THE EVOLUTION OF CRUISE MISSILE TECHNOLOGY

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The evolution of weaponry is directly "linked to the history of violence, peace and conflict." The history of violence, peace and conflict is also a history "of a series of ever-more-efficient devices to enable humans to kill and dominate their fellow human beings."[1] In the process, any such device or system that is effective is always copied and upgraded, thereby perpetuated. The infinitely ingenious human mind has always looked for creating and using new technology commensurate with necessity and the difficulties arising out of it. But this process of adoption and adaptation is sometimes slow. With this background, if we look at the evolution of cruise missile technology, it seems it is a sober success by gradually coming up to this stage.

However, to get an empirical notion on the evolution of a particular weapon system, one needs to establish an understanding of the "physical factors" required for effective weapons and the "psychological enabling factors" required to effectively employ these weapons.[2] Then only "an overall survey of weapons evolution becomes possible." Physical factors like the need for force, mobility, distance and protection are important physical limitations that stimulate innovations. On the other hand, the psychological enabling factors such as

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1. Dave Grossman, "Evolution of Weaponry" (Academic Press, 2000) available at: http://www.killology.com
2. Ibid.

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resistance to killing, posturing, leadership or decision-making and conditioning are important aspects that instigate the surmounting of physical limitations.[3] Since both physical and psychological factors are ubiquitous, parallel evolution is widely evident. For example, when the Americans and British started thinking of radio-controlled "flying bombs" a few years before World War I, the Germans showed better technology during World War II.

Here an endeavour is made to track the evolution of cruise missile technology empirically. Though there are studies on the chronology of cruise missile development, the factors that steered the system towards maturity have been only scantily investigated so far. Whether it was the sheer technological curiosity or the necessity of war-fighting or any other factor that propelled the process of its onward journey, is the topic of discussion in this paper. Moreover, which technological problems cropped up in what phase and what solutions were applied thereto which kept the evolution cycle rolling is enquired into but with an empirical approach.

PHASE – I: THE GENESIS: EARLY YEARS TO 1941

The first reference on the genesis of modern cruise missile technology can be traced back to the pre-World War I period when the search for using radio communication to control aircraft was started. Among many, Elmer Ambrose Sperry, an American who invented the gyrocompass, succeeded in arousing the US Navy's interest. In 1911, when Sperry applied radio control to airplanes, he realised that for radio control to be effective, automatic stabilisation was essential. So he decided to adapt his naval gyrostabilisers[4] for this. In 1916,

3. Ibid., pp.1-5.
4. Bion J. Arnold to Secretary of War, "Secret Report on Automatic Carriers, Flying Bombs (FB), Aerial Torpedos (AT)," January 31, 1919, quoted in Kenneth P. Warrell, *The Evolution of Cruise Missiles* (Alabama: Air University Press, 1998).

Sperry and his son Lawrence joined Peter Hewitt, an electrical engineer, to develop an explosive-laden pilotless airplane, the "aerial torpedo". Together, they tested an automatic control system on a Curtiss flying boat and a twin-engine aircraft.[5] The American experiment to develop cruise missile technology is discussed in detail subsequently.

Early British Efforts

Almost during the same time, the Europeans, especially the British, also worked on the "flying bombs."[6] In fact, the possibility of automatic flight control was suggested in 1891 by British scientist Sir Hiram Maxim, who proposed "to secure longitudinal stability by the automatic actuation of elevators in response to disturbances detected by a gyroscope."[7] The pioneering attempts to achieve automatic flight were stimulated by the prospect of using uninhabited aeroplanes as missiles. Prof. A.M. Low and his team worked on this problem during World War I at Brooklands and Feltham.[8] Shortly after the War started, the British War Office asked Prof. Low to work on a rangefinder for coast artillery. But the project was subsequently changed to a radio-controlled "flying bomb" to intercept zeppelins and attack grounds targets. During the first demonstration, the vehicle crashed, and the second one, though it flew satisfactorily for a while, subsequently lost control and flew towards the assembled spectators before crashing.[9] Later, H.P. Folland, designer of the famous SE-5 pursuit plane, designed another missile. But that also did not succeed, failing to get airborne on all three attempts in July 1917. With these successive failures the British ended the radio controlled cruise missile project, at least for a while.[10]

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5. Gordon Bruce, "Aerial Torpedo is Guided 100 Miles by Gyroscope," *New York Tribune* (October 20, 1915) cited in Warrell, Ibid., p. 7.
6. "The 'Aerial Target' and 'Aerial Torpedo' in Britain," http://www.ctie.monash.edu.au/hargrave/rpav_britain.html
7. "Automatic Flight," The Forty-Sixth Wilbur Wright Memorial Lecture, *Flight*, May 16, 1958, p. 658.
8. Ibid., "Professor A.M. Low and the 'Aerial Target'", http://naarcee.bizland.com/feedback.htm
9. Rhodi Williams, "The First Guided Missile", *Royal Air Force Flying Review*, May 1998, pp. 26-27.
10. G.W.H Gardner, "Automatic Flight: The British Story", *Journal of the Royal Aeronautical Society*, vol. 62, July 1958, p. 478.

The British, however, did have a successful inter-War missile development programme – the target missile.[11] The Royal Air Force (RAF) began this programme by converting three Fairley IIIF float biplanes. The initial two launches crashed and the third, launched on September 14, 1932, flew for just nine minutes.[12] In January 1933, the converted aircraft *Fairley Queen* survived two hours of the Royal Navy's anti-aircraft bombardment. In February, the Air Ministry contracted for a cheaper target missile, a version of the Tiger Moth trainer, called the Queen Bee. It first flew under radio control in 1934. In all, the Fairley Corporation built 420 such devices between 1934 and 1943.[13]

Parallel attempts were made in other European countries. In September 1914, an American attaché reported about an Italian aerial torpedo, while a successful French pilotless aircraft test of 36 miles was reported in 1917.[14] Also, the French did get a pilotless aircraft airborne for 51 minutes on September14,1918.[15] However, the fate and process of development of all these early experiments could not reach the intended destination except with the Americans who continued their efforts.

Early American Efforts

Sperry's "flying bomb" project got official attention and funds in the post-War period. Secretary of the Navy Josephus Daniels, formed a five-member committee to investigate the idea and approved $2000,000 for the flying bomb in May 1917.[16] Initially, successful manned experiments began in June at Amityville, Long Island, but failure dominated the new phase with the unmanned vehicle. The major problem was how to get the machine off the ground. Since the experiments were using catapult launching, the

11. For details, see Chris Gibson and Tony Buttler, *British Secret Projects: Hypersonics, Ramjets and Missiles* (Midland Publishing Limited, 2007).
12. Warrell, n.4,p. 20.
13. Thomas P. Hughes, *Elmer Sperry* (Baltimore, Md.: John Hopkins, 1971), p. 265.
14. Warrell, n.4, p. 8.
15. Ibid.
16. "Hewitt-Sperry Automatic Airplane", http://en.wikipedia.org/wiki/Hewitt-Sperry_Automatic_Airplane

take-offs upset the azimuth control.[17] Therefore, there was considerable doubt about both the catapult system and the device's flying ability. Also, the manned tests brought to fore the problem of mismatch of the control system and missile. The control system for the N-9 proved to be inadequate for the more responsive flying bomb. To enhance the longitudinal stability, the designers lengthened the fuselage by two feet and made other suitable modifications.[18]

The first successful flight took place on March 6, 1918, when the flying bomb flew 1,000 yards as planned. Beside the catapult launch, Sperry wanted a better launching device. He then tried a test-bed of an auto-missile combination consisting of a Marmon car fitted with an OX-5 aircraft engine and an overhead frame for the "flying bomb".[19] The experiments were tried on a straight section of the Long Island Railroad, but the flanged wheels could not keep the Marmon on the tracks.[20] While the Norden catapult proved satisfactory, the "flying bomb" did not. Successive failures discouraged neither the designers nor the defence establishments owing to the perception that "the device still had a promising future."[21] The first attempted unmanned flying bomb by the US Navy, launched on August 18, 1920, was also a failure. The third flying bomb, launched on April 25, 1921, flew less than two minutes. The missile's lack of progress, coupled with declining funds, led the US Navy to cancel the programme in 1922. Meanwhile, the US Army had developed a somewhat more successful "flying bomb".

Elmer Sperry, though he was unsuccessful before the war, could convince the army subsequently by a flying demonstration in late 1917. Maj Gen George O. Squier, who watched the demonstration, recommended the flying bomb project to the Chairman of the Aircraft Board. A four-member

17. Lee Pearson, "Developing the Flying Bomb," www.history.navy.mil/download/ww1-10.pdf
18. Charles Keller, "The First Guided Missile Program", *Journal of American Aviation Historical Society* Winter 1975, p.271.
19. Warrell, n.4.
20. Keller, n.18, p. 271.
21. Warrell, n.4, p. 12.

board explored the possibility of developing such weapons and only one member, Charles F. Kettering, inventor of the automobile self-starter and later Vice President of General Motors, gave a positive report. Money was sanctioned to develop the device[22] and a team was formed consisting of Kettering's company Dayton Metal Products, Elmer Sperry, S.E. Votey of Aeolian Player Piano, Orville Wright and C.H. Willis. The flying bomb that emerged from this experiment was a biplane smaller than the Navy-Sperry device. Similar to the Sperry flying bomb, an air log impeller actuated a standard National Cash Register counter which "measured" the distance and, after a designated number of turns, cut the ignition and folded the wings. There were no ailerons. Wright suggested a 10 degree positive dihedral for stability, which gave the aircraft its characteristic look. The device came to be called the Kettering "Bug", perhaps due to its appearance, although its official name was the "Liberty Eagle".[23]

However, Kenneth P. Warrell identifies the following lessons learnt from all these initiatives during the pre- and post-World War I:

- Designers experienced difficulties just getting unmanned aircraft into the air. Launch problems caused a number of crashes, complicating the development of the "flying bombs".
- Building a stable aircraft that could fly without pilots was not easy. Limited knowledge on aerodynamics, lack of testing, and haste in building the machines guaranteed problems. Little wonder, the flying bombs had basic aerodynamic faults.
- Many other technical problems hindered the progress, particularly as neither guidance systems nor engines performed as designed.
- Destruction of the flying bombs on most of the tests restricted the programmes. This fragility was due to the fact that these machines were designed to be cheap and fly short one-way missions. The army was unable to recover many for subsequent testing, thereby rapidly exhausting the

22. Guy L. Gearhart, "Resume of Aerial Torpedo Development," April 10, 1926, cited in Warrell, n.4, pp. 13-14.
23. Bryan Dorn, "Cruise Missiles: The 'Poor Man's Air Force", *New Zealand International Review*, vol. 30, 2005.

number of available vehicles. Also the wrecks yielded little positive data on why the crashes occurred.

- Despite all the fanfare, expense and effort, the experimenters achieved minimal success. Only one of the 12 Sperry-Navy tests succeeded. Taken together, there were only 8 successes on 36 attempts. The flying bomb idea could not be realised despite best efforts; the theory remained more advanced than the technology of the day.[24]

Despite these hurdles, US interest in the "flying bomb" continued in the post-War period. The US Army contracted Sperry Gyroscope Company in February 1920 to design and manufacture four gyro units, and then in April 1920 to perfect the automatic control.[25] But subsequent difficulties with the automatic controls encouraged Sperry to use radio-control guidance. Also, the US Navy's interest in radio-controlled vehicles reemerged in the mid-1930s. The US Navy began flight tests in February 1937 and by the end of the year, had achieved good results. It first used the device as a target in exercises with the carrier *Ranger* in August 1938. Lieutenant Commander Delmar Fahrney suggested combat uses for drones (termed "assault drones") as early as August 1936.

Despite all the technical advances, the drone programme advanced relatively slowly. But the attack on Pearl Harbour gave impetus to the programme. In the mid-1930s, interest in Kettering-General Motors A-1 appeared. It was monoplane powered by a 200 hp engine designed to carry a 500-pound bomb load to 400 miles range at 200 mph.[26] But during all its tests up to 1942, directional control did not function properly. In October 1942, the new idea of air launching emerged. The A-1, with air launch technique, coupled with a TV sensor, was expected to become a useful military weapon. In 1943, the US Army tested models of the missile mounted on the bomber in a wind tunnel at Wright Field but the tests failed.[27]

24. Warrell, n.4, pp.16-17.
25. Gearhart, n.22, pp. 1-3.
26. Warrell,n.4, pp.23-25.
27. R.L. Mayrath, Memorandum Report, "Controllable Bomb, Power Driven", November 13, 1942, cited in Warrell, n.4, p. 29.

During the same time, another American guided missile project was initiated, mainly as defence to prevent another Pearl Harbour. It was viewed that the quickest way to get aerial torpedoes into action was to use radio-control target drones. In March 1942, the US Army initiated projects involving two types of aerial torpedoes, one with a 2,000-pound bomb load; the other with a 4,000-pound bomb load. Fleetwings was contracted on July 10, 1942, to build two aircraft of the first type (XBQ-1 and XBQ-2A), whereas Fairchild was contracted on October 1, 1942, to construct two of the larger craft, designated XQB-3.[28] The US Army Air Force (AAF) also requested for US Navy aerial torpedoes for testing – the Interstate TDR-1, TDR-1, XTD2R-1 and XTD3R-1 which the army redesignated respectively, XBQ-4, XBQ-5 and XBQ-6.[29] The entire XBQ series consisted of twin-engine devices that looked like aircraft. During World War II, the only AAF "flying bomb" used in combat had the code-name APHRODITE. Its first mission, on August 4, 1944, failed. One modified B-17 crashed with the pilot aboard. The Germans shot down a second machine, a third overshot its target by 500 feet, and a fourth impacted 1,500 feet short of its target. Two further attempts on August 6 also failed, one missile crashing in England, and the other into the North Sea.[30] Concurrently, the US Navy engaged in a similar project, using B-24s, a different radio-control system, and a television sensor. During the first trial, on August 12, the weapon blew up, killing Navy Lieutenants Wilford J. Willy and Joseph P. Kennedy, Jr. A second attempt that day demolished some German facilities at Heligoland.[31] Subsequently, there were no further naval efforts.

In retrospect, the American "flying bomb" experiments, before and during World War II, were failures. Technical problems proved very complicated and the results presented only marginal improvement over the World War I experiments. Thereafter, American flying bomb development shifted

28. "Summary of Power Driven Weapons Developed by Special Weapons Branch Equipment Laboratory", November 20, 1943, pp. 4-5.
29. Ibid.
30. Paul A. Whelan, "History of the Third Air Division in World War II: 1943-45", Ph.D. dissertation, St. Louis University, 1968, pp. 249-462, cited in Warrell, n.4, p. 32.
31. Third Air Division, "Final APHRODITE Project Report", (AFSHRC-527.431-1), cited in Warrell, n.4, p. 34.

from pre-set guidance to radio-control from an accompanying aircraft. But the Germans came up with a breakthrough to make the flying bomb a marginal, if not truly practical, weapon.[32]

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PHASE II: WORLD WAR II AND AFTER

Though the Germans started working on guided missiles in the form of glide-bombs as early as October 1915[33], their first considered "flying bombs" trials were done only in the 1930s. While the two German companies, Askania and Siemens, did some work in the field, an independent inventor, Paul Schmidt, achieved success. He began work in 1928 on a pulsejet. In 1934, along with G. Madelung, Schmidt proposed a flying bomb powered by a pulsejet. While the German Air Force wanted such a device, it abandoned the project because of range, accuracy and cost problems. Nevertheless, the Argus Company began work on the pulsejet in 1938 and in 1940, the Air Ministry brought Schmidt to Argus.[34]

German Efforts: V-1 or the Vengeance Weapon

As the name of the weapon (vengeance) indicates, there were many factors that encouraged the Germans to develop what would become the V-1.[35] They were: [36]

- The bombing of Germany infuriated Hitler; to take revenge, he demanded a terror weapon for retaliation against Britain.
- The capture of France in 1940 reduced the distance to England, thereby

32. Warrell, n.4, p. 35.
33. Michael Armitage, *Unmanned Aircraft* (New Delhi: Brasseys, Ritana Books,1995), p. 1.
34. Basil Collier, *The Battle of the V-Weapons, 1944-45*, (London: Hodder and Stoughton, 1964), p. 18.
35. While most authors assert that "V" stands for *vergeltungswaffe* (vengeance weapon), some claim it initially stood for *versuchmuster* (experimental).
36. Warrell, n.4, pp. 41-42.

One source indicates that they wanted to launch 5,000 V-1s per day against England. According to another figure, the planned rate was 6,000 to 9,000 per month.

ending the need for some form of radio-control which experts thought to be necessary over the much longer distance between Germany and Britain.

- The war depleted and dispersed the Luftwaffe's (German Air Force) ranks by 1942, making the pilotless bombers more attractive.
- Inter-Service rivalry came in – the German Air Force wanted a weapon to match the army's V-2. Therefore, in June 1942, Erhard Milch, GAF production chief, gave the highest priority to a proposal by three German companies to produce a pilotless bomber constructed from cheap materials: Argus the engine, Fiesler the airframe, and Askania the guidance system.

The V-1 was small missile powered by a pulsejet.[37] It flew in December 1942, first in a glide test. The engine operated a Venetian blind-type device which opened to admit air and then closed to fire at 50 cycles per second. This propulsion system gave the V-1 its characteristic buzzing sound, therefore, it was called the "buzz bomb". The weapon's average range was about 150 miles. By this time, the Germans had decided to build both the V-1 and the V-2, but problems associated with mass production were believed to have adversely affected the missile's speed, accuracy, and operational altitude.[38] The Germans used a gyro autopilot, powered by compressed air, to follow a course determined by a magnetic compass and a barometric device to regulate altitude. The downward attitude of the V-1 usually cut the fuel flow to the engine, causing it to stop and explode.[39] The Germans are known to have planned

37. "Rocket and Missile System", *Enclopaedia Britannica*, http://www.britannica.com/EBchecked/topic/1357360/rocket-and-missile-system/57343/The-V-1

38 Warrell, n.4, p. 43.

39. *Air Intelligence Report No. 2258*, cited in Warrel, n.4, p. 43.

for a V-1 production rate of up to 8,000 per month by September 1944, with operations starting from 64 sites on December 15, 1943. One source indicates that they wanted to launch 5,000 V-1s per day against England. According to another figure, the planned rate was 6,000 to 9,000 per month.[40] But numerous technical problems delayed the start of the V-weapon campaign by at least three months.

By June 18, 1944, the Germans had launched their 500th V-1; by June 21, their 1,000th; by June 29, their 2,000th; and by July 22, their 5,000th.

Following the cross-Channel invasion of June 6, 1944, mainly to relieve his troops, Hitler expedited the V-1 campaign. By June 18, 1944, the Germans had launched their 500th V-1; by June 21, their 1,000th by June 29, their 2,000th; and by July 22, their 5,000th.[41] But about 20 percent of the V-1 proved defective, exploding half way, crashing shortly after take-off, or deviating well off course. Out of all the tests between August 18 and November 26, 1944, only 31.4 percent of 258 V-1s impacted within either 30 km of the aiming point at 225 km range or 15 km at 100 km range. The Germans attributed at least 35 percent of the failures to premature crashes.[42]

During the course of the summer campaign, the Germans introduced the new air launch method. The first air launch known to the British occurred on April 6, 1944, at Peenemunde with the first recognisable air launch against England on July 9, 1944.[43] The final act in the V-weapon campaign against Britain came in March 1945 when the Germans introduced a long-range version of the V-1. Fitted with a wooden wing (which weighed 395 pounds compared with 445 to 480 pounds of the metal wing) and a reduced warhead, it could fly 220 miles as compared to the standard range of about 150 to 160

40. United States Strategic Bombing Survey, *V-Weapons (Crossbow) Campaign*, January 1947, p. 214.
41. David Irving, *The Mere's Nest* (London: Kimber, 1964), p. 236.
42. Warrell,n.4, p. 50.
43. Roderic Hill, "Air Operations by Air Defence of Great Britain and Fighter Command in Connection with the German Flying Bomb and Rocket Offensives, 1944-45," *London Gazette*, October 19, 1948, p. 5599, cited in Warrell, n.4, p. 58.

miles.[44] One estimate shows that the Germans built 30,000 V-1s—half the 60,000 planned.[45]

The German V-1 had many *advantages*.[46] First, it was a cheap weapon that did not use critical materials; therefore, the missile was employed in mass. Second, the missile could be launched regardless of weather conditions. Third, because of its relatively high speed and low altitude approach, it was difficult to spot and attack. Fourth, it was durable as a target since it had few vulnerable parts and no aircrew could be killed or injured unlike in the manned bomber. However, the weapon had a number of *limitations*.[47]

- While the remarkable and cheap pulsejet engine did the job, the ground-launched version required a booster and a long ramp which, in turn, meant a fixed and vulnerable launch site.
- The much larger and more complex V-2 had mobility but the smaller and simpler V-1 did not.
- Fixed launch sites, along with fixed targets indicate that the missile's flight path was predictable. This, in turn, meant that defenders could mass their forces in a relatively concentrated and narrow zone.
- As the missile flew a constant course, altitude, and speed, it was easy to engage it once located.
- Its poor accuracy limited it to use against the largest of targets (cities)
- The V-1's small warhead restricted its impact.

Also, owing to the success of the Allied forces' defence against the "flying bomb", many observers as well as the public downgraded the device. But it proved to be a remarkable achievement that was somewhat cost-effective. But, on balance, "at that stage it proved doubtful as weapon of war."[48] Most

44. Air Intelligence Report No. 2321, March 8, 1945, cited in Warrell, n.4, p. 60.
45. USSBS, Aircraft Factory Division Industry Report, 115 (AFSHRC-137. 302-3), cited in Warrell, n.4, p. 61.
46. Warrell, n.4, p. 62.
47. Ibid.
48. Ibid., p. 62.

importantly, German efforts were the primary catalyst in rejuvenating the dormant US missile programme.

The US version of the V-1 differed only slightly from the German version, except in launch and guidance procedures.

American Efforts: JB-2 (the Terror Weapon)

Towards the end of the War, the US recovered 2,500 pounds of V-1 parts from Great Britain. The American Air Force (AAF) was ordered to design 13 copies of the "flying bomb" and within three weeks, the AAF had completed its first JB-2.[49] But there were some inherent drawbacks in the system. Mainly, there were problems with the logistics and with the accuracy of the system. In comparison, the US version of the V-1 differed only slightly from the German version, except in launch and guidance procedures. The JB-2 cost about $8,620 and the weapon required about 1,047 man-hours to produce which was close to the man-hours needed to produce the V-1.[50] The difficulty with the German catapult propellant and production encouraged the US to use something new to get the missile airborne and attain the minimum speed required for pulsejet operation. The AAF considered a number of alternative launch technologies such as flywheel, cart powered by an aircraft engine, and powder. They adopted the ground launch technique, but a shortage of powder led to consideration and testing of an air launch. But the first flight on October12 failed.[51]

As the major concern of the AAF was for accuracy, it strived for an improved guidance system. Tests with the German method of "pre-set controls" achieved results similar to the Germans; the Americans experienced an average error of over eight miles at a range of 127 miles. Therefore, the airmen installed radio-control guidance in the missile.[52] The AAF equipped the JB-2 with a

49. Richard Hallion, "The American Buzz Bombs," *Aeroplane Monthly*, November 1976..
50. Berend D. Bruins, "US Naval Bombardment Missiles, 1940-58", PhD Dissertation, Columbia University, 1981, p. 105..
51. Warrell, n.4, p. 65..
52. David Griggs, "The Role of the Controlled Buzz Bombs in the German War" (AFSHRC-519.311-1), cited in Warrell, n.4, p.65.

radar beacon that assisted tracking by a ground radar unit and remote control equipment. But the tests revealed an average error of about 6 miles on 14 tests and almost twice that at 127 miles on 20 tests.[53]

The US Navy was also involved in such experiments. By April 1945, the navy had named their version of the V-1 "Loon" and extended their study of launch platforms to include landing craft (LSTs), PB4Y-1s and off the beach. The navy launched its first Loon on January 7, 1946. After a number of trials, the navy achieved success but in March 1950, it terminated the Loon programme to make way for the more advanced and promising Regulus.[54]

In the post-War I period, essentially as follow-ons to the German V-1, the US had 19 different guided missile projects, both powered and unpowered, in progress though "of doubtful value."[55] In August 1945, the AAF asked for a 600-mph, 5,000-mile-range missile with a 2,000-pound warhead. Northrop presented a proposal in January 1946 for a subsonic, turbojet-powered, 3,000-mile range missile. Jack Northrop, the company President, nicknamed the former (MX-775A) Snark, and the latter (MX-775B) Boojum, both names from the pages of Lewis Carroll.[56] Snark was larger and heavier than previous "flying bombs" and possessed much greater performance. It flew in a nose-high flying altitude because it lacked a horizontal tail surface as did so many of Northrop's machines. Instead of conventional control surfaces (ailerons, elevation), the Snark used elevons and had a disproportionally small vertical tail. Northrop, therefore, produced a new design – the N-69, which was initially called "Super Snark".[57] The company made some modifications by lengthening the fuselage, sharpening the nose shape, replacing the external scoop with a flush scoop, and increasing the launch weight.[58] It added a larger wing but slightly shortened the wing span. It broadened the wing by extending

53. Summery Handbook (AFSHRC-145.96-195), cited in Warrell, n.4, p. 67.
54. Warrell, n.4, p. 68.
55. Tara Kartha, "The Rationale of Cruise Missiles – I", *Strategic Analysis*, August 1998, p. 805.
56. Max Rosenberg, "The Air Force and the National Guided Missiles Program, 1944-50," June 1964, [AFSHRC-202-46 II], p. 78.
57. "SM-62 Snark (United States), Obsolete Systems - Offensive/Defensive Weapon Systems," http://www.janes.com/articles/Janes-Strategic-Weapon-Systems/SM-62-Snark-United-States.html
58. Warrell, n.4, p. 86.

it further behind, thus, increasing the wing area from 280 to 326 square feet. In addition, because wind tunnel and N-25 tests showed some instability in pitch, Northrop redesigned the wing with a leading edge extension, thereby giving the Snark wing its "saw tooth" shape.[59]

Consequently, numerous problems beset the Northrop missile during testing. The Snark proved unstable in all except the straight and level flights. The programme suffered numerous test failures. By May 1955, wind tunnel and flight tests indicated that Northrop's operational concept, the terminal dive of the missile into the target, would not work because of inadequate elevon control. Five flight tests of the N-69C, a non-recoverable radio-controlled missile with fuselage speed brakes, confirmed these findings. Eventually, the Snark programme did not appreciably improve and the central problems of guidance and reliability remained. In 1961, John F. Kennedy scrapped the project. Generally, the reasons for the demise of the Snark were linked with its air breathing companion, the Navaho.

Concurrent with the Snark was the emergence of the Navaho cruise missile[60]. Compared to the Snark, it was much more ambitious. The Navaho programme called first for the design, construction, and test of a turbojet test vehicle, followed by a 3,600-mile-range interim missile, and culminating in a 5,500-mile-range operational weapon.[61] However, the experiments of the missile faced many problems. Most serious problems, however, centred on the ramjets and auxiliary power unit— the latter did not operate successfully until February 1956.[62] The first XSM-64 launch attempted in November 1956 ended in failure after a mere 26 seconds of flight. With the lack of positive results, cost pressures, schedules slippages, and increasing competition from ballistic missiles, the US Air Force (USAF) cancelled the programme in early July 1957.[63]

59. Ibid.
60. "North American SSM-A-2,4,6/B-64/SM-64 Navaho," Directory of U.S. Military Rockets and Missiles, Andreas Parsch, http://www.designation-systems.net/dusrm/app1/sm-64.html
61. SAC History, July-December 1951, pp.24-26, cited in Warrell, n.4, p.97.
62. Robert L. Perry, "System Development Strategies: A Comparative Study of Doctrine, Technology and Organisation in the USAF Ballistic and Cruise Missile Programs, 1950-1960", Rand RM-4853 PR, 1966, pp. 43-45.
63. James N. Gibson, *The Navaho Missile Project* (Schiffer Publishing Ltd, 1996).

The coincidence in timing of the development of cruise and ballistic missiles and the competition between the two types comprised an important factor in the demise of the Snark and Nevaho.

However, the Navaho project was a leap forward in the state-of-the-art of US missile technology. It showed the path for new technology that ultimately transformed it into a complex missile. For example, aerodynamic heating (300 degree at Mach 2 and 660 degree at Mach 3) required new materials. The USA used titanium alloys as well as precious and rare metals at contact points on much of the electrical gear. Other complicated areas included the canard configuration, ramjets, guidance, and the massive rocket booster.[64] Most importantly, experiments on the Navaho and later on the tactical Matador, led to important technological breakthroughs like the ATRAN (Automatic Terrain Recognition and Navigation), "a forerunner of the TERCOM that was to give the cruise its true "strategic" capability".[65]

But, according to Warrell, the Snark and Navaho, in spite of all adaptations, failed to come up anywhere near the expectations. For Warrell, the important reasons included : (1) the technology of the day could not meet the ambitious requirements of accurately and reliably flying 5,000 miles over many hours without the intervention of a pilot or navigator, therefore, many of the missiles crashed or did not perform satisfactorily; (2) the manufacturers failed to master the situation, and overly optimistic estimates and loose management led to cost overruns and delays; (3) the coincidence in timing of the development of cruise and ballistic missiles and the competition between the two types comprised an important factor in the demise of the Snark and Nevaho.[66]

The Interregnum

In a broader sense, the first generation cruise missiles developed during the first three decades of the 20th century such as the German V-1, employed

64. James F. Scheer, "Project Fantastic", *Skyline*, August 1956, pp. 77-78.
65. Kartha, n.55, p. 805.
66. Warrell, n.4, p. 101.

during World War II, were largely unsuccessful. The second generation cruise missiles like the Snark, Navaho, Matador and Regulus seemed to hold considerable promise as interim weapon systems. But the fact was that, for all these second generation cruise missiles, the operational requirements were beyond the technological capability of that age. This led to very serious programme delays and these weapons, instead of preceding the intercontinental ballistic missiles (ICBMs) into service in the strategic role as intended, became contemporaneous with them. On the other hand, ballistic missiles were proving to be more accurate and more reliable weapons, and, above all, they were impregnable to enemy defences. Nor were the cruise missiles able to compete with the advantages of the manned bomber.

Moreover, there were some critical operational objections. First, bombs and bombers were proven weapons that could hit distant targets with very reasonable accuracy; cruise missiles, on the other hand, were proving to be often wildly inaccurate. It was realised that cruise missiles were more vulnerable than the bomber to enemy defences because they flew a steady and predictable flight path without carrying any defences. Also, cruise missiles lacked the flexibility of the manned bombers. They could not disperse for survival; they could not adopt an ostentatious alert posture in a crisis; they could fly only one, terminal, sortie. It was true that cruise missiles put no crews at risk, and that they were far less costly than bombers, but these advantages were not enough to prevent the demise of the cruise missile in favour of the manned bomber and the ICBM in the late 1950s.

This coincidence of the emergence of ballistic missile development brought home the impression that it could do the same job as the cruise missile in a better way. By October 1953, the US Air Force learned that a megaton-class warhead weighing 1,500 to 3,000 pounds would become available shortly, making the ICBM much more feasible and encouraging its development.The only two advantages that cruise missile seemed to offer were: (a) they appeared to be cheaper; and (b) the crew was not put at risk. But the list of disadvantages overwhelmed these two advantages.[67] Those days, the two systems (cruise

67. Warrell, n.4, p. 103.

and ballistic missiles) appeared to have comparable capabilities, but a closer examination of these weapon systems reveals something else. In the 1950s, the ICBMs had an edge in accuracy due primarily to their much shorter flight time.[68] Second, the Snark and Navaho test record indicates that their reliability was also substantially less than that of the ICBMs. The ICBMs reached the targets much faster than the cruise missiles. Second, once launched, the ICBMs were invulnerable to counter-measures, while the cruise missile could be downed by fighters and increasingly, after 1960, by surface-to-air missiles. A third factor was political-psychological. While the ICBM was a new weapon, the cruise missile physically resembled the bomber. The fact that the Soviets had made so much of the Sputnik and other missiles aired the "missile gap"[69] between the two adversaries. This forced the US to come up with some sort of equally modern and impressive weapon.

PHASE III: THIRD GENERATION CRUISE MISSILES

Return of the Missile Age

For quite some time, ballistic missiles had occupied the attention of nations as comparatively advanced and efficient weapon systems. But, gradually, their relative value waned with the innovations in the nuclear arsenal, especially during the 1950s onwards. Ballistic missiles designed for strategic purposes needed high acceleration at launch. For this, a huge quantity of fuel is required in order to boost them into their required trajectory and to give them the velocity that will carry them over the long ranges. In the case of a single-stage ICBM, this large quantity of fuel can take up as much as 93 percent of the whole system, leaving only 7 percent for the motor, the guidance system and the structure of the missile itself.[70] In the late 1940s and early 1950s, the early crude atomic warheads weighed as much as 5,000 kg. Any intercontinental

68. Armitage, n.33, p. 51.
69. "Missile Gap" refers to the perceived Soviet superiority in ICBMs due to exaggerated estimates by the Gaither Committee in 1957 and USAF in the early 1960's. See "Who Ever Believed in the 'Missile Gap?': John F. Kennedy and the Politics of National Security," *Presidential Studies Quarterly*, December 1, 2003.
70. Armitage, n.33, p. 50.

missile to carry them was bound to be not only an enormous and unwieldy vehicle, but its development, particularly in terms of required accuracy, was beyond the available technology of the time. Hence, the renewed emphasis on cruise missiles and the constant efforts to overcome the most serious drawback in the system – the inaccuracy of delivery – are clearly perceptible.

Perception of relative value of these two weapons systems changed sharply in October 1953 owing to developments in the nuclear arsenal design. By that time, it was believed that smaller and lighter nuclear warheads could be produced.

Even by 1958, inertial guidance systems were still demonstrating errors of .03 degrees per hour, or almost two miles for a cruise missile flying for one hour at 600 knots. Most of the missiles were, of course, required to fly a great deal further than this. Nevertheless, cruise missiles comprised the only practicable alternative to the manned bomber. As a result, ICBMs were accorded a much lower priority than cruise missiles. For example, in the USA, the Atlas ICBM programme attracted only $26.2 million, while the Snark and Navaho claimed a total funding of $450 million of defence finance.[71]

Interestingly, this perception of relative value of these two weapons systems changed sharply in October 1953 owing to developments in the nuclear arsenal design. By that time, it was believed that smaller and lighter nuclear warheads could be produced. This development brought the nuclear tipped ballistic missiles with strategic ranges into the limelight. For example, systems like the Atlas, Thor and Titan were accelerated. In the USA, the Thor was launched in January 1957, the Titan followed in February 1959 and the Atlas went on to reach full operational status in October 1959, five months ahead of the Snark.[72] In this way, ballistic missiles overtook cruise missile, at least in the striking role. Other comparative advantages attached to ballistic missile which indeed widened the gap between the two competing families of systems are:

71. Ibid.
72. Ibid., pp. 50-51.

- An ICBM could reach its target in minutes as compared to the several hours needed by cruise missiles and the shorter flight time contributed to the greater accuracy of the ICBM.
- The steady flight path of all cruise missiles made them highly vulnerable to the adversary's defences, whereas there was no defence at all against ICBMs.
- There may also have been an element of prestige in the equation. The Soviets were developing ballistic missiles, and in October 1957, they had caused profound dismay in the Western world by launching the Sputnik I satellite by these means.

The US decision-makers learned of the energetic Soviet efforts in the ICBM field and, thus, in July 1954, the US Air Force assigned highest priority to ballistic missiles. Due to the launch of the Sputnik in October 1957 and fears of a "missile gap", the American ICBM programme got top level support; as a result, the Americans launched their first medium-range ballistic missile (Thor) in January 1957, the first Atlas in June 1957, and the first Titan in February 1959.[73] Thereby, the dormant ballistic missile development process got some attention.

However, other cruise missile like the Martin Matador, Crossbow, Hound Dog and decoy missiles like the Buck Duck, Bull Goose and Quail were successful to some extent. Owing to financial pressure and technical problems, these programmes were postponed at certain stages. Therefore, America's experience with cruise missiles in the 1950s and 1960s was largely unsuccessful.[74] But nuclear strike was not seen as the only role for cruise missiles.The concern about the growing effectiveness of Soviet air defences that had led to unease about the vulnerability in flight of cruise missiles was also leading to a search for means of improving the survivability of manned bombers. This led to the development of cruise missiles in two other important roles: (1) as decoys; and (2) as airborne stand-off weapons.

73. For details on the US missile programme, see Curtis Peebles, *High Frontier: The US Air Force and the Military Space Program* (Air Force History and Museums Programe 1997).

74. Warrell, n.4, p. 128.

Cruise Missiles as Decoys. To avoid the adversary's defences, employment of decoys became the fashion. Since radar is the principal means by which aircraft are detected, identified, and engaged by opposing defences, it is on the basis of radar characteristics that most of the emphasis is placed in the design of decoy aircraft. During the mid-1950s, the US Air Force developed three systems for this role. The first was the Consolidated-Vultee Buck Duck, which underwent trials during the early months of 1955. A second decoy aircraft was the Bull Goose, a ground-launched device started in 1952, designed to be carried by attacking bombers. But trials showed that the Bull Goose could not convincingly simulate the B-52 on the radar, and in 1957, this project was cancelled.[75] Another successful programme was the Quail decoy developed from an operational requirement of January 1956 for an aircraft to simulate US Air Force bomber aircraft.[76]

Stand-off Cruise Missiles. Stand-off strike was chosen as the other role for unmanned aircraft and two significant developments in this field had taken place in the US Air Force: (1) the GAM-67 Crossbow; and (2) the AGM-28 Hound Dog. The Crossbow was an air-to-ground cruise missile designed to home on to enemy air defence radars. Designed by the Radiophone Company to meet an operational requirement of the early 1950s, the Crossbow was a high-wing twin-fin weapon carrying a 1,000 lb warhead.[77] But subsequent tests found that it had a slower airspeed than required and its range turned out to be less than that of Soviet radars. The Hound Dog was a response to the US Air Force requirement in 1956 for an air-to-surface missile with which to arm the B-52 bomber.[78] This was a "reasonably successful venture." Although its inertial navigation guidance system produced errors of about one mile over the maximum range, this was not critical with the size of the nuclear warhead fitted. But the less satisfactory features were: (1) the general

75. Armitage, n.33, p. 51.
76. "MCDONNELL ADM-20 Quail," National Museum of the US Air Force, http://www.nationalmuseum.af.mil/factsheets/factsheet.asp?id=384
77. "GAM-67 CROSSBOW", National Museum of the US Air Force, http://www.nationalmuseum.af.mil/factsheets/factsheet.asp?id=9502
78. "AGM-28 Hound Dog Missile History/Data", *AMMS Alumni*, http://www.ammsalumni.org/html/agm-28_history_data.html

unreliability of the missile; and (2) the undesirable addition to the drag of the parent bomber that the Hound Dog generated, thus, reducing the top speed of the B-52 aircraft. This consideration led to the Hound Dog being phased out in 1976, and it was replaced by the SRAM (Short Range Attack Missile), of which by 1974 over 11,000 were fitted to the fleet of B-52 bombers.[79]

The Cold War competition had its impact on the evolution of cruise missile technology evolution as well. By this time, further concerns about the likely Soviet developments in its air defence had highlighted the compelling need for a Quail replacement. The US Air Force was aware of the Soviet use of the Air-borne Warning and Control System (AWACS) and look-down/shoot-down interceptors. Therefore, studies were undertaken to propose the successors to the Quail. The first one was the SCUD (Subsonic Cruise Unarmed Decoy), an advanced decoy cruise missile with a range of 2,000 km and a speed of .85 Mach,[80] and the second system suggested was SCAM (Subsonic Cruise Attack Missile), an armed version of the same vehicle. At the same time, the USAF Air Systems Command put forward a proposal for yet another cruise missile, the SCAD (Subsonic Cruise Armed Decoy) which could equip the B-52 in the decoy role.[81]

The reluctance of the USAF to reconsider the strike cruise missile was revisited when in October 1967, the Soviet SS-N-2 Styx anti-ship cruise missile sank the Israeli destroyer *Eilat*.[82] This incident led to renewed and widespread interest in the cruise missile as a weapon. The American Navy put out a study contract with McDonnell-Douglas to explore the possibility of these missiles for its own purpose. This led to the start of the AGM-84 Harpoon programme which had as its objective an anti-ship sea-skimming missile able to carry a 250 lb conventional warhead over a range of 40 nautical miles.[83] The first long-term importance of the Harpoon was that it eventually led to more advanced weapon systems, particularly in the case of the submarine-launched version of the Harpoon that was added to

79. Armitage, n.33, pp. 53-54.
80. Richard K. Betts, *Cruise Missiles: Technology, Strategy, Politics* (Washington DC: The Brookings Institution 1981).
81. Ibid.
82. "SS-N-2 STYX," http://www.globalsecurity.org/military/world/russia/ss-n-2.htm
83. "AGM-84 Harpoon SLAM (Stand-Off Land Attack Missile)", http://www.fas.org/man/dod-101/sys/smart/agm-84.htm

the programme in 1971. Second, another proposal envisaged a cruise missile system launched from a new class of nuclear powered submarine, known as Submarine Tactical Anti-ship Weapons Systems (STAWS). Third, a proposal was made to fit cruise missiles into ten converted Polaris ICBM submarines.[84]

Because cruise missiles can strike targets at long ranges, it was recognised that they could supplement or replace manned aircraft for many strategic missions.

PHASE – IV: THE WAY FORWARD

Cruise Beyond 1970s

The performance of the cruise missile was of interest to other countries than just the United States. Since the late 1970s, the US cruise missile programme attracted the attention of defence officials around the globe. Because cruise missiles can strike targets at long ranges, it was recognised that they could supplement or replace manned aircraft for many strategic missions. Until the late 1980s, other than the US, much of the technology needed to produce accurate land attack cruise missiles was available only to France and the Soviet Union. The history of French effort is as old as the history of aviation itself. Even before World War I, a French artillery officer, Rene Lorin, had proposed the use of flying bombs to attack distant targets.[85] This aircraft, he suggested, could be stabilised in flight by a combination of gyroscopes and a barometer, guided along track by radio signals from an accompaying piloted aircraft and propelled by a pulsejet or a ramjet engine to hit the target.[86] This seems to have been one of the first attempts to design a weapon along the lines of the V-1; but there were other and similar inventions by Victor De Karavodine and Georges Marconnet of France, although none of these early inspirations actually resulted in an aircraft being produced in that country or anywhere else.[87]

84. Armitage, n.33, p.57.
85. Dennis Larm, "The Unmanned Aerial Vehicle's Identity Crisis," http://www.dtic.mil/cgibin/GetTRDoc? AD=ADA424221&Location=U2&doc=GetTRDoce.pdf, p. 13
86 Armitage, n.33, p.1.
87 Ibid.

The Gulf of Tonkin incident of August 4, 1964,[88] led to the American involvement in Vietnam. The US unit from Davis-Montham was alerted and dispatched to Kadena Air Force Base on Okinawa, from whence it was planned that the Ryan drones would fly surveillance and reconnaissance missions over China and Vietnam. In an attempt to give the missions a 'cover', the Nationalist Chinese logo was painted on the drones before they left Kadena, but concealed by a patch that was removed immediately before take-off.[89] Since several drones were lost over China, the American origin of the aircraft was very clear to the Chinese from the components recovered. This must have guided the Chinese to think about their own programme thereafter.

Yet another nation, Israel, has actively employed unmanned aircraft in war since 1973. Israeli efforts for cruise missiles probably started with three machines: the Tadiran Mastiff, the Israel Aircraft Industries Scout and the Mazlat Pioneer.[90] All three are miniature Remotely Piloted Vehicles (RPVs). Not much is known about the subsequent programme, but Israeli use of unmanned aircraft during the air operations over the Bekaa Valley in 1982[91] is well known. Also, since the 1950s, China is known to have developed and deployed a number of coastal defence, ship-launched, and air-launched anti-ship cruise missiles, based originally on the Soviet P-15 missiles (NATO designation of SS-N-2A Styx).[92]

Period of Revival

The revival of interest in cruise missiles started in the 1970s, and had its root in the "politico-strategic factors" of the age. Firstly, formal discussions had begun between the US and Soviet Union on Strategic Arms Limitations Talks (SALT-1) in November 1969. Secondly, the agreement was reached by

88. Edward J. Marolda and Senior Historian, "Tonkin Gulf Crisis, August 1964," http://www.history.navy.mil/faqs/faq120-1.htm
89. Armitage, n.33, p. 71.
90. See Ralph Sanders, "UAVs, An Israeli Military Innovation", *JFQ* / Winter 2002–03, pp. 114-18, available at: http://www.dtic.mil/doctrine/jel/jfq_pubs/2033.pdf
91. Matthew M. Hurley, "The BEKAA Valley Air Battle, June 1982: Lessons Mislearned?", *Aerospace Power Journal,* Winter 1989, http://www.pakdef.info/forum/showthread.php?t=8588
92. Shirley A. Kan, "China: Ballistic and Cruise Missiles", *CRS Report for Congress*, August 10, 2000, p. 18..

May 1972 on anti-ballistic missile systems. Thirdly, an interim agreement was also reached on strategic offensive weapons. The ceiling that the treaty placed on nuclear weapons meant that as the new American Poseidon-equipped submarines became operational, the older Polaris-armed boats would have to be withdrawn.[93] But the treaty did not mention cruise missiles, and the Soviets were not prepared to negotiate about such systems since they had a monopoly. Fourthly, there was growing evidence in the late 1960s and the early 1970s of a constantly increasing efficiency in Soviet air defences.[94] Owing to this, there was serious concern in the US about the vulnerability of the B-1 bomber aircraft. Fifthly, the cost of the new generation US long-range bomber, the B-1, was itself under heavy criticism. President Carter decided to discontinue the production of the B-1 in June 1977, saying that it was "a very expensive weapon system conceived in the absence of the cruise missile factor."[95] With the cancellation of the B-1, the ALCM's work was accelerated and the US Administration took the decision to deploy about 3,000 of these weapons on the 151 B-52G bomber aircraft.[96] By that time, new technologies were making possible an entirely new concept of air-breathing missiles that could be launched from outside the enemy's air defences to make their way with great accuracy to distant targets.

Innovations in the navigation, guidance and propulsion technology to strengthen the accuracy of the weapons available then had actually strengthened the concept of cruise missile and the determination to march ahead. The most important developments in the field of navigation and guidance were: (1) the Terrain Contour Matching (TERCOM)[97] for strategic

93. Armitage, n.33, p. 72..
94. During the mid-1960s the Soviet air defence system blossomed to approximately 9,000 SAM missiles and 3,500 interceptor aircraft. "History of The B-52 Stratofortress", http://www.geocities.com/goose_topgun2k/b52.html
95. Jeffrey G. Barlow, "Congress and the Manned Penetrating Bomber Debate", *Backgrounder #125*, http://www.heritage.org/research/nationalsecurity/bg125.cfm
96. Ibid.
97. For details, see Mark W. Cannon, Jr, *Terrain Contour Matching (TERCOM): Sensitivity to Heading and Ground-Speed Errors* (Ohio: Aerospace Medical Research Lab Wright-Patterson AFB, May 1978).

New technologies were making possible an entirely new concept of air-breathing missiles that could be launched from outside the enemy's air defences to make their way with great accuracy to distant targets.

systems; and (2) the Digital Scene Matching Area Correlator (DSMAC)[98] for technical employment and for terminal guidance. TERCOM (Terrain Comparison Navigation Technique) uses a form of map in which variations in the height of the terrain to be traversed is converted into a digital presentation across a matrix of cells. For example, in the version produced by E-Systems Company, there is a matrix of 64 cells, each of which covers an area of 400 square feet on the ground. Each square is allotted an average elevation which is stored in the computer memory of the missile. The cruise missile carries a radar-altimeter which compares the reading, taken from the terrain below, with the digital map, by means of the computer and determines what corrections are required, if any, to bring the two to match and, thus, to put the missile back on track.[99] Also, instead of constant readings, the missile can depend on modern inertial platforms and their high quality gyroscopes to carry it with very good accuracy from one distinctive geographical feature to the next. This feature is known as "way-points", at which periodic updating is carried out before the missile sets out on the next stretch of its path.[100]

To supplement the input of TERCOM data, another important targeting technique developed was the Digital Scene Matching Area Correlator (DSMAC). Analogue and digital versions of DSMAC were tested during 1979 in experiments comparing photographs taken in flight by the missile, with photographs of the target stored in an on-board computer. This system is claimed to direct the missile very close to the target, at least within tens of feet. During the same period, the density of computers was greatly increased by the use of solid-state and micro-circuit electronics. In another crucial step, the size of the inertial navigation system was drastically reduced. Such inertial

98. Marshall Brain, "How Cruise Missiles Work", http://www.howstuffworks.com/cruise-missile.htm/printable
99. Armitage, n.33, pp. 88-89.
100. Ibid.

navigation weighed around 300 lb, whereas by 1970, the size and the power needed for such a system had fallen to such an extent that it could weigh as little as 29 lb.[101] The total guidance package consisting of the inertial system, radar altimeter and computer, together weighed only 115 lb, and occupied as little as 1 1/3 cubic feet of storage space.

The other revolutionary technical development during the same period was the improvement in propulsion technology. Very small fuel-efficient jet engines had been developed in the US, and by 1962, the Williams Research Company had produced the WR-2, an engine that delivered 70 lb of thrust which was used to power small target drones such as the US MQM-74. By 1967, the WR-19 engine had demonstrated a thrust of 430 lb for a weight of only 68 lb and a fuel consumption of .7 lb per hr per lb of thrust.[102] Also, further improvements in the same area took place with the use of advanced fuels such as Shelldyne. Though it was much more expensive than the conventional fuel, Shelldyne H has 33 percent more energy per unit volume than JP-4 and could give improvements for the cruise missile in the range of about 10-20 percent.[103] Above all, by this time, nuclear warheads could also be miniaturised. Therefore, very small, highly accurate, reliable and long-range cruise missiles were viewed to be a feasible option for the strike missions. Using these all innovative technologies, the US started examining a variety of proposals for a new cruise missile. By the end of 1972, the choice had narrowed down to a Submarine Launched Cruise Missile (SLCM) called the Tomahawk.[104]

All these advancements in technology that had taken place over the intervening decades, transformed the cruise missile into a most reliable and affordable weapon system to be acquired by many other states in subsequent stages of global politics.

101.Ibid.

102.Ibid.

103.George N. Lewis; Theodore A. Postol, "Long-Range Nuclear Cruise Missiles and Stability", *Science & Global Security: The Technical Basis for Arms Control, Disarmament, and Nonproliferation Initiatives*, 1547-7800, vol 3, issue 1, 1992, pp. 49 – 99

104."BGM-109 Tomahawk", http://www.globalsecurity.org/military/systems/munitions/bgm-109.htm