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SCHOOL OF ADVANCED AIRPOWER STUDIES

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**THE LONG ROAD TO DESERT STORM AND BEYOND:  
THE DEVELOPMENT OF PRECISION GUIDED BOMBS**

**By**

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THE DEVELOPMENT OF PRECISION GUIDED BOMBS***

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## ABSTRACT

This paper examines the long development of precision guided bombs to show that the accuracy attained in Desert Storm was an evolution not a revolution in aerial warfare. This evolution continues and gives offensive airpower the advantage over the defense. Guided bomb development started during World War One with the “aerial torpedo”. During World War Two the German Fritz X and Hs-293 were visually guided bombs and both experienced success against allied shipping. The Army Air Corps also developed a wide variety of TV, heat, radar, and visually guided bombs. The visually guided AZON was successful in Burma and the radar guided Bat was successful against Japanese ships. During The Korean War visually guided RAZON and TARZON bombs had some success. In Vietnam the Paveway I laser-guided bombs and Walleye TV-guided bombs were successful on a much broader scale. Paveway II and III, Walleye II, and GBU-15s were developed and successfully combat tested throughout the 1970’s and 1980’s. When Desert Storm initiated in 1991 there were very few guided weapons that had not been extensively tested on training ranges and in combat. The precision demonstrated to the World during Desert Storm started evolving when airpower was first envisioned as a new dimension for conducting war, and was far from a revolution. Now, the continued development of imaging infrared, laser radar, synthetic aperture radar, and millimeter wave radar autonomous seekers further increases the flexibility, range, and effectiveness of guided bombs.

## BIOGRAPHY

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## INTRODUCTION

During Desert Storm the media received a major opportunity to show airpower's accuracy and destructiveness. High-tech precision guided weapons, not new to America's air arsenal, received a good portion of the media's attention during Desert Storm. Precision guided munitions (PGMs) development started however, long before the computer revolution of the 1970s and 1980s and dates back to airpower's introduction in World War One. By tracing the development of guided bombs, this paper reveals the precision achieved in Desert Storm was a long evolution, and not a revolution for aerial warfare. The evolution did not stop after, or even during Desert Storm. The Department of Defense is developing many new technologies that will further increase the lethality, effectiveness, and flexibility of guided bombs. The result of this evolution is the capability to devastate an enemy with conventional munitions, in minimum time, and with limited collateral damage. Nuclear weapons become less important as possible combat weapons and can be greatly reduced in number.

Destroying a target with aircraft-delivered weapons is much easier said than done. Even before the Wright brothers flew the first powered heavier-than-air vehicle in 1903, writers, balloonists, and soldiers speculated on the destructive capability of aerial weapons. The early airpower theorists did not yet understand all the factors affecting a bomb's accuracy. A bomb's impact point is greatly influenced by two sets of forces. Altitude, airspeed, dive angle, and separation effects caused by airflow around the airplane are the first set of forces affecting the bomb. As the bomb falls, its flight path is further shaped by the second set of forces: gravity, aerodynamic drag, wind, air density, and even the minor changes caused by Coriolis effect. The magnitude of the error caused by the second set of factors is directly proportional to the distance the bomb travels through the air, the bomb's slant range. The trick to precision bombing is to



arrive at a release point with the unique set of release conditions matched to the desired impact point. Furthermore, the release conditions or release point must be adjusted for anything that will affect the bomb after release. Wind velocity, air temperature, and density can be measured at the release point but they do not remain constant throughout the bomb's fall, or even change at a constant rate. The result is an infinite number of release points for any desired impact point and each release point has a unique set of release conditions. The immensity of this problem shows why airmen have always had so much trouble hitting a target and saw the need to perfect precision bombing.

The term "precision bombing" became widely used at the Air Corps Tactical School (ACTS) as the Army Air Corps developed its strategic bombing doctrine. The ACTS approached the problem by trying to perfect the aiming device. One result was the famous, and widely-used, Norden bomb sight. This approach continues today with the aid of high speed computers and the result is very accurate bombing in aircraft like the F-16, F/A-18, and F-15E. The computers attempt to correct for factors affecting the bomb after release but have to use generic wind models that will never be perfect. Even with modern aircraft, long slant ranges, resulting from bombing from medium to high altitude, cause unacceptable miss distances, as was seen during Vietnam and Desert Storm. The other approach to precision bombing is to guide the bomb after release and steer it to the target. Guidance systems have been added to all categories of weapons including air-to-surface, surface-to-air, air-to-air, and surface-to-surface. It would take an entire book to adequately cover just one of these categories; therefore this paper is limited to examining the development of free-falling guided bombs.

The first American guided weapon was actually developed and tested during World War One. World War One's "aerial torpedo" proved successful but the war ended before its "mass

destruction” capability was used in combat. World War Two presented the second major opportunity to develop and implement guided bombs. The Luftwaffe was first to successfully employ guided bombs and the U.S. Army Air Corps and Navy followed closely behind. After World War Two, conventional weapons development took the back burner to force reductions and nuclear weapons development. Bomb sights and aiming devices continued to improve heavy bomber and fighter bombing accuracy but guided bomb development was stagnant. The Korean War revived the need for accurate conventional bombing and guided bombs gained renewed interest but experienced limited success. After Korea, a decade passed before the United States became seriously involved in Southeast Asia. Between these two wars conventional weapons development progressed very slowly. The Southeast Asia conflict and advances in electronic technology brought a leap in capability for guided bombs. Following Vietnam, guided bombs continued to improve. Precision bombing was battle tested on a limited basis by the Israelis in 1973, the British during the 1982 Falkland’s War, and by American aviators in the 1986 attack on Libya. By January 1991, when the Coalition’s air campaign against Iraqi forces started, precision guided bombs were not new or untested in combat. The most recent test for guided bombs was the decisive Allied air campaign conducted against Iraq during Desert Storm.

## EARLY GUIDED BOMBS THROUGH WORLD WAR TWO

What is regarded as one of the most destructive weapons invented during the war has been placed in the secret archives of the War Department at Washington, there to remain, it is hoped even by the inventor, for all times <sup>1</sup>

### **World War One**

Although these words sound like the proverbial doomsday weapon, this quote describes

the “aerial torpedo”, a small plane with automatic controls developed by Charles F. Kettering during World War One. Mr. Kettering, later the president of General Motors, developed and tested his plane at the Dayton-Wright experimental plant in Ohio. The fuselage was shaped like a torpedo and was loaded with mustard gas and high explosives. After flying a preset course the wings collapsed and the bomb fell on its target. It had a maximum range of 100 miles and was designated to attack large German cities near the battle front during the 1919 Spring Offensive. The Army’s tests were successful but the Armistice was signed before the weapon was employed.<sup>2</sup> Even though this wasn’t a bomb in the classical sense it was the first example of an American guided weapon.

Aerial bombing was almost nonexistent prior to the first World War but developed rapidly during the war. The airplanes of the early 1900s never achieved the range and payload capacity to make bombing effective. Although airpower’s contribution to the outcome of World War One was not decisive, men like General William “Billy” Mitchell, Italian General Giulio Douhet, and British Air Chief Marshall Sir Hugh Trenchard believed in airpower’s potential and started developing the doctrine that guided Allied air forces through World War Two. After World War One these airpower enthusiasts helped develop the ideas that big bombers would change the way wars are fought and that airpower alone could be decisive.

### **Post World War One**

Development in all military areas was drastically cut as America withdrew into isolation and significantly reduced the military in 1919. Airpower enthusiasts were not deterred by the drastic cuts and the precision bombing theory continued to develop. In the late 1920s the ACTS expanded the thoughts of the early theorists and believed the enemy’s “vital centers” could be destroyed with well-planned and well-managed bomber formations. The ACTS believed the

destruction of these centers, the nodal points of the “industrial web”, would destroy the enemy’s ability and will to wage war.<sup>3</sup>

By 1935 the 19th Bomb Group (BG), at Rockwell Field, CA, established the ability to routinely drop bombs in the “pickle barrel”. Equipped with Martin B-10s and new Norden bombsights, the 19th BG’s average miss distance was 164 feet from a release altitude of 15,000 feet above ground level (AGL).<sup>4</sup> This degree of accuracy appeared to validate the theory that strategic bombing could effectively destroy pinpoint targets. The data was flawed however, because the 19th BG collected it on clear days with the absence of enemy anti-aircraft artillery (AAA) and minimum resistance from mock enemy fighters. It was not surprising, therefore, that the accuracy documented in World War Two produced a completely different set of figures for unguided bombs with miss distances often exceeding thousands of feet.

Following World War One the British Royal Air Force developed a radio controlled glide bomb in the 1920’s called the Larynx. The Larynx was first used against Iraq in 1925 to control small native uprisings. By 1926 interest in guided bombs faded when the British Air Staff decided that larger manned bombers were the best method to solve the bombing problem.<sup>5</sup>

## **World War Two**

The German Condor Legion experienced great difficulty attacking maneuvering ships with free-falling bombs during the Spanish Civil War.<sup>6</sup> To overcome this difficulty; Germany started developing guided weapons in 1939 before they invaded Poland. Dr. Max Kramer, while working for the German company Ruhrstahl A.G., started the development of guided bombs in 1938 by adding radio-controlled spoilers to the cruciform (X-shaped) tail surface of a 250 kg bomb. By 1940 the system was incorporated on a 1400 kg armor piercing bomb designated the FX-1400 and called the Fritz X. The Fritz X was 10 feet 6 inches long and weighed 3469 lb

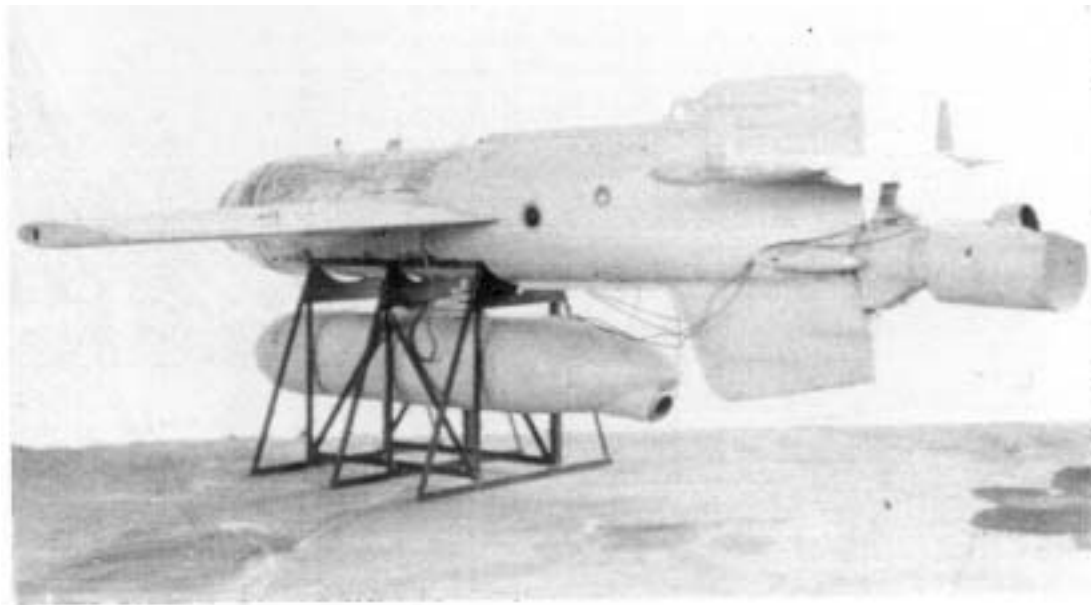
(1570 kg). Its armor piercing warhead, with 660 lb of high explosives, could penetrate and sink even the largest battleships. The Luftwaffe started operational testing of the Fritz X in early 1942. The normal attack profile was a level delivery from 18,000 feet, initiated three miles from the target. This profile required good visibility and was restricted by anything more than very limited cloud cover. After release, the delivery plane decelerated rapidly, almost to a stall, and lowered flaps allowing the bomb to get in front of the aircraft. A bright flare on the tail enabled the bombardier to visually guide the bomb with radio signals by superimposing the bomb over the target. Wire guided versions were also developed and employed to counter jamming. During its fall the Fritz X reached a terminal velocity of 950 feet-per-second and the impact point could be corrected 1640 feet in range and/or 1148 feet laterally.<sup>7</sup> The Fritz X was not a glide bomb but followed a ballistic flight path that resulted in only limited maneuvering capability.

A special squadron, III/Karnpfgeschwader (KG) 100, was trained in Dornier Do 217K- 2s to employ the Fritz X against ships and was operational in March 1943. Seven hundred and fifty Fritz Xs were produced and stockpiled at numerous coastal airfields throughout Europe. On 9 September 1943 a flight of six Do 217s launched from Istres, France to attack the defecting Italian Fleet.<sup>8</sup> The fleet, consisting of three battleships, including the ultra-modern Roma, six cruisers, and many auxiliary ships, was spotted around 3: 50 pm. The Roma started an evasive turn but took a direct hit just forward of the front stack. A major fire started and when the fire reached the forward magazine a huge explosion ripped open the hull. The Roma sank quickly, took 1254 men to the bottom of the Mediterranean, and became the first capital ship sunk by a guided bomb.<sup>9</sup>

A proficient bombardier could consistently guide the Fritz X to within 15 ft of a moving target during training. However, during combat operations, direct hits were recorded in only

about 30 percent of Fritz X launches.<sup>10</sup> In 28 attacks between August 1943 and February 1944 the Germans sank only one ship and damaged four others with the Fritz X.<sup>11</sup>

The requirement to rapidly slow the delivery aircraft to keep the bomb in the bombardier's field-of-view was hazardous to the crew. The plane became an easier target for fighters and AAA. To overcome this hazard, Professor Herbert Wagner designed and developed the Henschel Hs-293 (Fig 1)<sup>12</sup> The Hs-293 was a glide bomb resembling a small plane. It had a conventional wing, a small liquid-fueled rocket attached to the bottom of the warhead, and a large flare on the tail to allow visual contact for guidance. The Hs-293, weighing between 1,500 and 2,000 pounds, was smaller than the Fritz X. The warhead weighed 1,100 pounds, but did not have an armor-piercing design, and was limited to use against lightly armored ships.<sup>13</sup>



**Fig 1. Henschel Hs-293 (AF Museum, WPAFB)**

The Hs-293 was first used against Allied shipping in the Bay of Biscay on 25 August 1943. The attack profile was normally a level release at 3280 ft (1000 m) approximately 6 miles

from the target. The plane would follow the bomb toward the target with the bombardier aiming for the ship's waterline.<sup>14</sup> The Hs-293 sank 400,000 tons of Allied shipping including a couple of destroyers. During training, the Germans achieved 90% direct hits; but during combat, Allied fighters and AAA brought that down to 40-50%<sup>15</sup>

The Germans continued to improve the capability of the Hs-293 as the war progressed. The B model was changed from radio remote control to wire-guided control. A long thin wire transmitted the bombardier's steering commands directly from the plane to the bomb negating the effects of Allied radio jamming efforts. The wire guided bomb had a maximum range of 19 miles. The Hs-293D and H models were developed with TV guidance but the war ended before development was complete.<sup>16</sup>

The entire German guided bomb program was directed toward interdicting Allied supplies by attacking Allied ships. Germany was in control of western Europe by 1940, well before the Fritz X and Hs-293 were operational. The Luftwaffe, with its limited strategic bombing capability, did not establish a requirement for guided weapons for use against bridges, factories, choke points, or other land-based interdiction and strategic bombing targets associated with a long war of attrition. Without this requirement, the German weapons developers never conceived other uses for guided bombs.

Although the Germans achieved initial successes, the loss of air superiority signaled the end of Germany's guided bomb program. The last successful Hs-293 attack was against the Allied fleet supporting the Anzio beachhead. On 16 February 1944, the Luftwaffe sank the liberty ship Elihu Hale and the LCT-35. Additional attacks were attempted without success. The final attempt to sink Allied shipping with the Hs-293 occurred during D-Day at the Normandy beachhead on 6 and 7 June. After these unsuccessful attacks, and with little hope of further

success, the Luftwaffe withdrew the aircraft to Germany and Norway. The entire German guided bomb program ended on 21 August 1944 when the special bombing units were disbanded<sup>17</sup>

America had the advantage of observing World War Two for more than two years before the Japanese attacked Pearl Harbor on 7 December 1941. During a visit to England, General Henry “Hap” Arnold noticed that even in congested cities a high percentage of bombs fell in vacant lots and other open areas. He deduced that bombs gliding in on a flat trajectory could not avoid hitting buildings. On his return to America he directed the Air Proving Ground Command (APGC) to develop glide bombs for the strategic bombing of cities and industrial areas.

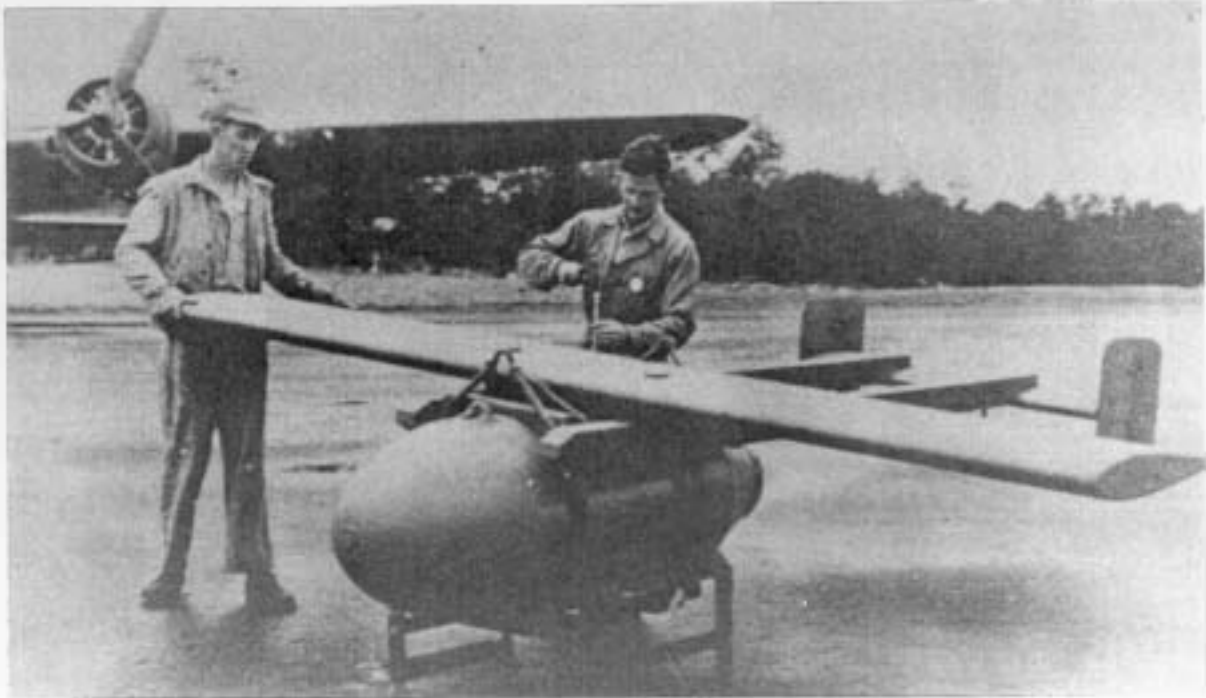
The directive to APGC called for development of all munition types, including power driven bombs, high angle bombs, different types of remote control, and various seekers General Arnold wanted the glide bomb capability quickly and directed development be concentrated on a glide bomb with fixed controls and no remote control devices.<sup>18</sup>

The first result of General Arnold’s directive was the Glide Bomb 1, or GB-1. The Air Proving Ground’s concept for guided weapons married conventional bombs to an airframe with some sort of guidance system. The GB-1 fitted a M34 2000 lb general purpose (GP) bomb to an airframe with a 144” wing span and a twin-boom tail (Fig 2). A Hammond autopilot was used to keep the bomb on its original flight path and the elevators controlled the preset glide path. B-17’s carried one bomb under each wing and the bombardier preset the controls before release.<sup>19</sup> The bomb’s range, from 15,000 feet AGL, was about 20 miles. The GB-1 however, had an average miss distance from 3000 to 5000 feet in range and from 700 to 1000 feet in azimuth.<sup>20</sup>

The GB-1 was first used on the 25 May 1944 bombing raids of Cologne, Germany. Since the GB-1 was just one of many weapons that devastated Cologne that day, its effectiveness could not be determined. The GB-1 also had two main drawbacks. The bomb’s large wings



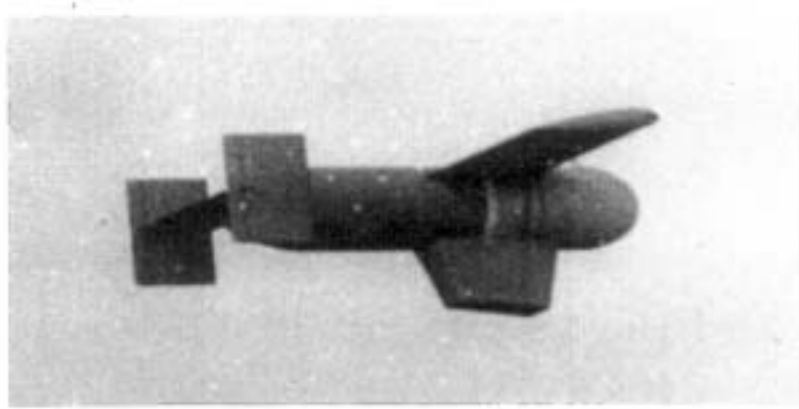
necessitated external carriage, limiting each bomber to only two bombs, and the large increase in drag reduced the B-17's speed and range. The bomb's gliding capability also required release well before the target, reducing the bombardier's time for target identification. These drawbacks made the GB-1 incompatible with the mass bomber formations commonly used by Eighth Air Force in Europe. After Cologne the GB-1 was rarely used but, development of other glide bombs continued throughout the war.<sup>21</sup>



**Fig 2. GB-1 Preset Glide Bomb (AF Museum, WPAFB)**

The only other glide bomb used in combat was the GB-4. The GB-4 utilized the GB-1's warhead and flight surfaces but added a television camera and radio remote control (Fig 3). During testing the GB-4 achieved a 200 ft CEP and 80% reliability rate.<sup>22</sup> Eighth Air Force first used the GB-4 against Nazi submarine pens at Le Havre, France in 1944.<sup>23</sup> The late introduction

of the GB-4, its requirement for good weather, and the relatively poor quality of 1940's television limited its usefulness. The bomb's relatively small size was also unable to penetrate the massive concrete structures.



**Fig 3. GB-4 TV-Guided Glide Bomb (AF Museum, WPAFB)**

The guided weapons program was the Army Air Force's third largest development program behind unguided bombs and jet propulsion.<sup>24</sup> As a result, APGC developed fourteen different glide bombs. Some of the descriptions sound similar to the guided weapons of today. The GB-6A (Fig 4) had a heat homing seeker and test results were encouraging. The GB-8 was visually aimed and radio-remote controlled by two operators, one for range and the other for azimuth. It only achieved a CEP between 1000 and 2000 feet.<sup>25</sup> The GB-12 and 13 were developed for use against ships. The GB-12 had a light contrast seeker that could lock on to ships and the GB-13 was designed to track flares as a seeker development project. The final World War Two glide bomb development was the GB-14-a bomb equipped with a radar homing seeker similar in concept to today's anti-radiation missiles.<sup>26</sup> Glide bombs were only one variety of guided bombs developed at APGC.



Fig 4. GB-6 Heat Homing Glide Bomb (AF Museum, WPAFB)

The other type of Army Air Force guided bomb, the vertical bomb or VB series, were similar in concept to the free-falling, German Fritz X. The vertical drop bomb had less range and latitude control for aiming corrections but had a simpler design and proved more successful. The VB-1 (Fig. 4) and -2 were the only VB guided bombs in development that were used in combat during World War Two.

With the emphasis to get guided bombs into operational use, the first bombs concentrated on less sophisticated designs. VB-1 development was initiated in early 1942 after poor results from saturation bombing against point targets like bridges, roads, railroads, and ships.<sup>27</sup> To simplify the initial design, the engineers designed the bomb with steering control in AZimuth ONLY and called it the AZON (Fig 5). AZON came in two versions. The VB-1 was an AN-M65 1000 lb GP bomb with a special nose cap and tail fins. The VB-2 was a 2000 lb version of the VB-1 using the M34 bomb. The tail unit contained the radio receiver, a stabilizing system to keep the bomb from rolling, the control surfaces, and a flare to help the bombardier maintain

visual contact.<sup>28</sup> This design allowed B-17s and B-24s to carry the bombs internally. Special devices were also developed and attached to the bombsight to aid the bombardier in bomb control. The result was a big improvement in bombing accuracy.

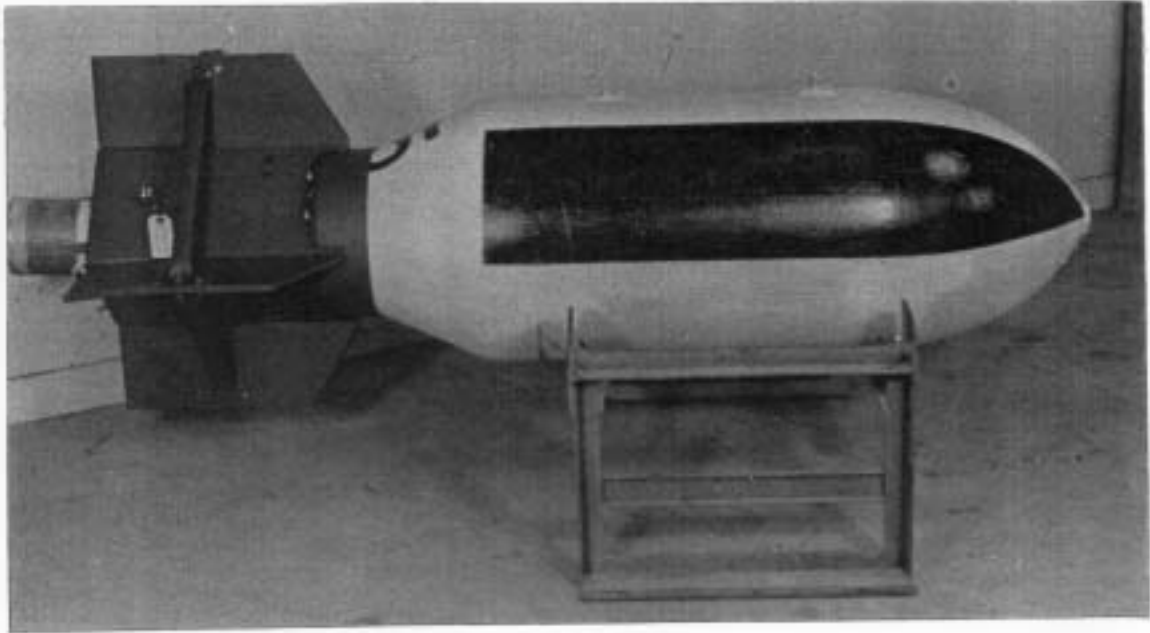


Fig 5. VB-1 AZON (AF Museum, WPAFB)

The AZON improved standard bombing accuracy by thirty times, according to National Defense Research Committee (NDRC) calculations. The NDRC based this calculation on test data that compared the probability of obtaining a direct hit on a 50 foot square target with different type bombs. This means that thirty times as many standard bombs must be dropped to achieve the results of one AZON.<sup>29</sup> The large improvement in accuracy generated a large demand for the bomb.

Procurement of AZON started in June 1943 with an order for 110,600. But, production was cancelled in October 1944 after only 14,070 units were made because targets were becoming scarce, good weather was always required, plenty of bombers were available for mass bombing,

and sufficient AZONs were still in supply. The first production lot was available in November 1943 and B-17 crew training started on 4 February 1944 with a projected departure date to Europe on 1 March 1944. B-24 crews started training for deployment to the China-Burma-India theater in April 1944.<sup>30</sup>

Fifteenth Air Force started employing AZON against railroad bridges in northern Italy in April 1944. The results were generally poor. In four missions against the bridges, 73 bombs were dropped with no more than 10 direct hits. One mission aborted for bad weather and 25% of the bombs failed to work. The major hardware problem was flare failure.<sup>31</sup> The Army Air Force employed 3000 AZONs in Europe with mixed results. Commanders in the Mediterranean would not allow AZON-only test missions and on one occasion flatly refused to give credit to AZON hits. When AZON was dropped on other missions with conventional bombs it was impossible to determine its effect.<sup>32</sup>

The 7th Bombardment Group experienced better success in Burma in late 1944 and early 1945. They claimed the destruction of 27 bridges with only 459 AZONs in two months. Flare failures were still a problem but the 7th Bombardment Group claimed direct hits with 12 percent of the bombs.<sup>33</sup> A total of 1357 AZONs were dropped in Burma destroying 41 bridges and damaging 12 more. Average errors observed were 131 feet in azimuth and 207 feet in range<sup>34</sup>

Several other vertical bomb developments started during the war but were never used

in combat. APGC developed the VB-3/4 to overcome the AZON's accuracy and target limitations caused by guidance in only one direction. The VB-3/4 added Range control to the AZON and were called the 1000 lb and 2000 lb RAZONs. The tail retained the octagonal shroud of a latter AZON tail design and added a second tail unit to increase directional control. The Army Air Force tested the RAZON in late June 1945. The war's end created personnel, equipment, and priority problems that led to delays and incomplete development. The final report showed RAZON, with a CEP of 135 feet, achieved a higher accuracy than AZON bombs, but also noted several problems. The primary defect was excessive failure of the bomb's radio receiver relay mechanism. Also, when the bomb failed to guide, or failed after the bombardier made a few corrections, the miss distance was very large, often greater than 5000 feet. The final report recommended replacing the radio receiver and additional testing.<sup>35</sup> Other World War Two vertical bomb developments included the VB-5 with a light contrast seeker, the VB-6 "Felix" with a heat seeker, and VB- 7/8 with television seekers in the nose VB-9 through -12 incorporated major design changes including a circular lifting wing around the center of the bomb (Fig 6). The VB-9 had a radar seeker that proved impractical at the high delivery angles of vertical bombs. The other versions continued to test television, heat, and direct visual guidance systems but the engineers and designers could not complete development prior to the war's end.<sup>36</sup>

The guided weapon systems used and developed during the war generally required clear weather, easily identifiable targets, and air superiority. In fact, many aviators considered visually guided weapons delivery to be more dangerous for the crew than conventional bombing.<sup>37</sup> First, the bomber must stay on a predictable flight path after bomb release to maintain visual contact and guide the bomb to impact. From medium altitude the bomb's time of fall could be several

minutes. Secondly, the good weather required for accurate bombing was also good for enemy fighters and AAA gunners. Finally, if Allied targeteers considered the target valuable enough to attack, the enemy probably valued it enough to heavily defend it.

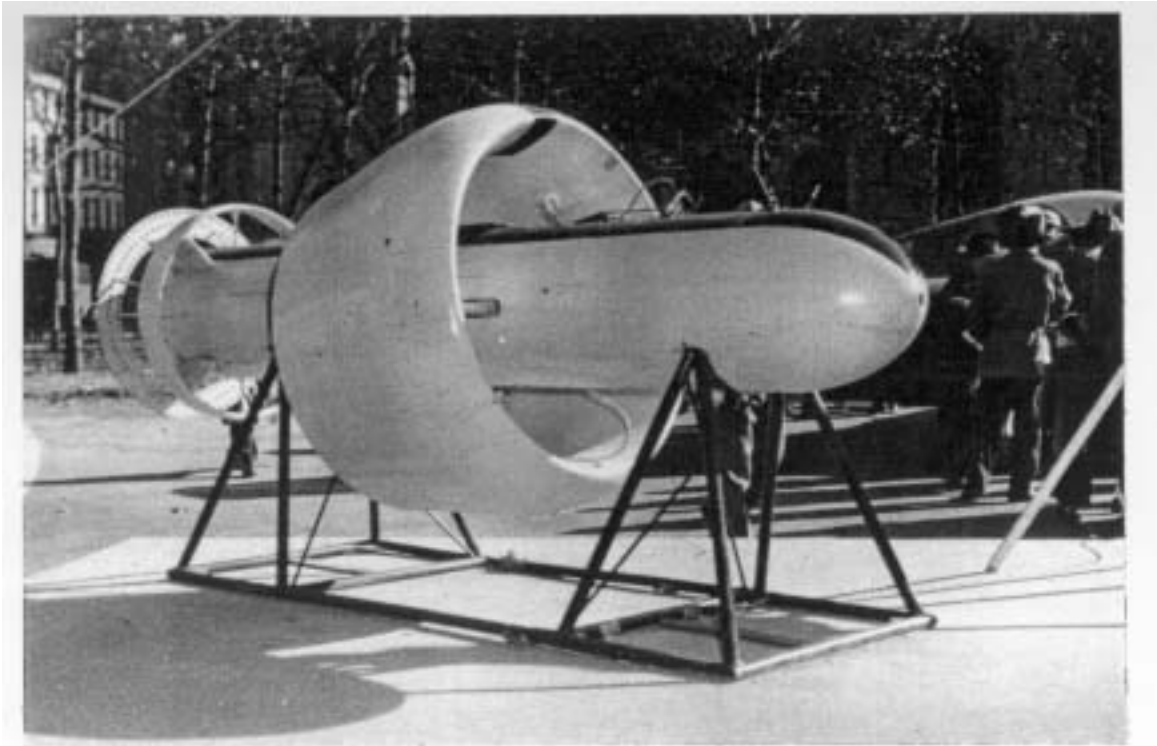


Fig 6. VB-10 "ROC" (AF Museum, WPAFB)

After the war, the Army Air Forces dropped AZON from the inventory in favor of more promising guided weapons like the VB-3/4 RAZON. The entire conventional weapons development program virtually stopped as America quickly reduced its military forces after the war. Nuclear weapons development programs took priority. When North Korea invaded the South in 1950, the Air Force realized the need to revive its conventional weapons development program.

The U.S. Navy also developed its own guided weapons prior to and during World War Two. Driven by the requirement to attack surfaced German submarines off America's Atlantic

coast, the U.S. Navy developed the radar guided BAT. The BAT program started in April 1942. Dr Hugh Dryden of the National Development and Research Committee (NDRC) designed and developed the glider while scientists at M.I. T. and Bell Laboratories developed and designed the radar homing system for mass production. The BAT was a fully-active (sends and receives its own radar signal) radar-guided bomb launched from medium altitude. After the crew in the launching aircraft detected enemy ships with the aircraft's radar, the BAT was launched. Following the launch, the BAT was fully autonomous and the radar seeker provided both night and adverse weather capability. The BAT contained a 1000 pound warhead and maintained a 150 ft CEP. The Navy successfully completed the first tests on 22 December 1944 and production started shortly thereafter. By late 1944 the German submarine threat was defeated but the war in the Pacific raged on. The Navy successfully combat tested the BAT against the few remaining Japanese ships in August 1945. U.S Navy patrol planes achieved limited success with the world's first autonomous, radar equipped; guided bomb.<sup>38</sup> The BAT's primary disadvantage was the inability to distinguish between enemy and friendly ships. In bad weather the aircrew would have great difficulty distinguishing between the two.

Other U.S. Navy guided bomb developments included the GLOMB, Pelican, and Dove. The GLOMB (GLider bOMB) was a towed glider containing a 2000 lb GP warhead or 4000 lb light case bomb. The bombardier in the tow-plane controlled the GLOMB after release with radio remote-control based on television pictures received from a camera in the GLOMB's nose. The Pelican was another glide bomb designed for carriage on large patrol aircraft but the Pelican incorporated a semi-active radar seeker. The Pelican's seeker homed on the radar energy transmitted from the patrol planes search radar and reflected off the target ship. The U.S. Navy's final World War Two guided bomb development was the heat seeking Dove. Similar in concept



to the Army Air Corps' VB-6 Felix, the Dove was also a high angle bomb with a heat seeker attached to the nose of the standard 1000 lb bomb.<sup>39</sup> The U.S Navy was unable to complete development of the GLOMB, Pelican, and Dove prior to the end of the war.

By the end of the second World War both the Army Air Corps and the U. S Navy had started development of the guided bombs that would later prove themselves in Southeast Asia and wars in the middle east. However, in 1945 America was tired of conventional wars and possessed the only atomic weapons in the world. America's massive armed forces were virtually dismantled. There was no perceived need for large land armies or naval forces when our national leaders believed a few large bombers could devastate an enemy's homeland. As a result, most conventional weapons development came to a screeching halt. When the USAF and U.S. Navy found themselves involved in a conventional ground war in Korea they had to fight with virtually the same bombs and technology they used during World War Two.

## THE KOREAN WAR

The Korean War started with North Korean forces invading South Korea in June 1950. With the North Koreans advancing rapidly, interdiction would have been effective in slowing them down and providing time for the South to regroup. The North Koreans had a small, poorly-equipped air force presenting little threat to bombers loitering over targets to deliver guided bombs. The environment also provided many lucrative targets and generally good weather conditions. Korean terrain is very hilly with numerous road and railroad bridges crossing many rivers and forming many natural chokepoints. This were ideal conditions for the VB-3 RAZON.

The 19th Bombardment Group (BG), flying B-29s for the Far Eastern Air Forces (FEAF), were trained and equipped to drop RAZON and TARZON (TAllboy RAZON) optically guided bombs prior to the start of the Korean War. The VB-3 RAZON was the same high-angle, free-fall, 1000 lb, radio controlled bomb tested at the end of World War Two. The VB-13 TARZON was an American adaptation of the British 12,000 lb Tallboy, with an M-109 (12,000 lb) or M-112 warhead. The TARZON's guidance was essentially the same as the RAZON with control in both range and azimuth.<sup>40</sup>

The Air Proving Ground (APG) trained the initial cadre of three officers and six airmen for the 19th BG in 1949. When the war started, the 19th BG had only one of the three trained officers and three or four of the airman. The specially equipped planes had not been maintained and the bomb tail units were still at Guam. In August 1950 the APG sent a team of specialists to retrain the 19th BG aircrews. The first RAZON mission was flown on 24 August, within two weeks of the training team's arrival.<sup>41</sup>

Improperly tuned radio receivers on the RAZON tail unit caused the first two missions

to be only “partially successful” Most of the problems were corrected and five full crews were trained before the APG team departed on 31 October 1951. During the training period the 19th Bombardment Group flew 21 sorties and dropped 154 RAZONs. They destroyed ten bridges, damaged five more, and damaged three bridge approaches. Of the 154 RAZONs dropped, 92 (60%) responded to control inputs but 14 of these were duds. The 19th BG recorded 20 direct hits that exploded as well as some direct hits with duds. With 49 additional bombs hitting within 40 feet this small sample established the RAZON’s operational circular error probable (CEP) near 40 feet.<sup>42</sup> By December 1950 the last group of 150 RAZONs achieved 96% reliability. The 19th BG dropped 489 RAZONs in combat, 331 (67%) were controllable and they claimed 15 destroyed bridges. In December 1950 the RAZONs were relegated to smaller targets and a training role as the 12,000 lb VB-13 TARZONs became available.<sup>43</sup>

FEAF’s use of the large TARZON guided bombs was inconclusive. On 14 December 1950 the first TARZON was dropped from 20,000 ft in an attempt to close a railroad tunnel; but the bomb missed. After several modifications to the control assembly, the second TARZON achieved a direct hit on a small factory. A total of ten bombs were dropped in December with only one direct hit and miss distances up to 2,200 ft. In February 1951 only two TARZONs were dropped due to a short supply of bombs, but these two bombs destroyed two bridges. March brought even better success. Five successive TARZON missions were able to destroy their targets. By April 1951 the 19th Bombardment Group destroyed five more bridges on six TARZON missions. Disaster struck on 30 April with strong evidence that the bomb could not be jettisoned safely. One B-29 crew experienced engine problems shortly after takeoff and needed to jettison the bomb. The bomb exploded 1.5 seconds after impacting the water causing a severe hazard to plane and crew. FEAF officials suspected this same hazardous condition caused a

ditching B-29 to explode earlier in April.<sup>44</sup>

The FEAF suspended TARZON operations in May 1951 with only 33 TARZON combat drops and 27 (81%) successful attacks. Unfortunately, the sample of TARZON deliveries was too small to draw any conclusions. On 15 August a FEAF conference recommended the RAZON-TARZON program be abandoned completely. Their reasoning concluded that TARZON bombing tied up too many specially modified B-29s from the limited medium bomber force. Additionally, after the summer of 1951, few targets remained that required the power and accuracy of the TARZON. Finally, on 29 October the USAF sent all guided bomb equipment and personnel back to the Air Proving Ground for research and training.<sup>45</sup>

The results of the Korean guided bomb experience were basically the same as World War Two. Good weather and air superiority were essential to effective bombing. The APG also recommended that dedicated TARZON units be established in each numbered or theater air force to maintain a trained and ready force.<sup>46</sup> After the Korean War, considered by many to be an aberration that would never happen again, conventional weapons development lost priority once again to nuclear weapons and the buildup of Strategic Air Command. The guided bomb program completely stopped and American airpower experienced another 15 years of limited conventional weapons development before combat in Southeast Asia reestablished the need for precision guided bombs.

## THE VIETNAM WAR

American air power, both Air Force and Navy, introduced operationally effective television, infrared, laser, and even visually guided munitions to air warfare in Southeast Asia (SEA). The need to interdict bridges and railroads existed, as in the previous two wars, but Vietnam brought new requirements that demanded new solutions. The continuous flow of supplies into South Vietnam moved mostly at night to avoid American airpower's ability to interdict supplies during the day. The immorality of bombing innocent civilians also played on American minds, and military commanders demanded the capability to destroy vital targets, in or near populated areas, without collateral damage. Many of these targets were also protected by restricted zones placed around Hanoi and Haiphong. Some of the solutions from America's arms industry were the early versions of the laser and TV-guided bombs that later gained worldwide recognition in Desert Storm. The Air Force and Navy each had separate development programs for PGMs. These separate programs produced some redundancy but were also complementary in many aspects.

The two primary types of precision guided, free-fall bombs used in SEA were laser and television guided bombs.

### **Laser Guided Bombs (LGBs)**

The U.S. Air Force's LGB program started in 1965 after the feasibility of laser guidance was demonstrated by the U.S. Army. Scientists and engineers at the U.S. Army Missile Command, Redstone Arsenal started investigating laser guidance as a method of directing anti-tank munitions in 1962. By 1965 the Redstone Arsenal team had demonstrated the feasibility of laser guidance and shared the information with the U.S. Air Force. In November 1965 and January 1966, Aeronautical Systems Division (ASD) awarded contracts

to Texas Instruments (TI) and North American Aviation-Autonetics (NA-A) to develop and test prototypes of laser guided bombs. Testing of the two different prototypes started in the summer of 1966 at Eglin AFB, Florida. The two prototypes varied significantly. TI's bomb was less expensive, used a less complicated guidance technique and tail control fins but constituted a higher risk design. NA-A's design used a previously demonstrated guidance technique, canards for control, but was three times more expensive.<sup>47</sup> TI's prototype proved to be the better design and by the middle of 1967 the Air Force had conducted tests with laser guidance kits on M-117, 750 lb general purpose (GP) bombs and Mk-84, 2000 lb GP bombs.<sup>48</sup> On 15 June 1968 the U. S. Air Force issued Development Directive 69 approving \$4.7 million for 293 laser kits for fiscal year 1968. Testing of the engineering prototypes started in November 1967 and the testing program was transferred to Southeast Asia in May 1968.<sup>49</sup> The concept of attaching guidance kits to general purpose bombs followed the practice established during World War Two with the original vertical and glide bombs.

The guidance kits used in SEA remained unmodified throughout the war. Once the weapons were deployed, the biggest changes occurred in the designating systems and delivery tactics. The basic LGB kit consisted of the nose seeker, guidance and control unit (GCU), and tail fins. The GCU and seeker form the nose of the bomb. A set of canards, controlled by the GCU, steer the bomb after release. The tail fins are fixed and provide stability for the bomb. The first LGBs, designated "Paveway I", were controlled by what is now called "bang-bang" guidance. The seeker consists of four detector elements divided into four quadrants. The GCU attempts to maintain the reflected laser spot in the center of the seeker's field of view. When the seeker detects the laser reflection outside the center of its field-of-view, the GCU fully deflects the canards to correct the steering toward the proper quadrant. As the reflection inevitably

overshoots the seeker's center, the canards fully deflect in the opposite direction. The canards have only two positions: fully deflected or streamlined. Every correction causes the bomb to oversteer, resulting in the bomb constantly correcting (Fig 7). This is where the “bang-bang” term originated. Accuracy was improved by slightly canting the tail fins causing the bomb to spin, thus dampening out the oscillations.<sup>50</sup>

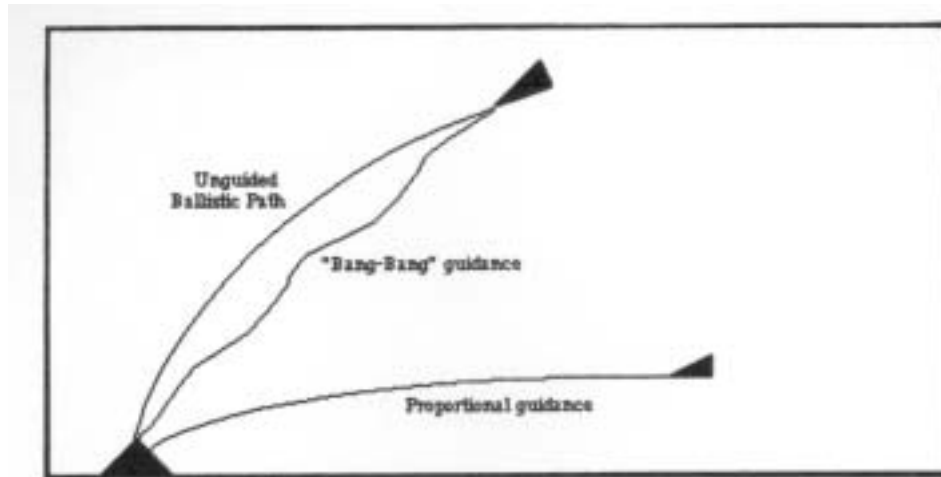


Fig 7. Guided Bomb Flight Paths

The laser guided bombs were first tested in Vietnam in May 1968 with the 8th Tactical Fighter Wing (TFW) stationed at Ubon, Thailand. From 22 May to 9 August 1968 the missions were limited to targets in Route Package One, the southern area of North Vietnam, where the threat was lower and crews could concentrate more on tactics development. The bombs used in these tests were the 750 lb M-117 with the KMU-342B guidance kit and the 2000 lb Mk-84 with a KMU-351B guidance kit. The Mk-84 combination, later called the GBU-10, proved to be as accurate as the laser-guided M-117, plus provided more than twice the explosive power.<sup>51</sup>

The results of this initial testing were published in a utility and cost effectiveness comparison by 7th Air Force. They determined that aircraft carrying LGBs were able to destroy over 20 times as many targets as the same number of aircraft dropping groups of six unguided

M-117 bombs. The cost per target was less for the LGBs and the ability to release accurately from medium altitude resulted in fewer aircraft losses from AAA and small arms fire. These were the characteristics that airpower theorists had always wanted--the ability to destroy any selected target, at will, with minimum losses.

During testing the 8th TFW started their delivery from 20,000 feet above the target, rolled into a 45 degree dive and released the bomb at 12,000 feet. A second aircraft, orbiting at medium altitude, would aim and hold the laser spot on the target until the bomb impacted.<sup>52</sup> With this second aircraft designating the target, the delivery aircraft could perform escape maneuvers immediately after bomb release.

Laser designators were installed on several types of aircraft. The White Lightning or "Zot" was installed in the F-4D's back seat, it was also referred to as the Paveway designator. Pave Nail was a designator and night observation device, installed in a turret on OV-10 FAC aircraft. Some AC-130s were modified with Pave Spectre designators boresighted to the infrared and low-light-level TV. Pave Spectre and Pave Nail provided a night target-locating laser designating capability for use on the Ho Chi Minh trail. In the latter part of the war Pave Knife and Pave Spike pods were added to the F-4. These pods allowed a single aircraft to designate the target and deliver the weapons as well as provided better maneuverability during target designation.<sup>53</sup>

As the war progressed and experience with laser guided bombs increased, Air Force leaders discovered the need for a greater variety of LGBs to increase effectiveness against certain targets. A laser guidance kit for the M-118, 3000 lb GP bomb became available in October 1969 for use against larger, hardened targets and for better effectiveness against large bridges. A smaller bomb with greater maneuverability was also required to attack the many small and



moving targets on the Ho Chi Minh trail. The Air Force adapted the 500 lb Mk-82 GP, later called the GBU-12, for this purpose and the M-117 LGB was phased out of production in 1968.

Bombing results continued to improve and 7th Air Force planners expanded the LGB target list. In 1969, 1612 LGBs were dropped with 923 (57%) direct hits, an additional 1114 damaged targets, and no aircraft losses. Road cutting became a primary target as the Air Force attempted to stem the flow of supplies to the south. From October 1968 through August 1969, 993 roads were cut with LGBs while in the next highest target category, artillery guns, only 390 were claimed.<sup>54</sup> Although the accuracy of LGBs made road cutting easier, the dirt and gravel roads of Southeast Asia were even easier to repair by the extremely dedicated Viet Cong and North Vietnamese. It could even be argued that bombing roads created the loose soil and rock need to repair the craters caused by the bombing. By 1971, Air Force leadership recognized the full value of PGMs and production was increased to 920 kits per month (480 Mk-84s, 400 Mk-82s, 40 M118s).

The targets vulnerable to LGBs were virtually limitless. If a target could be illuminated with a laser then a fighter could destroy it, and usually on the first pass. The bombing restriction of North Vietnam, started in March 1968, restricted guided weapons to South Vietnam, Cambodia, and Laos until 1972. In 1972, when the war evolved to a clash between conventional forces, President Nixon removed many of the bombing restrictions, and LGBs proved very effective. In the populated areas near Hanoi and Haiphong, LGBs became the Air Force's weapon of choice for effectiveness and the ability to limit collateral damage.

The conventional war also brought full-size North Vietnamese divisions, armed with tanks, into the open. Seventh Air Force found F-4Ds, armed with 500 lb LGBs, very effective against the tanks when attacking from medium altitude. The F-4Ds comprised only 10.4% of the

tank killing effort but provided 22% of the reported tank kills. The LGB's 65% effectiveness during tank attacks provided commanders with a high degree of confidence in the system.<sup>55</sup>

Another small test was accomplished with specially equipped B-52Gs attacking trucks at night. The B-52Gs were equipped with infrared sensors, moving-target-indicating radar, low-light-level TV, Tropic Moon III laser designators, and Mk-82 500 lb LGBs. From 21 November to 28 December 1970, the B-52s made 59 drops from 40,000 feet, destroying 35 trucks with a good probability of damaging others.<sup>56</sup> Unfortunately this program was stopped as it could have provided valuable information for the current controversy on the conventional capability of long-range bombers using precision guided munitions.

Between 1 February 1972 and 28 February 1973, 10,651 laser guided bombs were dropped in SEA. Over 90% of these bombs were the 2000 lb Mk-84 LGBs and the rest were a mix of 500, 750, and 3000 pounders. Nearly 50% (5,107) of the bombs were direct hits and only 15.2% were no-guides. The CEP for this period was 23 feet despite many of the missions being flown in the heavily defended Hanoi/Haiphong area.<sup>57</sup> In contrast to this, the F-105's bombing accuracy, in the same areas (Route Packages 6A and 6B), during the last phases of Rolling Thunder was considerably less. The F-105's CEP was 447 feet and direct hits were claimed on only 5.5% of all sorties. Even when AAA was absent, the F-105's CEP was 365 feet.<sup>58</sup> On the other hand, the accuracy of bombing with LGBs was unaffected in the presence of AAA and other threats. It should also be noted that twice as many LGBs were dropped per target in heavily defended areas compared to low threat areas. In high threat areas four-ship electronic counter measure (ECM) pod formations were flown and all bombs were released in one salvo.<sup>59</sup> In another comparison made during Linebacker I, the five bridges destroyed in one day on the Northwest Rail Line with 24 laser guided bombs would have required 2400 unguided bombs.<sup>60</sup>

The U.S. Air Force used laser guided bombs for five years in SEA. In a briefing on guided weapons effectiveness, General Eggers, the Deputy Director for Operations, J-3, stated the Air Force dropped over 20,000 laser guided bombs in Southeast Asia. During the 1972 Easter Offensive, the Air Force dropped 6000 LGBs with 84% guiding and 64% achieving direct hits.<sup>61</sup> But LGBs did not do all of the precision guided destruction. The other primary guided bomb used during the war in SEA was the television or Electro-optical Guided Bomb (EOGB).

### **Electro-optical Guided Bombs**

The US Navy led the Air Force in fielding an operational EOGB. The Navy's free-falling AGM-62 Walleye was introduced in March 1967. The Walleye had small aerodynamic wings giving it a limited glide capability and making it a hybrid of the Glide and Vertical bombs of World War Two and Korea. The image produced by the camera in the bomb's nose was presented to the pilot before the bomb was released. The pilot pointed the aircraft toward the target area, aligned the TV seeker to a target, locked the seeker to the aim point, and then released the bomb. After the pilot released the bomb he could no longer monitor its progress or update the aim point, thus allowing him to devote his full attention to egressing the target area and avoiding enemy threats.

The Walleye was not a modular kit attached to a general purpose bomb. The Navy designed the Walleye as a complete munition with a 850 lb linear-shaped-charge warhead capable of penetrating 18 inches of steel-reinforced concrete or the armored hull of a ship.<sup>62</sup> This penetration capability made the Walleye very effective against small bridge abutments and bunkers.

The U.S. Navy also has other special considerations in weapons development and deployment. The restricted storage and munitions buildup space on aircraft carriers and resupply

ships limits the number of ordnance options available to the Navy. Therefore, the Navy desires unitary, multi-purpose rounds with less emphasis on general purpose bombs with numerous fuse, tail fin, or guidance kit options.

The Navy used three Walleyes against the massive and infamous Thanh Hoa Bridge in North Vietnam on 12 March 1967. The Walleyes all hit within five feet of the aim point but the bridge still stood. Against smaller bridges, barracks, and bunkers the Walleye was very effective.<sup>63</sup>

A larger version of the AGM-62, with a 2000 lb warhead, was introduced in 1972. The Walleye II proved to be more effective against the bigger bridges, but still required long, stable final approaches. Just prior to the war's end the Walleye II was modified with a data link. The data link allowed the aircrew to monitor the bomb after release and correct the aim point, or manually control the bomb through impact. The data link also allowed two-aircraft tactics where the delivery aircraft could drop the bomb and egress the target area without acquiring the target. The second, or controlling aircraft, flew outside the range of enemy threats and guided the bomb.<sup>64</sup> The Walleye was, however, limited to larger targets that presented enough contrast for crew identification and seeker lock-on.

The 8th TFW received the AGM-62 Walleye in August 1967 under the code name Combat Eagle and was fully operational just before the 1 April 1968 bombing halt in the north.<sup>65</sup> Eighth TFW aircrews found the Walleye to be particularly effective against bridges but did not advocate its use in high threat areas. To deliver the Walleye the pilot started his run at the target from 12-14,000 feet AGL and 450 knots. Target acquisition and lock-on required a long, stable final approach. In low threat areas the crews could make individual passes, but in high threat areas like Route Package 6, they had to maintain four-ship pod (to enhance defensive electronic

counter-measures) formations. The attack profile in high threat areas started at 16,000 feet AGL with a 30 degree dive at .9 Mach. This minimized the time in the lethal AAA zone, but provided the crews less time to identify and lock the target. This lowered the mission success rate.<sup>66</sup> The range at release depended upon the pilot's ability to see the target and this depended on target size, weather conditions, lighting conditions, and target contrast with the surrounding area. The 8th TFW dropped 206 Walleyes before the end of the war.

The Walleye was used much less extensively than the laser guided bombs. Weather and restrictive target requirements were the primary limitations. Only 898 Walleye Is, 79 Walleye IIs, and 3 Walleye IIs with data link were dropped in SEA through the combined efforts of the Air Force and the Navy.<sup>67</sup> The bombs that were dropped were reliable and very successful. A full 68% of all Walleyes dropped were direct hits<sup>68</sup>

The USAF also developed an electro-optical, modular guidance kit that fit on a Mk-84 2000 lb GP bomb and called it the HOBOS (Homing Bomb System). It was first used in combat in February 1969 and was available when the bombing of North Vietnam resumed in April 1972. The HOBOS's guidance system and employment tactics were very similar to Walleye's and was the forerunner to the present day GBU-15. Once again the 8th TFW had the honor of employing the newest ordnance in the inventory. Between 6 April and 30 June 1972, the 8th TFW destroyed 106 bridges with HOBOS and LGBs.<sup>69</sup> Of the 500 EOGBs delivered in SEA between April and October 1972, 80% guided and 52% achieved direct hits.<sup>70</sup> By March 1973 the 8th TFW was experiencing difficulty flying all the tasked EOGB sorties due to the lack of suitable targets. Based on this, 7th Air Force decided that EOGBs were no longer required in theater.<sup>71</sup>

During the Vietnam War, Air Force and Navy aircrews combined to drop 26,690 guided weapons. Laser guided bombs were the vast majority of the guided bombs, comprising 94% of

the total. Mk-84 LGBs formed 84% of the laser guided bombs and 79% of all guided bombs. Walleyes were 4% and HOBOS were only 2% of the total guided bombs dropped in Southeast Asia. Although 26,000 is impressive, 3,376,000 ballistic bombs (over 500 lbs) were dropped and that doesn't include B-52 and non-U.S. expenditures. Guided bombs were effective when used, even though they were less than 1% of all bombs dropped.<sup>72</sup> A wealth of experience with guided bombs was gained in Southeast Asia but guided bombs were not yet America's primary aerial ordnance.

There was also no doubt among precision guided bomb droppers that the medium altitude delivery tactics used during Vietnam required air superiority and dedicated support to counter SAMs and AAA. When American air power returned to North Vietnam in 1972 they used a vast array of equipment and tactics to overcome the threat. Dedicated fighter support worked to keep the MiGs away from the bomb carriers. The bomb carriers carried ECM pods and flew special pod formations that optimized the effects of ECM. Wild Weasels and chaff corridors minimized the SAM threat, and medium altitude deliveries allowed the crews to stay out of the heaviest AAA. The lesson for future crews was that precision was not gained by a lone aircraft carrying a guided bomb; precision bombing required the combined effort of many assets.

## THE MIDDLE EAST AND THE 1970s

The next test for American guided weapons was the 1973 Middle East Conflict. During this conflict between Israel and Egypt the Israelis used the Walleye I and HOBOS against Egyptian armored forces. Targets included tanks, armored vehicles, bridges, fortifications, and buildings. The desert war in the Middle East had a significantly different character than the war in Southeast Asia.

This war lasted only 18 days but demonstrated the massive expenditure of ordnance and destruction of forces in the dawning age of PGMs. The Arab forces lost 475 aircraft, 2300 tanks, and 10,000 soldiers. The Israelis lost 115 aircraft, 200 tanks, and 2400 soldiers.<sup>73</sup> The major differences in this theater and Southeast Asia were open terrain, good weather, and the use of more guided weapons even though guided bombs were still only a small portion of the total weapons used. The Israeli Air Force used 88 Walleye Is with 84 (96%) direct hits destroying 70 tanks/armored vehicles (several bombs claimed multiple vehicles) and 18 bridges. The results of the other four bombs were not observed. Only 32 HOBOS were used and the success rate was a little lower with only 25 (78%) direct hits, 4 misses, and 3 not observed.<sup>74</sup> Although the number of targets destroyed by guided bombs was small, the results were decisive in stopping Arab tanks during the later stages of the war. The desert environment of the Sinai Peninsula with its clear weather, and no vegetation, provided ideal contrast conditions for the electro-optical seekers.

Throughout the 1970s the Department of Defense continued to update and improve the laser and TV guided bombs Paveway II, the second generation of LGBs, became available in 1975. Paveway II used the same 500 and 2000 lb GP bombs, added a kit for the MK-83 1000 lb GP bomb for the Navy, improved electronics, improved seeker sensitivity, and used folding tail fins that extended immediately after the bomb was released. The Paveway II guidance kit was

also adapted to the British Mk 13/18 1000 lb bomb that was used successfully by the RAF in the Falklands War.<sup>75</sup> The new electronics design incorporated integrated circuits improving reliability and lowering costs. The improved seeker had greater sensitivity increasing detection range. The folding fins improved the bomb's aerodynamics, giving it better maneuverability as well as making handling and loading easier (Fig 8). The compactness of the new tail also made the bomb compatible with more aircraft and increased each aircraft's bomb carrying capacity.<sup>76</sup>



**Fig 8. Paveway II LGB (Armament Division, Eglin AFB)**

The HOBOS was also slated for improvement during this period. Like the Navy's data link modified Walleye II, the Air Force sought to overcome the need to fly long, stable final approaches prior to weapons release. The solution, designated the GBU-15 (Fig 9), was to improve the bomb's aerodynamics for better range and add a data link. The GBU-15 was developed with both TV and imaging infrared (IIR) seekers. GBU-15 development began in 1974, the first test flight accomplished in 1975, and production of the TV version started in 1980.



The Air Force planned to procure 2400 TV and 1200 IIR bombs with the F-4, F-15, F-16, F-111F and Australian F-111 Cs capable of carriage and delivery. These improvements gave Air Force fighters the ability to use the two-aircraft tactics developed by the Navy for use with data link modified Walleye IIs. Another key improvement was the ability to lock the GBU-15's seeker to the target after the weapon's release or manually control the bomb all the way to impact without ever locking-on. This improved stand off capability because the bomb could be launched before the aircrew acquired the target and allowed acquisition when target contrast improved. Also, as the aircrew flew the bomb toward the target via data link inputs, he still had the capability to lock-on if he experienced any electronic jamming.<sup>77</sup> The ability to manually fly the bomb gave the crew the advantage of selecting the target's most vulnerable spot, for instance a particular door or window. These improvements came with fairly high costs compared to earlier EOGBs and LGBs. The GBU-15 TV variant cost approximately \$195,000 with the IIR version approaching \$300,000. By comparison, Paveway II LGBs cost around \$20,000.<sup>78</sup>



Fig 9. GBU-15s on F-111F (Armament Division, Eglin AFB)

## THE 1980s AND THE LIBYA RAID

In Vietnam, LGB droppers had to rely on AC-130s and OV-10s to acquire night targets with their low-light-level TVs and infrared sensors. This required very complicated coordination to get the fighters on target. In the early 1980s F-111Fs and F-4s received the Pave Tack pod. Installed in the F-111F's weapons bay or the F-4's wing pylon, the Pave Tack pod provides a high-resolution thermal-imaging sensor for target detection and tracking. Boresighted to the thermal sensor is a laser designator that provides highly accurate ranging information and illuminates the target for the laser guided bombs.<sup>79</sup> Finally, the F-111's terrain following radar provides the ability to penetrate enemy territory at night, in all types of weather, and at altitudes as low as 200 feet above ground level. Together these two systems give a single F-111F the ability to attack a target from low or medium altitude, with a good probability of success, day or night.

When President Reagan ordered a strike against Libyan sponsored terrorist organizations in April 1986, the 48th TFW, based at RAF Lakenheath, UK, used F-111Fs and Paveway II Mk-84s for the attack on Tripoli. The attack took place at 0200 hours Libya local time. Attacking at night from low level increased the level of surprise and significantly reduced the threat of visually-aimed AAA and infrared SAMs like the Soviet such as SA-9. The capability to attack pin-point targets at night ensured most civilians were at home, out of harm's way, and the terrorists were in their barracks. Department of Defense spokesman Robert Sims announced that: "Only 1 to 2 percent of the bombs impacted on civilian areas."<sup>80</sup> Compared to the bombings of any previous war by any air force, this was a major accomplishment.

In the mid-1980s, Pave Way III LGBs became available. The result of Pave Way III

development was the GBU-24/B Low Level Laser Guided Bomb (LLLGB). Texas Instruments (TI) received the contract to develop the LLLGB in 1980. The requirements established in the late 1970s called for a weapon that enabled fighters in NATO to stay at low altitude while penetrating enemy airspace, throughout the delivery, and during egress. Additionally, Tactical Air Command wanted greater stand-off range to stay away from defenses near the target.<sup>81</sup> The GBU-24/B incorporated a scanner seeker, either conical or bar scan, giving the bomb a much larger field of view than the streamlined seekers of Paveway I and II bombs. To allow the bombs to maintain a low altitude flight profile TI also added a barometric sensor and microprocessor operated autopilot. The “bang-bang” guidance of earlier LGBs also had to be changed to proportional guidance to provide stability, increase range, and improve accuracy. With proportional guidance, the bomb’s seeker corrects small laser spot deviations with small canard deflections, avoids overshoots, and generates a smooth flight path (Fig 8). A smoother flight path saves the bomb’s kinetic energy and increases its range and accuracy. The final change was the addition of larger tail fins to improve the bomb’s aerodynamic qualities. After the GBU-24/B started production TI modified the kit to accept the BLU-109 improved 2000 lb penetrating bomb (I-2000). Penetrating hard targets requires specific impact angles. Software changes to the bomb’s autopilot provided the GBU-24A/B with selectable flight profiles. The aircrews could select the desired profile before flight based on target characteristics (vertical or horizontal orientation), weather, and planned tactics.<sup>82</sup> But, the LLLGB is not perfect, it has one major limitation. If the seeker fails to identify a laser spot, the bomb attempts to maintain the pre-programmed flight profile and grossly overshoots the target. An overshoot, especially in a heavily populated area greatly increases the probability of damaging an unintended civilian target. This limitation, and lack of aircrew experience with the LLLGB, were two reasons the

48th TFW chose Paveway II LGBs for the Libya strike. TI also developed a 500 lb version of the LLLGB, the GBU-22, using the MK-82 GP bomb body. In Paveway I and II bombs the smaller size improved the bomb's accuracy, but the GBU-22 did not provide any significant increase in accuracy or range, provided less fire power, and the Air Force chose not to purchase it. The final variant of the LLLGB is the GBU-27. The GBU-27 is a modified LLLGB designed for delivery by the F-117. The GBU-27 uses different software than the GBU-24 and has a different tail design. By 1985 TI had delivered 5482 GBU-24s when the program was cancelled by USAF Secretary Verne Orr for cost overruns. TI modified 4100 GBU-24/B kits to accept the I-2000 and 1200 were converted to GBU-27s. By March 1991, TI delivered an additional 300 GBU-27s.<sup>83</sup>

The LLLGB provides the Air Force with a near zero CEP weapon but the improvements have essentially doubled the cost of laser guided bombs from approximately \$20,000 for Paveway II to \$65,000 for Paveway III. The 1980s also brought the development of the LANTIRN navigation and targeting pods. The LANTIRN pods provide an infrared sensor and laser designator for the F-16C and F-15E. The addition of LANTIRN pods to F-15Es and F-16Cs will triple the number of available PGM capable aircraft and greatly increase the night/adverse weather precision bombing capability in the Air Force.<sup>84</sup>

The last addition to free-fall precision guided bombs during the 1980s was the addition of a separate GBU-15 IIR seeker. The seeker developed for the AGM-65D IIR Maverick replaced the TV seeker in the GBU-15 guidance kit to give the GBU-15 a night capability.

The arsenal of guided bombs now covered the spectrum of day or night with the flexibility of laser guided bombs and the extreme accuracy and stand-off capability of the GBU-15 glide bomb family. These were the capabilities the Coalition air forces used to execute the decisive air campaign in Desert Storm.

## DESERT STORM AND THE 1990s

Desert Storm was the culmination of years of sporadic precision guided bomb development. Delays in development after World War Two and the Korean War were corrected by rapid development during the war in Southeast Asia. After America withdrew from the war in Vietnam, weapons development continued at a steady pace. Events in the Middle East and south Atlantic demonstrated the capabilities of the new generation of guided bombs. Then Iraq invaded Kuwait and positioned large armored forces near Saudi Arabia.

This presented the coalition forces with large conventional formations in open terrain. During Desert Storm, the U.S. Air Forces employed 7,400 tons of precision guided munitions accounting for 15,500 pieces of ordnance. Although this is a small number compared to the 88,500 tons/210,800 pieces of total air delivered ordnance, it constitutes a significant increase in percentage compared to the Vietnam War; 8.5% in Desert Storm compared to less than 1% in Vietnam.<sup>85</sup>

Over half of the precision guided bombs (56%) were Paveway II and III bombs dropped by F-117s, F-111Fs, and F-15Es.<sup>86</sup> Only a few GBU-15s (approximately 80) were used but the GBU-15s accuracy and target discrimination capability was essential in shutting off the oil Iraq was dumping in the Gulf.<sup>87</sup> Although the guided bombs are still a small percentage of the total, the accomplishments were large.

The 48th Tactical Fighter Wing deployed 66 F-111Fs, with Pave Tack laser designator pods, from RAF Lakenheath, England to King Fahad Royal SAB, near Taif, Saudi Arabia. The wing flew 2958 sorties and claimed an 88% mission success rate. At the beginning of the air war 48th TFW aircraft concentrated on command and control bunkers and airfields. The wing was credited with destroying 113 bunkers and 245 (40% of the total) hardened aircraft shelters. Later

in the air war, while concentrating on isolating the battlefield, the wing destroyed 160 bridges (50% of the total) along the Tigris and Euphrates rivers. Finally, in the last two weeks prior to the ground war, the F-111s directed their efforts against Iraqi armor and destroyed 920 tanks and APCs with GBU-12s (500 lb Paveway II LGBs). In all, the 48th TFW dropped 7.3 million pounds of guided bombs and conducted all of these missions at night.<sup>88</sup> But, the 48th TFW was not the only wing dropping precision guided bombs.

The other major contributor to the USAF precision bombing effort was the 37th Tactical Fighter Wing flying F-117s from Tonopah Test Range, Nevada. The 37th TFW deployed 42 aircraft to Saudi Arabia, flew 1271 LGB sorties, and claimed direct hits on 43% of the Desert Storm strategic target list, with only 2% of the total attack sorties flown during the war. Their selection of laser guided bombs included GBU-27s, GBU-10s (2000 lb Paveway IIs), and GBU-12s. Although the F-117s were only 6% of the fighter assets in Desert Storm, the targets they destroyed were critical to the strategic air campaign.<sup>89</sup> The stealth qualities of the F-117A allowed the crews to fly into the most heavily defended areas, especially around Baghdad, and accurately deliver munitions from medium altitude. In the first 36 hours of the air war numerous targets were attacked in and near major Iraqi cities and, even according to Iraqi claims, only 23 civilians were killed.<sup>90</sup> Compared to the tens, and sometimes hundreds, of thousands of civilians killed during Allied bombing raids during World War Two, guided bombs have provided the capability to accomplish the strategic bombing envisioned by Air Corps Tactical School strategists in the 1930s, without destroying entire cities.

The smallest U. S. Air Force contributors to the guided bomb effort were the F-15Es and F-16s. Unfortunately, the F-15Es had only 6 aircraft equipped with LANTIRN laser designating pods and these aircraft concentrated on attacking the mobile SCUD launchers.<sup>91</sup> The F-15E's

synthetic aperture radar (SAR) and the IR capability of LANTIRN uniquely qualified the F-15E for this difficult and demanding mission. Some F-16s were equipped with LANTIRN navigation pods but not targeting pods with the laser designator. They were however, able to team up with F-111Fs and provide additional carrying capacity for LGBs during the armor busting campaign. The USAF was only one member of the coalition guided bomb capability during Desert Storm.

The U.S. Navy contributed to the guided bombing effort with GBU-16s and Walleye IIs with data link. The RAF provided Buccaneers with laser designating capability for the British version of Pave way II LGBs, the Mk 13/18. Finally, the French and Saudi Arabian air forces both have laser guided bomb capability.

There was also one bomb completely conceived, developed, and employed during the 43 days war. The GBU-28, a 4,700 lb laser guided bomb was developed, built, tested, and used in combat in a 17 day period. The deepest Iraqi bunkers were secure from the best penetrating bomb, the GBU-24A/B, with the I-2000 warhead. Coalition leaders required the capability to destroy these vital command and control facilities. Texas Instruments and Lockheed combined their efforts to build the 18 ft long bomb. TI adapted the seeker from the GBU-24 and Lockheed built the bomb body from discarded eight inch howitzer barrels.<sup>92</sup> The Air Force initially contracted for 30 bombs but the cease fire started after only two were employed. Two more of the bombs were used in testing before the bombs were dropped in combat and the Air Force expended two or three more in additional tests after the war<sup>93</sup> The Air Force has recently ordered an additional 100 GBU-28s with the BLU-113 (8 inch gun barrel) bomb body and stocks will likely remain low due to the limited number of targets and the only fighter capable of employing it is the F-111F.<sup>94</sup> Where does guided bomb development go from here?

## **Current Development Projects**

As usual, at the end of most wars, we find ourselves in the middle of a major force restructuring that includes large reductions of all the military services. The reductions are a result of the collapse of the USSR and Warsaw Pact, and the accompanying diminished threat, and was underway before Desert Storm commenced. Another influencing factor is the current fiscal difficulties the World's nations are experiencing. After each of the two world wars and Korea, conventional weapons development was nearly stopped until the next war got it moving again. In the early 1960s, under President Kennedy, we found ourselves shifting to a more conventionally oriented deterrence, based on the strategy of Flexible Response. This required a large build-up in NATO to counter Warsaw Pact forces, which in turn kept conventional weapons development funded. We seem to have learned from our past and are continuing to develop the next generation of guided weaponry. The first of these development programs is the Joint Direct Attack Munitions (JDAM) program.

The JDAM program is a three phase program to improve the accuracy of conventional weapons without greatly increasing the costs above current guided bomb prices. For example plain, dumb conventional weapons cost approximately \$1.00 per pound; the MK-82 500 lb bomb costs approximately \$500 and the MK-84 2000 lb costs almost \$2000. Adding current guidance systems to these bombs can raise the cost to well over \$200,000.<sup>95</sup> The first phase of JDAM is to add an inertial or GPS guidance package to the tail unit of GP bombs (Fig 10).



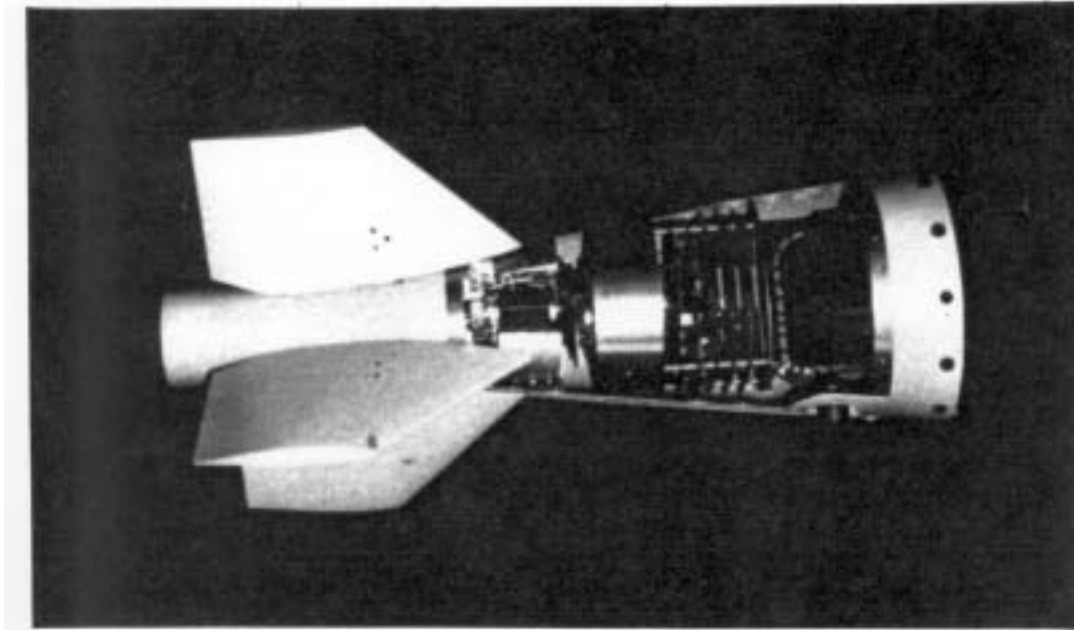


Fig 10. Inertially Aided Munitions Tail Unit (Armament Division, Eglin AFB)

Boeing and Northrop demonstrated the feasibility of inertially aided munitions (IAMs) between 1987 and 1989. Northrop's bomb uses the inertial-guidance unit from an AMRAAM missile, a digital processor and autopilot, a pneumatic fin actuation system, and a thermal battery for power after release.<sup>96</sup> The bomb's guidance system is programmed with target coordinates before or during flight. Prior to release, the bomb's inertial reference is updated from the aircraft's inertial or GPS system. After release, the inertial-guidance unit and autopilot steer the bomb to the target coordinates. There is no seeker involved in guiding the bomb after release. Actual tests have achieved accuracies around 10 meters. IAMs' advantages are numerous. The entire guidance kit fits inside the bomb's standard tail fin eliminating the requirement for carriage and release certification for each aircraft type. This will save money and time. Using the standard tail fin will also reduce weapon assembly time and maintenance requirements since load crews will need no additional training and weapon's parts are common. IAMs also extend the effective range and accuracy of current unguided weapons by trading kinetic energy for distance

and correcting for wind drift and nonstandard air density. Since neither the aircraft nor the kit needs to send or receive any type of electronic emissions, it is jam-proof and launching aircraft are less detectable. IAMs are also unaffected by weather or darkness giving it a true 24 hour capability. The digital autopilot will allow aircrews to select impact angles to increase the bomb's effectiveness against vertically or horizontally oriented targets. And, finally, area targets can be more efficiently attacked by designing honeycomb or grid type impact patterns instead of the standard straight-line stick of bombs.<sup>97</sup> Northrop estimates each IAM tail kit would cost \$12,000-\$15,000 if they produce 25,000 units. ASD's target is to keep the cost below \$20,000 and projects a cost of \$17,000. The price will likely be somewhere in the middle but still less expensive than the GBU-10 2000 lb Paveway II LGBs. IAMs are also less accurate but delivery aircraft will not require very expensive laser designators like PAVE TACK, LANTIRN, or data link pods.<sup>98</sup> The result is fairly accurate delivery, 24 hours a day, from any type aircraft, without the need to modify the aircraft. The second phase of the JDAM program is to develop a 500 lb class close air support (CAS) weapon for the Navy. As mentioned earlier, ships have storage and weapon build-up limitations so the Navy desires a unitary bomb, incorporating IAM technology, that requires no major build-up and satisfies many requirements. To allow flexible use of the weapon, the Navy's goal is to develop a single fuze allowing impact, proximity, depth bomb, delay, and mine capabilities, as well as being cockpit selectable.<sup>99</sup>

JDAM's third phase is to incorporate new seeker technology into the weapon to achieve near zero CEP accuracy regardless of weather or time of day. The Wright Aeronautical Laboratory at Eglin AFB, FL is developing several alternatives for the autonomous seeker program. These seekers are based on millimeter wave radar, laser radar, synthetic aperture radar, and IIR technology as well as high-speed integrated circuits and new computer technology. Each

system has passed the initial technology demonstration phase and the millimeter-wave radar and IIR seeker have entered more advanced phases. ASD at Eglin AFB has successfully launched a Maverick missile configured with a Hughes Aircraft Co. millimeter-wave radar seeker from an F-16. The Maverick, launched from five miles, autonomously searched for and destroyed an air defense unit vehicle target in March 1992.<sup>100</sup> The first test launch of the IIR seeker was scheduled for 11 February 1992, but the F-4 launch aircraft developed the proverbial hydraulic leak just before takeoff.

All the autonomous seekers are being developed under the Autonomous Guidance For Conventional Weapons (AGCW) program. Texas Instruments is the primary contractor for the IIR seeker. The objectives of the program are to demonstrate the terminal guidance function and performance of an autonomous GBU-24A/B; plan development of a modular autonomous IIR seeker for application to a number of existing and proposed standoff weapon systems; and incorporate new technology leading to reduced costs. The IIR seeker uses a focal plane array IR detector eliminating the need for expensive interlace mirrors and motors. It also reduces signal processing complexity and saves several boards of electronics. The seeker's field-of-view was also increased to provide better look-down capability. Better look-down capability provides the ability to control the weapon's trajectory and optimize the impact angle for vertically or horizontally oriented targets. The heart of the autonomous weapon is the target recognition algorithm. The autonomous target recognizer will replace human interface and make targeting decisions based on the prestrike target data entered into the bomb's computer by the aircrew<sup>101</sup>

All of the conventional weapons with autonomous seekers function basically the same. The target must be fixed and well enough described to generate a digital, multi-dimensional data base. The aircrew loads this data base into the weapon prior to weapon release. Target

information is obtained from overhead photography such as Automated Tactical Target Graphic (ATTG) or the new Basic Target Graphic (BTG). After the aircrew launches the weapon it flies a preplanned midcourse using an internal inertial navigation system or Global Positioning System (GPS) satellites and an autopilot. Mid-course position updates are also available by programming the seeker to identify prominent features along the preplanned flight path. As the weapon approaches the target area, the seeker compares the prebriefed target description with the targeted uncertainty area to identify the target. When the target is identified, the seeker provides the guidance signals to direct the weapon to a direct hit.<sup>102</sup>

The advantage of this attack method is the increased standoff range achieved by eliminating the requirement for the aircrew to identify the target prior to release and thus keeping the aircraft out of target area defensive systems. The major disadvantage is the requirement for fixed, distinct targets thereby reducing the weapons flexibility. There are two other seekers in development at Wright Aeronautical Laboratories, the laser radar (Ladar), and synthetic aperture radar seekers.

McDonnell Douglas and General Dynamics/Hughes have each developed a Ladar seeker under the Air Forces Advanced Technology Ladar System (ATLAS) program. Both systems use a carbon dioxide imaging system to detect and classify targets by measuring high- resolution shapes in three dimensions. The sensed image is compared to the stored reference and the weapon is guided to the target with near zero CEP. The guidance and navigation systems are also designed to perform autonomous point-to-point navigation, offset aimpoint guidance, terminal guidance for fixed and movable targets, submunition cuing, and terrain following or obstacle avoidance. The Ladar has extremely good resolution but cannot see through severe weather. Weather will be a limiting factor in only extreme cases since the weapon will be able to autonomously get below the clouds in most situations.<sup>103</sup> Raytheon and Loral have each

developed synthetic aperture radar seekers under the Air Force's Autonomous Synthetic Aperture Radar Guidance (ASARG) program. Synthetic aperture radars provide an all-weather capability against fixed, high value targets. The seeker's task is to produce a radar image of the area surrounding the target's position, find the portion of the radar map that best matches the prebriefed reference template, and then guide the bomb to the target aimpoint. Aircraft equipped with synthetic aperture radars, like the F-15E, can transfer radar map information directly to the weapon, greatly increasing the weapon's flexibility, and adding a mobile target capability. The synthetic aperture radar's design requires the radar to use Doppler shift to generate the high-resolution radar maps. This creates a small blind cone along the radar's flight path. To overcome this blind cone the weapon must initially fly an indirect path toward the target. Enroute to the target the seeker continuously updates the navigation system's position and corrects any drift. At a preselected range from the target, the weapon turns directly to the target and receives guidance commands from the navigation system since the target is now in the radar's blind cone. A small blind cone and accurate navigation system result in very precise weapons delivery, day or night, in any type of weather.<sup>104</sup>

The Air Force's cost goal for all of these autonomous seekers is under \$100,000. The final selection criteria will have to be based on performance, flexibility, and, of course, the cost. The U.S. military is not currently engaged in war and the urgency for fielding these new systems does not exist. Each system has strengths and weaknesses and a combination of seekers should not be ruled out. A possible future step in seeker development is the incorporation of automatic target recognition

Automatic target recognition (ATR) was initially part of the LANTIRN pod concept. The sensor and internal programming identify possible targets from the clutter normally seen by the

aircrew, and at a much faster speed. ATR experienced development problems and was not included in the first LANTIRN pods. Technology advancements now appear to make ATR feasible and the Air Force has started a demonstration program.<sup>105</sup> ATR can also be used in weapon seekers. Initial target recognition should be able to distinguish a tank from a truck but not whether the tank is a Soviet T-72 or American M1-A1. A seeker with this capability would make an excellent interdiction weapon but not be useful when troops are in close contact. The next logical step in seeker development is to develop the computer algorithms and sensors capable of distinguishing between two different tanks and then targeting the correct one. The engineers must first identify the unique characteristics of each possible target and develop the sensors capable of identifying these characteristics. The list of possible distinguishing identifiers might include magnetic signature, electronic emissions, IR pattern, acoustic emissions, size, and shape. The weapon must also identify the target from any aspect. Although these problems are not insurmountable, technology will have to advance for some time before this capability can be produced and packaged in an affordable weapon.

Although this paper has been limited to guided bombs, the technology making these bombs so accurate and efficient can, and has, been adapted to all categories of missiles such as anti-tank, air-to-air, and surface-to-surface.

## EPILOGUE

General Douhet, the Italian airpower theorist, believed the bomber would always get through and deliver such destruction the enemy would lose the will to fight. In the late 1930s the Air Corps Tactical School further developed the doctrine of strategic bombing to target and destroy an enemy's industrial, transportation, and communication infrastructure through precision bombing. The cadre at the ACTS believed the destruction of these targets would severely reduce the enemy's ability to conduct war. Once the enemy lost its ability to fight, they would then lose the will to fight. From the time airplanes were first used as military instruments, airpower theorists and enthusiasts have asserted the airplane's ability to destroy virtually any target.

When aerial bombardment first started, pilots and observers dropped bombs over the side of open cockpit aircraft. The belligerents of World War One then developed crude bomb sights and bomb racks to increase accuracy. Then, between the World Wars, airmen and engineers built bomb sights that allowed "pickle barrel" bombing on benign practice ranges. During World War Two, even the practice of precision bombing with unguided bombs was dropped in favor of area bombing with massive formations. The results during World War Two showed "daylight precision bombing" often struck miles from the target. In further attempts by both sides to improve the precision needed to efficiently destroy targets, the first visually-guided radio-controlled bombs appeared and experienced limited success against bridges and ships. Next, the Korean War brought slightly improved and much larger visually-guided bombs. No bridge could stand up to an accurately placed 12,000 lb TARZON bomb. But, targets were limited and guided bombs still did not win favor; besides atomic, and then thermonuclear, bombs could easily compensate for any limitations in accuracy. Nuclear weapons started proliferating during

the 1950s and the doctrine of massive retaliation quickly became a situation of mutual destruction if either of the superpowers attacked the other with nuclear weapons. During the 1960s America's deterrence doctrine shifted from massive retaliation to flexible response and America needed improved conventional capability to deter the Warsaw Pact and fight ever recurring limited wars. America then became involved in the Vietnam War and employing nuclear weapons was not a realistic option. But Vietnam presented the opportunity to extensively test the capability of guided bombs against a vast array of targets and scenarios. Finally, during the two decades preceding Desert Storm the Air Force nearly perfected precision bombing. During the late 1970s and throughout the 1980s, precision guided bombs steadily improved to meet the challenge of the European environment. Weapons designed for the harsh environment of Europe would work even better in the benign environment of the Middle East. The lethality of precision bombing televised to the World during Desert Storm had its roots with the visions of the earliest airmen and progressed slowly for nearly 80 years. Now, the next generation of precision guided weapons promises better standoff, as well as all-weather capability. This paper's examination of the development of precision guided bombs clearly shows the Air Force has been pursuing the capability to destroy precise targets for many years. Precision guided bombs slowly evolved along with all aspects of airpower and are not the "revolution" presented by the media during Desert Storm. The early airpower pioneers' vision of aerial destruction, even without the threat of global Armageddon promised by the use of nuclear bombs, may have truly arrived. But what impact will this change in warfare have on the nature of war, military doctrine, and the structure of military organizations?

Vietnam, Arab-Israeli wars, and Desert Storm show us that precision guided weapons can devastate pinpoint targets and large armored units in the open. Our precision weapons are no



longer restricted by darkness and will soon be able to overcome adverse weather. Iraqi attempts to hide their tanks under the sand were not even successful. Yes, someone will probably develop countermeasures to guided bombs but, for now, the bombs and the offense have the advantage. James F. Digby and T. Finley Burke, two prominent RAND analysts, wrote several studies in the mid-1970s considering the consequences and capabilities of PGMs and the chances they provide for avoiding nuclear weapons. Some of their observations were:<sup>106</sup>

1. It will be dangerous to concentrate a great deal of military value in one place, either at sea, on the battle field, in the air, or in large supply areas.
2. Smaller units with greater fire power, autonomy, and mobility will be needed.
3. Hiding will become more important and large units such as armor and motorized infantry divisions will not be able to hide.
4. The forward edge of the battle area will become less defined.
5. Standoff and accuracy will mean a smaller percentage of weapons will be carried to the battle area.
6. Collateral damage has and will continue to decrease.
7. New weapons may lead to a revision of roles and missions for each service
8. The pace of war will become faster, with more munitions expended in a given period of time and a corresponding increase in the destruction of equipment and soldiers.
9. The cost of maintaining and developing large amounts of high technology hardware will be expensive and require long lead times.
10. Less concentration and more concealment to avoid PGM attacks will make forces less vulnerable to nuclear attack.
11. Large quantities of conventional PGMs can replace small numbers of nuclear weapons.
12. Ground based air defense will become extremely lethal.
13. PGMs will give small states the ability to defend with a modest military

From these observations and predictions Digby and Burke believed that PGMs gave a decided advantage to the defense because defenders with PGMs could hide in small, powerful units and defeat attackers who come into the open. But in a situation like Desert Storm, PGMs gave a decided advantage to the offense. Offensive airpower was able to hide at night and/or behind electronic masks or stealth while ground forces, even in small scattered units, were unable to hide.

Many of Digby's and Burke's predictions came true but Desert Storm was a clash of large conventional forces, unable to hide in a desert environment. Both authors failed to realize the value of air superiority and the advantage it gave airpower and strategic bombing with PGMs. A stout air defense requires an extensive command and control system that relies on communications networks. The command nodes, communication facilities, and electrical power grid necessary to make it all work are vulnerable to PGMs, especially when combined with air superiority. PGMs provide the holder of air superiority with a more efficient and destructive force to use against, and defeat, the enemy. The loser of the air superiority battle will also lose the ability to employ precision guided bombs and will be forced to disperse and hide, if that is possible. The side controlling the skies will be able to defend the large powerful ground formations necessary to defeat the enemy's ground forces (those that are left after the air campaign). The victor in the Middle East was the side controlling the skies. With air delivery as the primary means of delivering long range precision munitions, the belligerent controlling the skies holds an overwhelming offensive advantage.

Nuclear weapon stockpiles are also decreasing around the world but not necessarily as a result of the increased capability of PGMs. Given the fact that new IAMs will give virtually every bomber and every bomb a precision capability, and new penetrating bombs able to destroy even the hardest targets, is there still a need for the wide area destruction available with nuclear weapons? That is a question we will hopefully be able to answer "no" to in the near future.

The dilemma that must be solved involves the increase or decrease in stability caused by PGMs. PGMs could increase stability and lower the probability of using nuclear weapons by providing smaller nations and alliances with the ability to stop or deter a powerful aggressor. On the other hand, the efficiency of PGMs increases the rate of destruction and might prompt a

faster escalation to nuclear weapons if survival is threatened. If ground forces must disperse and form small units to survive then wide-area nuclear weapons become more desirable. These arguments are not new and may never be solved.<sup>107</sup> To help overcome the dilemma, (as long as there is a threat to national interests) America must maintain an Air Force powerful enough to gain air superiority anywhere in the world. With air superiority and PGMs, the enemy's leadership, command and control network, transportation infrastructure, industrial base, and military forces can all be destroyed with conventional strategic bombing. Nuclear weapons and delivery vehicles can also be destroyed outright, with long range aircraft employing conventional PGMs. But not even an airpower zealot would guarantee the destruction of an enemy's entire nuclear capability as seems to be the case in Iraq. Conventional PGMs and air superiority can replace a large number of nuclear weapons; the real challenge is to eliminate them all.

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