Table 12. Summary of differences between B-52 derivatives [4]

Model	Built	GTOW (lbs)	Payload (lbs)	Combat radius (nm)
B-52A	3	420,000	34,000	3110
B-52B	50	450,000	63,000	3110
B-52C	35	450,000	64,000	3305
B-52D	170	450,000	64,000	3305
B-52E	100	450,000	65,000	3320
B-52F	89	450,000	65,000	3345
B-52G	193	488,000	104,900	3785
B-52H	102	488,000	105,200	4510

Table 13. Important Dates for the B-52 Derivatives [4]

Model	Final Assembly		First Flights	First Acceptance	First USAF Fly-Away*	Last Delivery**
	First In	Last Out				
YB			4-15-52			
XB			10-2-52			
A	7-20-53	6-28-54	8-5-54 (1)	6-17-54 (1)	11-27-5 (3)	6-25-59
RB	2-12-54	7-12-55	1-25-55 (5)	9-3-54 (7)	3-3-55 (5)	11-3-55
B	2-11-55	12-15-55	7-7-55 (28)	11-4-55 (28)	11-9-55 (28)	8-31-56
C	10-13-55	7-9-56	3-9-56 (55)	2-28-56 (54)	6-14-56 (55)	12-22-56
D (S)	5-28-56	8-7-57	9-28-56 (89)	11-30-56 (95)	12-1-56 (95)	11-1-57
D (W)	5-16-55	8-1-57	5-14-56 (1)	6-26-56 (1)	6-26-56 (1)	11-9-57
E (S)	7-1-57	3-10-58	10-3-57 (190)	10-7-57 (190)	10-7-57 (190)	7-2-58
E (W)	7-16-57	2-12-58	10-17-57 (70 & 71)	11-27-57 (73)	12-3-57 (71)	5-28-58
F (S)	1-20-58	12-3-58	5-6-58 (232)	6-18-58 (232)	6-18-58 (232)	2-25-59
F (W)	1-29-58	8-25-58	5-14-58 (128)	6-13-58 (128 & 129)	6-14-58 (128 & 129)	12-29-58
G	5-19-58	8-25-60	8-31-58 (176)	10-31-58 (173)	2-13-590 (183)	2-7-67
H	9-1-60	6-22-62	3-6-61 (371)	3-3-61 (368)	5-9-61 (366)	10-26-62

( ) = Seattle (S) or Wichita (W) Unit # ** = Except Current Test A/C
* = Excluding Boeing Test A/C Dates = Month-Day-Year

7.6.1. XB-52 and YB-52

The XB-52 and the YB-52 were the experimental versions of the B-52 aircraft created in Boeing's Seattle plant. Contrary to popular belief, there was actually no difference between the two aircraft. The YB was instrumented for flutter tests so that the Air Force could expend an additional $10,000,000 in production funds [4]. Although the XB-52 was rolled out of the factory on November 29, 1951, the YB-52, rolled out on March 15, 1952, made the maiden flight of the B-52 Stratofortress because the XB-52 underwent a massive wing failure during a full pressure test of the pneumatic system during flight preparation. The first flight was from Boeing Field in South Seattle to Moses Lake, Washington.

7.6.2. B-52A

The B-52A was the first of the production aircraft. These aircraft differed significantly from the XB and YB-52s designed only three years earlier. Due to lessons learned in the maiden flight of the experimental aircraft, the cockpit of the B-52A was changed from the tandem setup to the now familiar side-by-side type, per General Curtis LeMay's request. The fuselage was also lengthened by four feet, improved engines were installed (see Table 19 B) and 1,000 gallon external tanks that could also be jettisoned were fitted to the wings. The Air Force originally ordered 13 B-52As, but due to another set of major modifications pending with the B-52B design, only three B-52As were built; the remaining ten of the order became B-52Bs. The first production B-52A flew on August 5, 1954 again from the Seattle plant. The first B-52A had a designation of NB-52A, because it served as the launch vehicle for the X-15. The other two aircraft mainly served as test beds for the technologies used on the B-52 Stratofortress.

7.6.3. B-52B and RB-52B

As seen in Table 11 in Chapter 6, the B-52A was extremely expensive, approximately $29 million per aircraft. The price of the B-52B, on the other hand, dropped significantly as the popularity of the aircraft grew and more orders were placed. By the first flight of the B-52A, 50 B-52Bs had been ordered by the Air Force, which clearly explains the sizable drop in unit price.

The B-52B was outwardly identical to the B-52A, but also boasted reconnaissance capabilities and an enhanced bombing navigation system. Of the 50 B-52Bs built, 23 were used for bombing and 27 for reconnaissance, designated RB-52B. In reconnaissance configuration, the B-52s bomb bay was transformed into a two-man pressurized capsule, in which crewmembers would perform their missions. Unfortunately, the crewmembers were extremely vulnerable in this position and their downward ejection seats were quite dangerous. In addition to reconnaissance capabilities, later B-52B aircraft used newer versions of the J57 engine (see Appendix B), which allowed water injection and had titanium rotors, thereby increasing the thrust rating.

The B-52B made its maiden flight in December 1954, but faced numerous problems throughout its operation, including faulty water injection pumps and alternators and deficient bombing and fire control systems. Despite these problems, the first B-52B was delivered to the Air Force on June 29, 1955. An upgrade program called Sunflower made it possible for seven of the early B-52B models to be upgraded to a B-52C. Other upgrade programs such as Harvest Moon, Blue Band and Quickclip made further improvements.

7.6.4. B-52C and RB-52C

The first of the B-52C aircraft was flown on March 9, 1956. The B-52C was the first version of the B-52 to have anti-nuclear blast white paint on its underbelly and 3,000 gallon under-wing fuel tanks. The new paint was intended to reflect some of the thermal radiation caused by the detonation of a nuclear bomb. The fuel tanks substantially increased the fuel capacity of the B-52 to 41,700 gallons thereby increasing the aircraft's unrefueled range. Some of the B-52Cs also sported enhanced fire control systems (see Appendix B). All 35 B-52Cs were all created at Boeing's Seattle plant.

7.6.5. B-52D

Boeing's Seattle plant began to transfer its production of the B-52 to Boeing's Wichita, KS plant with the B-52D. Out of the 170 B-52Ds that were built between June 1956 and November 1957, 101 were constructed in Seattle and 69 in Wichita. The first B-52D was rolled out of Wichita on December 7, 1955 and made its first flight on May 14, 1956. Seattle's first D-model flew in September of the same year.

The B-52Ds were built exclusively for long-range bombing and became the backbone of the Air Force bombing fleet for several years. The B-52D saw a lot of combat during the Vietnam War, where it was involved primarily in the bombing of targets in South Vietnam and were referred to as "iron bomb" carriers. Many of the changes to the B-52D were made to enable the aircraft to alter its role from a high altitude nuclear bomber to a high altitude conventional weapon user. The B-52D was also laden with operational issues including the malfunction of the water injection pumps, fuel leaks and icing of the fuel system.

7.6.6. B-52E

The B-52E was the first Stratofortress to use new low-altitude equipment, which was added to help evade the Soviet radar and missile network. It also sported upgraded bombing and navigation equipment (see Appendix B.) The B-52E was the first aircraft to test the Hound Dog missile, the first thermonuclear air-to-ground missile. The Wichita plant built 58 B-52Es and the Seattle plant built 42; a total of 100 B-52Es were purchased by the US Air Force.

7.6.7. B-52F

The B-52F was the last of the B-52 series to be produced at Boeing's Seattle plant. A total of 89 B-52Fs were built, 45 of which were built in Wichita and 54 of which were built in Seattle. The first B-52F was flown on May 6, 1958. This derivative of the B-52 was the beneficiary of numerous improvements including better engines and secondary structural changes. These changes were minor in comparison to the greater range and flexibility requirements outlined in 1956 by the increasingly powerful SAC and implemented in the B-52G.

7.6.8. B-52G

Production of the B-52G was authorized in August of 1956 to fulfill the greater range and flexibility requirements of the SAC. The requirements included an increased range of 30%, a decrease in maintenance man-hours by 25%, a decrease in empty operating weight of 15,000 pounds and an increased electronic warfare capability of 70% [4]. Externally, the B-52G looked very similar to its predecessors; only the height of the vertical tail, a foot longer fuselage and smaller external fuel tanks and nacelles reveal that the aircraft is indeed a G series. The majority of the changes occurred inside the aircraft. The design improvements to the outside and inside of the B-52G to achieve the new SAC requirements included:

- A conversion from bladder cells to an integral fuel tank.
- A "wet wing" that used long alloy wing skins so that stiffeners were an integral part of the structure with a minimum of chord-wise joints.

- The vertical fin height was reduced from 48 to 40 feet.
- The aileron system was eliminated.
- A new fire control system that allowed the gunner to operate from the front compartment instead of the rear turret.
- Lowering the crew deck by two inches to increase visibility for in-air refueling.
- Design as a missile platform instead of a bomber.
- Replacement of pneumatic system with hydraulic pumps.
- Cockpit layout changes to enhance crew comfort.

Unfortunately, the B-52G still experienced problems, some of which were direct results of the design improvements. The shorter fin and lack of ailerons made the aircraft more susceptible to Dutch Roll. In addition, the spoilers created a nose-up pitch-up when extended again due to the lack of ailerons. This made aerial refueling troublesome.

The B-52G was manufactured solely at Boeing's Wichita plant. 193 B-52Gs were delivered between November 1, 2958 and February 7, 1961. To illustrate the aircraft's enhanced performance of the over its predecessors, the maiden flight of the B-52G on December 13, 1960 flew 10,000 miles without refueling in 19 hours and 47 minutes.

7.6.9. B-52H

The B-52H was the last and perhaps the finest series of the B-52 family of aircraft. A new engine technology had been introduced to the Air Force known as the turbofan. The turbofan added a large diameter fan element to the engine, substantially increasing the thrust. For the B-52H, Pratt & Whitney's TF33-P-3 turbofan engines replaced the old J57 turbojet engines. The specific fuel consumption was reduced from 0.8 to 0.56 lb/lb/hr. The TF33 produced 17,000 pounds of thrust, which gave the B-52H a 30% increase in power over the B-52G. In addition to new engines, the B-52H also had improved refueling capability, due to a new spoiler position.

A new role had been defined for the B-52 as a low level penetrator, which would require the aircraft to fly low at high speeds with rapid control inputs. In order to serve in this new role, the aircraft was equipped with advanced capability radar for terrain avoidance, an anti-jamming unit and improved low level mapping capability. The pilot was also assisted in controlling the B-52H with control wheel steering, which reduced the amount and frequency of control forces required to fly the aircraft. Low-level flight can also place the aircraft in areas where air turbulence has its greatest effects. Boeing and the Air Force initially instructed pilots to avoid high-turbulence areas. After numerous losses, several additional modifications were made to the B-52H to deal with the greater turbulence effects. More information on this topic can be found in Section 8.3.

Boeing delivered a total of 102 B-52Hs to the US Air Force. These aircraft have served in numerous contemporary conflicts including the Persian Gulf War, Kosovo and Operation Enduring Freedom in Afghanistan. One of the greatest triumphs of the B-52H, was its breaking of the unrefuelled range record. On, January 11, 1962, the B-52H broke the record of the PV-2 Neptune "Truculent Turtle" set in 1946, by flying 12,532 miles from Kadena Air Force Base in

Okinawa to Torrejon Air Force Base in Madrid, Spain at an average speed of 575 mph in 22 hours and 9 minutes (more than half of the time it took the PV-2).

Chapter 8. Operating Experience

This chapter presents the operating experience of the B-52, from its first roll-out to its operational role in the Vietnam war and Desert Storm. A description of some of the earlier accidents and anomalies encountered by the aircraft is provided, which leads into the updates installed over the lifetime of the B-52 and the maintenance necessary to keep the aircraft flying. At the end of the chapter, we illustrate how the operating costs make the B-52 an economically viable bomber.

8.1. Combat Experience

The B-52 was designed and envisioned as a strategic nuclear bomber. Its program originated in the fledgling years of the Cold War when *containment* and *massive retaliation* were the guiding foreign policy principles. However, as conflicts such as Korea and Vietnam emerged, the directive of foreign policy evolved to *flexible response*, and the B-52 had to adapt. In its new role, it proved to be an effective conventional bomber.

The first use of a B-52 in conflict came on June 18, 1965 in Vietnam. The B-52 participated in *Operation Arc Light* and *Arc Light II*. Initial bombings were moderately effective, with mixed results for target accuracy. On its first mission, in fact, two aircraft collided in airborne refueling confusion. As the B-52 gained more combat operational experience, it grew into a workhorse role for the Vietnam War. Over eight years of combat, from 1965 to 1973, the B-52 flew over 100,000 sorties and coined the term, “carpet bombing”. Most missions originated from air bases in Guam, from where the B-52 flew 5,000 miles to Vietnam in 16-18 hours. In those years, it was responsible for dropping 380,000 tons of ordnance on Laos and 750,000 tons of ordnance on Cambodia in supply flow interdiction missions.[6] These interdiction missions, however, were veiled in military confidentiality as they occurred beyond the Vietnam boundary. The most prominent role the B-52 played in the Vietnam war came over the course of 12 days in 1972 during *Operation Linebacker II*. President Nixon, striving to obtain, “peace with honor” grew frustrated over North Vietnamese intransigence at the negotiating table. To force their hand, Nixon ordered massive bombing attacks against the military infrastructure of the North. The B-52 struck 34 out of 100 targets in heavily guarded air space. In those 12 days, the B-52 dropped 15,287 tons of ordnance and shot down two MiGs at the expense of fifteen aircraft.[6]

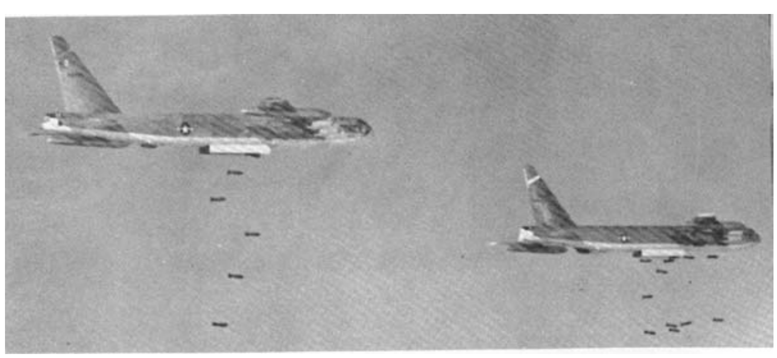


Figure 57. B-52s releasing bombs 30 miles from Saigon on July 7, 1965 [26]

Twenty years after the Vietnam War, the B-52 again saw combat in the first Persian Gulf War. In Operation Desert Storm, approximately 80 B-52s were based in Diego Garcia, Saudi Arabia, Spain and England. The B-52 focused on repeated, round-the-clock bombing of Iraq to chip away at the morale of Iraq's Republican Guard. The Persian Gulf War also showcased the B-52 as the debut aircraft for the Air Launched Cruise Missile (ALCM). To deliver the ALCM, seven aircraft flew from Barksdale AFB in Louisiana directly to Iraq (requiring two mid-air refuelings), covering 14,000 miles in 35 hours, a combat mission record at the time.[6] While the B-52 accounted for only 10% of the total number of aircraft, it dropped about one-third of the total ordnance by ton in 1,624 sorties. Additionally, although the oldest bomber used in combat, it had a mission capable rate of 81%, two points higher than its maritime rate.[24]

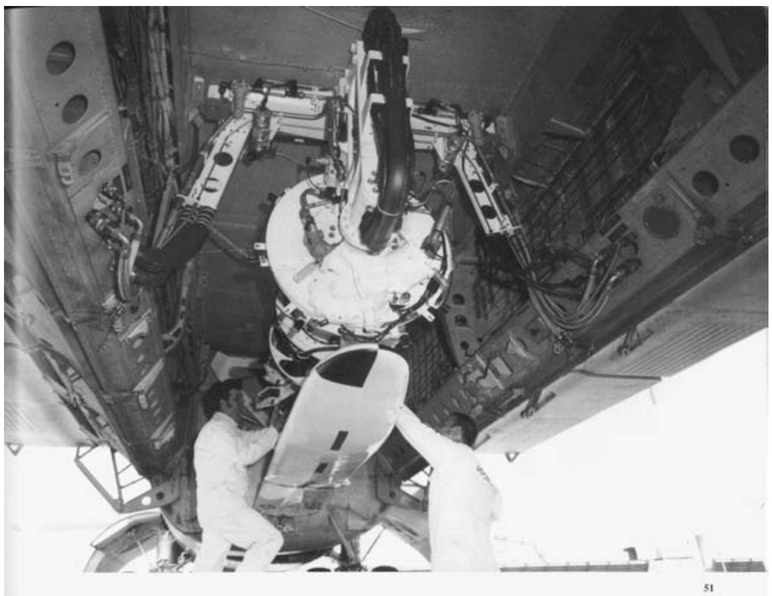


Figure 58. Crewmen load an ALCM into the bomb bay of a B-52 [29]

The B-52 has also been utilized in recent conflicts in Kosovo, Afghanistan and Iraq. In Kosovo, the B-52 flew 187 sorties and delivered 6,600 weapons at a 98% mission capable rate. It also flew repeatedly from Diego Garcia to Afghanistan in *Operation Enduring Freedom*, dropping bombs and providing low-level loiter ground support for troops searching for the Taliban in mountainous caves.

8.1.1. Change in Mission Profile to Low-Level Flight

By 1959, the SAC grew worried about the advances in Soviet radar and air defense. Bombing missions at 50,000ft were no longer safe or a reliable method to deliver munitions. Instead, aircraft had to fly beneath the radar, as low as 500ft, to avoid Soviet air defenses. The B-52 was designed for cruise and bombing missions at 50,000ft. The new SAC requirements of 1959, (which was one motivation for the extensive changes made to the B-52G model), required the B-52 to adapt to low-level flight. The USAF funded a series of upgrades to the existing fleet to install the avionics and structural improvements necessary for low-level flight. However, the upgrades could only do so much for the infrastructure of the B-52, and it suffered from the higher aerodynamic loads at lower altitudes. The acceleration of wing fatigue took its toll on the B-52 fleet. It would have been difficult for the Boeing engineers to have anticipated the low-level requirement in 1948. The aircraft might have looked or performed quite differently if the low-level missions were anticipated during the early design phases. Future life of the B-52, discussed at length in Chapter 9, might be elongated if the USAF were to restrict the B-52 from future low-level flights. Further discussion of the impact of low-level missions and its relation to accidents and upgrades is found in Sections 8.3 and 8.4.

8.2. Other Experience

As an extraordinarily capable aircraft, the B-52 has been employed for other operations beyond its combat duties. In 1956, in one of the first operations to involve the B-52, *Operation Redwing* dropped nuclear warheads on the Eniwetok and Bikini atolls. The B-52 dropped 16 of these warheads, including the Cherokee drop, where the bombardier released the weapon 21 seconds too early with nearly catastrophic consequences.[6] These drops tested the effect of nuclear radiation upon the aircraft, ultimately culminating in painting the underbelly of the B-52 with special radiation reflective paint. In a similar exercise in 1962, *Operation Dominic*, the B-52 performed 29 of 36 free fall deliveries of atmospheric detonation nuclear weapons.

The B-52 has also assisted the USAF in other aviation and research milestones. In 1957, three B-52Bs circumnavigated the globe in record time, just over 45 hours.[23] It also served as a launch platform for experimental aircraft, such as the X-15, X-24 and Pegasus, as seen in Figure 59.

Figure 59. B-52 with the X-15 underneath its wing amongst onlookers. [24]

8.3. Accidents and Anomalies

From February 1956 to June 1994, a total of 109 B-52s were lost according to official records. This number includes attrition resulting from both mechanical failure and hostile action.

The first such incident occurred on February 16, 1956, when the 3rd Bomber Wing suffered a loss during a routine training mission. In the middle of the mission, the B-52 caught fire which resulted in a loss of flight controls. The plane entered into a terminal dive, and broke up into numerous pieces near 10,000 ft. Among the 8 crew members, only 4 managed to escape safely using parachutes. The wreckage landed in the town of Tracy, California.

The likely cause of the accident was traced to a faulty alternator. This led to the grounding order on 20 B-52Bs known to be fitted with such alternators. Future deliveries of new B-52 were suspended until May when Boeing engineers were confident that the fault had been rectified.

There were also accidents in B-52 history when the aircraft was carrying nuclear weapons. During one such incident, the recovered wreckage fell to earth about 20 miles south of Hardinsburg, Kentucky. In that incident, the external casing survived unbroken and there was thus no hazard from radiation.

In truth, each accident has its own story, from its cause to investigation and the efforts the SAC took to remedy the faults. Table 14 details the B-52 attrition numbers by cause. It is difficult to draw definite confusions or lessons from Table 14, as there are many messages in the data. Different model aircraft, with different levels of upgrades might have crashed for similar reasons (e.g. landing accident), but different root causes. Much of the reporting and details surrounding the accidents are sparse. For instance a report of "crashed after takeoff," does not give insight as to the series of events leading to the accident.

Despite a dearth of detail surrounding the accidents, some common themes are clear. Nineteen aircraft were lost between ground fires, ground accidents and mid-air collisions. The mid-air collisions were mostly associated with in-flight refueling. The aircraft either collided with the tanker or with another B-52 in refueling procedure confusion. These collisions and ground accidents are operational faults that should have been eliminated. Unfortunately, the USAF was loathe to cite its own shortcomings in these incidents, so further detail is not available.

The accident data also points to some design flaws in the B-52. Some of the takeoff accidents involved improper trim settings of the stabilizers. Also, the wing structure suffered from accelerated fatigue failure due to the higher aerodynamic loads of low-level flight. Problems identified early in the B-52 lifetime were corrected in later derivatives, such as the redesigned empennage of the G and H models. Other fixes were delivered to the fleet by the way of upgrades. Section 8.4 discusses the upgrade programs in more depth, and their connection to B-52 accidents.

Table 14. B-52 aircraft attrition tabulated by reported reason of failure. [6]

Accident Reason	Aircraft Lost	Accident Reason	Aircraft Lost

Combat	21	In flight fire	3
Structural failure	8	Mid-air collision	9
Ground fire / accident	10	Engine failure	4
Takeoff anomaly	8	Poor weather	3
Landing anomaly	6	Low-level / night mission	4
Loss of Control	7	Out of fuel	2
Electrical failure	3	Unknown or Other	21

8.4. Upgrades

Over past 50 years, the B-52 has undergone many upgrades. Some of these upgrades focused on one or two aircraft, some on one set of derivatives and some on the entire fleet. The highlights of the many upgrades are detailed below. The different upgrades can be divided into two distinct classes. The first class of upgrades are those that augmented the capability or mission capacity of the B-52. This would include modifications for newer weaponry or improved avionics. The second class of upgrades were those initiated to resolve a design flaw or faulty part on the aircraft. In one instance, it appears as though these modifications were coupled. Terrain avoidance radar and structural improvements were installed on the B-52 to allow for sustained low-level missions. However, around the same time, the B-52 experienced some catastrophic structural and wing failures, usually due to fatigue. Thus, the USAF funded another upgrade program to improve structural fatigue endurance.

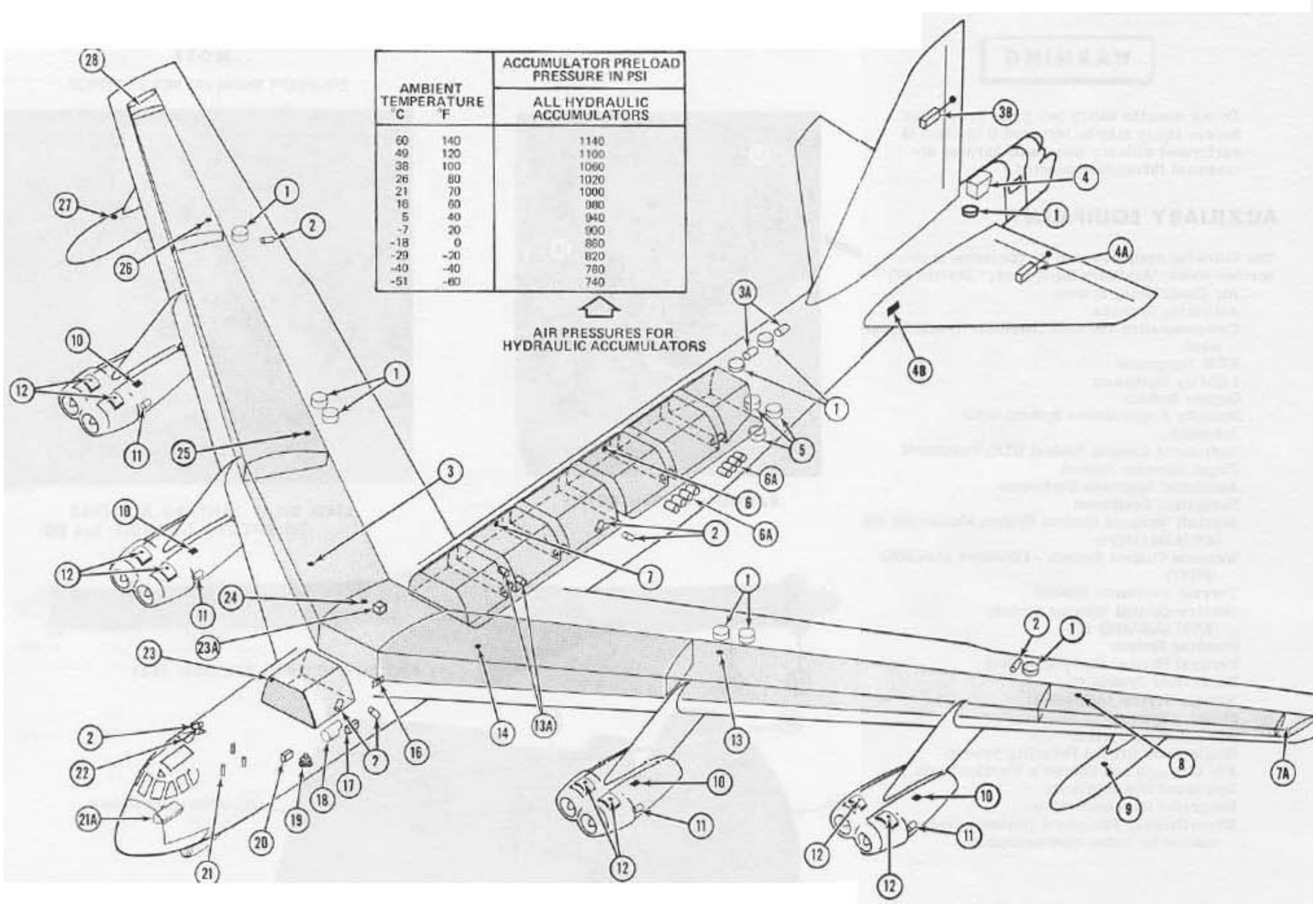
8.4.1. Major B-52 Upgrades[6]

- *ALCM* - modification to B-52H to carry Air Launched Cruise Missiles (ALCM). The SAC thought this was a necessary step to maintain a competitive edge over Soviet air defenses.
- *Big Belly* - increase the bomb payload capacity of B-52D to approximately 60,000lbs. This feature was heavily exploited during the Vietnam War.
- *Big Four* - Upgrades to the bombing / navigational system, radar capabilities and structural enhancements for low-level flight.
- *ECP1050* - Response to wing fatigue failure. Structural improvements to extended fatigue life.
- *Hi Stress* - Concurrent program with *Big Four* to upgrade the structure especially for low-level flight.
- *Quickclip* - The last of three upgrade programs to solve fuel leakage problems across the entire fleet.
- *Quickstart* - Installation of cartridge starters to B-52G and H models. The starters allowed for reduced time for the B-52 to get to the runway and overall response time in case of surprise attack.
- *Sun Bath* – Increase the conventional warfare payload capacity of the B-52F

8.5. Maintenance Support

The current fleet of B-52s in the US Air Force was built before the mid 1960s. Meaning, most of the aircraft are older than the maintenance crew that maintain them. The aircraft average only about 14,700 total flight hours, much lower than a commercial aircraft from that era. In contrast, a Boeing 727 might have 65,000-70,000 flight hours. Additionally, B-52 missions tend to last seven to ten hours, so the number of cycles on each aircraft is lower still. However, to ensure that the B-52 are safe, reliable and in combat condition, routine maintenance is still required at the various Air Force bases which house the aircrafts.[16]

All the maintenance work done on the B-52 requires good scheduling, with the relevant maintenance staff and parts so that the aircraft can be flight ready when needed. Logistics personnel must produce a utilization plan that balances mission requirements and still provides necessary "down time" for aircraft repairs and modifications.



AMBIENT TEMPERATURE °C	°F	ACCUMULATOR PRELOAD PRESSURE IN PSI ALL HYDRAULIC ACCUMULATORS
60	140	1140
49	120	1100
38	100	1060
26	80	1020
21	70	1000
16	60	980
5	40	940
-7	20	900
-18	0	860
-29	-20	820
-40	-40	780
-51	-60	740

AIR PRESSURES FOR HYDRAULIC ACCUMULATORS

SPECIFICATIONS

TYPE FLUID	USAF SPECIFICATION	NATO SYMBOL
FUEL 12 Tanks	MIL-T-5624 (JP-4)	F-40
FUEL (Alternate)	MIL-T-5624 (JP-5)	F-44
FUEL (Av Gas)	MIL-G-5572	See Section V
OIL (Turbine) 8 Tanks	MIL-L-7808	0-148
HYDRAULIC FLUID 9 Reservoirs	MIL-H-5606	H-515
GENERATOR DRIVE UNIT OIL 4 Reservoirs	MIL-L-7808	0-148
WATER (EVS WINDOW WASH) 1 Tank	DISTILLED WATER	—

AIR CONDITIONING PACK OIL
AS SPECIFIED ON PACK NAMEPLATE
1 PACK

BATTERY WATER
DISTILLED WATER
3 BATTERIES

LIQUID OXYGEN
MIL-0-27210 TYPE II
3 CONVERTERS

STARTER CARTRIDGE
STOWAGE PROVISIONS FOR 8 TYPE MXU/4A.

POWER CARTS

- COMPRESSOR, TYPE MA-1A (OR EQUIVALENT)
- EXTERNAL HYDRAULIC TEST STAND, TYPE D-5A (OR EQUIVALENT)
- GENERATOR SET, TYPE MD-3 (OR EQUIVALENT)
- EXTERNAL GROUND BLOWER, TYPE A-2 (OR EQUIVALENT)
- EXTERNAL GROUND SUPPORT BLOWER, TYPE MC-1 (OR EQUIVALENT)

1. Hydraulic reservoir	13. No. 1 Main Tank
2. Accumulator	13a. AGM-9A Launcher Hydraulic Accumulator
3. No. 3 Main Tank	14. No. 2 Main Tank
3a. Rudder Elevator Hydraulic Pumps	15. Deleted
3b. Powered Rudder Actuator	16. AGM-69A Environmental System Pressure Connector (air)
4. Drag Chute	17. Aft Battery
4a. Powered Elevator Actuator (typical)	18. Air Conditioning Pack Reservoir
4b. FCS Cooling Air Ground Connector	19. SPR Receptacle
5. Liquid Oxygen Converters	20. Forward Battery
6. Aft Body Tank	21. Drinking Water Containers
6a. Starter Cartridges (Stowed)	21a. EVS Window Wash Water Tank
7. Mid Body Tank	22. Air Refueling Receptacle
7a. Left Wing Surge Tank	23. Forward Body Tank
8. Left Outboard Wing Tank	24. Center Wing Tank
9. Left External Tank	25. No. 4 Main Tank
10. Air Bleed System Ground Connector	26. Right Outboard Wing Tank
11. A-C Generator Drive Unit Reservoir	27. Right External Tank
12. Engine Oil Tank	28. Right Wing Surge Tank

Figure 60. Ground servicing diagram for the B-52H, including access points and ground service carts required. [27]

B-52 maintenance requires a suite of different types of support staff. Among the maintenance personnel, there are crew chiefs, specialists, weapons loaders and the support section. The crew chiefs are responsible for inspecting, servicing and performing general maintenance. They work round the clock to coordinate maintenance actions and prepare the aircraft for the next flight. The specialists are highly professional technicians in their respective fields of propulsion, pneumatics, hydraulics, electronics, communication, bombing, navigation and guidance & control. The weapons loaders work together as a team so that the bombs and missiles on the aircraft can be loaded onto it in the shortest time possible. They have developed innovative ways to ensure rapid and accurate loading of aircraft armaments. The support section provides parts, tools, logistical support and other specialized support functions.

Currently, the PDM Programmed Depot Maintenance (PDM) cycle, the military equivalent of a D check, is completed once every four years to catch minor corrosion on the B-52. The 48 month schedule is a balance between the demand for reliability and cost. Aircraft at PDM require roughly 150 calendar days, and about 2,000 man-hours of labor at a cost of about $3.2 million per plane. A majority of the work involves looking for corrosion and fixing minor problems. The aircraft are regularly checked in the field under USAF's Structural Integrity program, which looks at the plane's primary structures for fatigue stress and early cracking.

One of the most time consuming maintenance tasks is the upkeep of the old TF-33 turbofan engines. The engines require both field maintenance and depot maintenance. As mentioned in Section 9.3.2, approximately 70 engines in the B-52 fleet undergo field maintenance each year and 87 engines are removed from the wing each year for depot maintenance.

Figure 61. Engine maintenance on the TF-33 engines (above). The behemoth size of the B-52 requires the use of cranes, bucket trucks and other heavy machinery. [25] [26]

8.6. Operating Costs

The SAC initially wanted at least a quarter of the B-52 fleet to be operational at any given time. With over 600 aircraft, this translated to having 150 planes able to take to the skies on short notice. This placed a financial strain on the Air Force on the order of hundreds of millions of dollars each year, and they soon realized that this level of readiness was just not feasible. Eventually, they compromised, with one-eighth of the fleet, around 75 aircraft, ready on short notice, forming the airborne alert force.

The build-up of the capability of the B-52 fleet continued through to the 1960s, despite low budgets of $15 million in FY1960 and $25 million in FY1961. These meager sums barely provided for 10 aircraft on a year-round basis, and cost projections in the early 1960s indicated that at least $225 million would be required to cover annual operating costs to sustain one-eighth of the force. If other factors such as spares, fuel, personnel and training were taken into account, those costs would rise to $800 million a year [6].

During the Vietnam War, it cost around $1000 an hour to fly the B-52 bomber, in then-year dollars. A round trip from Guam to Vietnam took 8 hours [20]. An example of the huge costs of waging war is shown in Table 15, which outlines the cost of the "Arc Light" bombing campaign, which took place in Southeast Asia between 1965 and 1973. Each bombing sortie cost approximately $41,421 in then-year dollars. About half of this cost came from munitions and ordnance, while the other half went to personnel and aircraft maintenance and operating costs. The eight-year campaign cost a total of $5.2 billion dollars in then-year dollars. Today, the same campaign would cost $26.3 billion dollars [21].

In the 1990s, it cost about $6 million per year to maintain, operate, and support one B-52 bomber. It is estimated that the B-52 costs about $7,000 plus per hour to fly (based on an operational life of 35,000 hours per aircraft.) In 1991, B-52s were used on a 35.3-hour, non-stop mission from Barksdale AFB, Louisiana to Iraq and back, a distance of over 14,000 miles. This mission cost $247,100 per B-52 in direct operating costs. This does not include the cost of in-flight refueling or fighter escort. However, the B-52 is still a bargain if you consider $21,000 per hour operating cost of the B-1 [21].

Today, the B-52 is still an economically viable weapons system. Even though the fleet is aging, the maintence costs of keeping the current B-52 fleet flying are relatively low. Fishman provides some statistics on current yearly maintenance costs of the B-52 fleet:

> "It costs $4.1 million to overhaul one B-52. The Oklahoma City B-52 facility costs $80 million a year. The Air Force pays Boeing another $100 million a year to provide upgrade support. The Air Force has spent $5 billion on hardware to upgrade B-52s since 1980. But with a much-reduced fleet, that cost is now running $70 million a year. So keeping 94 B-52s flying costs about $250 million a year – less than half the cost of one new B-2." [19]

Table 15. Cost Statistics on the "Arc Light" Campaign of Southeast Asia (1965-1973) [21]

Total Sortie Statistics	
Total Sorties	126,615 launched 125,479 reached target 2,949,000 tons of bombs dropped
Average Cost per B-52 Sortie	
Aircraft POL (Petroleum, Oil, Lubricants)	$3,397
Depot Maintenance	$4,424
Transportation	$3,468
Systems Support Supplies	$1,349
Base Operating Support	$1,270
KC-135 Aerial Tanker Support (refueling)	$1,368
Munitions/Ordnance (av. bomb load-27tons)	$22,500
Aircraft Spares	$872
Military Personnel	$2,773
Total	$41,421
Total Cost per B-52 Sortie in 2003 Dollars	$242,808
Total Cost in Then-Year Dollars: (Successful Sorties)	$5,158,339,972 (124,532 sorties x $41,421sortie cost)
Total Cost in 2003 Dollars	$26,304,538,637

Chapter 9. The Future of the B-52

As the oldest plane in the fleet and the longest aircraft program in USAF history, it might be conceivable that the B-52 would be rapidly ushered towards retirement. However, the USAF has no intentions to cast away the B-52. In fact, the future for the B-52 looks as bright as if it were 1965.

9.1. Projected Lifetime

Of all of the B-52s manufactured, only the B-52H models remain in service with the USAF today. Boeing delivered a total of 102 B-52Hs to the USAF between May 1961 and October 1962 for a cost of $9 million a piece. Although all of these aircraft underwent structural upgrades in the 1960s and 1970s to be better equipped for low-level missions, the planes are still over 40 years old.

The projected service life of the B-52 airframe is estimated to be around 35,000 flight hours. As seen in Figure 62, the upper wing surface is the limiting factor in the service life of the aircraft. This estimate is based upon structural limit testing along with standard mission profiles and loadings.

According to an independent task force, the average B-52H airframe has about 14,700 flight hours. This is an average usage of about 370 flight hours per year. The most extensively used aircraft has approximately 21,000 hours and is used for 380 hours per year. Referring to Figure 62, the B-52H has at least 17,800 flight hours remaining in its service life. If current usage rates continue, then there are at least 40 years of reliable operation remaining. Heeding these calculations, the USAF envisions using the B-52 at least through 2037. In contrast, commercial aircraft fly 3,000 to 4,500 hours per year. At this rate, the B-52 would have met its service life limitations in only 10 years. [16]

Figure 62. Projected Service Life of the B-52 Structural Components [16]

Another factor in projecting the useful life of the B-52 is the mission it flies. In recent conflicts in the Middle East, the B-52 mission profile was primarily long range, conventional weapons delivery often with long loiter times over the target. These flight profiles are less stressful than previous low-level flight mission profiles. If the USAF were to commit the B-52 to only these mission profiles and eschew low-level operations, the B-52 service life might be further extended.

9.2. Strategic Niche

Although the B-52 is an aircraft built with technology from the 1950s and 1960s, it is not outdated hardware. The B-52 can serve a role and perform missions that no other bomber in the USAF arsenal can. Similarly, the B-1 and the B-2 also have their strategic niche. This division of roles between the Air Force bombers ensures that each aircraft has a place in future strategic planning.

9.2.1 Comparison to Other Bombers

Comparison of the B-52 to other Air Force bombers illustrates its usefulness. Obviously, the B-2 is a stealth bomber and employs technologies unavailable to the B-52, but the mission and purpose of the B-2 is vastly different from the B-52. It is more productive to compare the B-1 and B-52.

For the majority of bomber missions, there is little difference between the B-1 and B-52. However, there are a number of performance disparities that allow the B-52 to perform missions that the B-1 cannot. For instance, the B-52 is both a nuclear and conventional weapons bomber, whereas the B-1 is solely a conventional bomber. The B-52 has a longer range, higher ceiling and higher cruise velocity than the B-1. It also has a faster turn rate, shorter takeoff ground roll and higher climb rate (assuming no afterburners) than the B-1. Moreover, the B-52 is more flexible in the payloads it can carry, and is the only bomber in the Air Force capable of launching Air Launched Cruise Missiles (ALCM) and propaganda leaflets. Both the ALCM and the leaflet dispenser have been used heavily in recent conflicts in the Middle East. In contrast, there is no missile, bomb or munitions that the B-1 can carry that the B-52 cannot. [16]

Another advantage the B-52 has over its fellow bombers is its operational readiness. As seen in Figure 63, the B-52 was mission capable nearly 80% of the time in 1998, whereas the B-1 was only mission capable about 50% of the time and the B-2 only 35% of the time. In fact, one reason for the retirement of many B-1s recently is their poor mission ready performance. Between its readiness, range and payload advantages over the B-1, the B-52 is truly the USAF workhorse.

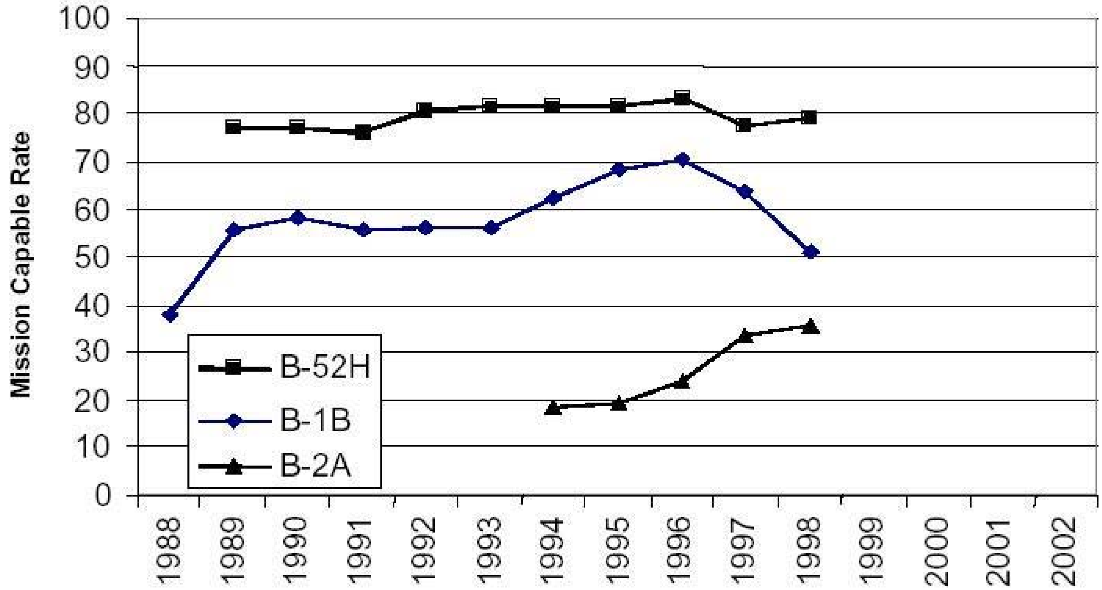


Figure 63. Bomber Readiness Rates 1988-1999 [16]

9.2.2. The Future of the Bomber Fleet

The current composition of the USAF bomber fleet further assures dependency upon the B-52 in the next 40 years. The Air Force recently reduced its bomber fleet from 208 aircraft to 157 by cutting 33 B-1s and 17 B-52s. Of these 157 aircraft, only 96 are designated for combat, as shown in Table 16. The retirement rate for the B-1s was almost double that of the B-52. Thus, the B-52H comprises the majority of the USAF bomber fleet.

Table 16. Current USAF Bomber Inventory [16]

Aircraft	Combat Coded	Training	Test	Other	Total
B-1	36	19	4	4	60
B-2	16	0	1	4	21
B-52	44	12	2	18	76
Total	96	28	7	26	157

Securing the B-52's place in the bomber fleet is the absence of new bomber acquisition programs. The Air Force does not envision a Long Range Strike Aircraft (LRSA) becoming operational until 2037 (approximately the year of the B-52 retirement). The Air Force has only begun to examine timelines for the development and acquisition process for a LRSA. Current projections estimate that the USAF will start an acquisition program for a new bomber around 2014.

9.3. The Case to Re-engine

The topic of replacing the vintage 1950s era TF-33 engines currently on the B-52H with newer commercial turbofan engines has been a polemic issue debated for at least twenty years. There have been four separate studies since 1996 alone to study this issue. However, except for the most recent report in 2002, all have argued against replacing the engines on the B-52. The envisioned scenario is to substitute one engine for each pylon on the B-52, converting it to a four-engine aircraft instead of eight. There are three candidate engines from the three major aircraft engine manufacturers for the TF-33 replacement:

- Rolls Royce RB-211
- Pratt & Whitney 2040
- General Electric CF6.

Although the improvements in aircraft performance and operation offered by installing new engines on the B-52 are incontrovertible, all previous studies found that the program would not be cost effective. In 1996, the Boeing Company offered an unsolicited proposal to the Air Force to re-engine the B-52s with Roll Royce RB-211s. A USAF study did not find the proposal to be cost effective and two other studies since 1996 reached the same conclusion. However, in 2002 the USAF tasked the Defense Science Board to conduct a broader, more in-depth analysis of the re-engine option. This most recent task force criticized some of the methodologies and analyses of the previous studies and found that re-engining the B-52 would be immensely worthwhile. They recommended that the USAF begin the acquisition process for the new engines and its associated upgrades with all possible urgency. The projected engine overhaul would occur in three phases: [16]

1. $3M study to determine cost, benefits and develop executable program
2. 4-year, $227.7 Engineering and Manufacturing Development (EMD)
3. 6-year production, overlapping EMD by two years.

9.3.1. Performance and operations

From an aircraft performance perspective, installing commercial turbofans on the B-52 is a simple decision. The newer engines offer significant reductions in fuel consumption over the TF-33s, leading to a much-improved range and loiter performance. The current unrefueled range of the B-52H with a maximum takeoff gross weight of 488,000 lbs is 5,088 nmi. Under the same conditions, the re-engined B-52H would have an unrefueled range of 7,420 nmi, a 46% increase. With this improved range, the B-52 could strike anywhere on earth with only one refueling, whereas current B-52s would require two.

During Operation Enduring Freedom, the B-52 flew from Diego Garcia (a US military support base in the middle of the Indian Ocean) to Kabul, Afghanistan for sorties every day. However, the B-52 could not accomplish this mission without mid-air refueling. A re-engined B-52 would not only enable the aircraft to fly the mission without refueling, but also simplify and assuage the demand for tankers and logistics in the air. Figure 64 depicts the augmented range-loiter time of a re-engined B-52, assuming maximum takeoff weight, a two-hour fuel reserve and a weapons load of 12 JDAMs and 27 Mk 82s. With only a 25% increase in range, it is estimated that the B-52 would require 33%-66% fewer tanker sorties to complete the same missions. During

Operation Enduring Freedom, this would have alleviated the ramp space demand at Diego Garcia and allowed some tankers to be deployed elsewhere to support other missions. Tanker availability was a leading constraint of planning and execution of Operation Enduring Freedom missions. [16]

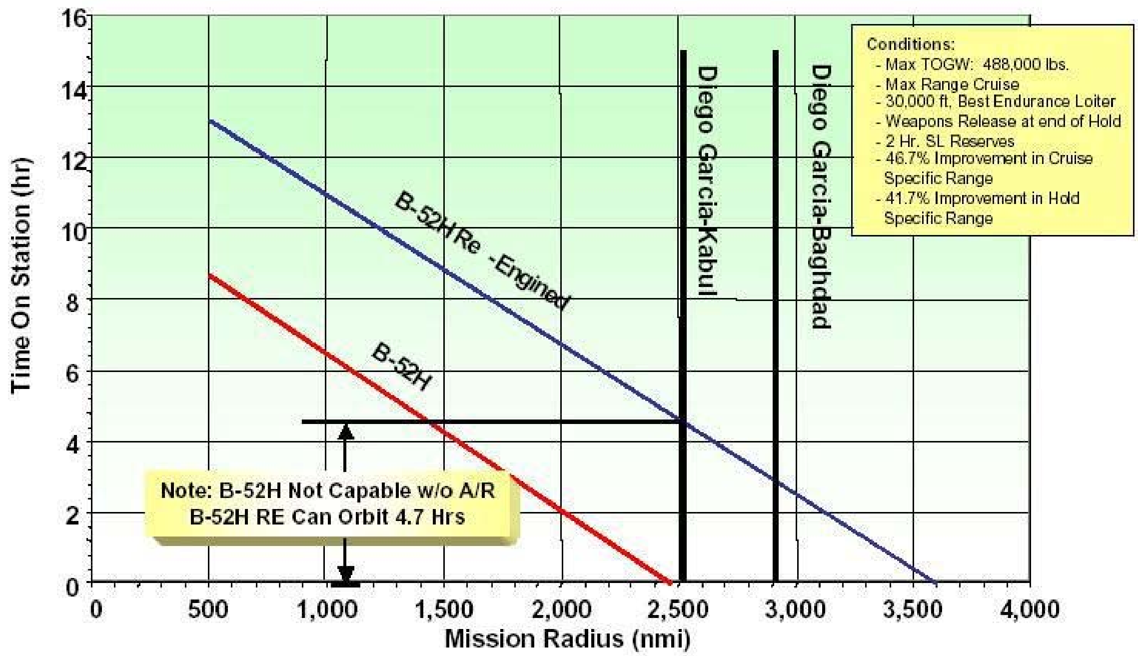


Figure 64. Range-loiter Performance for Unrefueled B-52 Mission [16]

9.3.2. Economics

The economic evaluation of installing new engines on the B-52 involves assessing the cost savings over the projected lifetime of the B-52 and comparing it to the cost of the engine overhaul. The Operation & Maintenance (O&M) outlay savings fall under three categories:

- Fuel
- Depot Maintenance
- Field Maintenance

The TF-33s currently in use by the B-52H fleet consume 3,310 gallons of fuel per hour. The new engines envisioned as replacements consume 2,218 gallons per hour. Over the next 35 years, the B-52 is expected to fly 22,000 hours per year. These figures lead to a savings of 840 million gallons of fuel. Assuming the cost of fuel remains constant, accounting for the added cost of delivering some fuel in-flight and a discount rate of 3.9%, the fuel savings alone over the remaining B-52 lifetime would be approximately $1.8 billion.

In addition to the cost savings offered by commercial turbofans in terms of fuel efficiency, they also tout better reliability over the current TF-33 engines. Each year, 87 engines are removed from B-52s and sent to depot maintenance for a cost of $710,000 each. Even if the cost of depot maintenance and the rate of engine removal remain constant (a generous assumption), this will cost the Air Force $4.4 billion dollars over the remaining service lifetime of the B-52. With the reliability of current turbofans and the low usage frequency of the B-52, no depot maintenance would be required in the re-engine scenario. Furthermore, in addition to the 87 TF-33 engines removed from the B-52s for depot maintenance, approximately 70 engines undergo field maintenance each year at a cost of $462,400 each. In contrast, Boeing estimates that the annual cost of field maintenance for the replacement turbofans will only be $13 million per year. [16]

The total cost savings offered by re-engining are itemized in Table 17. Both annual and lifetime savings are shown. Lifetime estimates utilize a discount rate of 3.9% and assume that savings are only accrued once an overhauled B-52 returns to service according to the timeline in Figure 65. Thus, multiplying annual savings by years remaining in the B-52 lifetime does not equal the lifetime savings estimates.

Table 17. Operation and Maintenance Cost Outlays in Millions of 2002 Dollars [16]

	TF-33 Outlay		Re-engined Outlay		Reduction	
	Annual	**Total**	**Annual**	**Total**	**Annual**	**Total**
Fuel	87.4	6,308	55.6	4,490	31.8	1,818
Depot Maintenance	61.8	4,459	0	0	61.8	4,459
Field Maintenance	32	2,337	13	1,680	19	657
Total	181.2	13,104	68.6	6,170	112.6	6,934

It is difficult to project actual program costs of re-engining the B-52 fleet, and it is somewhat dependent on how the Air Force finances the project, but total costs are estimated at $3 to $3.5 billion. Since the total cost savings estimated in Table 17 is $6.9 billion, it is clearly advantageous to pursue the re-engining option. If the USAF were to initiate and approve the project, Engineering and Manufacturing Development (EMD) could begin immediately with the first B-52 overhaul to be completed in 2007 and the entire fleet completed by 2012. Figure 65 best illustrates the estimated program cost and timeline. The numbers above the "Production" line indicate the number of aircraft overhauled with the new engines during that year.

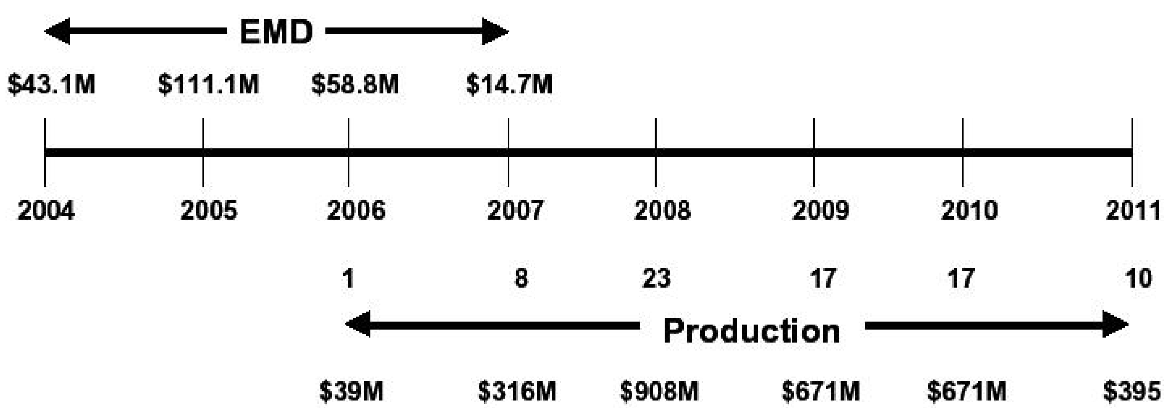


Figure 65. B-52H Re-engining Cost and Project Timeline [16]

9.3.3. Environmental Impacts

The re-engined B-52 would be beneficial to the environment is some respects, but detrimental in others. Re-engining the B-52 would bring the aircraft into EPA and ICAO emissions compliance as well as Stage III noise standards compliance. Noise emissions of the B-52 would be improved markedly. A 1000-foot flyover maneuver would likely carry about a 12 EPNdB reduction with the new engines. This would be approximately half of the current community annoyance per operation. Similarly, the thick black cloud of exhaust that is often associated with the B-52 (see Figure 66) is due to particulate emissions, which would be significantly reduced with re-engining. However, the production of NOx (oxides of nitrogen) would be increased twofold with the modern turbofans. For most of the B-52 base locations, the total impact on local air quality would not be an issue, as the frequency of B-52 usage is low and most bases are removed from urban centers of pollution. In terms of the global impact of emissions, while other cruise effluents will be reduced by 30%, the production of NOx will double. Thus, although the new engines offer reduced fuel-burn and carbon-dioxide emissions, they might be more deleterious overall to the global environment than the current TF-33s. However, this assertion is complicated when considering that fewer tanker sorties will be needed with the new engines and might offset the global impact of additional NOx produced.

9.3.4. Other Considerations

In addition to the performance benefits, the economic assessment and the environmental impact, there are other considerations involved in the re-engining effort. The B-52 is a system and the engines are not a module that can be simply replaced. A listing of the changes foreseen to the entire aircraft is depicted in Figure 67. The B-52 will exchange 8 old TF-33s for 4 modern high-bypass commercial turbofans. The collection of 4 engines will be heavier than the set of 8 TF-33s and produce 9,000 lbs more thrust per pylon (36,000 lbs total). Moreover, the engines would require the addition of about 5,400 lbs to the airframe itself and alter the moment on the wings, especially in the event of a single engine failure at takeoff. This augmented yaw demand scenario might require the installation of an auto-rudder and an auto-throttle to automatically detect the engine failure and automatically adjust the settings on the rudder and the throttle of the remaining engines.

Figure 66. Emissions from the TF-33 Engines on B-52Gs. [24]

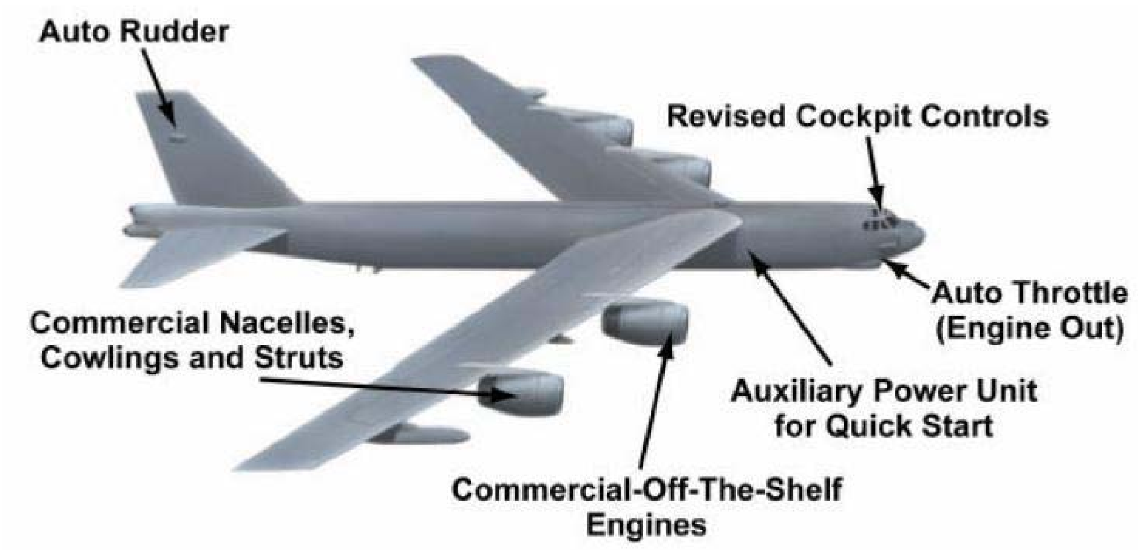


Figure 67. System-level Effects of Re-engining the B-52 [16]

Chapter 10. Conclusion

The previous chapters have discussed the political, economic and technical history of the B-52 Stratofortress. It comes as no surprise that the fame of an aircraft over 50 years old is due to its unmatched success as a military aircraft and the impact it has had on all future bombers. This chapter examines the value that was delivered to the key stakeholders described in Chapter 4, why the B-52 has been such a success and the legacy it has left for future military aircraft.

10.1. Value Delivered to Key Stakeholders

As stated in Chapter 4, the key stakeholders in the B-52 Stratofortress project included the United States Air Force, the Boeing Corporation, Pratt & Whitney and the United States State Department. Each of these groups participated in the B-52 project to gain specific value from the experience. The Boeing Corporation wanted to win the contract for the aircraft that would become the cornerstone of the next generation of long-range bombers. This would cement its position as a leading aircraft manufacturer. In addition, the company would be able to further develop the technology of swept wings (acquired from the Germans after WWII), also helping the Boeing Corporation to maintain is status as a forerunner in innovation. Pratt & Whitney sought to gain technical expertise in developing jet engines by manufacturing a state-of-the-art turbojet engine that met the range requirements of the B-52. Both companies also wanted a close relationship with the US Air Force.

By 1962, 744 B-52 Stratofortresses had been built by the Boeing Corporation, all using Pratt & Whitney engines. The success of the B-52 program, especially in terms of units sold and average lifetime, is representative of the value delivered to both Boeing and Pratt & Whitney, who benefited not only financially, but also competitively. These companies continue to be dominant in the aerospace defense industry where many others have folded or merged. This can be in part contributed to successful programs such as the B-52.

The US Air Force, a newly formed branch of the United States Armed Forces, needed a long-range heavy bomber that would help to separate itself from the Army as well as define its role within the military as a whole. The value expected by the USAF, as a customer, was clearly delivered by the B-52 aircraft. The B-52's use of new technologies in combination with its ability to fulfill the lofty requirements set by its customer, helped to make the USAF a prominent player in containment and deterrence. Clearly, the USAF has continued to find value in the B-52 Stratofortress, because its service record has outlasted any other aircraft, still flying missions for the Air Force all over the world.

Finally, at the time the B-52 was being developed, the United States State Department realized the need for a nuclear deterrent and an enforcer of containment policy. A long-range heavy bomber could accomplish this goal while forcing military activity out of Western Europe and basing bombing missions from within the US. Although there is no quantitative measure of containment or nuclear deterrence, the value delivered to the State Department by the B-52 is quite clear. The B-52 was never used in the capacity for which it was built; it never dropped nuclear munitions in combat (although it did drop nuclear bombs in atomic tests in Pacific atolls). In addition, the aircraft was frequently used in enforcing containment during the Vietnam War.

10.2. The Success of the B-52

One of the questions that arises after studying the B-52 Stratofortress and the wealth of value that has been imparted to its stakeholders is why the B-52 has been so successful. The B-52 has been the longest enduring military aircraft program ever. What features of its design and/or development program ensured this amount of success?

The answer to this question lies in the simplicity of the B-52 design. The requirements for range and payload were extremely aggressive, even by today's standards, and therefore the design of the B-52 was centered on fulfilling these requirements. Because range and payload requirements are the essence of every transport aircraft, the capabilities of the B-52 are still useful to the Air Force today. The Boeing engineers of the 1940s were motivated by the ambitious requirements to use the latest technologies, which included swept wings and turbojet engines. Although these are not drastic technological "leaps forward," they represent a culmination of many small technological advances that raised the bar for future bomber design. Again, these technologies are still seen in aircraft today, and therefore the B-52 has remained a contemporary bomber. Boeing engineers had experience with swept wings and jet engines from the B-47 and B-55. Other bombers, such as the B-1 and B-2 made technology jumps and demonstrations without extensive prior experience.

Success of the B-52 can also be imparted to an absence of political influence in design decisions. The post-WWII economy in combination with the recently discovered hostilities with the USSR ensured full political backing of military decisions. The Air Force was free to construct a bomber that fit their needs without "feature creep" and redesigns due to political interference. Decisions were made by technically capable officers at Wright Patterson Air Force Base and not politicians in Washington, D.C. The unilateral support of the B-52 has ensured its use throughout the second half of this decade, and will continue into the 21st century.

Finally, the end of the Cold War also ended the need for highly advanced bombers such as the B-1 and B-2. Each derivative of the B-52 engendered a new level of cost-efficient upgrades instead of large leaps in technology, such as stealth. In addition, recent conflicts involved nations not as technologically advanced as the US is now or the USSR was. These conflicts have called for heavy bombers, also known as "Bomb Trucks" that can deliver large amounts of conventional munitions to targets without the additional cost of stealth technology. These factors have ensured the B-52's continued use after the fall of the Soviet Union and the end of the Cold War.

10.3. The Legacy of the B-52

The success of the B-52 Stratofortress has imparted its legacy on all aircraft that have followed it. The B-52 configuration of swept wings and jet engines set the standard for all future transport aircraft and many military aircraft. In particular, the B-52 provided Boeing with the jet experience they needed to launch the 707 program, the first commercial jetliner, which set the stage for Boeing's position of dominance as the world's leading aircraft manufacturing company [4]. However, the legacy of the B-52 is not limited to its success in transforming commercial and military aircraft design. The Stratofortress project also has impacted how customers interact with the manufacturing company and how to design innovative, yet cost-effective aircraft.

One of the most important aspects of the B-52 development process was the involvement of the US Air Force early in the conceptual phases of the design of the aircraft. Major General Curtis E. LeMay and Colonel Henry E. "Pete" Warden played an integral role in developing the requirements of the second-generation long-range bomber and pushing innovative solutions by demanding the use of jet engines. The interactions of the Boeing engineers and these Air Force project managers led to a finished product that clearly met the needs of the customer. This type of open communication between aircraft manufacturer and customer has become intrinsic to modern development strategies, such as Systems and Lean Engineering.

As previously mentioned, the culmination of several small technological advancements led to the level of innovation associated with the B-52 Stratofortress. Despite its groundbreaking nature, the B-52 has still remained a highly cost-effective aircraft, as outlined in Chapter 8. There are several factors that contributed to this apparent dichotomy. The success of the B-52 wind tunnel testing program led engineers to perform wind tunnel tests on all future aircraft designs. Although recent emphasis has been placed on computational methods, wind tunnel testing is still used to calibrate the models and validate the numerical results.

Second, the B-52H, which was the last derivative and the aircraft that is still in service today, was built on lessons learned from previous derivatives. Consequently, few mistakes were transferred between aircraft iterations and large technological advancements could be easily incorporated into an updated design. Many later programs that have had multiple derivatives, such as the F/A-18E/F, have followed a similar derivative design approach.

Finally, the B-52 has outlasted other bombers of its era and has outperformed modern military aircraft not because it is technically superior, but because it is a highly cost-effective aircraft. Its low cost, distributed over 51 years of service, combined with high reliability and versatility have placed the B-52 Stratofortress as the number one bomber in the USAF arsenal. The B-52 has the highest rate of mission readiness, over the B-1 and B-2. In addition, the Stratofortress has been adapted numerous times from its original role as a nuclear bomber for various types of warfare in conflicts ranging from Vietnam to Operation Enduring Freedom. The B-52 Stratofortress has demonstrated the viability of creating an aircraft that is both innovative and cost-effective.

In the Introduction of Chapter 1, the following questions were posed concerning the B-52 Stratofortress, namely: what are the secrets behind the success of this aircraft; how could a bomber created over 50 years ago still play an integral role in United States Air Force operations; and what impact has the success of the B-52 had on subsequent bombers and commercial aircraft? This case study has attempted to answer these complex questions by examining the simple strategies employed by the key stakeholders and engineers to achieve an innovative, yet cost-effective product. Hopefully, the readers have gained insight into the answers to these questions and can use the lessons learned on future engineering endeavors.

References

[1] "A Century of Accomplishment: Progeny of the Swept Wing, Boeing's Jet Aircraft." Speech by Holden W. Withington to the Massachusetts Institute of Technology, September 14, 2000.

[2] "B-52 50th Anniversary – Timeline." http://www.boeing.com/defense-space/military/b52-strat/b52_50th/timeline.htm. April 2002.

[3] Gaddis, J. L. *Strategies of Containment*. Oxford: Oxford University Press, 1982.

[4] Boyne, W. *Boeing B-52: A Documentary History*. Jane's Publishing Company Limited, 1981.

[5] Mandeles, M. D. *The Development of the B-52 & Jet Propulsion: A Case Study in Organizational Innovation*. Air University Press, 1998.

[6] Dorr, R. F. and Peacock, L. *B-52 Stratofortress: Boeing's Cold War Warrior*. London: Osprey Publishing, 1995.

[7] Guse, P. "Boeing, U.S. Air Force Celebrate B-52 Stratofortress Golden Anniversary." http://www.boeing.com/news/releases/2002/q2/nr_020412m.htm. April 2002.

[8] Feltus, P., "Air Power: The B-52 Bomber." http://www.centennialofflight.gov/essay/Air_Power/B52/AP37.htm.

[9] Builder, C. H. "Service Identities & Behavior." in Hays, Vallance, & Van Tassel, ed. *American Defense Policy*. Baltimore: The John Hopkins University Press, 1997. 7th ed. pp. 108-121.

[10] Baugher, J. "Boeing B-52 Stratfortress." http://home.att.net/~jbaugher2/b52.html. June 2000.

[11] Conversation with Holden W. Withington. October 8, 2003.

[12] Boeing Aircraft Company. Document No. 10,000. *Preliminary Design Data: Boeing Model 464-49-0*. Seattle, WA, 1948.

[13] Raymer. *D.P. Aircraft Design: A Conceptual Approach*, Reston, VA. AIAA Education Series, 1999.

[14] Abzug, M. J. and Larrabee, E. E. *Airplane Stability and Control*. Cambridge: Cambridge University Press, 1997.

[15] Wetterhahn, R.F. "Death of the Beast: Saying Goodbye to a Trusty Old Cold Warrior." *Air & Space Smithsonian*. Vol. 10. Num. 2. p. 24-31, June/July 1995.

[16] "B-52H Re-Engining." Report to the Under Secretary of Defense by the Defense Science Board Task Force. December, 2002.

[17] Conversation with Holden W. Withington. November 12, 2003.

[18] Boyd, Charles. "Incremental Innovation." http://www.mgt.smsu.edu/mgt487/mgtissue/b52/innovation.htm.

[19] Fishman, C. "Fresh Start 2002: Nonstop Flight." *Fast Company*. Issue 54. January 2002. Page 82. http://www.fastcompany.com/online/54/B52.html.

[20] "ALOR: On Target." http://www.alor.org/Volume2/Vol2No47.htm

[21] Farah, J. "The Economic Costs of Modern War." Veterans For Peace Annual Conference. August 2003. http://www.veteransforpeace.org/The_economic_cost_of_082703.htm.

[22] "B-52 50th Anniversary- Photos." http://www.boeing.com/defense-space/military/b52-strat/b52_50th/images/p12427.htm

[23] "B-52 50th Anniversary- Story." http://www.boeing.com/defense-space/military/b52-strat/b52_50th/story2.htm

[24] "B-52 Stratofortress." http://www.globalsecurity.org/wmd/systems/b-52.htm

[25] "Post-mission maintenance performed on a USAF B-52." http://www.defenselink.mil/photos/Sep1996/960904-F-2352G-007.html

[26] Drendel, Lou. *B-52 Stratofortress in Action*. Carrollton, TX: Squadron / Signal Publications, 1975.

[27] "B-52H Flight Manual: USAF Series Aircraft", Secretary of the Air Force, August 1979, distributed through eflightmanuals.com in pdf format.

[28] Lecture by Alan Haggerty, "Risk analysis and management of uncertainty." November 25, 2003.

[29] Drendel, Lou. Walk Around, *B-52 Stratofortress*. Carrollton, TX: Squadron / Signal Publications, 1996.

[30] "Boeing B-52 Stratofortess" in *Jane's All the World's Aircraft 1952-1953.* Sampson Low, Marston & CO, LTD. London, 1953.

[31] "Pratt and Whitney J57 Turbojet." http://www.wpafb.af.mil/museum/engines/eng54.htm

[32] "B-52 Stratofortress History." Federation of American Scientists. February 1998. http://www.fas.org/nuke/guide/usa/bomber/b-52_hist.htm

[33] "B-52 Stratofortress." http://www.danshistory.com/b52.html

[34] Pike, J. "Bombers and Bomber Weapons." Global Security.org http://www.globalsecurity.org/wmd/systems/bomber.htm

[35] "B-52 Stratofortress Bomber." http://unsd.macrossrpg.com/b52stratofortress.html

[36] http://www.airforce-technology.com/projects/b52/b522.html

[37] http://www.air-and-space.com/strato/9201%20l.jpg

[38] "ASM: Centennial of Flight." http://www.asm-intl.org/Content/NavigationMenu/Magazines/AdvancedMaterialsandProcesses/Centennial_of_Flight/Centennial_of_Flight.htm

[39] Gunston, B. "J57-P Series" in *Jane's-Aero Engines*. Jane's Information Group. 1979.

Appendix A

Table 18. Requirements Iterations and Corresponding Boeing Design Models [5]

Date	Military Requirements/Characteristics	Boeing Proposal
August 1941	▪ 10,000 pound bomb load (Grand Slam configuration bomb) with a range of 10,000 miles (operating radius 5,000 miles) ▪ 72,000 pound bomb load (general purpose, conventional bombs) over shorter range ▪ Speed of 250 to 350 mph at 35,000 feet altitude ▪ Be able to operate from 5,000 ft runways ▪ Minimum crew of 5, an undetermined number of 20-milimeter cannon operators for offensive and defensive armament and a six-man relief crew ▪ Armor protection for the crew, fuel, engines, and other vital components consistent with weight and performance ▪ Reliability, ease of maintenance, reduction in fire hazards, good visibility, quick change features, and simplicity of design	
November 1945	▪ Operating radius of 5,000 miles ▪ Speed of 300 mph at 35,000 feet altitude ▪ Minimum payload of one 10,000 pound bomb, maximum payload of 80,000 pounds of general purpose bombs ▪ Armor production for crew, fuel, engines, and other vital components consistent with weight and performance ▪ Reliability, ease of maintenance, reduction in fire hazards, good visibility, quick change features, and simplicity of design	Model 462: Operating radius of 3,565 miles. ▪ Speed of 440 mph over target. ▪ Payload of 10,000 pounds ▪ Maximum gross weight of 400,000 pounds ▪ Tapered straight wing ▪ Powered by six Wright Aeronautical Corporation XT-35 gas turbine engines combined with propellers Model 462 accepted, but in 1946, air staff decides it doesn't meet range requirement
November 1946 – March 1947	▪ Operating radius of 5,000 miles and reserve of 2,000 miles with one "Fat Man" Mk III bomb ▪ Atomic bomb mission only; maximum payload of 20-30,000 pounds ▪ Tail Armament only; neither all-around protection nor parasite fighter ▪ Minimum crew size ▪ Procure only one wing	Model 464-16: ▪ Tapered straight wing aircraft with 4 turboprop engines ▪ Range of 13,800 miles ▪ Atomic payload only of 10,000 pound bomb ▪ Cruising speed of 420 mph, high speed at target of 440 mph ▪ No armor or defensive fire Model 464-17: ▪ Similar to 464-16, but could carry 90,000 pound conventional bomb load Model 464-17 accepted Improvements proposed in aerodynamics, lead to new Model 464-29 ▪ Cruising speed of 455 mph ▪ Range of 9,000 miles ▪ Max. gross weight of 400,000 pounds

Date	Military Requirements/Characteristics	Boeing Proposal
June 1947	▪ Operating radius of 5,000 miles with one 10,000 pound bomb ▪ Average speed of 420 mph ▪ Tactical operating altitude of 35,000 feet ▪ Service ceiling of 40,000 feet	Matches Model 464-29
October 1947	▪ Range 8,000 miles (radius of ~3,000 miles) ▪ Cruising speed 550 mph and 550+ mph high speed over defended area ▪ Droppable landing gear ▪ Full purging and self-sealing fuel tanks ▪ Minimum crew (pilot, relief pilot, navigator, bombardier, weaponeer, gunner) ▪ Mid-air refueling	
December 1947	SAC proposes: ▪ Speed of 520 mph over 4,000 miles of enemy territory ▪ Range of 8,000 miles ▪ Tail armament only ▪ Payload of 10,000 pound bomb ▪ Maximum gross weight of 280,000 pounds ▪ Turboprop, rather than turbojet (high fuel consumption) Air Staff recommends: ▪ Cancel Model 464-29 ▪ Range of 8,000 miles ▪ Cruising speed of 500 mph ▪ Maximum gross weight less than 300,000 pounds	Boeing's B-52 contract is cancelled, and the design competition is reopened.
1948	Air Staff requirements, March: ▪ Range of 8,000 miles ▪ Tactical operating altitude of 40,000 feet, with 45,000 feet desired ▪ Speed of 500+ mph, with 550 mph desired.	Model 464-35, February ▪ Max. gross weight of 300,000 pounds ▪ Range of about 8,000 miles ▪ Speed of 500 mph over 4,000 miles of enemy territory. Model 464-40, July ▪ Eight turbojet engines ▪ Max. gross weight of 280,000 pounds ▪ Range, with 15,000 pounds payload and high speed run over 4,000 miles of enemy territory, of 6,750 miles ▪ High speed at 35,000 feet altitude in target range of 536 mph ▪ Cruising speed of 483 mph ▪ Service ceiling at target weight of 45,200 pounds Model 464-49, October ▪ Swept-wing, eight turbojet engines ▪ Max. gross weight of 330,000 pounds ▪ Payload of 10,000 pounds ▪ High speed at target of 560 mph ▪ Target altitude of 49,400 feet ▪ Range of 6,750 miles

Date	Military Requirements/Characteristics	Boeing Proposal
Late 1948 – 1951	Air Staff impressed with Model 464-49 B-52 program neared cancellation in 1949-1950 Production decision made, January 1951	

Appendix B

Table 19. B-52 Major Model Differences [4]

Model	Air Force Serial #	Prod. #	Initial Delivery	Recon Cap	Fire Control System	Bomb-Nav Sys	Engines*	Take-off Thrust Wet	Take-off Thrust Dry	Drop Tanks (Gal. Each)	Gross Weight (lbs.)	Operat. Wt. Empty (lbs.)	Fuel Cap (Gal.)	Mil. Load Cap (lbs.)	Un-refueled Radius (nm)
XB-52	49-230	1 prototype	Apr 1953	No	None	None	4-J57-P-8 2-J75	N/A N/A	10200 15000	1000	405,000		38,865		3070
YB-52	49-231	1 prototype	Mar 1953	No	None	None	YJ57-P-3	N/A	8700	1000	405,000		38,865		3070
B-52A	52-011 thru 003	1-3	June 1954	No	A-3A	None	J57-P1W	11000	10000	1000	420,000		37,550	34,000	3110
B-52B	52-004 thru 013 52-8710 thru 8716 53-366 thru 376 53-377 thru 391 53-392 thru 398	4-13 14-20 21-31 32-46 47-53	Sept 1954 June 1955 Aug 1955 Nov 1955 Feb 1956	Yes Yes Yes Yes Yes	A-3A MD-5 MD-5 MD-5 A-3A	MA-6A MA-6A MA-6A MA-6A MA-6A	J57-P-1W J57-P-1WA J57-P-1WB J57-P-29W J57-P-29WA J57-P-19W	11000 11000 11400 12100 12100 12100	10000 10000 10400 10500 10500 10500	1000	450,000	172,285 - 177,832	37,550	63,000	3110
B-52C	53-399 thru 408 54-2664 thru 2688	54-63 64-88	Apr 1956 June 1956	No	A-3A (2688 – MD-9)	AN/ANSQ-48(V) AN/ASB-15 AN/APN-108 MD-1	J57-P-29WA J57-P-19W	12100 12100	10500 10500	3000	450,000	172,637 - 179,390	41,550	64,000	3305
B-52D Seattle B-52D Wichita	55-068 thru 117 56-580 thru 630 55-049 thru 067 55-673 thru 680 56-657 thru 698	89-138 139-189 1-19 20-27 28-69	Oct 1956 Apr 1957 June 1956 Mar 1957 June 1957	No	MD-9	AN/ANSQ-48(V) AN/ASB-15 AN/APN-108 MD-1	J57-P-29W J57-P-19W	12100 12100	10500 10500	3000	450,000	170,126 - 180,811	41,550	64,000	3305
B-52E Seattle B-52E Wichita	56-631 thru 656 57-014 thru 029 56-699 thru 712 57-095 thru 138	190-215 216-231 70-83 84-127	Nov 1957 Feb 1958 Nov 1957 Dec 1957	No	MD-9	AN/ANSQ-38(V) AN/ASB-4A AN/APN-89A MD-1, AJA-1	J57-P-29W J57-P-29WA J57-P-19W	12100 12100 12100	10500 10500 10500	3000	450,000	172,720 - 177,690	41,550	65,000	3320
B-52F Seattle B-52F Wichita	57-030 thru 073 57-139 thru 183	232-275 128-172	May 1958 June 1958	No	MD-9	AN/ANSQ-38(V) AN/ASB-4A AN/APN-89A MD-1, AJA-1	J57-P-43W J57-P-43WA J57-P-43WB	13750 13750 13750	11200 11200 11200	3000	450,000	170,158 - 174,665	41,550	65,000	3345
B-52G	57-6468 thru 6520 58-158 thru 258 59-2564 thru 2602	173-225 226-326 327-365	Oct 1958 July 1959 June 1960	No	ASG-15	AN/ANSQ-38(V) AN/ASB-16 AN/APN-89A MD-1, AJA-1	J57-P-43WB	13750	11200	700 (fixed)	488,000	158,737 - 172,066	47,975	104,900	3785
B-52H	60-001 and on	366 and on	May 1961	No	ASG-21	AN/ANSQ-38(V) AN/ASB-9A AN/APN-89A MD-1, AJN-8 J-4	TF33-P-3	N/A	17000	700 (fixed)	488,000	165,988 - 175,685	47,975 48,030	105,200	4510

* -29W engines have 5,000 #/Hr water rate capability. These engines to be modified to 10,000 #/hr capability, making them -29WA engines.
-19W engines are similar to -29W engines, but have titanium N1 rotors.
-43WA engines have 40,000 #/Hr water rate capability and beefed-up accessory drive gears.
-43WB engines have 40,000 #/Hr water rate capability and beefed-up accessory drive gears, but are "flat-rated" on water.