EXPLOSIVE LENS FLASHBLINDNESS PROTECTION SYSTEM

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Nuclear detonations emit thermal energy in the ultraviolet, visible, and near infrared spectrums, which if not protected against, may produce permanent chorio-retinal damage to the eyes or a temporary loss of vision referred to as "flashblindness." Since the loss of vision, for even a few seconds, may be disastrous to a high-performance aircraft pilot, he must be provided eye protection. This article discusses the development of an explosively actuated protective system designed to minimize the effects of flashblindness and to prevent permanent thermal injury to the eyes.

The design and development of a new type of eye-protection equipment was initiated in May 1960 by the Bureau of Naval Weapons in conjunction with the Naval Weapons Evaluation Facility and the Sandia Corporation. Called the explosive light filter (ELF) concept of flashblindness protection, it is an automatic, sequenced, explosively activated system. As shown in Fig. 1, this new flashblindness protection system consists of a Navy APH-5 flight helmet, modified to support the ELF lens (goggle); a sensing device used to detect a nuclear-detonated, electromagnetic radiated signal; and a battery-operated discriminator unit called the trigger, which is connected electrically to the lens and sensor.

Specifications for the ELF flashblindness protection system as set forth by BuWeps are listed in Table I. In addition to these specifications, the design was intended to ensure the incorporation of the following features:

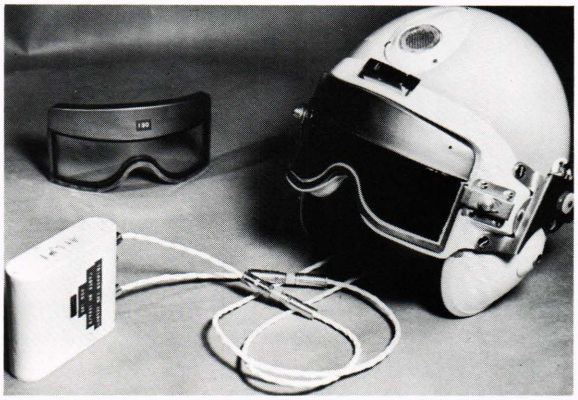

Fig. 1—ELF flashblindness protection system.

1. Equipment developed would be compatible with the APH-5 flight helmet and the standard oxygen-breathing mask.

2. Optical distortion of the lens would be minimal.
3. Electrical circuits would be kept to a minimum, for maximum safety.
4. Light emission from explosive detonation would be masked to prevent inherent flash-blinding effects.
5. System would provide for easy, rapid, one-hand replacement of the lens.

TABLE I
ELF DESIGN SPECIFICATIONS

	Minimum Specification	*Preferred*
Initial open transmission	70–80%	95%
Final optical density*	OD-3	OD-4 or more
Time to occlude fully (OD-3)	200 μsec	150 μsec
Goggle weight	2 lb max	0.75 lb
Time to remove actuated lens from eyes	5 sec	$<$ 2 sec
Reliability	0.97	0.995
Device safety	0.995	0.995
Operating temperature range	30°–120°F	0°–140°F

*Optical density $= \log_{10}\left(\dfrac{\text{incident intensity}}{\text{transmitted intensity}}\right)$

The system function is shown schematically in Fig. 2. The diagram suggests that the nuclear signal is radiated in all quadrants and receiver positions. The earliest detectable signal used for triggering occurs in the early microsecond region and exists in the form of an electromagnetic emission in the visible spectrum and an electromagnetic pulse in the RF band. Considering this large spectrum of radiation emitted from a detonation, the Navy developed both an optical sensing and triggering subsystem and an electromagnetic pulse (EMP) sensing and triggering subsystem for detection of the earliest available nuclear signal.

In the optical sensing system, a silicon detector cell is located in the forehead region on the helmet surface, whereas the EMP system makes use of a painted, silver epoxy antenna and ground plane, which are baked on the outer and inner surfaces of the flight helmet, respectively.

Upon reception of either an optical or an EMP signal, the appropriate triggering device processes the detected signal and initiates a firing pulse to the ELF goggle. This is done by releasing a stored capacitor charge if discrimination shows the detected signal to be from a nuclear detonation. This discrimination is effected by a comparison of the rate of signal rise with a preset trigger discharge threshold.

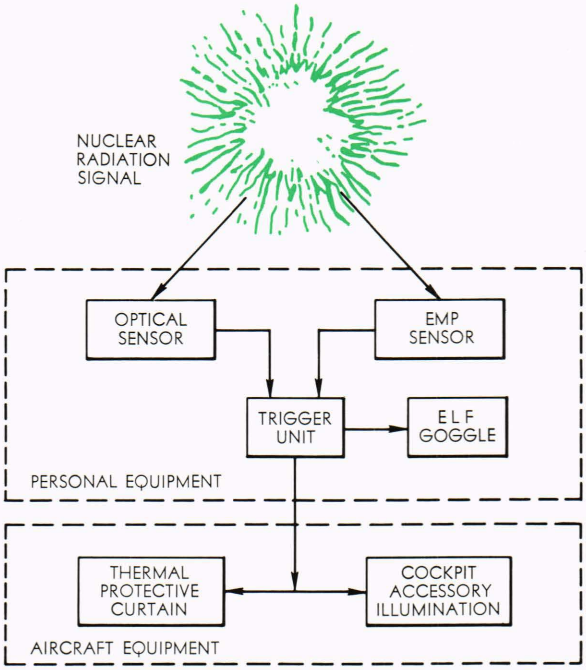

Fig. 2—System functional diagram.

As indicated in the functional diagram, the ELF trigger is equipped with an auxiliary output signal cable and connector. These provide automatic control for increasing the cockpit lighting intensity and for initiating closure of a thermal protective curtain in aircraft so equipped. The complete system is worn as personal equipment and thus requires the connection of only one single cable to the aircraft itself to activate the lights and thermal curtain.

The electrical system consists of a storage capacitor system (which includes a capacitor and capacitor charging circuit) and an amplifier which accepts and discriminates the electrical output of the sensor and actuates a circuit which discharges the energy storage capacitor through lens cables to the contact buttons. The trigger is powered with a self-contained Ni-Cd battery which may be recharged after each mission without having to extract the battery from the trigger case. The cable which transmits the cockpit-lighting and thermal-enclosure-actuation signal is furnished with a break-away type connector for use if emergency escape from the cockpit is necessary.

The mechanical portion of the ELF system consists of a visor frame assembly that is secured by means of side frame suspension arms to the helmet.

The visor frame is designed to rotate from the eye level position to a raised and locked position for ease in donning the helmet. Because the optical sensor protrudes beyond the normal helmet contour, it is necessary to slide the frame assembly forward before raising it. The frame is designed to support and hold the ELF goggle in place with thumb latches. The electrical contact buttons, which supply the firing signal, are mounted in the frame assembly and match with goggle contacts when inserted.

The ELF shutter, or lens assembly, consists of a double polycarbonate thermoplastic optical visor, a frame and lens closure, a reservoir assembly containing the opaquing material and the explosive train, an orifice, electrical contact points, and a housing to cover the reservoir and electrical components. The assembly is defined more clearly by the cross-sectional view in Fig. 3. Upon receipt of a firing pulse from the trigger, the detonators produce a velocity impulse, on the order of 7000 meters per second, to ignite a mild detonating fuse (MDF) immersed in the fluid in the reservoir. A thin copper foil, which seals the fluid in the reservoir, is caused to burst by the explosive force produced by the MDF. This drives the fluid through the orifice and into the void in the optical lens system. The orifice is designed to disperse the fluid uniformly onto the inner lens surfaces to occlude the transmission of incident light.

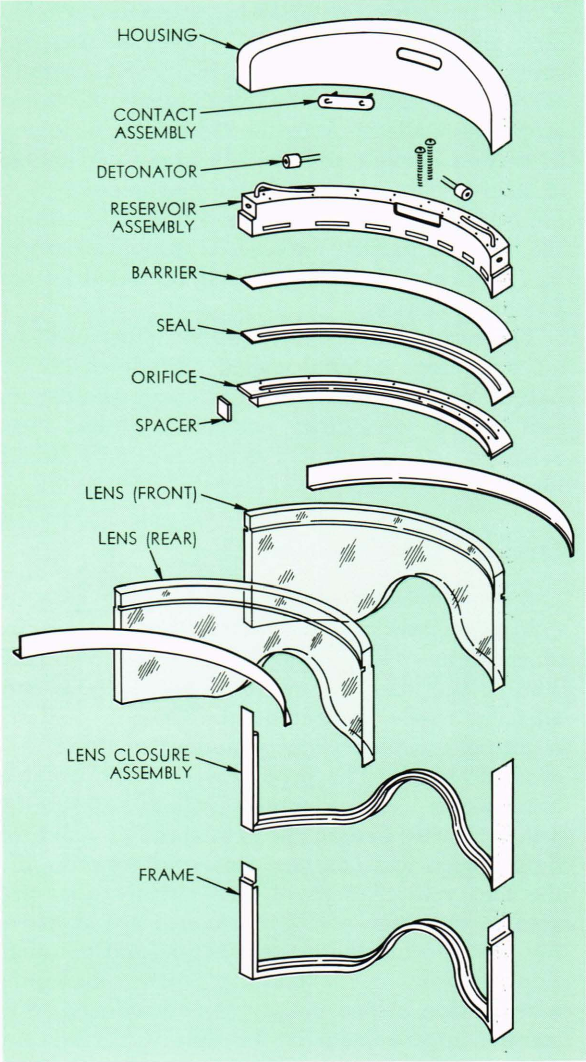

Fig. 3—Lens assembly, exploded view.

Goggle Design Techniques

The conceptual ELF lens design evaluation covered several techniques for occluding the lens systems:

1. The explosive blowing of dry bulk powdered carbon into a void between lenses.
2. The injection of encapsulated silicone oil into a void in advance of explosively blowing the powdered carbon, with the oil intended to wet the optical surfaces and act as an adhesive for the carbon particles.
3. The blow-down of a liquid opaquing material (colloidal suspended graphite) through a series of ports or slots by firing a group of explosive detonators positioned directly above the reservoir.
4. The hydraulically blowing of an opaquing material from a tubular reservoir into the lens void by placing the explosive component at the rear end of the reservoir behind the fluid to prevent the explosive gases from entering the void during the early stages of closure.
5. The distribution of a liquid opaquing material through an orifice into the lens void by initiating the explosion of an MDF immersed in the fluid within the reservoir.

During the conceptual design phases, approximately 700 models were fabricated in the various configurations mentioned. Evaluation of high-speed photographs made by framing cameras, and of optical densitometer data after test firing the samples, indicated that the closure technique using the MDF with explosive detonators at either end demonstrated the best capability of achieving closures within the time periods specified at the onset of the development program. The MDF configuration, shown by X-ray photography in Fig. 4, was then selected for fabricating prototypes and pilot-production ELF flashblindness protective goggles.

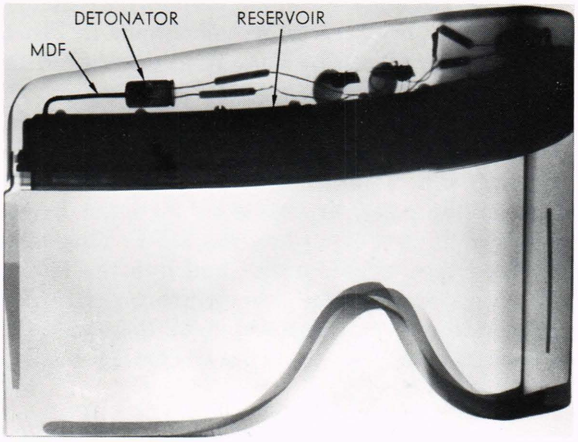

Fig. 4—Detonator/MDF assembly.

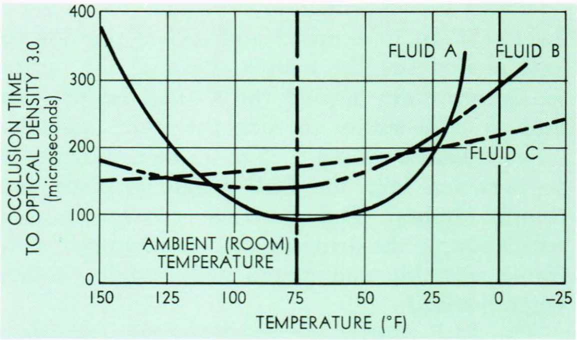

Fig. 5—Temperature effects of opaquing materials.

Opaquing Material Development

The use of dry bulk powders and colored gases was ruled out early in the development program on the basis of insufficient opacity at any reasonable explosive pressure. The problem of finding a suitable opaquing material was difficult, but the best opaquing performance was obtained by using suspensions of colloidal graphite in a liquid medium. Various colloidal graphite materials were first considered. Hexinol DAG's were tried, but the hexinol carriers boiled off during the test firing, leaving the graphite dispersed unevenly on the lens surfaces and without a wetting or spreading capability.

Superior opaquing materials must have carriers with such characteristics as low vapor pressure, low freezing (pour) points, moderately low surface tension (good wetting ability), and low viscosity, as well as a flat viscosity-versus-temperature curve. Figure 5 indicates opaquing performance with viscosity changes at various temperatures. Curve A has excellent time-density performance at room temperature; however, it becomes so thick at low temperatures that flow and lens closure are impossible. When it is heated, it flows too rapidly and its surface tension is so low that, while it covers the lens, the film is not sufficiently dense to occlude passage of light. Curves B and C suggest that by increasing the opaquing material's viscosity at ambient temperature by changing some of its properties, i.e., using different materials and different percentages of solid-to-carrier ratios, it is possible to find a material that will provide adequate coverage and densities in the desired time limit, even at extreme hot and cold temperature conditions.

Further, the carrier used must exhibit characteristics which induce a strong electrical bond to the colloidal graphite to keep it in suspension. The carrier must be moderately inert to prevent or minimize chemical attack on the lens material. Among the carrier materials investigated were alcohols, glycols, motor oils, silicon oils, lacquer, solvents, water, and oleic nitrile. The most successful carrier was found to be oleic nitrile. Colloidal graphites, made by Acheson and Dixon, were used in various particle sizes and in many percentages of solid-to-carrier ratios. While particle size is an important parameter, it was found that milling the colloidal particle reduced its size but destroyed its electrical characteristics and inhibited its suspension qualities.

The results of the development effort provided an opaquing material called "Modified Supernatant Arneel" which uses oleic nitrile as a carrier. Satisfactory opaquing performance has been achieved at temperatures as low as −65°F and as high as +165°F.

Orifice Development

A restrictive orifice, through which the opaquing fluid must flow, was required to prevent slugging of the fluid when projected into the lens void. The orifice had to induce a low-pressure area adjacent to the projected fluid mass so that the resulting turbulent flow would spread the fluid over the lenses. The prototype and pilot-production models were assembled without a restricting orifice. In this design, the area through which the fluid passed was constant from the reservoir into the lens void. Results of its relatively poor progressive coverage and performance are shown in Fig. 6A. During the modernization and optimization program at the Bermite Powder Company, a restrictive orifice design was introduced. Substantial improvement in the time to occlude and in the uniformity of coverage resulted as shown in Fig. 6B. The time between exposures was 25 μsec;

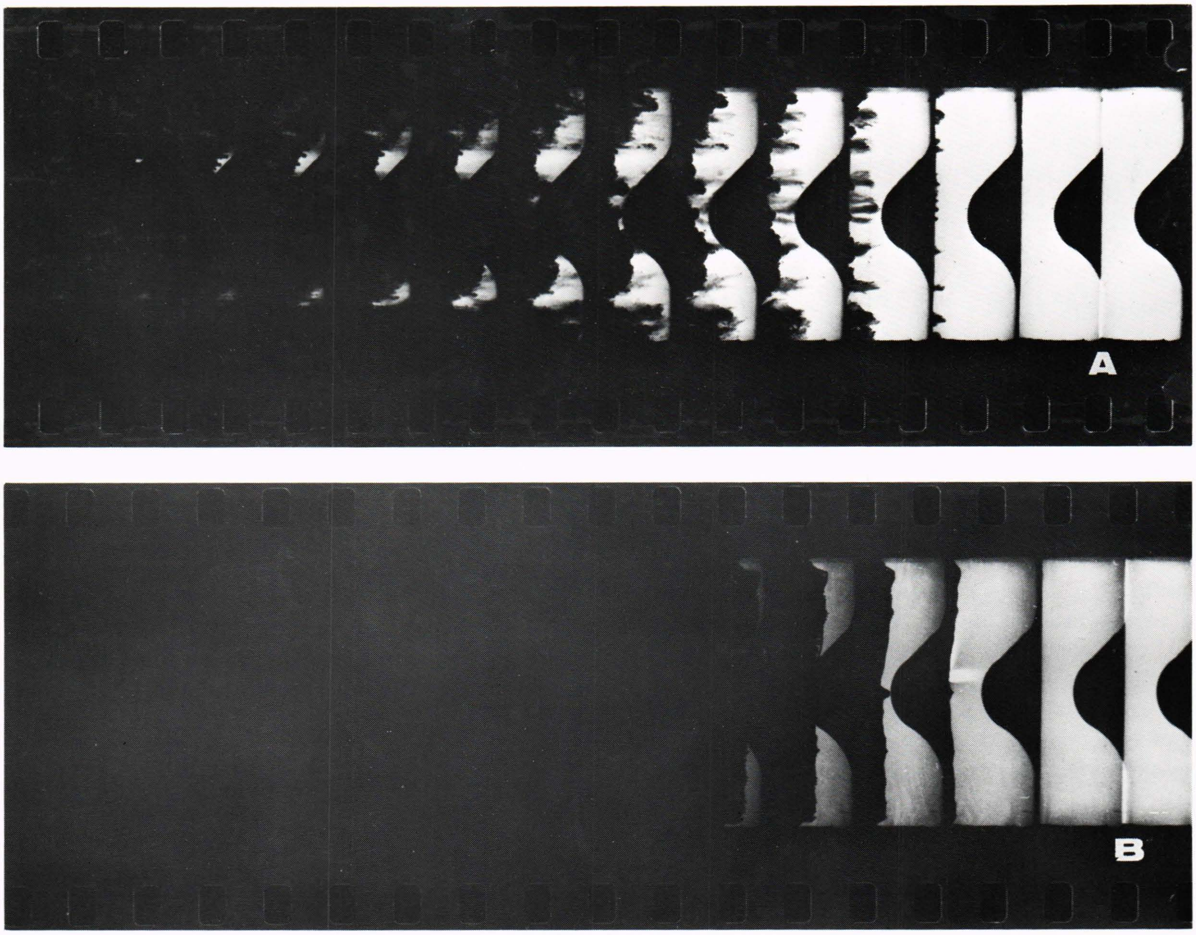

Fig. 6—Closure sequence without (A) and with (B) restrictive orifice.

the exposure time of each frame was 0.1 μsec. The production orifice design not only provides good performance in the occlusion process, but also provides a dependable seal against explosive outgassing and forms an inner support to position and hold the lenses in assembly.

Optical Lens Development

Lenses were initially heat-formed to fit the ELF goggle contour and curvature, using various plastic sheet materials. These materials did not provide the optical qualities desired, but were used to investigate their structural characteristics in withstanding the explosive forces inherent in the goggle configuration. Among the materials initially tried were acrylics and cellulose acetate butyrate. It was found that plastic lenses could be used in the goggle, but that a material having high tensile strength and IZOD impact strength, in addition to injection molding capabilities would be required to withstand the explosive forces involved, particularly at very high and very low operating temperatures. Cellulose acetate butyrate lenses were injection-molded both with and without optical corrections; however, these lenses were found, during structural firing tests, to be limited to normal ambient temperature conditions only. Some improvement was obtained when using cellulose propionate material. Lenses made from this material were found to have excellent optical characteristics, providing light transmittance in the open state as high as 70%. During firing tests, however, cellulose propionate lenses remained intact only at ambient temperatures between 30° and 110°F. The search for a stronger material led to the polycarbonate thermoplastics. "LEXAN" lenses were first injection-molded, initially using a polycarbonate formulation having a straw color. These lenses, when tested, were found to have excessive molding strains, which probably explains why they fractured during tests. Eventually, a colorless LEXAN material was formulated with improved structural characteristics, which, when molded under very close controls, produced lenses of excellent optical and structural qualities. While the lens design has undergone several changes to improve both its method of attachment and its tolerances to improve assembly procedures, the use of LEXAN for the ELF aperture has now been proved at temperatures as low as −65°F and as high as +165°F.

Test and Checkout Equipment

To evaluate the effectiveness of an eye protection system, it is necessary to compare the degree of occlusion of the protective device as a function of time, to the expected irradiance level as a function of time. A recording optical densitometer was designed by the Sandia Corporation during the early phases of development to enable comparative evaluation of the occlusive properties of the various samples and processes being investigated. This equipment, having been modified to include an environmental temperature-controlled test chamber, is currently being used to test and qualify the manufacturer's preproduction lot samples, and will be used for performance testing and quality assurance in the forthcoming production lot units. Subsequent to the contractor's quality assurance testing, several production lot samples will be tested for time-density performance by the Applied Physics Laboratory. Another optical densitometer is being developed by the National Cash Register Company to accomplish verification of the ELF goggle performance. Both densitometers have a display which is synchronized with the light source and which can be viewed or photographed.

Assurance will be provided the user of the ELF system that his equipment will function as required, when needed, by providing the user with a charge and test console upon which the batteries are stored when not being used. The charge and test console is designed to accept and house up to 30 trigger units. The triggers are maintained on a trickle charge of about 10 milliamperes. The charge and test console also contains a special discharge circuit to exercise the battery from time to time during long periods of non-use and thus assure that it will provide the maximum output capacity when needed. The charge and test console also is equipped with electrical circuits and meters to check the continuity of the entire ELF electrical system. The console includes a high-intensity, fast-rate-of-rise light emitter to test the optical sensor on the flight helmet. If the ELF circuitry is intact and continuous, a firing pulse is induced through a dummy goggle; if this has an energy threshold above 200,000 ergs, it illuminates a green firing signal on the charge and test console. The charge and test console for the EMP system is similar.

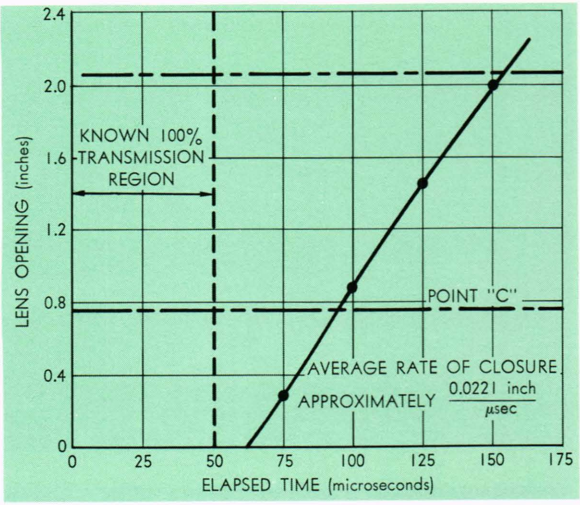

Fig. 7—Plot of data reduced from a framing camera exposure of a sample firing.

Results of Development

Goggle development and testing were completed satisfactorily in 1965. Preproduction lot samples have been fabricated using production techniques and procedures. Samples have been tested for structural and environmental integrity and have passed the rigid requirements set forth by military specifications for aeronautical equipment. Such tests covered drop testing, airborne and ground transportation vibration tests, short and long duration temperature tests, thermal shock tests, and temperature-humidity tests. Goggles were determined to be structurally adequate when fired at either −65° or 165°F.

Functional firing tests have indicated satisfactory time-density performance, obtaining optical density 3.0 in 200 μsec or less over an operational temperature range from 30° to 120°F. The goggles have maintained their protective closure for a minimum period of 10 seconds at optical density of 4.0 or greater. Data reduced from a framing camera exposure of a sample firing are plotted in Fig. 7 to show the actual time history of a closure sequence. While this plot shows that the time required to close the lens aperture completely was 153 μsec, it is significant to note that substantial eye protection was afforded after approximately 95 μsec, the time at which the occluding media passed the eye level designated as the "critical point C" on the plot.