Flight Tests of the KO-1 Aircraft at Night

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The KO-1 aircraft which has the functionality of tactical observation, was successfully developed in August of 2004 in South Korea. It is important for the KO-1 aircraft to achieve successful missions at nighttime as well as during daytime. The aircraft, equipped with interior and exterior lighting systems and lighting control panel modified from those of the KT-1 basic trainer, provides improved safety, operational effectiveness, and situational awareness during operation at night when used with night-vision goggles (NVGs). KO-1 is the first domestic aircraft that utilizes the night-vision imaging system (NVIS) technology in Korea. KO-1 NVIS was developed with the goal of defining the components of NVIS and establishing test and evaluation procedures for both the subsystems and main system. In this paper, we present the establishment of a KO-1 NVIS lighting system, NVIS component development, and representative ground and flight test results.

Key Words: KO-1, Night-Vision Imaging System (NVIS), Night-Vision Goggles (NVGs), NVIS-Compatible, Flight Test

1. Introduction

Since 1990, technologically advanced countries have utilized aircraft with night-vision imaging systems (NVIS) and night vision goggles (NVGs) to maximize the pilot’s mission and achieve particular missions at night. Through the NVIS and NVGs, it became possible to effectively accomplish night flight missions as they provided increased tactical capability, close air support, approach at low altitude, psychological peace for the pilot, etc. NVGs allow the user to see more things at night in a more natural way than unaided vision. The primary reasons for using NVGs are to increase safety, operational effectiveness, and situational awareness at night.

The Korean government began pursuing the development of the KT-1 low-speed forward air control (LSFAC) aircraft (KO-1 aircraft) for use by the Republic of Korea Air Force (ROKAF) as a succeeding program to the KT-1, a primary training aircraft, in 1999.

The KT-1, which has two seats in tandem, was upgraded to an observation aircraft with LSFAC capability. The primary purpose for the KT-1 LSFAC aircraft is to replace ROKAF O-2s, currently being used. The mission goal of this aircraft is to acquire enemy movement and topographical data, and to perform reconnaissance flights at low altitude during day and night. Especially during night, the KT-1 LSFAC aircraft is needed to maximize missions by acquiring correct visual information of enemy sites while flying at low altitude.

The KT-1 LSFAC is newly equipped with the NVIS for nighttime operations, along with a head up display (HUD), multi-function display (MFD), global positioning system (GPS), inertial navigation system (INS), mission computer (MC) with a weapons management and delivery system, and external fuel tanks. To accommodate these systems, the cockpit and external layouts of the KO-1 have to be different from those of the KT-1. Figure 1 shows the front cockpit and external layouts of KO-1.

The NVIS, the first night-vision enhancing system developed in Korea, became mandatory for the KO-1 lighting system by ROKAF. The KO-1 NVIS was developed with the intention of defining sublevel systems and determining which of these defined subsystems can be produced domestically. The development also established both component and system level test and evaluation procedures.

Through NVIS development for the KO-1, the technologies of NVIS were obtained in the form of developmental requirement specifications, system specifications, establishment of test and evaluation, developmental test, operator suitability test, and standardization. The KO-1 is currently in mass production in Korea.

In this paper, the developmental process for the KO-1 NVIS is introduced. This system is comprised of internal NVIS-compatible cockpit lighting, external NVIS-compatible lighting and a lighting control panel. Section 2 gives the role of NVIS and the types of NVGs used for ROKAF. Section 3 explains the establishment of the KO-1 NVIS. Section 4 introduces component test results and efforts taken to resolve unsatisfactory performance issues. Sections 5 and 6 present ground and flight test results. Section 7 contains concluding remarks and future works.

2. Role of NVIS and Types of NVGs

The role of the NVIS is to intensify available nighttime near-infrared radiation (600 nm to 930 nm) sufficiently to be visible to the eye on a miniature green phosphor screen. Nighttime infrared radiation comes from such sources as starlight, moonlight, etc. These sources are illustrated in...
Fig. 2, and typical irradiance values of sources of natural illumination at night are shown in Table 1. Relative irradiation response of night sky has an excellent feature at the wavelength of between 630 nm and 930 nm. The intensification process of NVGs at wavelengths of this region is used. In Fig. 3, the normalized characteristic response of the KO-1 NVGs (Type 1, Class C) is shown in relationship to the CIE photopic curve and night sky irradiation. KO-1 NVGs (KAN/AVS-9) are manufactured by Samsung-Thales.

The outside images of the KO-1 are seen using NVGs with a 40-degree field of view (FOV). The view through the NVG eyepiece is called NVIS phosphor-screen image. The pilot must glance down to see his instruments. The concept of KO-1 operation is shown in Fig. 4.

3. KO-1 Lighting System Establishment

The KT-1 has been modified for the crew station layouts, avionics suite, etc. to become the first KT-1 LSFAC prototype aircraft. Newly added HUD, MFD, and existing electronic displays are provided with NVIS compatibility by the original equipment manufacturers (OEM). The modification for NVIS compatibility is applied to all the standard light sources in the crew stations and to the exterior light sources. The KO-1 lighting system is operated through a 28 V DC power source only.

The retrofit of NVIS technology into existing the KT-1 crew station lighting system places extraordinary emphasis on the human factor design issues relating to pilot visibility and performance. With NVIS equipped, the crew members require the least amount of crew station lighting that will continue to provide both accurate and rapid retrieval of critical flight information. At these low operational light levels, lighting design parameters encompassing uniformity, balance, and color become critical factors in achieving an efficient and safe NVIS cockpit lighting design. Specifying MIL-STD-3009 alone will not necessarily ensure success in achieving a good cockpit lighting design. Combined with common sense and established lighting design practices, however, the probability of success is greatly increased.

At the first design stage, the KT-1 lighting sources are incandescent. The introduction of electro-luminescent (EL) lighting into existing incandescent lighting systems raises concerns not only about overall system effectiveness, but about pilot safety as well.

In the aspects of system integration, the specifications require that the number of different light sources and power be kept to a minimum in any given aircraft installation. It is known that mixing EL with incandescent lighting systems creates particular problems in overall system design such as light output, size of lamp, power dissipation, thermal consideration, dimming characteristic, brightness, and environmental conditions.
The KO-1 lighting system should be modified to be compatible with Type 1, Class C NVG as defined in MIL-STD-3009. The modification retains normal daylight and nighttime operating capabilities of the KO-1. The existing 28 V DC power source should supply power to all lighting components. Existing lighting controls shall retain the same lighting units and their positions shall remain the same.

The NVIS-compatible interior lighting system of the KO-1 satisfies the illumination levels, chromaticity, and NVIS radiance limits in accordance with MIL-STD-3009. The system also meets the requirements of luminance uniformity and crew station reflections specified in MIL-STD-3009. An indirect-type modification method is applied to KO-1 NVIS components. It is shown in Fig. 5.

The KO-1 interior lighting system is comprised of instrument lighting, console lighting, warning and caution lights, other indicators, flood and utility lights, and landing gear handle lights. Modifications to KO-1 NVIS components are shown in Fig. 6.

The subsystems of KO-1 can be grouped into three types: domestically developed subsystems, OEM subsystems, and domestically modified subsystems (i.e., OEM products which are assembled domestically). The percentage occupation of these types is shown in Table 2.

Table 2. Three types of development for KO-1 NVIS.

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<tr>
<th>Type</th>
<th>Implement and modification</th>
<th>Percent of occupation (in number of components)</th>
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<tr>
<td>Domestic Development</td>
<td>Bezel and Decal Panel</td>
<td>61%</td>
</tr>
<tr>
<td>OEM</td>
<td>Replacement Panel</td>
<td>6%</td>
</tr>
<tr>
<td>Modification</td>
<td>Modification Display Lighting</td>
<td>33%</td>
</tr>
</tbody>
</table>

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It is important that consideration of an exterior lighting design or modification for NVG operation begins at the same time as NVG-compatible cockpit lighting is contemplated. Exterior lighting should be modified in order to ensure the most effective tactical utilization of NVGs. The integration of exterior lighting systems requires the system designers to consider the current operational mission requirements associated with NVIS compatibility and low observable airframes. The KO-1 exterior lighting system is comprised of a pair of landing/taxiing lights, two position (for navigation) lights at the leading edge of each wing-tip fairing, a pair of anti-collision strobe lights about 7 inches aft of the position lights, and three tail (for navigation) lights at the trailing edge of each wing-tip fairing and at the aft body fairing. Two position lights and three tail lights are modified to be NVIS-friendly. The term NVIS-friendly is used to describe exterior lighting that is visible to the naked eye, yet compatible with NVG operation by limiting near-infrared emissions. There is no specification to measure NVIS-friendly compatibility. The KO-1 is newly equipped
with four flashing and four position infrared (IR) lamps to provide IR covert capability. These covert lights should not be seen either from the front of the aircraft or from the ground. Normalized characteristics of NVG-compatible lighting, GEN III NVG response, NVIS-friendly lighting, and IR-covert lighting are shown in Fig. 7.

All the existing lighting components are modified to be NVIS-friendly except for the landing/taxiing and anti-collision lights. The landing lights are not modified since they are not used with NVGs. In Fig. 8, the exterior layouts and types of lamps are shown.7,8)

Brightness control of the interior lighting system is divided into three sections: instrument panel, console panel, and flood lights. In the case of the exterior lighting system, the position, tail, and strobe lights are controlled by one switch (NAV/STROBE), which is located on the right console of the front cockpit. IR coverts are controlled by two switches (COVERT and EXTERIOR), which are located on the right console of the front cockpit. An on/off switch for the landing lights is on the left switch panel of the front seat instrument panel only. The position and function of the lighting control panel is shown in Fig. 9.7,8)

4. NVIS Developmental Efforts and Component Test Results

The interior and exterior lighting components to be evaluated are designed to be compatible with any NVGs that utilize GEN III image intensifiers meeting the specifications of MIL-STD-3009.

Among the NVIS components, the domestically developed components are the decal panel and bezel. The decal panel is composed of a housing (upper side) with diffusion material, printed circuit board (lower side), bushing, NVIS ring filter, MS90335 connector for power supply, etc. The housing is painted with three coatings. Two layers of white paint are first applied and those are followed by a black paint coating. A laser is then used to strip portions of the black paint to create white legend markings. In the process of testing, it was noticed that the legend marking of the decal panel housing changed color: from white to yellow. This creates performance problems since yellowish markings do not provide sufficient visibility when incandescent lamps are activated inside the housing. Upon investigation, it was recognized that there is a critical drying time after paint is applied to the housing.11) The bezel is composed of aluminum, NVIS film, a clamp, lamps, silicon for light leakage, etc. In Fig. 10, disintegration diagrams of the decal panel and bezel are shown. The environmental tests for those items were successfully accomplished.12)

The KO-1 annunciator panel (central warning system (CWS)) should satisfy both daylight readability and nighttime readability. The CWS consists of housing, overlay panel, lamps, electromagnetic interference (EMI) mesh screen (non-conductive), etc.13) The legend of the CWS front panel is shown in Fig. 11. At first, the EMI mesh screen did not meet daylight readability requirements. A major area of concern is the mesh screen located between the faceplate and light plate attached to the faceplate. An attempt was made to improve daylight readability by removing the mesh screen inside the CWS and designing an overlay panel to diminish the EMI effects. The unit was tested to verify that the system can meet the required EMI and radio frequency interference requirements.
EMI tests were performed at the following frequencies: 2 MHz to 18 GHz for RE102 test; and 10 KHz to 18 GHz for RS103 test. An antenna was fabricated and located in front of the display, diagonally across the array.

RE102 and RS103 tests were performed per the specifications of MIL-STD-461D to ensure that the system meets the required EMI requirements. The test results are shown in Fig. 12 in the vertical and horizontal directions. In Fig. 12, the smooth solid line is for the requirement and the other darker line is for the test result.

The performance factors for components are luminance, chromaticity, contrast, uniformity, NVIS radiance, light leakage, gloss, resistance insulation, circuit continuity, etc.\textsuperscript{14,15} In the case of the KO-1, the specification for chromaticity is reinforced so that chromaticity resides inside the shape of a half-moon, to achieve lighting uniformity and balance.\textsuperscript{16} The test sheets and chromaticity test results are shown in Fig. 13.\textsuperscript{13}

5. Ground Test Results

Ground trials allow the ROKAF pilot and co-pilot to evaluate each modification under a restrictive environment. The test area must be light-tight and free from unfiltered light as much as possible. The resolution target should be irradiated so that NVIS radiance of the white portions of the resolution target is equal to $1.6 \times 10^{-10} \text{NR}_b$.\textsuperscript{17}

Ground test items consist of lighting functional inspection, unaided eye inspection, NVIS-compatible tests,\textsuperscript{17} daylight readability, nighttime readability, visual acuity,\textsuperscript{18} and NVIS radiance. Among these NVIS-compatible tests, visual acuity plays an important role. The visual acuity test results of the KO-1 are shown in Fig. 14.\textsuperscript{13} The evaluation criterion of the visual acuity test is less than two steps with respect to the baseline condition (i.e., no lighting).

After evaluating ground test results, it was verified that not only the KO-1 interior and exterior lighting systems, but also the brightness control panel meets the requirement specifications.\textsuperscript{15} Preparations were then made for intra-electromagnetic compatibility (EMC) assessment for flight tests. The intra-EMC test results of the KO-1 are shown in Fig. 15.\textsuperscript{19}
Fig. 13. Component test results: (a) test sheets and (b) chromaticity.

Fig. 14. Ground test result for visual acuity.

Fig. 15. Intra-EMC test results (test matrix) for KO-1.
6. Flight Test Results

Prior to conducting flight test evaluations for the modified NVIS interior and exterior lighting, the test aircraft is required to successfully complete the required EMC and ground test.

The flight test for KO-1 NVIS lighting compatibility is accomplished in the best way under low illumination conditions (no moon and far away from city lighting). Although test results are verified mostly during ground testing, there are some tests that must be evaluated only during flight (e.g., exterior lighting effectiveness, effects of reflections on windows or canopy, etc.). The flight test procedures are uniquely conducted by the Agency for Defense Development (ADD) and ROKAF for evaluating the effectiveness of NVGs for specific functional, tactical or other mission-related requirements of the KO-1.

It is planned that the ROKAF pilot personnel participating in the flight tests for NVIS lighting development to undergo applicable training that covers the technical characteristics of NVGs, which includes pre-flight adjustment and focusing procedures. They are to be familiarized with the system limitations, and human-factor issues associated with NVG-aided flight operations.

To determine the adequacy and compatibility of modified lighting components during both NVG and non-NVG flight operations, qualitative evaluations were conducted using pilot and co-pilot questionnaires. The questionnaire/procedure provides an evaluation checklist and scaled rating to be completed by each pilot/co-pilot evaluator in addition to space for subject comments.

The flight test evaluation rating scale allows the pilot/co-pilot to rate each modification on a scale from one (1) to five (5). A rating of “1” (poor) is used to indicate that the applicable modification is unacceptable and requires corrective action. A “2” rating (fair) indicates a marginal modification that may require further evaluation and/or corrective action. A “3” (average), “4” (good), or “5” (excellent) rating indicates that the modification is operationally suitable, and meets or exceeds the minimum acceptable requirements for safe and effective flight operations.

A list of parameters that is assessed when the modified KO-1 NVIS interior and exterior lighting design is evaluated is shown in the following. The individual evaluation parameters to be addressed are dependent upon the type of lighting (component) evaluation, the flight condition, and whether or not NVGs are utilized. Table 3 shows interior and exterior evaluation parameters.

In the phase of takeoff and landing, NVGs are not worn. NVGs are stowed during takeoff and landing. NVGs are not worn until at least 2,000 feet above ground level (AGL) when climbing or in level flight and terrain clearance is ensured.

Six sorties for KO-1 NVIS flight tests were performed. Flight test results are shown in Fig. 16 (for front cockpit only). The cockpit instrument and console received eight “average” and 30 “good” evaluation ratings. In the case of flooding and utility lights, they received seven “good” ratings. Warning, caution, and indicator lighting received three “average” ratings and 13 “good” ratings. In the case of the HUD symbol, three “good” ratings were received. The overall cockpit rated “good”. External lighting also rated “good”. IR covert confirmation distance is above three nautical miles (NM) in MIL-STD-3009.

7. Conclusion and Future Work

ADD successfully finished the development of the KO-1 aircraft on 31 August 2004. The KO-1’s NVIS lighting system is comprised of an internal lighting system, external lighting system, and lighting control panel. There are three types of development for NVIS components. These are domestic development, OEM, and domestic modification. Among them, 61% of the system components are domestically developed. The region of chromaticity is reinforced inside the shape of a half-moon. Through respective component tests, it was verified that our system meets all the requirements for KO-1 NVIS compatibility. Considerable efforts were required to resolve the unsatisfactory performance problems of domestically developed subsystems. The CWS daylight readability problem, which was discussed in previous section, was also successfully resolved during this development. Ground and intra-EMC tests, which were performed to evaluate each modification under a restrictive environment, were executed with the assistance of a ROKAF pilot/co-pilot. The flight test procedures for NVIS lighting systems were uniquely conducted by the ADD and ROKAF to evaluate the effectiveness of NVGs for KO-1 aircraft. Six flight sorties were needed for the tests. Flight test results verify that our development suits the KO-1 NVG mission purpose. Through development of the KO-1 NVIS lighting system, the foundation of NVIS component manufacturing and NVIS test and evaluation methodology has been established. The data and experience achieved here will play key roles in analyzing and improving NVIS and NVG development technology in Korea, and can be applied to future fighter systems.

Table 3. KO-1 NVIS evaluation parameters.

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<tr>
<th>Section</th>
<th>Lighting Parameters</th>
<th>Mechanical Parameters</th>
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<tr>
<td>Interior</td>
<td>Display Luminance</td>
<td>Interference</td>
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<td></td>
<td>Illuminance</td>
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<td>Contrast</td>
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<td>Uniformity</td>
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<td>Color Cueing</td>
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<td>NVG Compatibility</td>
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<td>Daylight Readability</td>
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<td>Exterior</td>
<td>Intensity</td>
<td>Cockpit Interference</td>
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<td>Color</td>
<td>Distribution(Coverage)</td>
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<td>NVG Friendliness</td>
<td>Controls</td>
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<td>Minimum Distance(Covert)</td>
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