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PROJECT CHECO SOUTHEAST ASIA REPORT

GUIDED BOMB OPERATIONS IN SEA: THE WEATHER DIMENSION, 1 FEB - 31 DEC 1972

DABIN #Ø58Ø238

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REPLY TO
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TO: AFSHRC/CC

1. The list of CHECO reports you sent to us with your letter of 3 January are releasable as far as PACAF Public Affairs are concerned. When referring to CHECO documents, it's most helpful if you include the number assigned in the Research Guide you published in 1976.

2. We will be sending you the Air America documents as soon as we can spare the time to pack them up--we need the vault space.

3. Am retiring at the end of this month, so you probably won't be hearing from me again. It's been nice knowing you and working with your very supportive organization. Best wishes for the future.

Jim
JAMES C. NOLAN
Chief, Office of PACAF History

cy to HO, 24 Jan 83

UNCLASSIFIED/DECLASSIFIED CHECO REPORTS

1. Project RED HORSE (Unclassified), by Derek H. Willard, 1 Sep 1969 K717.0413-68

2. USAF Aerial Port Operations in RVN (Unclassified), by Jack T. Humphries, 5 Aug 1970 K717.0413-79

3. SEA Glossary 1961-1971 (Revised Report) (Unclassified), by E. J. Alsperger, 1 Feb 1972 K717.0413 76

4. OV-1/AC-119 Hunter-Killer Team (Declassified), by Richard R. Sexton and William M. Hodgson, 10 Oct 1972 K717.0413-34

5. Kontum: Battle for the Central Highlands 30 March-10 June 1972 (Declassified), by Peter Liebchen, 27 Oct 1972 K717.0414-30

6. PAVE MACE/COMBAT RENDEZVOUS (Declassified), by Richard R. Sexton, 26 Dec 1972 K717.0414-35

7. Air Defense in Southeast Asia 1945-1971 (Declassified), by Guyman Penix and Paul T. Ringenbach, 17 Jan 1973 K717.0414-36

8. The Battle for An Loc 5 April - 26 June 1972 (Declassified), by Paul T. Ringenbach and Peter J. Melly, 31 Jan 1973 K717.0414-31

9. PAVE AEGIS Weapon System (AC-130E Gunship) (Declassified), by Gerald J. Till and James C. Thomas, 16 Feb 1973 K717.0414-37

10. The 1972 Invasion of Military Region I: Fall of Quang Tri and Defense of Hue (Declassified), by David K. Mann, 15 Mar 1973 K717.0414-32

11. "Ink" Development and Employment (Declassified*), by B. H. Barnette, Jr., 24 Sep 1973 K717.0414-41

12. Guided Bomb Operations in SEA: The Weather Dimension 1 February - 31 December 1972 (Declassified), by Patrick J. Breitling, 1 Oct 1973 K717.0414-43

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GUIDED BOMB OPERATIONS IN SEA: THE WEATHER DIMENSION, 1 FEB - 31 DEC 1972

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HQ PACAF

Directorate of Operations Analysis
CHECO/CORONA HARVEST DIVISION

Prepared by:
Colonel Breitling
Project CHECO 7th AF

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DEPARTMENT OF THE AIR FORCE
HEADQUARTERS PACIFIC AIR FORCES
APO SAN FRANCISCO 96553

PROJECT CHECO REPORTS

The counterinsurgency and unconventional warfare environment of Southeast Asia has resulted in USAF airpower being employed to meet a multitude of requirements. These varied applications have involved the full spectrum of USAF aerospace vehicles, support equipment, and manpower. As a result, operational data and experiences have accumulated which should be collected, documented, and analyzed for current and future impact upon USAF policies, concepts, and doctrine.

Fortunately, the value of collecting and documenting our SEA experiences was recognized at an early date. In 1962, Hq USAF directed CINCPACAF to establish an activity which would provide timely and analytical studies of USAF combat operations in SEA and would be primarily responsive to Air Staff requirements and direction.

Project CHECO, an acronym for Contemporary Historical Examination of Current Operations, was established to meet the Air Staff directive. Based on the policy guidance of the Office of Air Force History and managed by Hq PACAF, with elements in Southeast Asia, Project CHECO provides a scholarly "on-going" historical examination, documentation, and reporting on USAF policies, concepts, and doctrine in PACOM. This CHECO report is part of the overall documentation and examination which is being accomplished. It is an authentic source for an assessment of the effectiveness of USAF airpower in PACOM when used in proper context. The reader must view the study in relation to the events and circumstances at the time of its preparation--recognizing that it was prepared on a contemporary basis which restricted perspective and that the author's research was limited to records available within his local headquarters area.

Robert E. Hiller
ROBERT E. HILLER
Director of Operations Analysis
DCS/Operations

DEPARTMENT OF THE AIR FORCE
HEADQUARTERS PACIFIC AIR FORCES
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REPLY TO ATTN OF: OAD

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V.H. Gallacher

V. H. GALLACHER, Lt Colonel, USAF
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ABOUT THE AUTHOR

(U) Colonel Patrick J. Breitling was Commander of the 10th Weather Squadron with headquarters at Udorn Royal Thai Air Force Base (RTAFB), Thailand. Formerly, as commander of Detachment 1, 10th Weather Squadron, Tan Son Nhut Air Base (AB), Republic of Vietnam (RVN), he took part in the planning for both LINEBACKER I and LINEBACKER II air operations against North Vietnam. During his 20 years in the Air Force, he has served as a detachment forecaster, weather reconnaissance observer, headquarters staff officer, special projects officer, and technical consultant. He received Master's and Ph.D. degrees from St. Louis University in radiation theory and atmospheric optics.

(U) During his tenure as Chief of the Aerospace Physics Division, DCS/Aerospace Science, Headquarters Air Weather Service, he worked extensively with several Department of Defense (DOD) agencies that design, test, and employ airborne photographic and electro-optical (EO) reconnaissance and sensor systems. In 1967, he developed computer techniques to simulate the effect on such systems of atmospheric attenuation (haze). These techniques were subsequently adopted by much of the reconnaissance and surveillance community. In 1970, he designed an Air Force-funded Atmospherics/Optics Measurement Program which produced atmospheric and photometric data that verified his theoretically-based techniques. In 1972, he assisted the Weapon System Evaluation Group in the study of atmospheric effects during the Operational Test and Evaluation (OT&E) of the Maverick EO air-to-surface missile.

FOREWORD

(U) The introduction of laser guided bombs (LGBs) and electro-optical guided bombs (EOGBs) into the United States Air Force (USAF) inventory revolutionized the air war in Southeast Asia. Targets which had withstood repeated conventional attacks by bombers--such as the Thanh Hoa Bridge in North Vietnam--fell quickly to the new weapons. Statistical studies made of the success rate of these weapons demonstrated that they were many times more effective than conventional weaponry on point targets.[1]

(S) In spite of this impressive record, the guided bombs were not as effective as they might have been. While they performed exceedingly well under optimum weather conditions, marginal to unfavorable atmospheric conditions degraded the capability of the aircrew to visually acquire the target. If the targets could be visually acquired by the aircrews at roll-in altitudes, they could be effectively attacked; if they could not be visually acquired, the LGB's effectiveness was eliminated since delivery was not possible unless special techniques were employed.* In the opinion of this author, weather was a more significant and detrimental factor than had been previously reflected in mission reports and other

---

*A limited adverse weather LGB delivery capability was successfully demonstrated during the PAVE NAIL OV-10 combat evaluation. OV-10s equipped with laser designators and operating below cloud cover located and illuminated targets for PAVE PHANTOM F-4s which would deliver MK 84 LGBs from in or above the clouds. The F-4 aircraft released the LGBs on LORAN coordinates provided by the OV-10s. Once these weapons passed through the clouds, they would guide to the target being designated by the PAVE NAIL aircraft. Of the 12 MK 84 LGBs delivered using this tactic, three achieved direct hits on the target, one impacted at a distance of seven feet from the target, four at 11-20 feet, one at 27 feet, one at 40 feet, and two in excess of 50 feet.

studies. In part this was the result of the crews' unfamiliarity with the sometimes subtle variances in atmospheric conditions that could degrade their weapon's effectiveness. Increased understanding of the relationships between weather conditions and guided bomb performance on the part of weathermen, crews, and mission planners could possibly increase guided bomb effectiveness in the future.

CHAPTER I

TECHNICAL ASPECTS OF THE EFFECT OF ATMOSPHERIC CONDITIONS ON GUIDED BOMB OPERATIONS

~~The LGB~~

(S) PAVEWAY I was the code name given to a family of air-to-surface weapons--the LGB.[2] The laser guided bombs consisted of guidance and control kits attached to the noses of certain standard high explosive bombs. No propulsion was used. The guidance and control kits consisted of (1) a seeker to detect 1.06 micron laser energy reflected from a target illuminated by an airborne laser, (2) guidance electronics to process this information and generate guidance commands, (3) fins to provide stability, and (4) a control section with control fins to perform guidance maneuvers. The common types of LGBs employed were the MK-82 500 pound bomb with the KMU-388/B kit, the MK-84 2,000 pound bomb with the KMU-351/B kit, and the M118 3,000 pound bomb with the KMU-370B/B kit. The seeker was gimbal mounted on a probe at the nose of the guidance and control kit. Wind passing through a ring-tailed fin on the seeker aligned the seeker head with the flight path of the weapon. The seeker had a 24-degree field of view, with its detector divided into quadrants. The reflected laser energy was focused onto a quadrant, developing guidance signals to maneuver the bomb so that the target was centered on the seeker head.[3]

(S) Illustrative of the airborne PAVEWAY I illuminator system lasers used to designate the ground target was the one called WHITE LIGHTNING or ZOT. This laser employed a neodymium doped glass rod as the primary

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energy producing element. The rod was excited by a Xenon flash lamp for a period of 40 nanoseconds, 10 times a second, and produced a beam of 1.5 megawatt intensity. A narrow bandpass filter (bandwidth 0.015 microns) passed only energy centered at 1.06 microns. The laser was aimed by means of a four-power sighting telescope with a field of view of 12 degrees. The laser beam aiming point and telescope cross hair image coincided. The reflected laser radiation was in the near-infrared spectrum and not visible to the human eye.[4]

(S) Following visual acquisition, the target* was continuously illuminated with the laser beam. This was accomplished by a self-illuminator delivery aircraft as in the PAVE KNIFE (F-4D) system or by another aircraft such as an OV-10 in the PAVE NAIL system. (See Figure 1.) For optimum performance the laser beam had to continuously paint the target from LGB release to detonation. The reflected laser beam appeared to the LGB seeker head as energy radiating from a point source. The seeker sensed the location of this energy relative to the field of view and generated appropriate guidance signals. These signals produced commands for the gas-operated control fins which guided the bomb to the source of the reflected energy. The recommended bomb release altitude was 10,000 to 14,000 feet above ground level (AGL) to allow the LGB time to acquire and "track" the target. Operating altitudes varied, however, with the terrain, weather, and enemy defenses. The bomb fell ballistically for

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*Note that the requirement existed to estimate an "offset aim point" for laser designation to compensate for winds during LGB deliveries. See p. 11, below.

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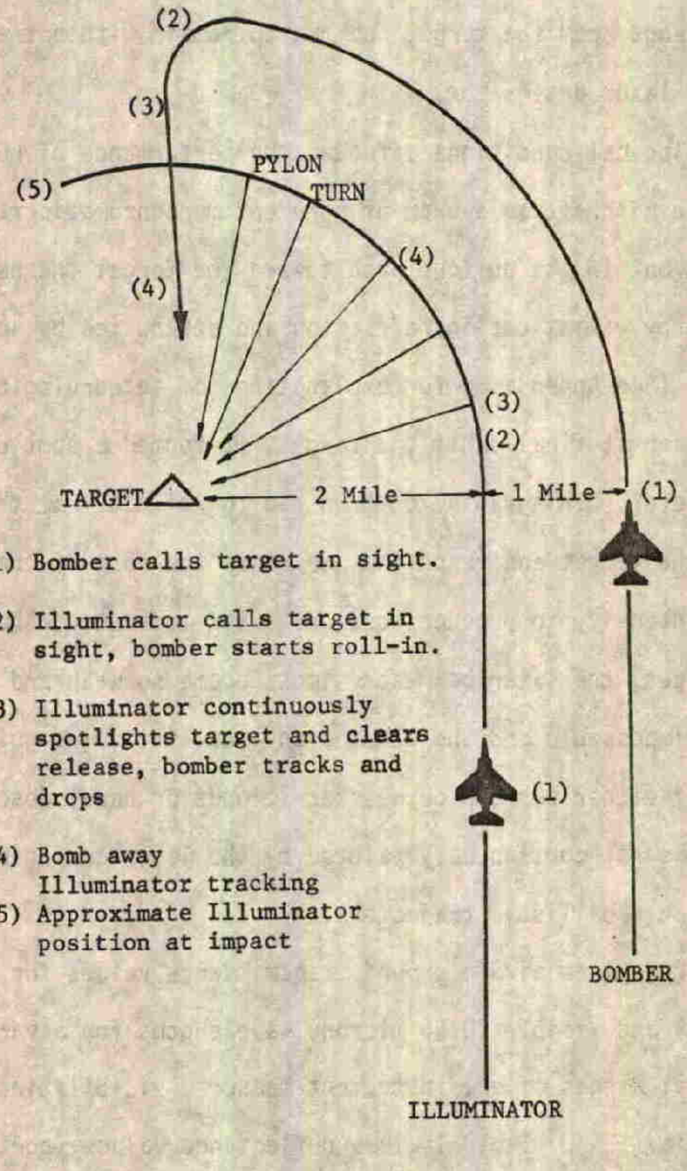

(1) Bomber calls target in sight.

(2) Illuminator calls target in sight, bomber starts roll-in.

(3) Illuminator continuously spotlights target and clears release, bomber tracks and drops

(4) Bomb away Illuminator tracking

(5) Approximate Illuminator position at impact

WHITE LIGHTNING
Low Threat Basic Delivery Concept

Figure 1

three seconds prior to starting its aerodynamic maneuvering. At all times during a bomb's fall, the illuminator aircraft could not exceed 25,000 feet slant range from the target and had to remain within the design limitations of the laser designator.[5]

(S) Meteorological conditions affected the performance of LGBs. The laser beam left the aircraft as a beam of coherent monochromatic radiation thinner than a hair, but in its oblique path toward the target the beam was bent and diffused by variations in refraction and attenuated by scattering and absorption. (See Appendix I for explanations of meteorological terms and effects.) When it finally hit the target, it formed a spot up to several feet in diameter. This radiation then had to reflect from the irregular surface of the target and reach the seeker in the nose of the LGB with sufficient intensity to produce lock-on. With moderate to heavy haze over the target, the laser beam sometimes became so weak and diffuse that lock-on was impossible and the bomb began a ballistic (no-guide) trajectory. Similarly, if either terrain or weather (clouds or haze) obscured the target so that it was not continuously painted by the laser during weapon guidance, the bomb began a ballistic trajectory.[6]

(S) Figure 2 depicts air to ground transmittance values for both laser (1.06 micron) and visible (0.55 micron) wavelengths for a variety of meteorological ranges, i.e., instrument-measured visibilities common to Southeast Asia (SEA). Table 1 gives reflectance values (portion of radiant energy reflected) for several common targets and backgrounds for the same two wavelengths. Note that most targets and backgrounds reflect more laser

AIR TO GROUND TRANSMITTANCE (T) OF RADIATION

Below Five Kilometers Altitude

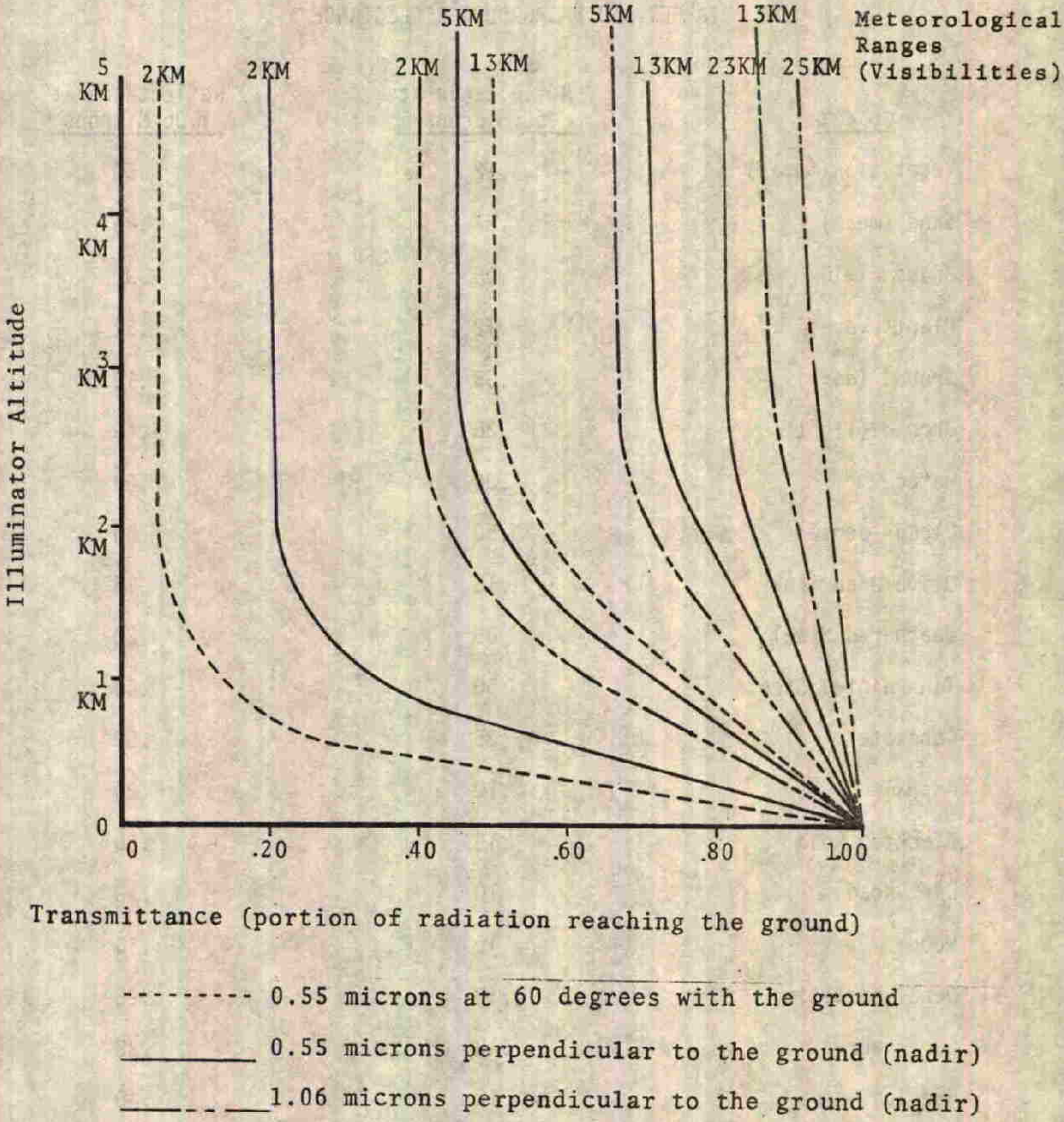

Figure 2

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TABLE 1

TARGET AND BACKGROUND REFLECTANCE

~~Object~~	Reflectance at ~~.55 Microns~~	Reflectance at ~~1.06 Microns~~
Vegetation (mean)	.12	.50
Sand (mean)	.27	.45
Grass Field	.06	.30
Plant Leaves	.12	.52
Ground (dark)	.05	.12
Ground (light)	.20	.45
Water	.04	.03
Cloud (dense)	.60	.50
Olive Drab Tank	.15	.15
Weathered Steel	.05	.20
Tan Painted Steel	.50	.40
Concrete	.25	.50
Asphalt	.10	.25
Blacktop Road	.15	.30
Dirt Road	.10	.10
Wood	.10	.15
Dead Vegetation	.10	.25
Earth Works	.10	.20
Red Soil	.10	.40

(1.06 microns) than visible light radiation. This gave the LGB an advantage over the EOGB in haze penetration because the EOGB operated in the visible spectral range; however, even the LGB could prove ineffective when the haze was heavy. For example, for a meteorological range (visibility) of 2 kilometers (km), and an aircraft flying at an altitude of 4 km (13,120 feet) acquiring a tan painted steel target, only about 6 percent (.40 T down X .40R of tan painted steel X .40T up) of the laser radiation leaving the illuminator got back to the seeker in the nose of the LGB. This was the case if the illuminator and the seeker were both pointing straight down. For oblique angles of view the transmittances were even lower. On the other hand, concrete runways (reflectance = .50) on a day with a meteorological range of 13 km (vertical transmittance .82) would return about 34 percent (.82T x .50R x .82T) of the laser radiation leaving the illuminator. Surface irregularities on some targets could also cause the reflected energy to be scattered in varying amounts and in all directions from the target. Some targets, such as gun revetments, can at times act as laser energy "sinks" and return little or no radiation.

<u>The EOGB</u>

(S) PAVEWAY II was the code name given a sophisticated weapon using self-contained television (TV) as a means of guidance. The MK-84 Electro-Optical Guided Bomb consisted of a KMU-353/B guidance and control kit mounted on the nose of a standard 2,000 pound MK-84 general purpose bomb. The KMU-353/B kit consisted of a guidance section, a control section, four stabilizing strakes, and an external electrical conduit. The guidance section consisted of a gyrostabilized platform, a five-inch focal-length TV system (with 525 raster scan lines), an electro-optical contrast tracker, and associated electronics. The EOGB system sensitivity was defined as the lowest apparent contrast level which the seeker had the capability to track and was, in part, affected by weather conditions. Apparent contrast is defined as the difference in brightness between a target and its background divided by the brightness of the background--$C_a = (B_t - B_b)/B_b$. A positive value for C_a indicates a target is brighter than the background, while a negative value indicates a background brighter than the target. To optimize weapon system performance a sensitivity threshold had to be determined. Initially, there was a requirement that the EO system be able to track a contrast edge which produced an apparent contrast of 0.25 at the entrance pupil of the TV seeker. This value, however, was found to be too high since the system locked onto only those targets which had a well defined black-white edge. It was also found that an EO system which would react to an apparent contrast as low as 0.15 would produce equally undesirable side effects. As the weapon approached the target, it would detect even minor contrast edges within its field of view and could be decoyed away from the primary target. A sensitivity setting of approximately 0.20 was finally selected to give the weapon an acceptable standoff capability against most targets, even during less than ideal weather conditions.[7]

(S) Target size and configuration were also important factors. Adequate lock-on required a sufficiently long vertical contrast edge within the field of view of the seeker. At the center of the TV seeker was a gate produced by two vertical and two horizontal lines in a "tic-tac-toe" pattern. This gate was large enough to hold six scan lines at one time. The EOGB was designed to maintain lock-on from release to impact when at least three of these six lines intersected the target contrast edge. For this, the target height had to fill half of the 1.3 mil gate, that is, be 0.7 mil high. Since one mil is the angle subtended by one foot at a distance of 1,000 feet, the height of the target determined the maximum slant range at which a target could be bombed. For example, a seven-foot long vertical edge could be bombed at a maximum slant range of 10,000 feet, because this was the point at which the seven-foot target would produce a sensor image.[8]

(S) Atmospheric haze degraded weapon efficiency by reducing the target/background contrast. At zero distance, the contrast between a target and its background is called inherent contrast. The apparent contrast is always less than the inherent contrast because of weather-caused atmospheric attenuation which occurs in the airspace between the sensor and the target. The greater the distance from target to TV seeker and the more turbid (optically dense) the air, the bigger the difference between the apparent and inherent contrast. Haze scatters target imagine-forming light <u>out</u> of the field of view of an optical sensor and also scatters <u>in</u> non-image-forming light. The apparent brightness of a ground target as seen from an altitude z, B_t^z, is equal to the inherent brightness at ground level, B_t^0, times the path transmittance, T, plus the haze-induced brightness, B*. Thus, $B_t^z = B_t^o T + B^*$. A similar equation holds true for the brightness reaching the sensor from the background, $B_b^z = B_b^o T + B^*$. Thus, at altitude z, the apparent contrast (C_a), already defined, equals $(B_t^z - B_b^z)/B_b^z$. The non-image-forming light or haze light (B*) is frequently called path brightness. Path brightness is a function of the length of the viewed path, its angle relative to the sun, the size and density of the haze particles, and the wavelength of the radiation. The effects of path brightness may be verified by the reader by looking straight down from an aircraft and then slowly scanning towards the horizon. The sudden drop-off in scene contrast is obvious. Additional visual scans at different angles to the sun reveal the well-known phenomenon (predicted by scattering theory) that looking into the sun produces maximum path brightness and contrast loss, while a smaller secondary maximum is found by looking directly down-sun. Angles 90 degrees to the plane of the sun usually produce the least contrast loss.

~~Additional Weather Factors Affecting Technical Operations of All Guided Bombs~~

(S) Other weather conditions also adversely affected the operation of guided bombs. First, the wind velocity and the wind shear below the attacking aircraft were important factors in determining guided bomb accuracy. Strong winds or large vertical wind shear caused significant downwind impact errors because the guidance and control units could not adjust in time to compensate for sudden changes in either wind direction or speed during freefall. It was, therefore, desirable to plan the release heading either directly upwind or downwind. Since the wind speed and direction over enemy territory was seldom known with any degree of accuracy, the pilot estimated these parameters from such observable phenomena as the movement of smoke near the target. For this purpose, FAC-assisted tactics usually involved the use of smoke rockets. The illuminator pilot estimated the wind field below the attacking aircraft and corrected the aim point of the laser designator relative to the target. No correction was used for winds less than 10 knots. A lack of wind over the target could be equally troublesome because multiple strikes on a target were not possible if the smoke and dust produced by the impact of the initial LGB or EOGB were not blown away by the wind prior to additional strikes. Secondly, attacking aircraft flying through rain clouds could degrade the performance of LGBs and EOGBs because precipitation damaged the face of the bombs' seeker heads.

CHAPTER II

THE WEATHER: IMPACT ON PLANS AND OPERATIONS

(S) The impact of weather on guided bomb plans and operations was frequently mentioned by General John W. Vogt, Jr., Commander of Seventh Air Force (7AF), in messages he sent to General John D. Ryan, USAF Chief of Staff, during the North Vietnamese 1972 spring and summer offensive. The following are excerpts from a few of those messages:

> [021200Z June 72] The last two strikes on the power plants were below our standards and for this reason I visited Ubon today to work out any problems they may have. I am reasonably confident our difficulty was weather, and not pilots or systems. Cumulus clouds were drifting across the laser beam in both instances and probably account for the less than precise bombing.

> [061130Z June 72] Weather, once again, interfered with optimum use of laser pods. . . .

> [101125Z June 72] Weather caused us many anxious moments today. . . . Weather reconnaissance flights indicated unworkable weather until just before noon, and marginal weather at that point. Trusting the weatherman's forecast, we launched the force with a 1515 TOT [time over target]. . . . The first flight found the target clear and rolled in with a successful run.

> [261020Z August 72] With laser work a few clouds in the local target area can disrupt the entire mission, as happened yesterday, even though the general area had only 3/8ths cloud coverage.

> [011031Z September 72] I am attempting to achieve as much damage to the northeast rail line as is possible with the few remaining weeks of good laser weather just ahead of us.

> [091140Z October 72] In reviewing LINEBACKER operations of the last several weeks, one thing is apparent. The transitional weather associated with the pending monsoon shift is causing many problems for visual strike operations and especially laser guided weapons delivery.

(U) Since weather conditions did affect the technical operation of guided bombs, general as well as specific weather problems had to be addressed in areas where such weapons would be employed. Two factors, topography and monsoon winds, influenced the general state of the weather in southeast Asia. The probability that a particular target would be workable depended on (1) its location relative to the Annam Mountain Range, which parallels the coast of Vietnam, and (2) whether the Northeast or Southwest Monsoon was the dominant weather system.

~~The Northeast Monsoon~~

(U) The Northeast Monsoon, so named because the low level wind flow is predominantly from the northeast, begins in late October and lasts through mid-March. The wind flow is across the water and brings clouds and rain to those portions of North Vietnam and upper South Vietnam between the sea coast and the mountains. The Annam Mountains served as an effective natural barrier in preventing the penetration of moisture to the interior regions of SEA. Consequently, the Northeast Monsoon brings relatively dry and cloud-free weather to Laos, Thailand, Cambodia, and southern South Vietnam. The passes between North Vietnam and the Ho Chi Minh Trail are often cloud-free during this time of year, but this depends on the strength of the winds and the amount of clouds which spill over the mountains and cover the Trail. During the late winter and early spring the farmers burn their fields, and heavy smoke haze often reaches to 20,000 feet. Horizontal visibilities aloft of less than three miles and vertical visibilities of only a few thousand feet are common during this period. During the two hours after sunrise and before sunset, slant range visibility, especially into the sun, is extremely limited, severely affecting air operations. In addition, the North Vietnamese deliberately set fires to hamper U.S. military operations.

~~The Southwest Monsoon~~

(U) The spring transition period begins in mid-March. Low level wind flow gradually turns southerly in April and by May southwesterly winds prevail over most of SEA. By this time cloudiness and rain over interior regions have increased significantly. The Annam Mountains again act as a barrier, and so much of North Vietnam is relatively cloud-free. The Ho Chi Minh Trail, which averages one or two inches of rain during the Northeast Monsoon, now experiences its wet season and vehicular traffic is severely retarded. September is the last month of the wet season over the interior. By the second half of the month the autumn transition period begins. From mid-September to mid-October, a significant decrease in connected cloud activity and precipitation occurs over interior SEA. By late October, once again, the Northeast Monsoon begins to dominate the general weather pattern.

Mission Planning

(S) Weather played an important part in mission planning. A major limitation on tactics involving both LGB and EOGB weapons systems was that good weather was essential for long-range standoff delivery. Clouds, haze, high winds, and precipitation all reduced the effectiveness of such weapons. Accurate forecasts were a major factor in achieving successful guided bomb strikes. A clear line of sight to the target was an absolute necessity. In the case of the LGB, the laser illuminator could not penetrate even the thin clouds. The EOGB had to "see" the target to acquire and lock on prior to release. For planning purposes, three-eighths or less cloud cover below 18,000 feet and visibility greater than three miles were considered favorable for LGB and EOGB operations. Four-eighths and five-eighths was marginal, and six-eighths or more with visibility less than three miles was unfavorable. While the cloud cover over enemy territory could be observed with meteorological satellites and forecast with acceptable accuracy, the visibility could not be remotely measured or forecast with the precision required for optimum EO system performance. As already mentioned, above, visual recognition/identification was the *sine qua non* of guided bomb tactics. Given that the cloud cover over a target was less than three-eighths, the probability of mission success was still uncertain because of the low-level haze common to SEA. Even after pre-strike weather reconnaissance appraised the target weather as favorable for tactical operations, rapid changes in the haze level sometimes produced unacceptable or unworkable conditions by the planned TOT. Consequently, many strikes diverted to secondary targets because the primary target was unworkable. Cloud forecasts for guided bomb operations were routinely given to mission planners 24 hours in advance and updated six to eight hours prior to TOT. Visibility, or more properly "seeability," forecasts were also prepared, but with less confidence. The impact of "seeability" on tactical air operations will be discussed in greater detail later.

(S) Another important aspect of mission planning was intensive and thorough target study. Successful LGB and EOGB strikes demanded painstaking preparation on the part of the Intelligence, Operations, and Plans staffs and a detailed prestrike briefing of the aircrew involved. Terrain features, cultural areas, target dimensions, target construction, and the similarity of nearby features to targets were but a few of the things that had to be known and understood thoroughly. In addition to these factors, EOGB strikes required special preplanning which considered sun angle and shadows. Shadows could create either desirable or undesirable contrast edges from the target or adjacent objects, respectively. Since the spectral response of the pilot's eyes and the EOGB are similar, the pilot's ability to clearly see and identify targets was normally a valid indication that an EO system could hit them. Aircraft headings into or away from the sun were avoided since they produced maximum target contrast loss. Reconnaissance photos of the targets were studied to determine the best contrast edge for the planned aiming point. Targets which had several identical contrast edges that could simultaneously appear within the field of view of the TV seeker were particularly difficult to hit successfully.

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A good example is a bridge with several vertical concrete supports. The EOGB TV seeker, unable to decide which of several equally well-defined edges to lock onto, would shift its focus from one bridge support to the next and finally impact the river bank at one end of the bridge. It was, therefore, imperative that the pilot select an area on the target with only one high contrast edge appearing on his scope. This would normally preclude the EOGB from being decoyed in flight by other contrast edges.[9]

(S) Another weather-related factor considered by mission planners was the use of smudge pots by the North Vietnamese to obscure large, important targets and degrade guided bomb effectiveness. In such instances, a weather forecast of conditions which would result in rapid clearing of any smoke accumulations and a reasonable chance of mission success prompted planners to strike the target with guided bombs. A forecast of light winds and heavy haze conditions, on the other hand, usually resulted in planners moving guided bomb missions to other target areas.

Operational Employment of Guided Bombs

(S) The "seeability" in the neighborhood of the target directly influenced both the attacking altitude and the total time spent over the target. Thus, weather-caused atmospheric attenuation was an important factor affecting guided bomb tactics; it was directly related to the degree of hostility of the target environment.

(S) Over low threat areas with little or no defending ground fire, the attacking aircraft commander could fully employ all the potential inherent in guided weaponry. If weather factors precluded achieving a lock-on at

12,000 to 14,000 feet, he could descend, approach the target from a variety of headings to find a cloud-free line of sight, achieve the lock-on, and release the weapons with some certainty of target destruction. The "one bomb to destroy one target" concept of guided weaponry was most commonly achieved in a low threat environment under favorable weather conditions. Even if the first bomb missed the target in a low threat area, aircraft could remain in the area for additional deliveries.

(S) In an 11 September 1972 message concerning low-threat EOGB tactics, the 8th Tactical Fighter Wing (TFW) stated,[10]

> High angle deliveries are appropriate on bridges or targets with some vertical dimension. Only one weapon should be expended by each aircraft with a release altitude of 12,000 feet or greater AGL, 30 to 60 degrees dive angle and .82 to .90 mach. A minimum acceptable parameter would be a 10,000 foot AGL release; low angle deliveries are more desirable for caves and storage areas near karst networks. Weapons release should occur at 28,000-30,000 feet slant range, up to 30 degrees dive angle and .87 to .90 mach. This equates to a minimum release altitude of 4,900 feet for a 10 degree dive. It is imperative that a good lock-on be attained for at least 5 seconds before release to insure a good contrast lock during low angle deliveries. A flight of two aircraft is effective for both low and high angle deliveries. The lead aircraft can deliver separately, one weapon on one pass, while the wingman provides element support. The roles then reverse and the wingman expends his weapons.

(S) Note that, while not mentioned, the tactics just described demanded nearly ideal weather conditions. At 28,000 to 30,000 feet slant range, only very large, high-contrast targets (concrete runways, large bridges, etc.) could be "seen" by the EOGB TV seeker with the haze levels ambient over North Vietnam. For smaller, less well-defined targets, the moderate to heavy turbidity of the SEA air would force the attacking aircraft to descend to very low altitudes for lock-on.

(S) In high-threat areas the optimum launch altitude for LGB/EOGBs was 12,000 to 14,000 feet. While a broken to overcast middle cloud layer at 10,000 to 14,000 feet allowed the attacking aircraft to work beneath the clouds, the pilots usually preferred to stay above 10,000 feet because North Vietnamese antiaircraft artillery (AAA) was much less effective above 10,000 feet than below. However, flying at that altitude above an overcast also was dangerous since surface-to-air missiles (SAMs) could suddenly appear through the clouds, catching the attacking aircraft with little chance for evasive action. A prestrike weather forecast or reconnaissance report of marginal weather over targets in high-threat areas usually resulted in the cancellation of the planned bomb strike. High priority targets, however, were sometimes attacked even under marginal conditions.

(S) The target environments over the upper regions of North Vietnam were as hostile as any likely to be encountered anywhere by tactical aircraft. Tracked by enemy radar even prior to ingress, subject to SAM and AAA fire from below and MIG attack from any direction, the pilot quite naturally wanted to keep his total time over the target to a minimum. To quote the 8th TFW manual on mission employment tactics, "Timing is of the essence, the mission itself is simply a mass roll in, one pass, haul ass, and RTB (return to base) operation."[11]

(S) For such tactics to be successful, it was imperative that the amount and location of clouds or haze layers over the target be known. A pre-planned cloud-free attack heading sometimes had to be aborted due to line-of-sight problems, and another heading, while cloud-free, was possibly over unacceptable threat areas or involved angles producing minimum laser reflectance from the target. Following the manual's guidance, the flight leader illuminated the target with his laser and, on command, all aircraft released their LGBs. Most targets were struck with a flight of four aircraft delivering eight bombs simultaneously. Occasionally, four bombs would be used on target, saving the other four for another target or as a back-up. This tactic usually resulted in the destruction of the target with a single pass. In the northern half of North Vietnam, where many targets were camouflaged, target acquisition--especially for EOGBs--was difficult. This resulted in both decreased accuracy and increased TOT. Consequently, LGBs were employed over heavily defended targets in the northern one-half of North Vietnam, almost to the exclusion of EOGBs, which were largely limited to use over the more lightly defended targets in southernmost North Vietnam and northern South Vietnam. Nevertheless, EOGB tactics did exist for high threat areas, and such tactics were addressed in an 8th TFW message thus:[12]

> High angle deliveries are mandatory in a high threat area. A 30 degree dive, .82 to .90 mach and a release altitude of 12,000 feet AGL are considered optimum by each aircraft. The delivery of two weapons on one pass usually forces the aircraft into more of the AAA environment while increasing the probability of an unsuccessful weapon through acquisition or tracking problems. Dive angles of 45 degrees or greater require excellent crew coordination but afford the best

> contrast for bridges, buildings and military complexes. A flight of two aircraft is not desirable due to lack of mutual support during the ingress/egress; but in the immediate target area, four aircraft delivering simultaneously are attempting to achieve individual release parameters and mutual support will be lost. Therefore, the lead aircraft should achieve parameters as required by the target and threat with the flight in pod formation. After established on the roll-in heading each aircraft acquires the target and pickles separately. Separate aim points should be briefed to increase target coverage and preclude target masking from one bomb impact to subsequent bomb impacts. The flight leader must also brief a minimum release altitude; if an aircrew has not released by the minimum altitude, the pass will be aborted and flight integrity will be maintained.

Note that by employing high dive angles in high-threat areas the path length between the aircraft and target is minimized, resulting in the least target/background contrast loss. Also, geometric considerations indicate that for a given amount of clouds below the aircraft, the higher the dive angle, the greater the probability of seeing the target. Thus, high dive angles optimized the chances for successful single-pass EO strikes.

CHAPTER III

MISSION EFFECTIVENESS AND WEATHER

The EOGB

(S) Table 2 lists EOGB expenditures data for the period 1 February through 31 December 1972. Of a total of 883 EOGB weapons scheduled (fragged) only 329 were released. The remainder were cancelled either on the ground or after takeoff for reasons listed under the heading CANCELLED OR RETURNED in the table. A total of 280 (or roughly 32 percent) of the EOGBs fragged were cancelled due to weather, the largest single reason for mission cancellation. Note that in November and again in December the bulk of cancellations were caused by adverse weather conditions, which resulted from the Northeast Monsoon over SEA. These are carried in the table under WEA, CANCELLED OR RETURNED. Weapons released and failing to guide to the target because of clouds, haze, or other weather-related factors are tabulated on the right side of the table under WEA, REASONS FOR NO-GUIDES. Note that of the 89 no-guides that occurred during this period only one was judged to be due to weather.

(S) One rather striking aspect of the "Reasons for No-Guides" was the large number of no-guides listed under Unknown--over 40 percent. Evidence suggests that many of these "unknowns" were in fact caused by unfavorable weather. This can be proven both theoretically and from actual measurements of contrast loss from aerial reconnaissance photography. The question arises, then, why the pilots did not recognize those occasions

TABLE 2

EOGB EXPENDITURES

MONTH	SCED	EXP	CANCELED OR RETURNED A/C	WPN	WEA	TGT	OTH	HIT	NO GUIDES	REASON FOR NO-GUIDES ACE	WPN	WEA	TGT	UNK
FEB	16	6	4	3	0	1	2	3	2	1	0	0	0	1
MAR	16	3	0	1	10	2	0	1	0	0	0	0	0	0
APR	32	5	1	2	24	0	0	0	5	3	2	0	0	0
MAY	34	22	2	6	4	0	0	7	13	0	12	0	0	1
JUN	50	31	2	13	4	0	0	21	3	2	0	0	0	1
JUL	36	9	11	6	8	2	0	2	4	0	3	0	0	1
AUG	75	24	24	8	16	2	1	12	4	0	2	0	1	1
SEP	302	129	71	43	49	5	5	67	30	0	10	0	5	15
OCT	102	58	16	22	6	0	0	41	17	3	6	0	0	8
NOV	136	31	4	12	88	0	2	17	8	0	0	0	0	8
DEC	84	11	0	2	71	0	0	5	3	0	0	1	2	0
TOTALS	883	329	135	118	280	12	10	176	89	9	35	1	8	36
								53.5%	27%	10%	39%	-	09%	41%

ABBREVIATIONS:

SCED - SCHEDULED
EXP - EXPENDED
A/C - AIRCRAFT

WPN - WEAPON
WEA - WEATHER
TGT - TARGET

OTH - OTHER
UNK - UNKNOWN
ACE - AIRCREW ERROR

These data were extracted from SECRET messages originated by the 8TFW, Subject: "F-4D MK-84 EOGB monthly status report for (month) 1972" for the months February through July and from similar messages, Subject: "F-4D, EOGB report for the week ending (Day, Month) 1972" for the months August through December.

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when the weather caused the bomb not to guide. The answer possibly lies in the subtle and not easily recognized impact of atmospheric attenuation on EO systems and in the relative unfamiliarity of many pilots with the practical aspects of light-scattering theory. Discussions with numerous 8th TFW pilots verified that most did not fully understand the total impact of weather effects. For example, one pilot asserted that he preferred an attack heading into the sun because this enhanced the target shadow effect. He did not understand that such a heading also maximized the effect of atmospheric haze.[13]

(S) In addition to the statistical data already mentioned, many EOGB reports of the month or week also contained short remarks which aptly described EOGB system problems caused by weather and related factors. During the Southwest Monsoon rainy season the weapon experienced many problems due to moisture in the system. The weapon had to be grounded for a period of time until improved kits were flown in from the U.S. A new electronic countermeasure (ECM) pod also caused considerable electromagnetic interference problems because it produced massive distortion of the TV picture. A wire screen placed over the lens eliminated this distortion but degraded contrast and reduced the lock-on capability of the weapon. Bright sunlight, high contrast targets, and ideal weather were required before the weapons would work effectively.[14]

(S) Specific weather-related performance problems with EOGBs were pointed out in an 8th TFW message to Seventh Air Force on 12 August 1972:[15]

> Only very large, high contrast targets permit the weapon to be employed using acceptable parameters for high threat areas. Acceptable parameters are releasing the weapon no lower than 10,000 feet AGL from a 30 degree dive. This requires a target large enough and with sufficient contrast to lock the weapon onto it by 13,000 feet AGL. Of course, the sun angle, cloud cover, and visibility must also be favorable to meet these parameters. The EOGB is difficult to use for multiple strikes on the same target. The first impact will destroy the target contrast for subsequent weapons and cause them to break lock.

(S) In spite of these problems, Headquarters USAF was interested in increasing the employment of EOGBs in place of LGBs in the summer of 1972. In a 30 July message, General John D. Ryan expressed concern over losses of PAVE KNIFE aircraft delivering LGBs. General Ryan suggested that future losses could possibly be minimized by an increased application of EO weapons.[16] The EOGBs had shown good results recently; however, General Vogt qualified those results and explained 7AF's preference for the LGB in a message to General Lucius D. Clay, Commander-in-Chief, Pacific Air Forces:[17]

> We agree that the EOGB with a modified guidance unit has potential under certain conditions, and we are using it whenever conditions permit. Particular effort is being expended to identify targets suitable for attack by EOGB and to obtain the quality of oblique photography necessary to insure successful operations. The results reflected in recent 8TFW operations may suggest an overall effectiveness that is not altogether justified in consideration of the several limitations inherent in the system. All of the weapons upon which these results were based were employed in the relatively low threat environment of RP [route package] -1 (southernmost North Vietnam). Conditions there permitted selection of ideal sun angles and axis of attack, low release by single

aircraft, use of unscreened weapons, ECM pods in standby, and even multiple passes when required for optimum lock-on. Many of these options are denied in high threat areas such as RP-4 (just below Hanoi and Haiphong) and comparable results cannot be expected. Specifically:

> A. Operation of EO weapons is highly dependent on weather conditions. Absence of contrast, as under an overcast or momentary interruption of visual contact by clouds or smoke, seriously degrades the lock-on capability of the weapon.
>
> . . . We will continue to make every effort to optimize the use of the EOGB. Nonetheless, it is apparent that in the current state of the art, the LGB is a far superior weapon system and the one we must rely upon to assure best possible accuracy and highest probabilities of destruction.

Still, the employment of EO weapons increased during September. As shown in Table 2, over one-third of the total planned EOGB drops were scheduled for September, and over one-third of all EOGBs actually expended were dropped during that month. On the 19th of September, the 7/13AF Tactical Air Command Liaison Office (TACLO) sent a message which reflected the increased EOGB effort during September. The message stated, in part:[18]

> At time of visit to 8th TFW by TACLO there were considerable interest in EOGB utilization compared to six months ago. Weapon now being fragged daily. It appeared that in the past there was a low level of interest in employment of weapon probably because LGB has been doing well and is much simpler. Visit by Lt Col Kitchens and Mr. Egbert greatly increased entire EOGB effort. They identified several problem areas not only with weapon itself but also with munitions build-up, load crews, aircrews, etc. Expect in near future there will be a marked improvement in each of these areas. One of the major problems is targeting. Presently, the EOGB is being utilized in RP-1 and MR-I (northern South Vietnam) where there are not many high contrast targets. As a result they are being deployed against targets having very little vertical development and poor contrast.

(S) So susceptible was the EOGB to atmospheric effects, that only targets with high inherent contrast could be struck with confidence. Against targets with little vertical development and poor contrast, the weapon was ineffective.

The LGB

(S) Table 3 is a tabulation of LGB expenditures for the period 1 February 1972 through 31 December 1972. Comparison with Table 2* shows that during the 335 day period, 329 (about one a day) EOGBs vs 9,094 LGBs (27 a day) were dropped. Although cost ($17,000 for an EOGB compared to $4,700 for an MK-84 LGB)[19] may have been a factor which contributed to the disparity in usage of the two weapons, the strike planners' preference for the LGB in high threat areas and the weather-related problems with the EOGBs certainly were major factors.[20] Another reason was the aircraft modification required for each EOGB delivery aircraft, which made a large EOGB strike force difficult to maintain. The LGBs required no such modification.[21]

(S) During the period covered in Table 3, no-guides numbered 1,422, or 15.5 percent of the LGB weapons released. Not counting the "Unknowns," which take into account a variety of problem areas, aircrew error accounted for the largest number of no-guides (29 percent). This usually meant that the aircrew released the bomb even though one or more recommended release parameters had not been met, the crew misidentified the target, or the

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*Note that the focus of these tables is not the same, and that direct comparisons are not possible for each heading. Thus, while Table 2 examines EOGB ~~hits~~, Table 3 provides figures for LGB direct hits.

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TABLE 3

LGB EXPENDITURES

MONTH	NO. RELEASED/DIRECT HITS: PWI	PK	GS	PN	B-57	TOTAL	DUDS/NO-GUIDES: PWI	PK	GS	PN	B-57	TOTAL	REASON FOR NO-GUIDES: ACE	MAL	WEA	ILL	TGT	UNK
FEB	188/71	354/184	70/36	317/175	56/34	915/500	2/17	13/64	4/17	15/60	0/6	34/164	66	32	7	0	0	59
MAR	263/166	377/162	75/35	264/143	73/53	1018/509	9/38	11/59	1/17	14/47	0/4	35/165	49	26	11	0	0	79
APR	22/6	99/44	8/3	60/32	11/7	200/92	2/6	2/22	1/4	1/10	0/0	6/42	19	7	2	1	0	13
MAY	422/192	566/293	20/15	141/68	0/0	1149/568	23/60	14/101	1/1	10/33	0/0	48/195	55	23	26	9	29	53
JUN	506/188	802/385	3/1	106/71	0/0	1417/645	28/78	26/168	0/0	5/4	0/0	59/250	86	72	15	0	16	61
JUL	541/254	530/226	0/0	192/84	0/0	1263/564	14/66	18/78	0/0	16/27	0/0	48/171	56	10	16	34	1	54
AUG	576/277	140/49	0/0	253/100	0/0	969/426	35/68	8/43	0/0	33/54	0/0	76/175	41	26	22	19	1	56
SEP	186/90	258/115	0/0	141/50	0/0	585/255	11/25	10/41	0/0	8/17	0/0	29/83	8	26	5	23	0	21
OCT	435/212	162/67	0/0	106/26	0/0	703/305	11/46	4/26	0/0	7/23	0/0	22/95	12	17	12	14	1	39
NOV	487/279	0/0	4/4	51/26	0/0	542/309	16/47	0/0	0/0	3/2	0/0	19/49	14	5	16	4	3	7
DEC	189/98	124/82	0/0	20/7	0/0	333/187	10/22	2/14	0/0	1/7	0/0	13/43	7	3	12	7	4	10
						9094/4360						383/1422	413	247	144	111	55	452
						47.5%							29%	17%	10%	8%	4%	32%

DUDS = 4.2% NO-GUIDES - 15.5%

ABBREVIATIONS:

PWI - PAVEWAY I
PK - PAVEKNIFE
GS - GUNSHIP
PN - PAVENAIL

ACE - AIRCREW ERROR
MAL - EQUIPMENT MALFUNCTION
WEA - WEATHER
ILL - ILLUMINATOR ERROR

TGT - SMOKE, DUST OVER TARGET
UNK - UNKNOWN

These data were extracted from SECRET messages, Subject: LOM MONTHLY REPORT FOR (MONTH) 1972, from the 8 TFW, UBON RTAFB and the 432nd TRW, UDORN RTAFB with some inputs from the 366 TFW Da Nang AFLO RVN and the 388 TFW Korat RTAFB, Thailand.

SECRET

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crew released in marginal weather. While weather accounted for 144 (or 10 percent) of the LGB no-guides, weather-related factors accounted for additional misses. Seven no-guides were listed under ACE as due to "released in marginal weather" and 45 of the 55 no-guides listed under TGT were due to "smoke or dust over target," a weather-related (atmospheric attenuation) phenomenon. Thus, the weather-caused number of no-guides should really be 189, or nearly 13 percent of the total.

(S) As noted in several LGB monthly reports, "The majority of the PAVEWAY and PAVE KNIFE laser guided bombs during the month were [released] in extremely high threat areas. The tactics required in this environment, coupled with poor weather in some instances, contributed to many of the unguides reported."[22]

(S) The relatively large number of LGB no-guides listed under "Unknown" parallel the statistics for EOGB no-guides. The "Unknowns" accounted for one out of every three no-guides. This would seem to be a suspiciously high total for a system that was hopefully well-understood by the F-4 crewmembers, even recognizing the differentials in crew experience. Once again, the subtle impact of atmospheric attenuation may have been the dominant factor at work and a good share of no-guides listed as unknown could have been in reality weather-caused. Gradual deterioration in the general weather conditions and increased enemy countermeasures were partially responsible for decreasing effectiveness at the end of the period.

CHAPTER IV

CONCLUSION

(S) The introduction of guided bombs added a new dimension to modern air warfare. The mission planners no longer had to live with weapon miss distances of hundreds of feet. A target in the middle of a densely populated region could be hit with nearly surgical precision. However, the employment of these weapons in combat in Southeast Asia revealed some shortcomings in their design, operation, and deployment. The impact of the weather was found to be a significant operational limitation. Guided bombs were not all-weather weapon systems. Clouds and haze were the largest inhibiting factors preventing the optimum exploitation of guided weaponry in the tactical environment. Pilots had to see and identify targets before hitting them successfully. Atmospheric attenuation brought on by the presence of meteorological parameters varied from the obvious inability of laser or visible light radiation to penetrate a cloud, to the gradual bending of the laser beam by temperature variations along its path, or the subtle loss of target contrast due to haze.

(S) The exact magnitude of the impact of weather on guided bomb operations is not now known and cannot be quantified from the data gathered thus far because of the large number of "unknown" no-guides. Past Operational Test and Evaluation of guided weapons did not include the establishment of attenuation thresholds (the dividing point between effective and non-effective sensor performance) beyond which system capability was sharply diminished. Such weapons were introduced into the air war in

SEA without this potentially valuable and operationally significant knowledge. Several thousand bomb releases demonstrated that guided bomb operations were much less successful if there were three-eighths or more clouds below 18,000 feet or the visibility was reduced by haze to less than three miles. During this time little knowledge was gained about line-of-sight attenuation or its variability. While the Air Force's weathermen could forecast cloudiness for guided bomb strikes, they could not--with any degree of accuracy--forecast "seeability" reduction due to haze. In fact, the parameters which define "seeability" (i.e., type and size of haze particles) were not routinely measured, either in SEA or elsewhere. Thus, the weatherman was unnecessarily limited in his ability to assist the tactical commander when it came to decisions relative to guided bomb operations.

(S) In April of 1972, a symposium on target detection from tactical aircraft was held at Wright-Patterson AFB, Ohio. A number of offices and agencies were represented, including the following: the Air Force Cambridge Research Laboratory (AFCRL); the Air Force Operations Evaluation Group for the Assistant Chief of Staff for Studies and Analysis, Hq USAF; the Air Force Armament Laboratory; the Air Force Avionics Laboratory; the Weapon System Evaluation Group; the Air Staff; and the Air Weather Service (AWS). The conferees met to discuss mutual problems related to the design, testing, and operational deployment of guided weaponry in the coming years. Much of the discussion at the symposium centered around the validity of using simulation models versus the actual testing of weapons at U.S. ranges, which did not adequately duplicate the atmospheric degradation common to SEA. What clearly emerged was an urgent requirement for a concerted effort by the many elements of the OT&E community to study the entire spectrum of problems which impact upon tactical target detection. First, the community needed to know more about the reflective properties of targets and backgrounds, the effect of target movement and size, sun glint, coloration, and related areas. The inherent contrast of targets and backgrounds was not being measured as part of EO weapon OT&E. Second, the concept of visibility had little meaning in assessing the capability of current EO systems. Visibility involves the ability of the normal human eye to see horizontally an object of fixed brightness against the background sky. Any relationship between this and the ability of a pilot to see a tank on a dirt road at a slant range of 25,000 feet was purely coincidental. In the tactical environment, "seeability," not visibility, was most important because it included not only slant path spectral (wavelength dependent) attenuation, but the probability of seeing the target through a variable amount of cloudiness, plus other considerations. The "see" in "seeability" refers to the fact that in tactical warfare a target had to be seen before it could be attacked with guided bombs. This meant that the pilot not only had to visually acquire the target, but also had to identify it. He had to determine if the target (tank, gun, bridge, etc.) was enemy equipment, a decoy, or a derelict. This intelligence can be determined from the shape, size, and target markings, but must be transmitted through an attenuating airspace. While such identification was not usually a factor for fixed targets (e.g., bridges and buildings), it was vital to the successful interdiction of mobile targets. A successful LGB strike, therefore, depended not only on attenuation at laser frequencies, but also visible-light target contrast loss, or "seeability." Clearly, then, in dealing with air-to-ground guided weaponry, "If you can't see it, you can't hit it." Third, the capability of the tactical pilot to detect targets and optimize the probability of weapon lock-on at acceptable stand-off altitudes and distances was not adequate.[23] Rectifying this would involve improved sighting optics, a zoom (magnification) capability, increased laser power output, the minimization of system resolution loss between the seeker and the pilot's display, and many other related improvements.[24]

(U) From the standpoint of the tactical decision maker, more definitive prestrike weather information should greatly improve the chances of mission success.

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EPILOGUE

(S) The Scientific Advisory Board addressed the subject of this paper at the request of Air Weather Service in early 1972.[25] The guided weaponry of the 1970s could not be properly supported with the meteorology of the 1950s. New concepts and techniques were needed to measure atmospheric attenuation in a variety of wavelengths over denied territory. This could possibly be achieved by remote sensing via meteorological satellites, sensors seeded behind enemy lines, or remotely piloted vehicles (RPVs), among others. The concept of using the RPV equipped with remote sensors to relay spectral data back to the decision maker was generating a great deal of interest at the writing of this report. The RPV as a multi-spectral FAC might solve many problems facing the weatherman and his tactical customer in the future.

(U) Possible changes in aerial warfare brought on by an increased use of EO guided weapons in the next decade demand closer working relationships among the people who design, test, support, and deploy these weapons. Weapon system design must be optimized to reduce weather impact, OT&E must include both simulated and actual bad-weather testing to establish realistic operating thresholds, equipment and techniques must be developed to give the weatherman the data he needs to support the decision maker, and the pilot must thoroughly understand his weapon system so that he can critically evaluate its performance.

(S) Improvements in the employment of guided weaponry in a tactical environment can best be made after gaining a more definitive understanding of why the bombs sometimes fail to guide. The large number of no-guides attributed to unknown causes suggests that improvements in both crew debriefing procedures and crew training might provide part of the answer. While crews did complete an 8th TFW Form 38 during debriefing and this form did include a space for detailing "Weather and Weather Effects," really definitive information on the possible impact of weather effects was seldom included. The weather effects portion of the debriefing should be improved and expanded to include a series of questions to give a clearer picture of the state of the atmosphere even if weather was not a factor. The items (some of which appeared on the Form 38) in Appendix II would be useful to obtain more information on weather effects. (It should be noted that the Form 38 is no longer in use at the 8th TFW.)

(U) In addition to changes in the debriefing form, additional crew training dealing with possible weapon system limitations should be undertaken. Such training should include an extensive review of weather effects and atmospheric optics. The concept of "seeability" and the spectral nature of radiative transfer should be stressed during these training sessions. Each pilot and backseater should have a firm grasp of why the guided weapons succeed or fail.

(U) For several years the photo reconnaissance community employed theoretically-based computer models of atmospheric attenuation to optimize the design and performance of their photo system. Such models were developed by AFCRL, AWS, the National Aeronautics and Space Administration, and others. The most widely used of those, the AWS Haze Model, was employed by the Air Force Avionics Laboratory to produce printouts of target contrast losses, backgrounds, slant paths, aircraft altitudes, sun angles, haze (turbidity) levels, and related parameters.[26] Although somewhat limited by their basic input data, such models were helpful in gaining valuable insights into the impact of a highly variable atmosphere on EO system performance. An equivalent amount of research by AWS, AFCRL, and others into the development of mathematical models of the probability of seeing the ground through various amounts of cloudiness proved fruitful.[27] A great deal of measured and observed data was used to verify the validity of these mathematical models, but more work needs to be done.

(U) Most of the techniques, expertise, and equipment developed for the photo reconnaissance community is applicable to the solution of problems currently confronting the tactical weapon system OT&E community.

APPENDIX I*

METEOROLOGICAL ASPECTS OF SIGHT

(U) Seeing an object or acquiring a target requires the combination of an illumination source, reflection of the illumination energy from the object or target (or emission of energy from the object itself), and both receiving and distinguishing the reflected energy by a sensor system like an eye or a lens. The eye or any other receptor system can only see those energy transmissions that are large enough to excite its sensors, i.e., at or above the sensor's threshold of perception. However, the receptor will not always see all of the sufficiently large energy transmission because of other interfering radiant energy. For example, a green object in the grass or a white object on snow is hard to locate by eye because the background is reflecting radiation at the same wavelength as the object, and there is little or no contrast between object and background. A distant aircraft is hard to see against the sun because the sun's radiation is so much stronger than that reflected from the plane, and a far-off mountain is harder to see through haze because the haze particles are so brightly illuminated by the sun. The particles reflect energy back into the eye, while also blocking energy reflected from the mountain.

(U) The atmosphere is the medium through which a target is illuminated by some type of energy. It is also the medium through which the energy

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*Prepared by Major Edward B. Hanrahan, Ph.D. Climatology, University of Illinois, while serving as a member of the Project CHECO staff.

reflected from a target must pass to arrive at the receptor. The condition of the atmosphere, that is, meteorology, affects this transmittance or passage of energy in several ways. Visual sighting, radar tracking, and laser illumination and detection all fundamentally operate in the same manner. Meteorological effects on a laser beam, however, may be more easily visualized by most people, so it is presented as the main example. As illustrated on page 39, a laser beam is

Attenuated (its transmittance through the atmosphere is decreased, reduced in power or in the amount of energy striking a square inch of the target) by:

- Reflection off particles in a turbid atmosphere, e.g., air containing dust, soot, haze, or smog.
- Absorption (soaking up) by particles and gases in the atmosphere such as ozone, water vapor, water drops, and dust.
- Scattering from molecule to molecule in the air.

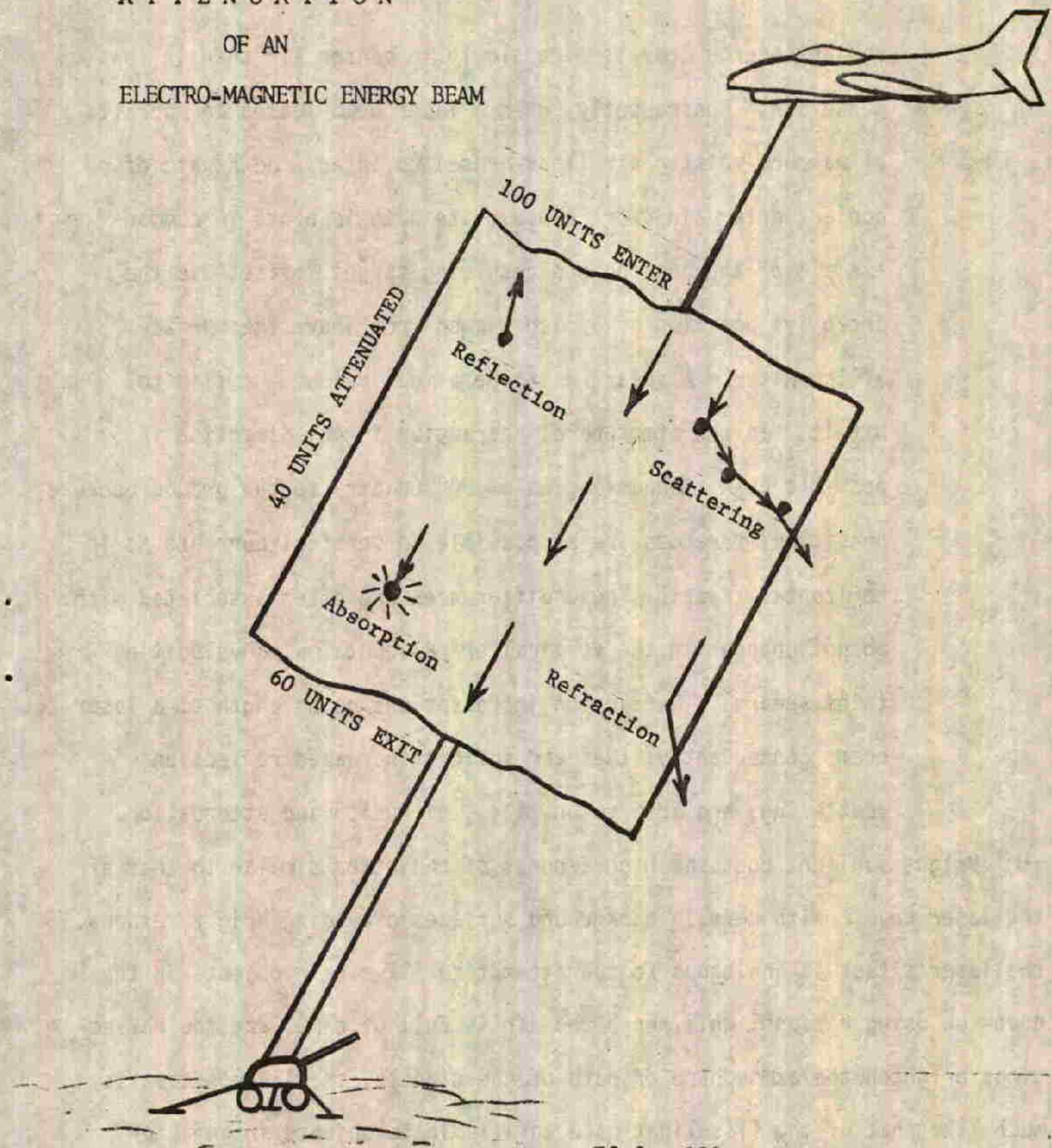
Diffused, spread over a wider cross-sectional area and consequently weakened because the "unfocused" beam puts less energy on a square inch of the target. For our purposes here, diffusion may be considered a type of attenuation. It is caused by,

- Reflection (as under attenuation above).
- Scattering (as under attenuation above).
- Refraction, bending as variations in the density of the atmosphere cause changes in the speed of energy transmission. The

ATTENUATION

OF AN

ELECTRO-MAGNETIC ENERGY BEAM



If for 100 energy units entering a segment of a beam, 60 exit the segment still within the beam cone, 40 units were attenuated by reflection, absorption, scattering, and refraction. After the attenuated initial beam reaches the target, only a fraction of that energy is reflected back toward the sensor in the receptor system. The fraction of the energy reflected back toward the sensor is also attenuated in much the same way the initial beam was attenuated.

radiant energy travels more slowly in denser air than in less dense air. Consequently, when a laser beam leaves an updraft of warmer, moister air (less dense) to enter a downdraft of cooler, drier air (more dense), its path is bent. A common example of the bending and resulting target "offset" is the deceptive position of a fish viewed from above the surface of the water. A spear has to be aimed "below" the fish to hit it. In the atmosphere, refraction in any direction is possible even at beam angles of 90° (nadir) to the ground because density differences are as possible in vertical currents as in horizontal layers. These differences are often associated with abrupt changes in the vertical or horizontal wind velocities (wind shears). Refraction increases the path length of a laser beam; consequently, the beam suffers increased reflection, scattering, and absorption, i.e., diffusion and attenuation.

(U) Bright sunlight contains high amounts of radiation similar to that of the laser beam. With certain background surfaces providing bright returns, the laser's task is analogous to the attempt to illuminate objects in the noon sun using a flashlight. When the air is full of haze, and the reflections brighten the atmosphere or path of the signals, the laser's task is much like that of the flashlight used to illuminate objects in an automobile's bright headlights (highbeams) during a snow storm. The brightness in the atmosphere, the path between the target and receptor, reduces the contrast-making ability of one's illumination beam (flashlight, laser, sun, etc.) and hence reduces the seeability of the target. This path brightness effect induced by haze or otherwise is also as troublesome after sundown, as can be quickly verified by trying to use a flashlight on a dark night in a snow storm or in fog.

(U) The turbidity of the atmosphere, the amount of dust, soot, salt, and other haze-causing particles in it, as well as the presence of water forms such as snow, rain, and fog, determine visibility. Atmospheric visibility refers to a human observer's estimate of the maximum distance at which he can distinguish objects, his threshold of sight in the given atmospheric conditions. In contrast, meteorological range refers to a machine measurement of atmospheric transmittance of a beam of light, i.e., how much the light beam is reduced between illuminator and target or between target and receptor because of dust, haze, rain, etc. For our purposes, visibility and meteorological range may be considered the same. Both are indications of attenuation and diffusion, and, consequently, the magnitude of the energy reaching a receptor. This is an important factor in "seeability" or whether or not a sensor can see a target.

(U) Equally important in determining "seeability" is distinguishing the target from its background or environment. Some sensors, electro-optical in particular, are designed to notice or see something different. The sensor sees the contrast caused by the different magnitudes of radiative energy returned from different surfaces. For example, the eye notices the contrast between the black car and the white snow, but cannot so easily see the camouflaged truck in the Southeast Asian vegetation. The very subtle or comparatively low magnitude contrasts are below the sensor's threshold of sensitivity. Although not exactly the same problem, a laser receptor may not see a truck in contrast to the high level of background infrared radiation when the sun is in line behind the truck. The laser energy return from the truck is "unseeable" in that radiant environment. Any one or a combination of the meteorological effects discussed above can make targets unseeable.

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APPENDIX II

PROPOSED ITEMS TO INCLUDE ON AF FORM 38

1. Target.
2. Aircraft altitude (AGL) and time of release (local).
3. Aircraft dive angle (degrees from horizontal).
4. Angle between aircraft heading and sun (assume aircraft heading is 12 o'clock).
5. Smoke or dust over target.
6. Height of clouds above and below aircraft.
7. Was target in cloud shadow?
8. Was target moving?
9. Was target detected because of sun glint?
10. Estimate of target threat environment.
11. Time over target (detection to destruction).
12. Estimate of slant path seeability conditions.
13. Sharpness of target shadow.
14. Other high-contrast edges near the target.
15. Was the optimum attack heading and dive angle covered during the prestrike briefing?
16. Was target prestrike photography adequate?

FOOTNOTES

1. Intvw (S) Maj Paul T. Ringenbach, Capt David K. Mann, and Mr. Mel Porter, CHECO Historians, with Gen John W. Vogt, Jr., Commander 7AF, 12 Nov 72.

2. 7AFM 55-1, "TACAIR Operational Procedures," Dept of Air Force, 15 Dec 71 (S). For a general introduction to guided bombs see Project CHECO, ~~Second Generation Weaponry~~ in SEA, 10 Sep 70 (S).

3. Capt W. N. Comey, "M118 and MK-84 Laser Guided Bombs," ATDC TR-69-129, Sep 69 (S) is the source for the technical data in this section on LGBs.

4. ~~Ibid~~.

5. Ibid. and Tactical Analysis Bulletin, Vol 69-1, 10 Mar 69 (S). Source for Fig 1 is Hq PACAF Dir of Tact. Evaluation report, "Combat Accuracy PAVEWAY 1 - MK-84/KMU 351/B" 27 Aug 69, Fig 2.

6. AFCRL Environmental Research Paper No. 318.

7. Capt M. O. Martin, "Evaluation of MK-84 Electro Optical Guided Bomb," ADTC-TR-69-145, Aug 69 (S).

8. ~~Ibid~~.

9. Ibid. and TACTEST No. 67-48 "PAVEWAY Electro Optical Guided Bomb System," Final Report, Feb 70 (S).

10. Msg (S) 8TFW to 7AF/DO, Subj: "EOGB Tactics," 111220Z Sep 72.

11. 8TFWM 3-1 (S) "Mission Employment Tactics," Nov 71.

12. Msg (S) 8TFW to 7AF/DO, 111220Z Sep 72.

13. Intvw (C) author with 8TFW pilots at Ubon RTAFB, Thailand.

14. Msg (S) 8TFW to CSAF, 250930Z May 72; Msg (S) 8TFW to CSAF, 180230Z Jun 72; Msg (S) 8TFW to CSAF, 101040Z Jul 72; Msg (S) 8TFW to CSAF, 100915Z Aug 72; Msg (S) 8TFW to CSAF, 180131Z Aug 72.

15. Msg (S) 8TFW to 7AF/DO, Subj: "EOGB Performance," 120230Z Aug 72.

16. Msg (S) CSAF to AFSC/CC, AFLC/CC, TAC/CC, CINCPACAF, 181550Z Jul 72.

17. Msg (S) Gen Vogt to Gen Clay (exclusive for), Subj: "Laser Designator Assets and EO Usage," 301133Z Jul 72.

18. Msg (S) 7/13AF (TACLO) to TAC/DR/DO, Subj: "EOGB Difficulties," 190805Z Sep 72.

19. Rprt (C), Air Operations Report 72/1, Electro-Optical Guided Bomb "EOGB," Accuracy and Effectiveness in SEA from 1 February 1972-31 October 1972, Hq 7AF, Tactical Analysis Div, 29 Nov 72, p. 11.

20. Msg (S), Cmdr 7AF to CINCPACAF, 301133Z Jul 72.

21. Msg (S), 8TFW to 7AF/DO, 120230Z Aug 72.

22. Msg (S) 8TFW to CSAF, 090405Z Aug 72.

23. Proceedings of a Technical Workshop, "Target Detection from Tactical Aircraft," sponsored by the Air Force Avionics Lab, 11 and 12 Apr 72.

24. Msg (S) 8TFW to 7AF/DOXO, Subj: "Combat ROC Modification to Laser Determination Systems," 120940Z Jul 72.

25. Draft Report of the SAB Meeting (Remote Meteorology Sensing Committee, 7 Aug 72).

26. Patrick J. Breitling, Ph.D. dissertation, St. Louis University, 1972.

27. Iver Lund, "Photogrammatically Determined Cloud-Free Lines of Sight Through the Atmosphere," ~~Journal of Applied Meteorology~~, II (Aug 72).

GLOSSARY

AAA	Antiaircraft Artillery
AB	Air Base
AFB	Air Force Base
AFCRL	Air Force Cambridge Research Laboratory
AGL	Above Ground Level
Apparent contrast	The contrast at some altitude distant from the target
AWS	Air Weather Service
Brightness	The amount of radiation in a particular spectral interval reflected from the surface of a target or its background
Contrast	The difference between the brightness of a target and its background divided by the brightness of the background. $C = (B_t - B_b)/B_b$
DCS	Deputy Chief of Staff
DOD	Department of Defense
ECM	electronic countermeasure
EO	electro-optical
EOGB	Electro-Optical Guided Bomb
FAC	Forward Air Controller
Ho Chi Minh Trail	The NVA logistic supply route through the Nape, Mu Gia, and Ban Karai Passes from NVN into Laos, thence down the eastern Laotian panhandle where roads and trails turned eastward into RVN.
Inherent Contrast	The contrast at zero distance to the target
km	Kilometer
LGB	Laser Guided Bomb
Micron	Unit of wavelength equal to 10^{-6} meter
OT&E	Operational Test & Evaluation

PAVE KNIFE	(S)	A laser illuminator pod and associated cockpit display for the F-4 aircraft which enables one F-4 to illuminate a target for its own LGBs, or for LGBs delivered by another strike aircraft.
PAVE NAIL	(S)	An OV-10A aircraft modified with an electro-optical viewing device, a laser target range/designator, and a LORAN navigation system.
PAVE WAY		Guided bombs developed for delivery from tactical aircraft.
RP-1		Route Package 1 - Southernmost North Vietnam
RP-4		Route Package 4 - just below Hanoi and Haiphong
RPV		Remotely Piloted Vehicle
RTAFB		Royal Thai Air Force Base
RTB		Return to Base
RVN		Republic of Vietnam
SAM		Surface-to-Air Missile
SEA		Southeast Asia
7AF		Seventh Air Force
TACLO		Tactical Air Command Liaison Office
TFW		Tactical Fighter Wing
TOT		Time Over Target
Transmittance		The ratio of the amount of spectral radiation emerging from an airspace to the amount that entered. $T = I/I_0$
TV		Television
USAF		United States Air Force

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