the PNVG. In other words, the artificial horizon symbology no longer matches the exterior world scene as displayed. This cannot be avoided on a helmet-mounted system because the pilot's helmet does move with respect to the aircraft (tilt, look over shoulder, etc). This mismatch could be disorienting to the pilot if not properly taken into consideration. All Nellis AFB VCATS-trained pilots are quite familiar with this issue and will have no surprises with PNVG. Any new pilots will be properly trained prior to use of PNVG. In most cases, the pilot will simply shut off the HMD attitude reference indicator.

## 6. CONCLUSION

The PNVG conceptual working model developed under the phase I SBIR demonstrated the feasibility of a very wide FOV image for night operations. The eleven advanced technology demonstrators delivered under Phase II and successful completion of safety-of-flight testing will allow the warfighter to evaluate the operational utility of the PNVG in actual flight tests on aircraft. It is noted that for flight testing on aircraft other than the F-15C, additional safety-of-flight testing and analysis will be necessary, such as cockpit compatibility, electromagnetic compatibility, and emergency ground egress. As a result of performance-based evaluations in both simulators and in operational aircraft, a better understanding will be gained of the PNVG's impact on such areas as improved situational awareness, reduced fatigue during long missions, ejection compatibility, and overall increased mission performance and safety.

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