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Chemical Lightsticks as a Night Vision Goggle Compatible Lighting Technique for Aircraft Cockpits: Characteristics, Pros and Cons

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ABSTRACT

Night vision goggles (NVGs) are used for night flying in many military aircraft in the US Army, Navy, and Air Force. NVGs are seen as a means of improving flying safety by providing aircrew with a direct view of the outside world scene thereby improving situation awareness. However, NVGs cannot operate effectively in a cockpit environment unless the interior lighting is NVG compatible. NVG compatible means the lighting is sufficient for the aircrew to view their instruments with their unaided vision but the lighting does not interfere with the NVG's view of the outside world. There are several ways to achieve NVG compatibility by using plastic and glass filters, and by changing light sources to eliminate near infra-red light from the cockpit. One less desirable technique for achieving NVG compatible lighting is to use chemical lightsticks to flood-light the cockpit instrumentation. This paper presents a number of issues associated with using "chemsticks" as a means of achieving NVG compatibility including spectral effects, temporal effects, and temperature effects. It is concluded that chemsticks are marginal as a means of achieving NVG compatibility. Also, if they are used, then pilots and associated support personnel need to be informed of the chemstick's limitations and characteristics to assure safe NVG flight operations.

INTRODUCTION AND BACKGROUND

During the past decade, night vision goggles (NVGs) have found their way into most USAF aircraft cockpits as a means of enhancing both safety and capability during night operations. However, before NVGs can reach their full potential in an aircraft cockpit, the cockpit instruments, displays, and lighting must be made NVG compatible. Standard cockpit lighting typically involves incandescent lamps with filters to provide red, white, or blue-white illumination for night flight [5]. Unfortunately, incandescent lighting produces far more near infra-red energy than it does visible and the NVGs are highly sensitive to this near infra-red light. The effect of this is that the internal cockpit lights overpower the NVGs and the pilot cannot see the outside world through the aircraft windscreen and canopy. The primary technique for making an aircraft cockpit "NVG compatible" is to greatly reduce or eliminate light within the cockpit in the red and near infra-red spectral regions where the NVGs are highly sensitive. In addition, there must be sufficient visible light in the green or blue-green spectral regions for direct viewing of the aircraft instruments and displays [4]. Figure 1 shows the human visual system photopic sensitivity curve in comparison to the spectral sensitivity of the third generation ANVIS (aviator's night vision imaging system) night vision goggles with Type A and Type B coatings on the objective lenses [2]. It is clear from Figure 1 that there is a relatively small (but highly significant) overlap between the visual sensitivity curve and the NVG sensitivity curves. Although this overlap looks to be somewhat small, one must remember that the NVGs amplify light on the order of 5000 to 6000 times. Therefore, even a small overlap can cause lighting incompatibility problems. This is especially true for light which is perceived by the human visual system as being red (wavelengths between about 620 and 700 nanometers) since the eye is not very

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sensitive here but the NVGs are. The NVIS (night vision imaging system) B coating was devised to shift the NVG spectral sensitivity away from some of the lower red wavelengths so that red could be used in the cockpit without significantly interfering with the NVGs.

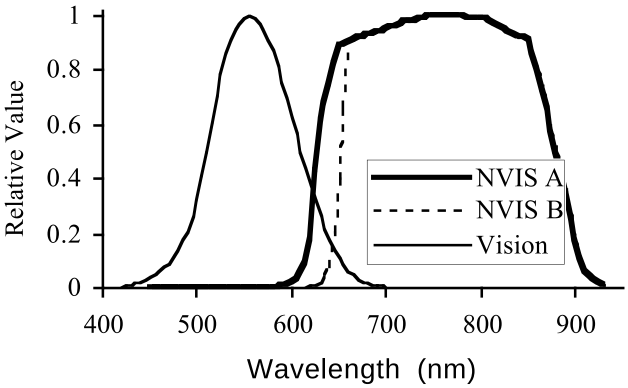

Figure 1. Relative spectral sensitivity of night vision goggles (with NVIS A and B coatings) compared to human vision.

Techniques have existed for some time to make the aircraft cockpit NVG compatible [4] and these techniques have continued to be improved. However, modifying an aircraft cockpit to make it properly NVG compatible according to the NVG compatible lighting Mil Spec [2] can be expensive. For this reason, operational squadrons have looked for cheaper and hopefully, temporary means of making the cockpit NVG compatible. One of these approaches is to use inexpensive green chemical light sticks [3], commonly referred to as "chemsticks", to provide flood-lighting of aircraft instruments. Not surprisingly, the list of military uses on the packaging of these lightsticks does not include use as a means of obtaining aircraft cockpit NVG compatibility [3]. The chemsticks emit no infra-red radiation (unlike incandescent lights) but they do have a relatively long emission tail in the red part of the spectrum. Figure 2 is a composite graph showing the typical chemstick emission spectrum (for green chemsticks [3]; they do come in other colors including near-infra-red), the human visual sensitivity curve, and the NVIS A and B curves. From this graph it is apparent that the chemsticks have a good spectral distribution in terms of providing light that the human visual system can easily see, but they do have a somewhat long tail that overlaps the low end of the NVG sensitivity curves.

The chemsticks that have been used for NVG compatible cockpit lighting come in 3 sizes of cylindrical shapes as shown in Table 1. Chemical light sticks have been produced in other shapes but they contain the same chemicals as the ones measured for this study.

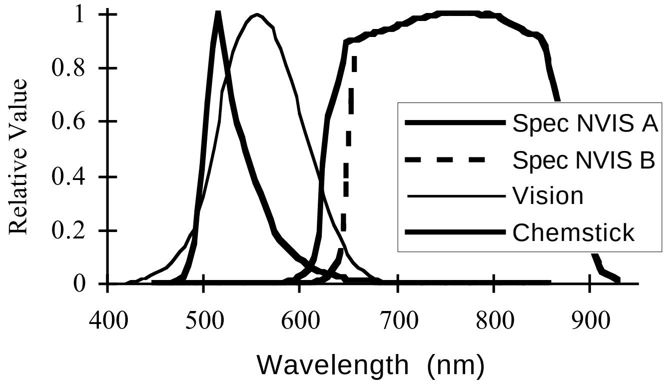

Figure 2. A typical chemstick emission spectrum compared to human vision spectral sensitivity and NVG spectral sensitivity

Table 1. Chemstick sizes typically used in aviation

Size	Length (in)	Diameter (in)
Small	1.5	3/16
Medium	4	1/2
Large	6	5/8

The chemsticks are activated by physically breaking the glass ampule that is contained within the plastic outer casing. This releases the chemical inside the glass ampule which mixes with the chemical in the outer case. The light stick is usually vigorously shaken to mix the two chemicals together thoroughly. The light stick begins to emit light immediately after activation.

CHEMSTICK CHARACTERISTICS

Spectral shift with time

Prior to this investigation, it was thought that the chemsticks had fairly stable spectral distributions. However, spectral distribution measurements of fourteen lightsticks showed that there was a greater than expected variance. In an effort to track down the source of this variance, several lightsticks were measured at different times after activation. Figure 3 shows the results of these measurements. The spectral distribution of the lightstick output shifts toward the red as a function of time after activation. It is possible to calculate the NVG compatibility of these spectral distributions using the methods called out in military specification (Mil Spec) MIL-L-85762A [2]. Table 2 is a summary of these calculations that show that the chemstick spectral distribution is not in compliance with this NVG light specification and that it becomes somewhat worse with time after activation. According to Table 2, after 92 minutes the chemstick spectral emission produces radiation in the NVIS A spectral region that is 10.82 times higher than the Mil Spec allows. This means that chemsticks are not in compliance with the Mil Spec, although, from a practical standpoint, they are considerably better than incandescent lighting by many orders of magnitude.

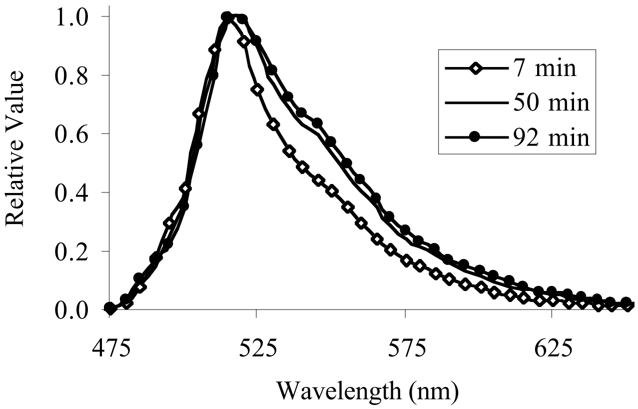

Figure 3. Chemstick spectral emission shift as a function of time after activation.

Table 2. Effects of time after activation on NVG compatibility. Each value is the average of measurements made on 3 chemsticks.

Time after	X spec value	X spec value
Activation	NVIS A	NVIS B
7 min	7.69x	3.34x
50	10.12	4.46
92	10.82	4.75

Luminous output versus time

One of the worst characteristics of chemsticks is that they slowly decay with time. That is to say, their light output decreases slowly with time, which makes it difficult for a crewmember to notice when the light level is getting too low until it is too late. Figure 4 is a graph showing the luminous decay characteristics of 14 chemsticks. These were all designated as "12 hour" chemsticks [3] and correspond to the "large" size chemstick described in Table 1. There are three main points to notice regarding this figure. First, there is a fairly significant variation in the luminance level as a function of time from lightstick to lightstick (the upper and lower dashed lines are +/- 2 standard deviations). Second, the light level drops off rapidly in the first few minutes and then drops off somewhat more slowly after that. Third, even though these are designated as "12 hour" light sticks, it is apparent from the graphs that after only 3 1/2 hours the light level is down quite substantially from starting light levels. It is the variability from stick to stick and the insidiously slow light fall off with time that make chemsticks a potentially dangerous method of making an aircraft cockpit NVG compatible. The variability makes it difficult to establish specific guidelines on how to set up a cockpit for NVG compatibility using chemsticks and the slow light loss with time makes it hard for the pilot to determine when the sticks have gotten too dim to be able to see critical instrument readings.

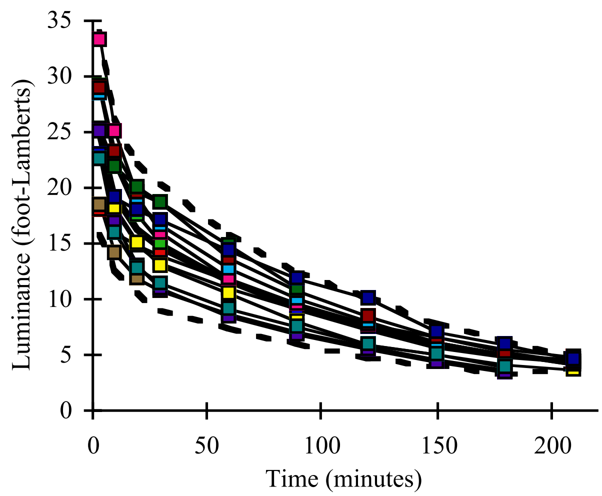

Figure 4. Variation in chemstick luminance decay with time for 14 chemsticks. The dotted lines are +/- 2 standard deviations.

Temperature effects on luminous output

In order to determine if temperature affects the luminous decay rate of the chemsticks, a special apparatus was designed and fabricated. The chemsticks, after activation, were placed in a transparent cylindrical cell that contained a holding mount to clamp onto the chemstick and a circulating, cooling/heating liquid. The liquid was set to the desired temperature and maintained physical contact during the time the chemstick was being measured. Both 4 inch and 6 inch chemsticks were tested at 3 different temperatures: 50, 70, and 80 degrees F. Figure 5 shows a summary of the results for the 4 inch chemsticks (the results for the 6 inch sticks were similar). Each curve is the average of 5 chemsticks. The decay effects of the 70F and 80F temperatures are similar although it appears the 70F starts off higher, decays more rapidly at first, and then decays more slowly after about 30 minutes. The 50F luminous decay is dramatically different. When first activated it is considerably lower in luminous output than either of the other two temperatures and it stays substantially lower throughout the two hour time period that it was measured for this graph. However, it should be noted that after about 20 minutes the 50F light output is relatively constant for this two hour measurement period unlike the higher temperatures.

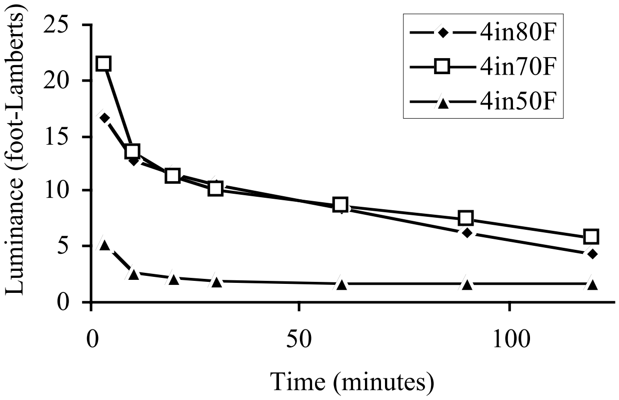

Figure 5. Effect of temperature on chemstick luminance decay.

During the time these chemsticks were being measured under various conditions a useful trick was discovered [1]. If the chemsticks were refrigerated (about 35F - NOT frozen) and then immediately activated in a room temperature (about 70F) air environment, then the luminous decay characteristics were significantly modified. Figure 6 shows the average of 2 chemsticks that were refrigerated (about 35F) before activation in a 70F air environment (dashed line) compared to the average of 2 chemsticks that were kept at room temperature and then activated (solid line). The refrigerated chemsticks started with a lower luminous output and dropped rapidly similar to the liquid cooled 50F sticks of Figure 5. However, as the chemsticks gradually warmed up in the 70F room temperature environment the luminous output actually increased until about the 1 hour point. After the 1 hour point these sticks slowly decayed. The significance of this effect is that it is possible to obtain a more uniform luminous output for a relatively long time (about 3 hours) if the chemsticks are thoroughly cooled prior to being activated in a room temperature cockpit environment. The chemsticks in this experiment remained overnight in the refrigerator to make sure they were completely cooled throughout. They were also taken directly from the refrigerator to the measurement room so only about 5 to 10 minutes elapsed between the time they were taken from the refrigerator and the time they were activated as shown on the graph. If a longer time elapses between removal from refrigeration and activation then one would expect somewhat different results.

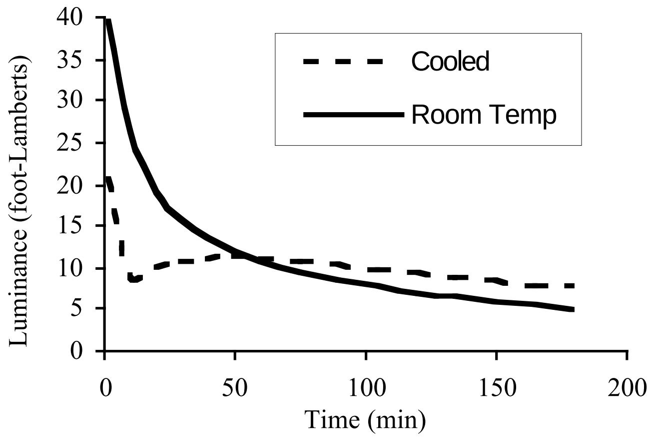

Figure 6. Demonstration of technique to reduce the rate of chemstick luminance decay by refrigerating the chemstick prior to use. The solid line is a chemstick at room temperature activated in room temperature; the dashed line is a chemstick refrigerated to about 35 degrees F then activated in room temperature (70 deg F).

DISCUSSION AND CONCLUSIONS

Although these chemsticks do not meet the MIL-L-85762A requirements for NVIS radiance by several times as noted in Table 2, their spectral distribution is such that they are reasonably compatible with the NVG spectral sensitivity. This assumes the chemsticks are positioned in the cockpit such that the NVGs cannot directly view them and such that they do not cause a direct reflection in the windscreen or canopy. The rationale for the Mil Spec on NVIS radiance was that no light source in the cockpit would have an apparent luminance, when viewing through the NVGs, any greater than tree bark (about 10% reflective) in starlight. This is a very stringent specification level.

All measurements of light output in this effort were actually a measure of the surface luminance of the chemstick itself. This provided a convenient and repeatable means of investigating the effects of time and temperature on the output of the chemsticks. The light levels measured (typically several foot-Lamberts to tens of foot-Lamberts) are far brighter than what the instrument panel indicia should be in order to provide sufficient, but low level, lighting for NVG operation (or ordinary night flying, for that matter). Instrument panel lighting would normally be set to less than a tenth of a foot-Lambert by the pilot in order to achieve comfortable lighting levels for night flying. However, if one is flying with NVGs, which have a light output of a few hundredths of a foot-Lambert (for very low outside illumination nights) to a couple of foot-Lamberts (for high moon illumination nights), it might be necessary for the pilot to adjust his/her instrument lighting somewhat higher to be compatible with the light output level of the NVGs. The problem with chemsticks is that adjusting the lighting level is very difficult, especially during flight. Since the chemsticks are used as an illumination source, the apparent luminance of the instruments they illuminate becomes lower the further the chemstick is positioned from the instrument and the more off-axis it is positioned. Typically, multiple chemsticks are used to illuminate the instrument panel; which means the resultant apparent luminance of any particular instrument indicia depends on the summation of light from all the chemsticks within a direct line of sight of the indicia. This is a very complex and interdependent situation. It is impossible to obtain a uniform instrument panel luminance distribution using the chemsticks; which is what, for normal lighting, cockpit lighting engineers strive for in order to meet pilot demands.

Other characteristics of chemsticks that have not been a part of the study reported here are the effects of humidity, age, and light exposure on the light output and spectral distribution of the chemsticks. These are subjects for future study.

Based on the data collected to date, it is concluded that chemsticks are marginally suitable for use as NVG compatible cockpit lighting. BUT, pilots need to LEARN and MAINTAIN awareness of the potential dangers of chemsticks. It is recommend that chemsticks be kept refrigerated and sealed in their packaging prior to transport and activation for use in the cockpit. The bottom line is that everyone involved should EXERCISE EXTREME CAUTION WHEN USING OR ADVOCATING CHEMSTICKS FOR NVG COMPATIBLE COCKPIT LIGHTING!

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BIOGRAPHY

H. Lee Task has been employed as a research scientist for the US Air Force since 1971. He has served as chief scientist for the Armstrong Aerospace Medical Research Laboratory (prior to its reorganization and disestablishment in 1991) and in March of 1997 was selected as the Senior Scientist for Human-Systems Interface of the new Air Force Research Laboratory at Wright-Patterson AFB, Ohio. He is currently involved in research and development in the areas of helmet-mounted displays, vision through night vision goggles, optical characteristics of aircraft windscreens, vision, and display systems. He has a BS Degree in Physics (Ohio University), MS degrees in Solid State Physics (Purdue, 1971), Optical Sciences (University of Arizona, 1978), and Management of Technology (MIT, 1985) and a PhD in Optical Sciences from the University of Arizona Optical Sciences Center (1978). During his career he has earned 39 patents and has published more than 80 journal articles, proceedings papers, technical reports, and other technical publications. He is a member of the Human Factors and Ergonomics Society (HFES), the American Society for Testing and Materials (where he is chairman of Subcommittee F7.08 on Aerospace Transparencies and is a Fellow of the Society), the Association of Aviation Psychologists, SAFE association where he is the editor of the SAFE Journal, the Society for Information Display (SID), and SPIE (the optical engineering society).