



**The Performance of Alkaline AA Batteries with the
Aviator's Night Vision Imaging System -
Before and After Activation of
the Low Battery Indicator**

By

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19970226 028

January 1997

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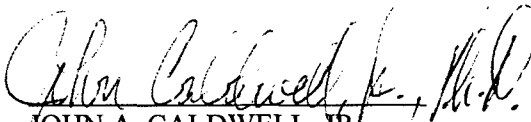


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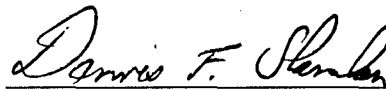
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REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1a. REPORT SECURITY CLASSIFICATION Unclassified		1b. RESTRICTIVE MARKINGS	
2a. SECURITY CLASSIFICATION AUTHORITY		3. DISTRIBUTION / AVAILABILITY OF REPORT Approved for public release, distribution unlimited	
2b. DECLASSIFICATION / DOWNGRADING SCHEDULE			
4. PERFORMING ORGANIZATION REPORT NUMBER(S) USAARL Report No. 97-07		5. MONITORING ORGANIZATION REPORT NUMBER(S)	
6a. NAME OF PERFORMING ORGANIZATION U.S. Army Aeromedical Research Laboratory	6b. OFFICE SYMBOL (If applicable) MCMR-UAC	7a. NAME OF MONITORING ORGANIZATION U.S. Army Medical Research and Materiel Command	
6c. ADDRESS (City, State, and ZIP Code) P.O. Box 620577 Fort Rucker, AL 36362-0577		7b. ADDRESS (City, State, and ZIP Code) Fort Detrick Frederick, MD 21702-5012	
8a. NAME OF FUNDING / SPONSORING ORGANIZATION	8b. OFFICE SYMBOL (If applicable) MRMC-UAS-VS	9. PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER	
8c. ADDRESS (City, State, and ZIP Code)		10. SOURCE OF FUNDING NUMBERS	
		PROGRAM ELEMENT NO. 0602787A	TASK NO. PE
		PROJECT NO. 3M162787A879	WORK UNIT ACCESSION NO. 164
11. TITLE (Include Security Classification) (U) The Performance of alkaline AA batteries with the aviator's night vision imaging system (ANVIS) - Before and after activation of the low battery indicator			
12. PERSONAL AUTHOR(S) Bill McLean, John A. Garrard, & Robert M. Wildzunas			
13a. TYPE OF REPORT Final	13b. TIME COVERED FROM TO	14. DATE OF REPORT (Year, Month, Day) 1997 January	15. PAGE COUNT 25
16. SUPPLEMENTAL NOTATION			
17. COSATI CODES		18. SUBJECT TERMS (Continue on reverse if necessary and identify by block number)	
FIELD	GROUP	SUB-GROUP	
10	03		
		battery, alkaline, lithium, ANVIS, night vision goggle	
19. ABSTRACT (Continue on reverse if necessary and identify by block number) The dual battery pack with the aviator's night vision imaging system (ANVIS) has a low battery indicator to alert the user to switch batteries at approximately 2.4 volts before the ANVIS performance is affected. With the original lithium batteries, the usable time after activation of the low battery indicator is approximately 30 minutes. Aviation units are now predominately using a pair of the AA alkaline batteries with ANVIS. This report investigated the usable time available with ANVIS after activation of the low battery indicator for alkaline AA batteries. Laboratory results showed that the ANVIS usable time for the alkaline batteries was typically more than five hours after the low battery indicator had been activated. Additionally, we found significant differences in the battery voltages at different airfields for supposedly new batteries, indicating that pilots are either mixing up the new and used batteries during flight, or the batteries are being short-circuited during storage.			
20. DISTRIBUTION / AVAILABILITY OF ABSTRACT ☐ UNCLASSIFIED/UNLIMITED ☒ SAME AS RPT. ☐ DTIC USERS		21. ABSTRACT SECURITY CLASSIFICATION Unclassified	
22a. NAME OF RESPONSIBLE INDIVIDUAL Chief, Science Support Center		22b. TELEPHONE (Include Area Code) (334) 255-6907	22c. OFFICE SYMBOL MCMR-UAX-SS

EXECUTIVE SUMMARY

The original batteries used with the Aviator's Night Vision Imaging System (ANVIS) were 3.0 volt lithium (BA-5567/U). The ANVIS dual battery case subsequently was redesigned to use either two small round lithium or two pair of the more common 1.5 volt AA alkaline batteries. ANVIS user's manuals and Army night vision goggle (NVG) academic instructional materials state that when the low battery indicator is activated, approximately 30 minutes of operating time are left on that battery compartment. The 30 minute useable operating time was based on a laboratory assessment of ANVIS performance with lithium, not alkaline batteries.

The primary purpose of this study was to estimate the amount of useable operating time with ANVIS after the low battery indicator has been activated when using alkaline AA batteries. The secondary purpose was to measure the voltages of the ANVIS batteries labelled as "Primary" (P), "Alternate" (A), and "Expired" at three major Army airfields at Fort Rucker, Alabama, and to determine if there were voltage differences between categories and airfields.

An ANVIS with tubes manufactured before 1988 and one of the latest ANVIS (F4949) with tubes manufactured in 1994 were selected to evaluate the minimum "useable" voltage. The decrease in luminous output from 3.2 volts to the low battery warning at 2.4 volts was approximately 3 percent for both older and newer goggles. The luminous output decreases from 3.2 to 2.0 volts were approximately 7 percent for the older goggle and 10 percent for the newer tubes. Considering that a clear helmet visor attenuates visible light by 10 percent, the 10 percent decrease in ANVIS luminous output at 2.0 volts is not operationally significant.

AA battery pairs, for which ANVIS users had reported a low battery indicator activation, were retrieved from one of the airfields and used to determine the amount of remaining useable time. Twenty-five percent of these reportedly expired battery pairs included those with voltages well below the 2.0 volt cut-off point and those that were practically new with voltages measuring greater than 2.8 volts. The time to reach 2.0 volts when connected to ANVIS was determined for the remaining 75 percent (18 battery pairs). Seventeen (94 percent) required 5 hours or more to reach the 2.0 volt level, with values ranging from 0.95 hour to 12.5 hours.

The voltages of 20 pair of AA batteries used with ANVIS in each category (new, used, and expired) were measured at three primary airfields at Fort Rucker, Alabama. The voltages of the supposedly new batteries at one of the airfields were significantly lower than the voltages of the labelled new batteries at the other airfields. This indicates that some ANVIS users at one airfield were either mixing up new (A) and used (P) batteries during NVG flights, or that some batteries were short circuited during storage or use.

Additional plots of voltage versus time used with ANVIS for alkaline and a small sample of lithium batteries are included in this report for comparison purposes.

Acknowledgments

The authors wish to acknowledge the assistance and excellent response to this battery survey by the aviation life support equipment personnel at Lowe, Cairns, and Hanchey Army airfields and the enthusiastic coordination by the Aviation Training Brigade at Fort Rucker, Alabama. Mr. James A. Lewis and Mr. Robert M. Dillard from the U.S. Army Aeromedical Research Laboratory provided the equipment and expertise to automate the testing procedures.

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Objective

The objective of this study was to determine the approximate duration and variability of a pair of government issued alkaline AA batteries connected in series to maintain more than 2.0 volts when used with the Aviator's Night Vision Imaging System (ANVIS) after the low battery light was activated (at approximately 2.4 volts). Figure 1 shows the location of the low battery indicator on the ANVIS mount, which is located on the helmet visor.

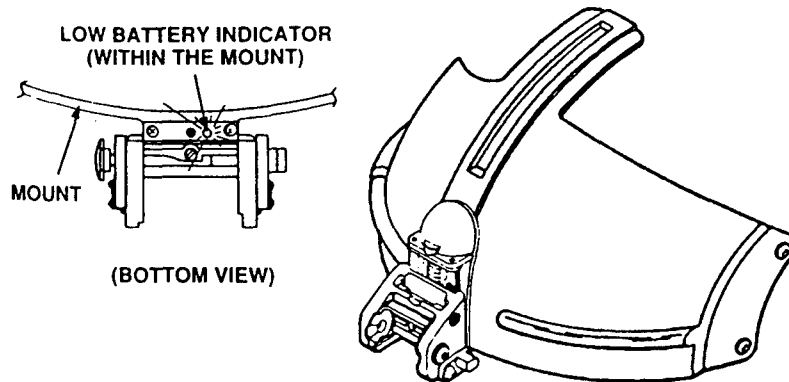


Figure 1. Low battery indicator

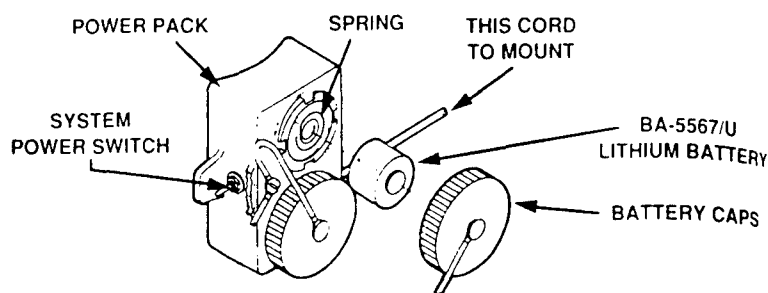
Military significance

AA alkaline batteries are much cheaper, commercially available, and more abundant than the original small round lithium batteries initially used with ANVIS (Department of the Army, 1983 and 1994). Therefore, alkaline AA batteries have been the preferred battery type for ANVIS for the last 5 years at most Army locations except in the cold regions. However, unlike the lithium batteries, which have been extensively evaluated (Petrenko, 1983), the useable life for the alkaline AA batteries with ANVIS after the activation of the low battery indicator has not been determined. This information will provide guidance to night vision goggle (NVG) pilots on the available reserve time for AA batteries during both training and combat missions.

Background

On a recent NVG training flight in a CH-47 helicopter, three of the five crewmembers (an instructor pilot, one of the student pilots, and one of the crew chiefs) had their ANVIS low battery light indicators activate. Two crewmembers switched to the supposedly new batteries, and the low battery indicator also activated within a few minutes. The crewmembers did not have spare ANVIS batteries, but fortunately one of the passengers did. Otherwise, the training mission may have been terminated, resulting in a loss of time and money. This incident inspired the study of the alkaline AA batteries with ANVIS.

Up to the mid-1980's, before the dual battery packs were available for NVGs, the battery type for the AN/PVS-5 NVGs was the mercury BA-1567/U (Department of the Army, 1980). After each flight, the NVG time was recorded on a label attached to the battery. When the battery reached 10 hours of use, it was discarded. The NVG users always carried a spare new battery in case of battery failure. As dual battery packs became available for the AN/PVS-5 NVGs, and ANVIS gradually began replacing the AN/PVS-5s, lithium batteries (BA-5567) replaced the mercury batteries in the supply system. Around 1990, the original dual battery pack design was replaced with a version that permitted the use of either lithium or AA type batteries. Figure 2 shows the differences between the original and present ANVIS dual battery packs and battery types.



Original Type Power Pack

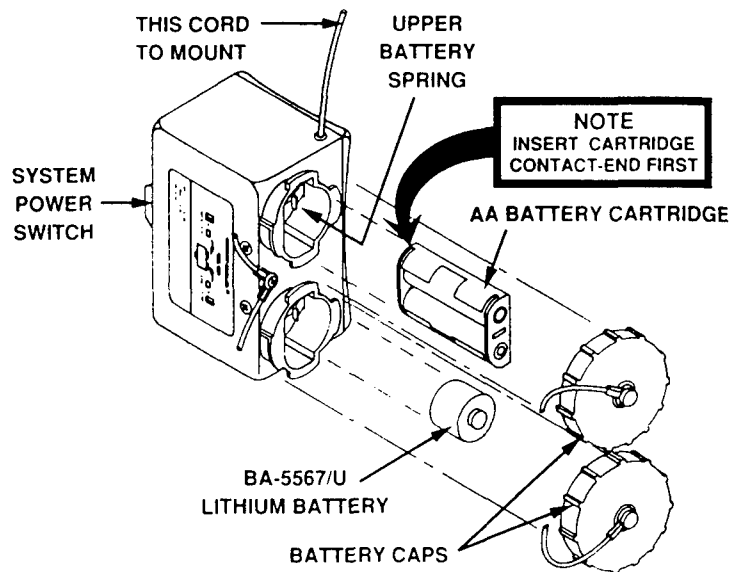


Figure 2. Dual battery type power packs.

A previous Fort Belvoir, Virginia, study (Petrenko, 1983) evaluated the ANVIS lithium batteries for duration as a function of temperature and current drain. With ANVIS, when using lithium batteries (BA-5567) above 0 degrees Centigrade, the time for the voltage to drop from 2.4 to 2.0 volts was approximately 30 minutes or more.

Standard operating procedure (SOP) (Brooks, B. 1996) (Stevens, J. 1996) for Army aviation at Fort Rucker, Alabama, is to use new batteries labelled "A" for alternate (either alkaline AA or a small round lithium battery) in one chamber and used batteries labelled "P" for the primary in the other chamber of the dual battery pack. Pilots check both battery cartridges before flight by turning-on the ANVIS to determine if the low battery indicator is illuminated for each chamber. For NVG operations, in accordance with (IAW) Fort Rucker SOP, only the "P" or used batteries should be used until the low battery light indicator on the ANVIS mount is activated. The pilot then would select the "A" or new battery(s) in the dual battery pack to complete the mission. The "A" batteries that are used in a flight after the low battery indicator is activated then are labelled "P" by the ALSE personnel, and new batteries are labelled "A" and added to the available battery supply for the ANVIS users. Rather than discard the AA batteries that were reported to have activated the low battery light indicator, the aviation life support equipment (ALSE) personnel have been providing these batteries to the pilots for their lip lights, which are useable with lower voltages (Garrard and Rash, 1995).

The U.S. Marines Night Vision Device Manual (1995) states "Alkaline batteries have a much flatter discharge rate than lithium batteries. Consequently, a drop-off in ANVIS image brightness and quality can be noted long before the low-battery indicator illuminates when using AA alkaline batteries." Therefore, the U.S. Marines replace both AA battery pair before each NVG flight. However, USAARL data do not support the statements found in the Marine manual. A comparison of output luminance versus input voltage at USAARL found no significant drop-off in luminance (approximately 3 percent) from 3.2 volts to 2.4 volts with ANVIS. The ANVIS image luminance begins to drop rapidly below 2.0 volts (see figure 3).

Air Force Squadrons use AA batteries and measure the voltages of a battery cartridge after each flight (Dawson, 1996). If the voltage of the cartridge is less than 2.79 volts, the batteries are discarded.

Luminance Output vs Voltage Input ANVIS

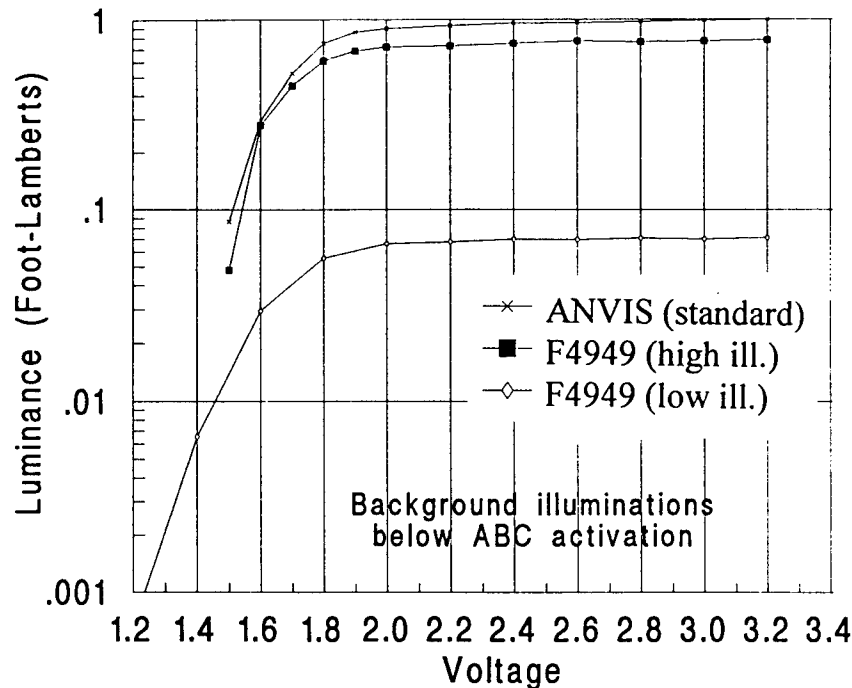


Figure 3. ANVIS luminous output versus voltage input.

In other references (Consumer Reports, 1994 and Linden, 1984), various types and makes of batteries have been tested using both continuous and periodic use scenarios. Primary variables that affected the duration of alkaline batteries were current drain (load) and voltage end point. To a lesser degree, temperature, manufacturer, periodic use, and shelf life also affected the duration, but were not evaluated in this study.

Methods

Twenty-four pair of alkaline AA batteries were obtained from the ALSE section of one of the airfields, Fort Rucker, Alabama. ANVIS users reported the low battery light indicator was activated during an NVG flight while using these batteries. The U.S. Army Aeromedical Research Laboratory (USAARL) measured the voltage of each battery using a digital voltmeter. Each pair of batteries was mounted in a standard dual AA battery cartridge and placed in one chamber of a modified ANVIS dual battery pack. The dual battery pack was connected to an ANVIS. The ANVIS objective lens caps were taped to produce a low luminous output from the eyepieces in room illumination. Previous measurements of four pair of ANVIS had shown that current drain remains constant (approximately .056 amp) regardless of ambient illumination. Only slight differences in current use were found between the latest ANVIS type (ITT F4949) and an

older standard ANVIS (AN/AVS-6). Modifications to the dual battery pack provided inputs to an automated oscillographic recorder for each channel of the dual battery pack and to the low battery light indicator. Voltage and time data were recorded at 1 minute intervals until the voltage fell below 2.0 volts.

As a secondary objective, USAARL measured and compared the differences in voltage of 20 pairs of AA batteries used for ANVIS at three primary airfields at Fort Rucker. The batteries were stored in three different categories: Alternate (new), primary (used), and expired (low battery light activated). USAARL initially intended to measure the voltage with the ANVIS turned on, but found that the voltages of the alkaline batteries changed rapidly in the first few seconds and minutes, inducing a timing variable for the measured voltage. Therefore, to minimize the interference at the ALSE shops, it was decided to first measure the voltages at the airfields without a load and to determine the voltages under a load in our Laboratory.

For comparison purposes, the voltage of four lithium batteries with various amounts of previous use were recorded under an ANVIS load for approximately 1 hour.

Results

Objective No. 1 - Expired batteries and rate of voltage change of alkaline AA batteries with ANVIS.

a. The mean, standard deviation (SD), median, minimum and maximum voltages from each battery and each pair of batteries unloaded and loaded were computed from the reportedly expired AA batteries obtained from Army airfield "A," and are shown in table 1. The appendix shows the individual and paired voltages of the batteries before and after testing with ANVIS. Measurements were taken with and without a current load from the ANVIS. Time between loaded and unloaded measurements was approximately 1 minute.

Table 1.
Expired batteries from airfield "A"

	Individual unloaded	Paired loaded	Difference between unloaded and loaded pairs*	Difference between paired batteries unloaded**
Number	52	26	26	26
Mean (volts)	1.320	2.447	0.193	0.0008
SD (volts)	0.1040	0.2823	0.0868	0.009
Median (volts)	1.31	2.43	0.18	0.00
Minimum (volts)	1.09	1.80	0.07	0.00
Maximum (volts)	1.6	3.12	0.46	0.03

* Difference in voltages between unloaded and loaded was determined after the batteries were connected to ANVIS for approximately 1 minute.

** Difference between paired batteries was measured between the two batteries removed from the same dual battery cartridge.

b. Figure 4 shows a scatter plot of the expired alkaline batteries showing each battery pair, and the mean of the 23 battery pairs from approximately 2.4 to 2.0 volts plotted against time.

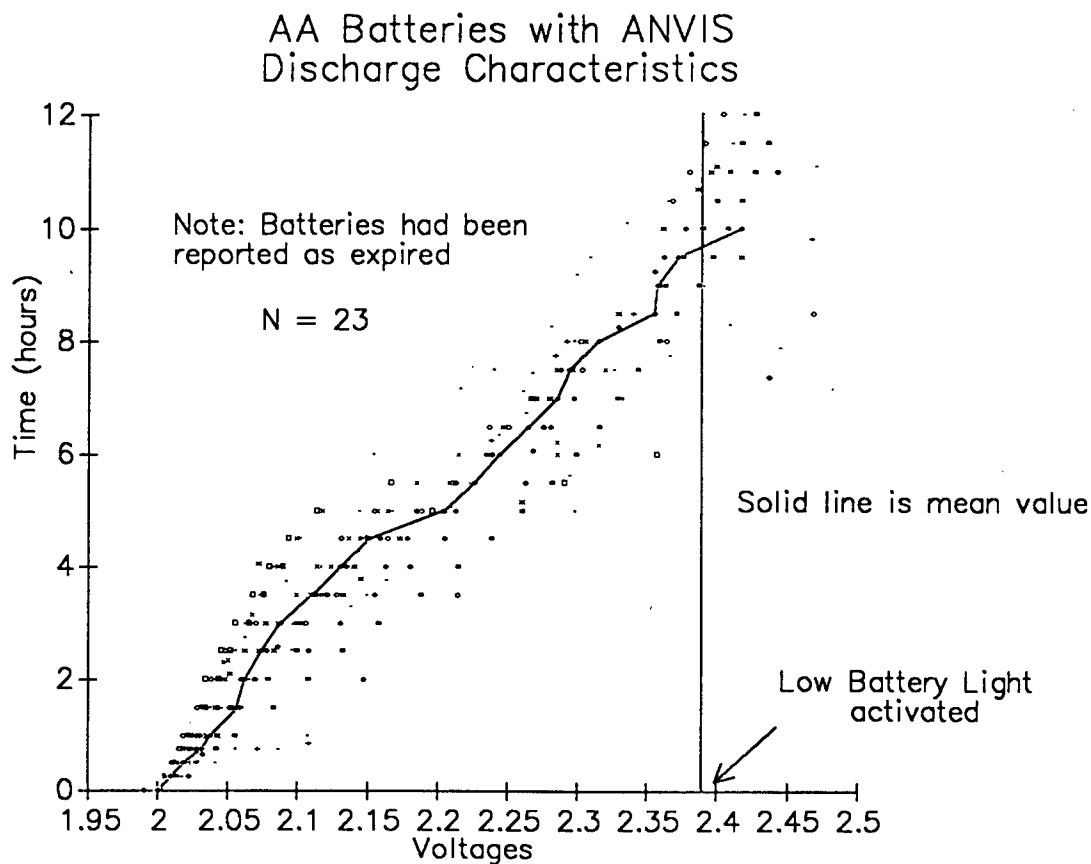


Figure 4. Scatter plot and mean voltages versus time for expired AA alkaline battery pairs connected to ANVIS.

c. Figure 5 is a scatter plot and regression between initial voltage after the low battery indicator was reportedly activated and the time required to decrease to the cut-off value of 2.0 volts.

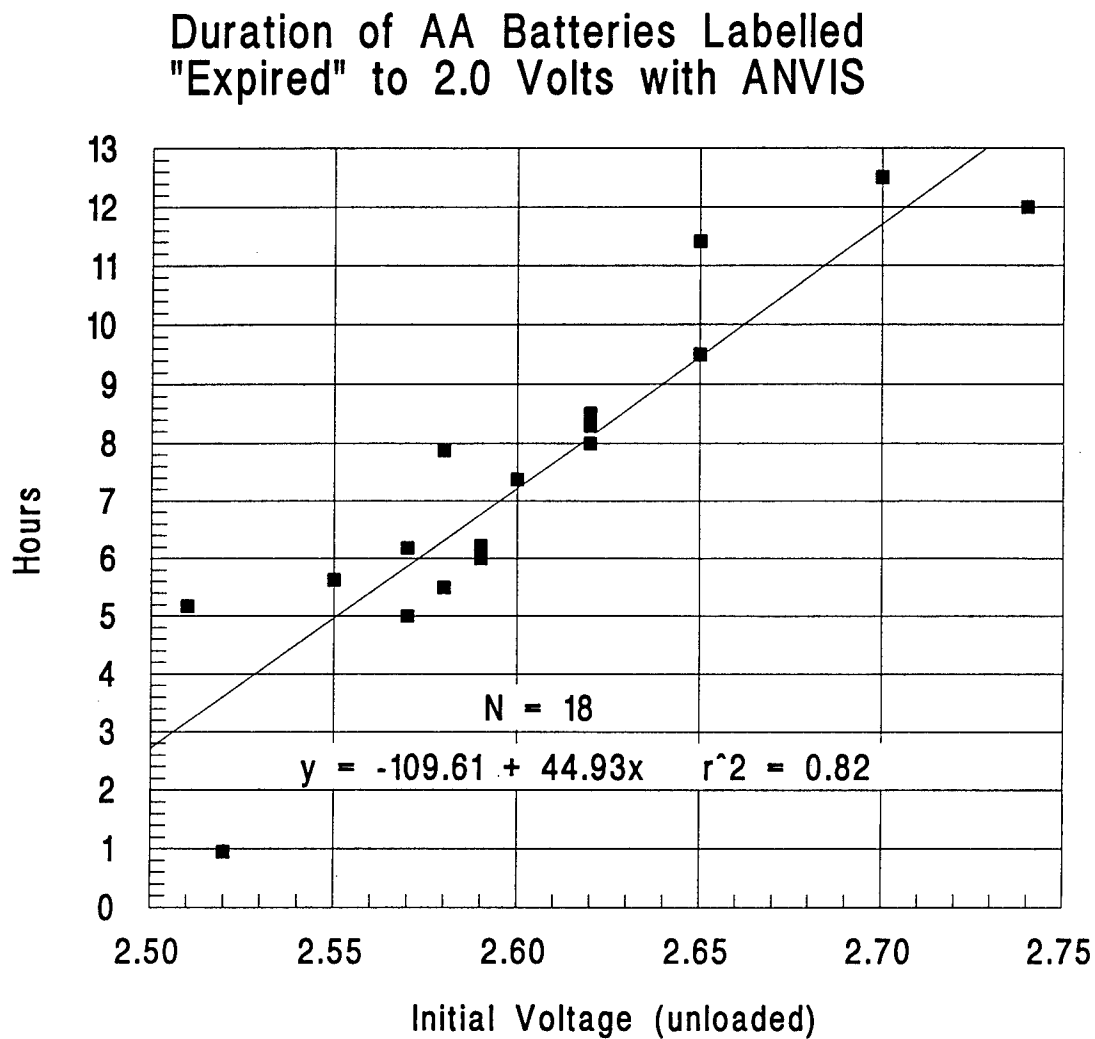


Figure 5. Regression between voltage and time for expired alkaline AA batteries.

d. Figure 6 is a plot of a pair of new alkaline batteries tested with the ANVIS for approximately 4 hours each day until the low voltage indicator was activated at approximately 2.4 volts.

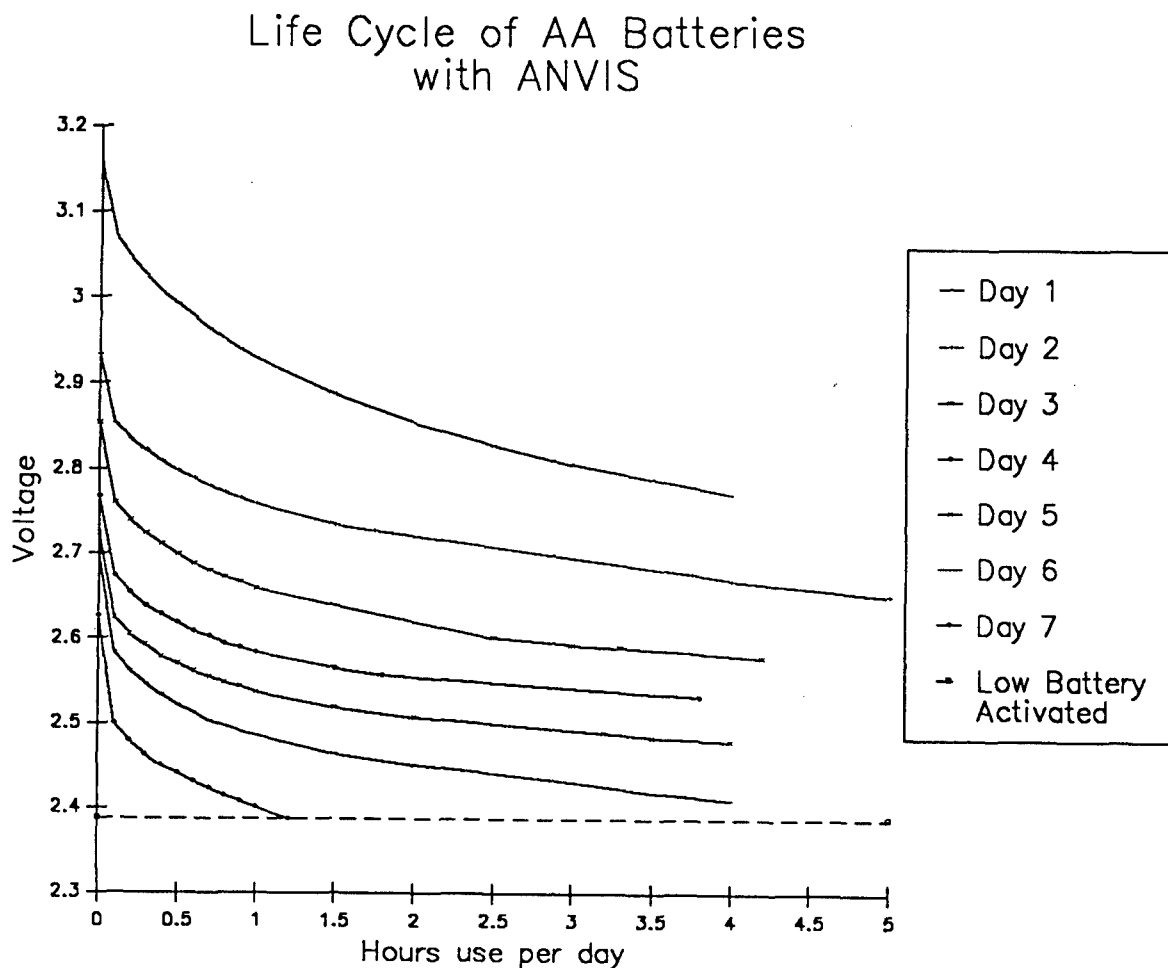


Figure 6. Voltage versus time with ANVIS (AA alkaline batteries for 4 hours per day).

e. Figure 7 shows a plot of time (on successive days) required to activate the low battery light for alkaline batteries that activated the low battery light on the previous day. This plot is a continuation of the batteries used in figure 6.

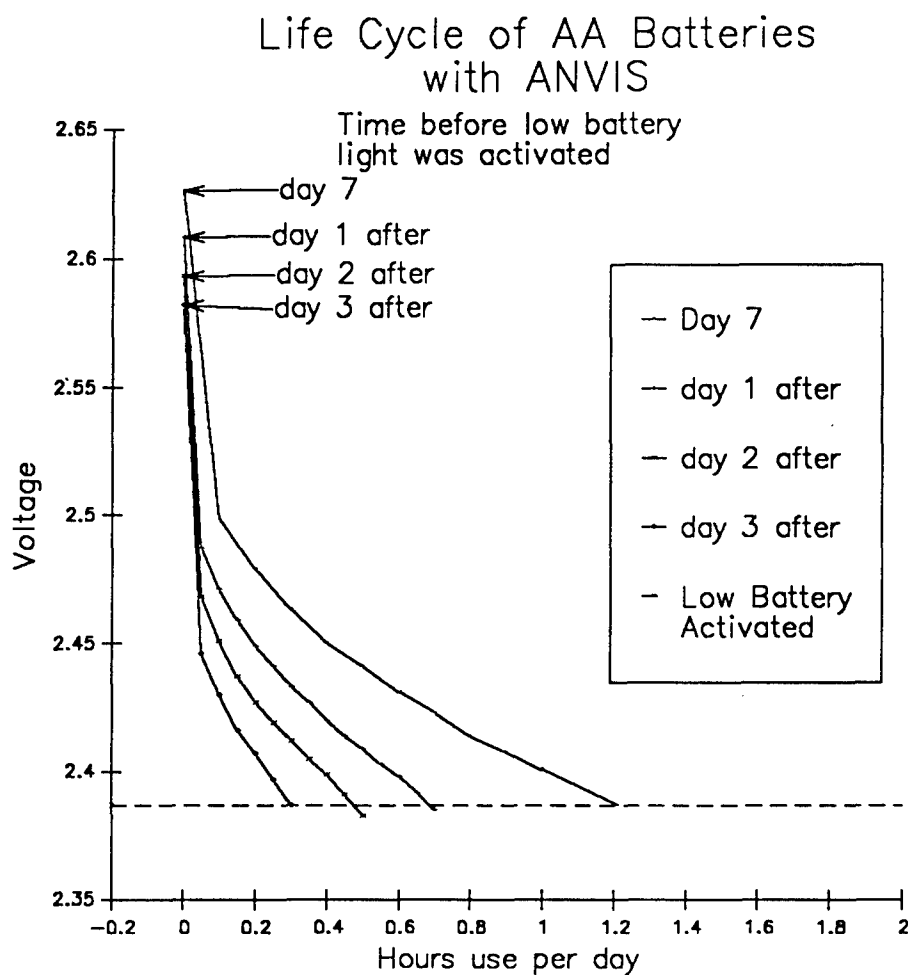


Figure 7. Time to activate low battery indicator on successive days.

Objective No. 2 - Voltages of alternate, primary, and expired batteries from each airfield.

a. Table 2 lists the number of AA alkaline battery pairs, mean, standard deviation (SD), median, minimum and maximum voltage values for the alternate (new) batteries at each airfield.

Table 2.
Alternate (new) battery pairs

	Airfield "A"	Airfield "B"	Airfield "C"
Number	20	20	20
Mean (volts)	3.03	3.03	2.88
SD (volts)	0.130	0.170	0.173
Median (volts)	3.025	3.14	2.905
Minimum (volts)	2.70	2.72	2.43
Maximum (volts)	3.21	3.18	3.17

b. Table 3 lists the number of AA alkaline battery pairs, mean, standard deviation (SD), median, minimum and maximum voltage values for the primary (used) batteries at each airfield.

Table 3.
Primary (used) battery pairs

	Airfield "A"	Airfield "B"	Airfield "C"
Number	20	20	20
Mean (volts)	2.82	2.82	2.77
SD (volts)	0.124	0.137	0.095
Median (volts)	2.785	2.84	2.735
Minimum (volts)	2.61	2.56	2.62
Maximum (volts)	3.05	3.15	2.97

c. Table 4 lists the number of individual AA alkaline batteries, mean, standard deviation (SD), median, minimum and maximum voltage values for the expired batteries at each airfield.

Table 4.
Expired individual batteries

	Airfield "A"	Airfield "B"	Airfield "C"
Number	52	40	40
Mean (volts)	1.32	1.35	1.38
SD (volts)	0.104	0.094	0.105
Median (volts)	1.31	1.32	1.35
Minimum (volts)	1.09	1.21	1.20
Maximum (volts)	1.60	1.55	1.61

d. Figures 8-10 show the cumulative distribution plots of the AA alkaline batteries in each category (alternate, primary, and expired) at each airfield. The airfields are labelled A, B, and C, arbitrarily.

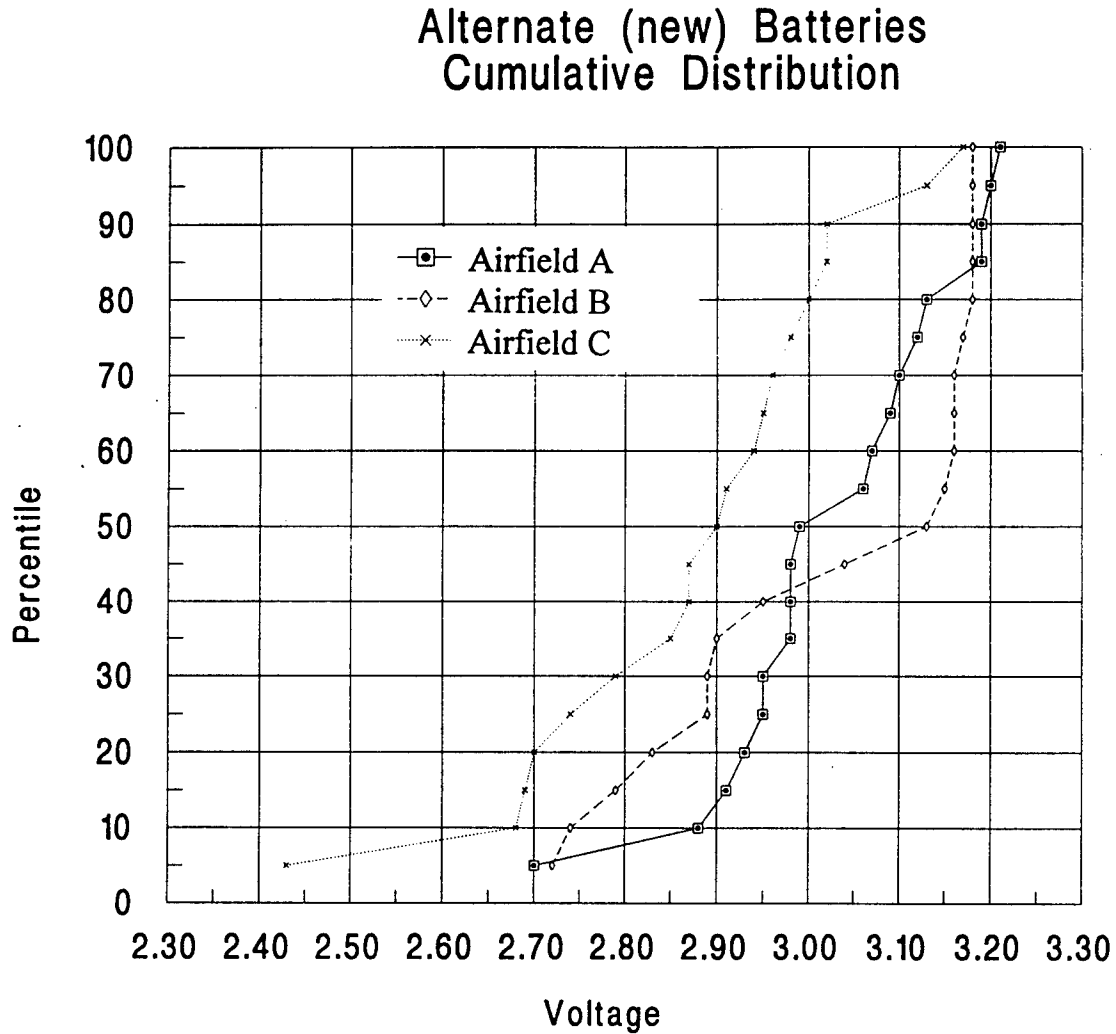


Figure 8. Cumulative distribution of the voltages of the alternate (new) AA alkaline battery pairs at three different airfields.

Primary Batteries Cumulative Distribution

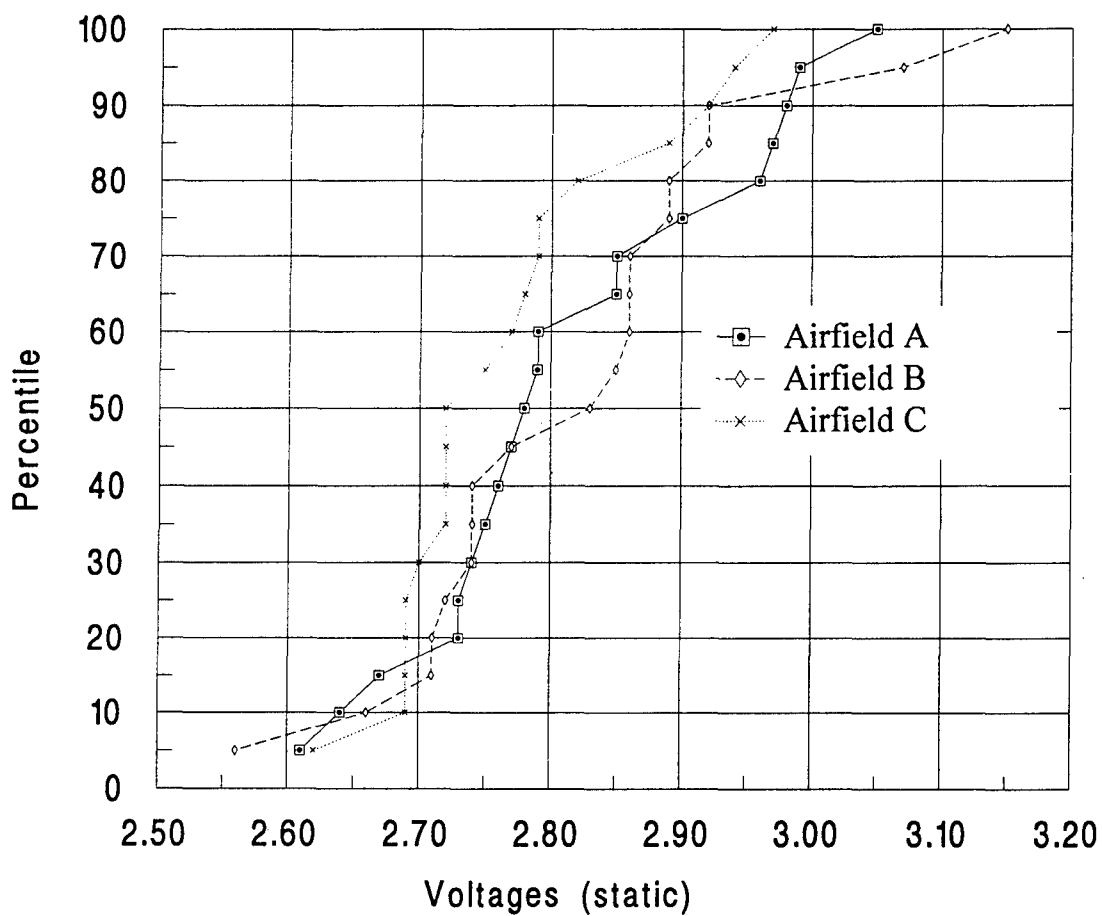


Figure 9. Cumulative distribution of the voltages of the primary (used) AA alkaline battery pairs at three different airfields.

Expired Batteries Cumulative Distribution

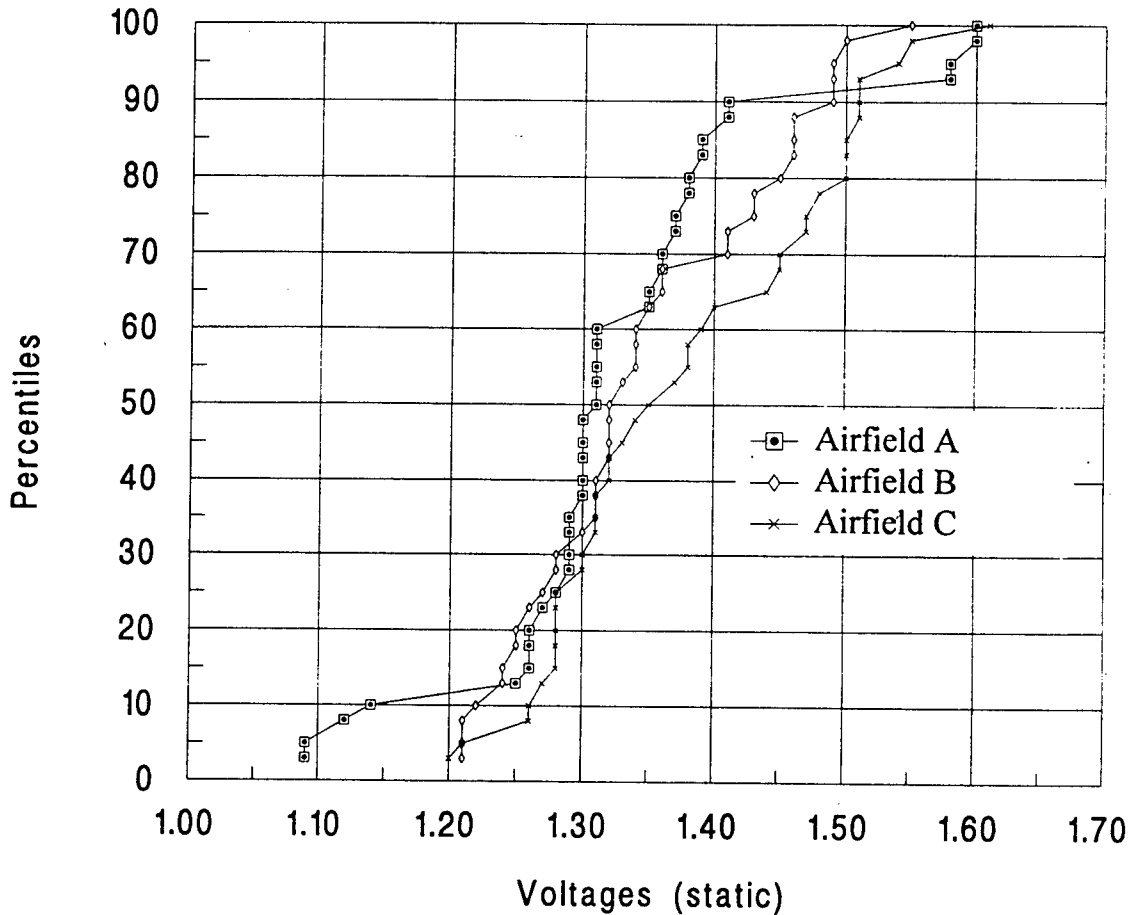


Figure 10. Cumulative distribution of the voltages of the expired individual AA alkaline batteries at three different airfields.

e. Battery voltage data were subjected to a one-way ANOVA to examine differences between voltages at three different airfields. The analysis on alternate (new) batteries revealed a significant main effect between airfields [$F(2,57) = 5.95$; $p < 0.05$]. In contrast, the data show no differences in voltages between primary (used) batteries among the airfields [$F(2,57) = 1.19$; $p = 0.3123$]. Tukey HSD *post hoc* analyses showed that the main effect of airfield on alternate battery voltages was due to significantly lower voltages at airfield C as compared to voltages at airfields A and B ($p < 0.01$). There was no significant difference in the alternate voltages between airfields A and B ($p = 0.99$).

As previously mentioned, unit SOP at Fort Rucker instructs ANVIS aircrew members to begin each flight using the primary battery cartridge and to switch over to the alternate cartridge only if the low battery indicator illuminates. Our data suggest that some aircrew members at airfield C may not be following unit SOP and may be using the alternate battery cartridges (i.e., new) instead of the primary cartridges (i.e., used) at the beginning of their NVG flights.

Objective No. 3 - Rate of lithium voltage change with ANVIS.

a. Figure 11 shows four lithium batteries of various capacitance measured for approximately 1 hour with ANVIS. Note the difference between the lithium and the alkaline curves. Resting voltages are all approximately 3 volts with lithium until a load is applied to the batteries. For the newest lithium battery, when the ANVIS was first turned-on, the low battery indicator light was activated for about 10 seconds, and then went out.

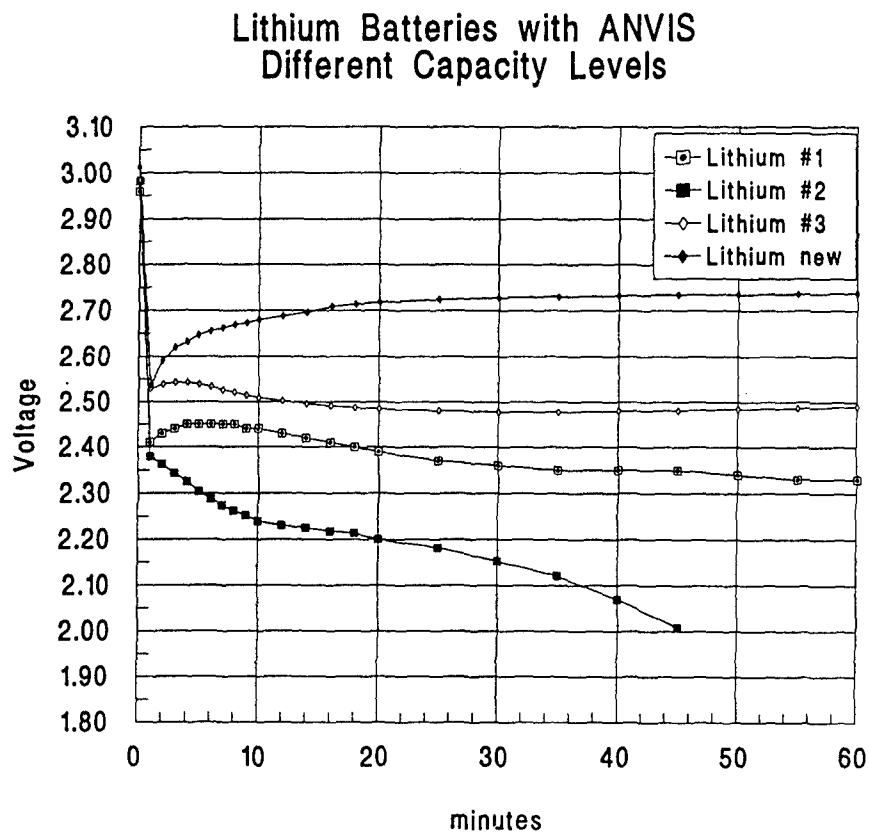


Figure 11. Lithium battery voltages versus time for four batteries with different capacitance.

b. Figure 12 shows a comparison of discharge voltages for an approximate 3-minute duty cycle between a relatively new AA alkaline battery and a new lithium battery.

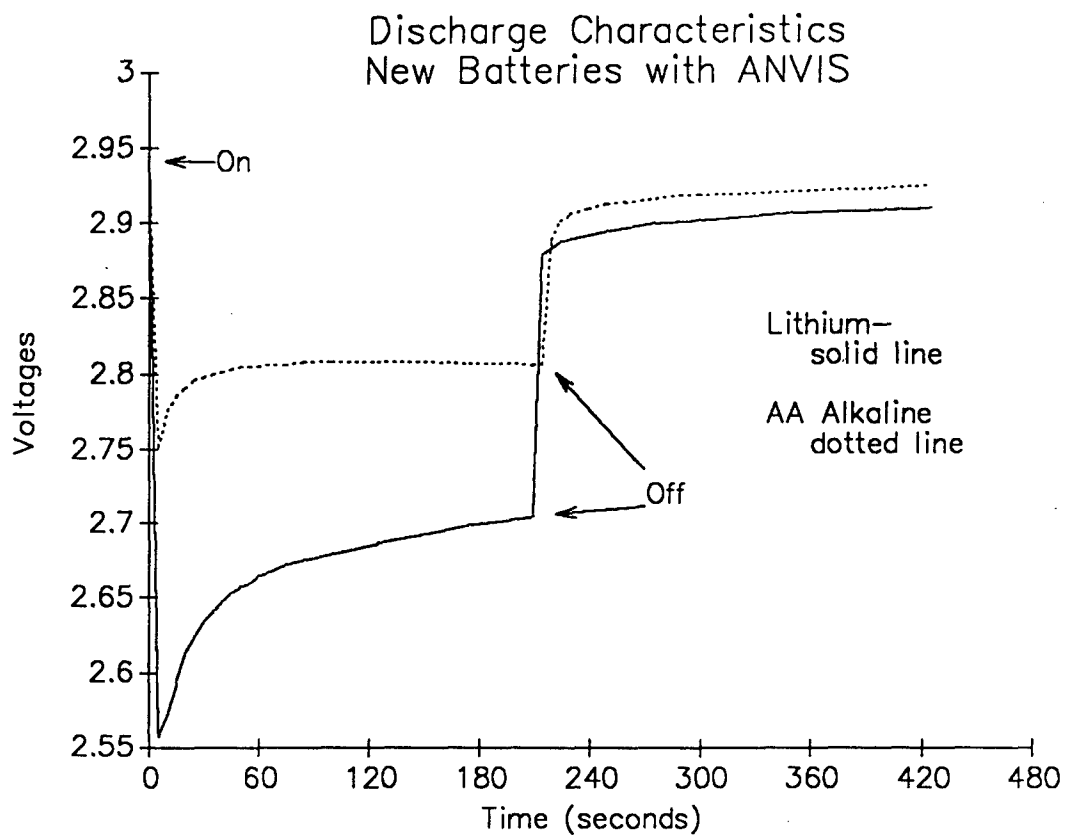


Figure 12. Comparison between lithium and a pair of AA alkaline batteries for 3-minute duty cycle.

Discussion

The incident described earlier with the two crewmembers having alternate (new) batteries activating the low battery indicator occurred at airfield "C." The comparison between the voltages for alternate (new) batteries was significantly lower at airfield "C" than at the other two airfields. This means that some ANVIS users at airfield "C" are probably using the alternate (A) batteries instead of the primary (P) batteries during NVG training, or the batteries are being short circuited during use or storage.

We also noted a difference in the way that airfields store AA batteries for ANVIS. Airfield "A" kept the batteries in the ANVIS cloth storage cases. Airfield "B" kept the primary and alternate battery pairs upright in two wooden trays. Airfield "C" placed the alternate and primary batteries on top of each other in rows for dispensing before NVG flights.

Besides confusing primary and alternate batteries during NVG flight, batteries could be discharged by any metallic or conductive object placed between the positive and negative terminals of the dual AA battery cartridges. If an AA dual battery cartridge is placed upside down in the battery case with the contact points toward the top of the battery case, the batteries also will be discharged.

We also noted that the difference in voltages between individual batteries of the reportedly expired battery pairs was negligible (see Appendix). In other words, we did not find any "dead" batteries paired with good batteries and very little difference between voltages in any of the pairs tested. Rather, it appears that the 1.5 volt AA alkaline batteries tend to drain equally when connected in series and used with ANVIS.

Some alkaline battery manufacturers are beginning to use a liquid crystal gauge on each battery to show the battery state. Whether this information is valid for ANVIS use for either the alternate or primary batteries has not been formally investigated. However, we monitored one pair of AA batteries with a liquid crystal gauge which indicated that the batteries were "dead" when as much as 2.8 volts remained.

Conclusion

The guidance given in the ANVIS operator's manual for amount of useable time for ANVIS after the low battery indicator has been activated was based on lithium batteries and is approximately 30 minutes. This study found that several hours (5-10 hours) of use are available with alkaline AA batteries after the low battery indicator is activated before there is an operational decrease in luminous output from ANVIS. However, this assumes that the batteries did not previously activate the low battery indicator with ANVIS use, were not shorted during storage, and were not reversed in the ANVIS dual battery pack. Variables such as temperature and shelf life also may affect the amount of useable ANVIS time, but were not evaluated in this study.

Battery cost is negligible compared to the cost of an NVG training flight. Therefore, we would not recommend extending training flights using batteries that have activated the low battery indicator. However, we suggest that dating and periodic voltage checks of the alkaline batteries intended as the back-up batteries (labelled alternate), and frequent briefings to student and IP NVG users about use of primary and alternate batteries should reduce the potential for battery-related problems during flight.

During combat, the pilots would be expected to use new batteries in both channels of the dual battery pack with ANVIS unless a shortage of batteries exists. In the rare case in which both battery channels (primary and alternate) activated the low battery indicator during a combat mission, and additional batteries were not available in the aircraft, our research indicates that after the initial activation of the low battery indicator, alkaline AA batteries would probably provide sufficient power to ANVIS for several additional hours without a noticeable decrease in ANVIS performance. Therefore, after evaluating the situation, the pilot may decide to complete or modify the mission rather than to abort.

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Appendix.

Before and After Voltages of Expired AA Batteries

(See the notes after the data form for an explanation of terms and procedures)

Airfield: "A", Fort Rucker, AL

Testers: WEM & JAG

Date: 15 July 96

Label #	Initial unloaded	Initial loaded	Final unloaded	Final loaded	Label#	Initial unloaded	Initial loaded	Final unloaded	Final loaded
A1	1.31	2.46	2.17	1.99	N1	1.35	2.55	2.16	1.98
A2	1.31	(A)			N2	1.35	(A)		
B1	1.14	1.81	2.24	1.81	O1	1.29	2.36	2.13	1.97
B2	1.12	(A)			O2	1.29	(B)		
C1	1.09	1.92	2.08	1.77	P1	1.31	2.46	2.16	2.00
C2	1.09	(A)			P2	1.31	(A)		
D1	1.30	2.43	2.17	1.99	Q1	1.38	2.67	2.18	1.98
D2	1.30	(B)			Q2	1.39	(B)		
E1	1.26	2.30	2.14	1.99	R1	1.33	2.53	2.14	1.99
E2	1.25	(A)			R2	1.32	(B)		
F1	1.37	2.64	1.86	1.58	S1	1.29	2.36	2.16	1.98
F2	1.37	(B)			S2	1.30	(A)		
G1	1.30	2.29	1.14	1.98	T1	1.60	3.12	2.04	1.79
G2	1.27	(A)			T2	1.60	(A)		
H1	1.58	3.09	2.13	1.99	U1	1.31	2.41	2.16	1.99
H2	1.58	(B)			U2	1.31	(A)		
I1	1.29	2.39	2.16	1.97	V1	1.26	2.18	2.20	1.99
I2	1.30	(B)			V2	1.26	(B)		
J1	1.26	2.33	2.14	1.99	W1	1.32	2.51	2.14	1.99
J2	1.26	(B)			W2	1.33	(A)		
K1	1.41	2.73	2.10	1.97	X1	1.31	2.47	2.14	1.99
K2	1.41	(A)			X2	1.31	(B)		
L1	1.28	2.30	2.16	1.98	Y1	1.30	2.38	2.15	1.98
L2	1.29	(A)			Y2	1.29	(A)		
M1	1.30	2.47	1.16	2.00	Z1	1.27	2.29	2.14	1.99
M2	1.30	(B)			Z2	1.28	(B)		

Notes:

The batteries were retrieved from one of the airfields at Fort Rucker, Alabama and taped together as pairs by ALSE personnel when the low battery indicator was reportedly activated. We added labels to each battery for identification purposes.

The heading "Initial unloaded" is the voltage of the individual batteries as we received them.

The "Initial loaded" heading is the voltage of the paired batteries after approximately 1 minute when connected to the ANVIS. The "Final loaded" heading refers to the voltage under load when the battery test was terminated at or below 2.0 volts.

In the "Final unloaded" column, voltage was measured 1 minute after the ANVIS had reached the "Final loaded" point and was turned off.

Batteries labelled "A1 and A2" were the first batteries tested and were measured without the use of the automatic recorder. A digital watch, the modified dual battery pack, an ANVIS, and a digital voltmeter provided the necessary equipment for the manual measurements.

Batteries labelled "B and C" had voltages less than 2.0 volts when initially loaded, and therefore were not included in the data analysis. These batteries had either shorted out before we received them, or the pilots had used them as lip lights until they had expired and turned them in as expired primary batteries with the ANVIS.

Batteries labelled "H and T" are obviously new or almost new. The pilots must have confused the two battery cartridges and implicated the wrong battery pair that had activated the low battery indicator, or the ALSE personnel made the mix-up.

In the "Initial loaded" column, the letters (A) and (B) under the voltage values refer to the specific channel used in the dual battery pack. In the beginning of the project, we did not know if there was a difference in current drain between the two battery channels of the dual battery pack, and we attempted to balance the number of batteries tested in each channel. Below the 2.4 voltage value that activates the low battery indicator, the red LED is connected to both channels, and therefore there is a little cross talk from the current drain between the channels. We elected to keep the battery chamber empty that was not being tested in the dual battery pack to insure the battery drain was maximized.

Some of the batteries that were connected to the ANVIS were drained well below the 2.0-volt desired end point at the termination of the test, such as "C, F, and T." The researchers were either distracted and did not terminate the test immediately after the 2.0-volt level had been reached, or the test had been run overnight and the voltage at 0730 (7:30 a.m.) was much less than 2.0 volts.