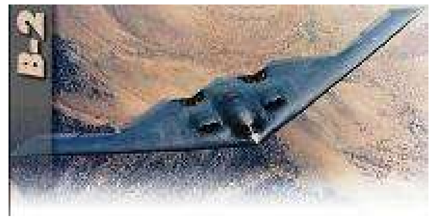
B-2 STEALTH BOMBER STORY

Contributed by Jim Inda, Retired Senior System Engineer



Plane image from the internet.

[1]The Northrop (later Northrop Grumman) B-2 Spirit, also known as the Stealth Bomber, is an American strategic bomber featuring low observable stealth technology designed for penetrating dense anti-aircraft defenses; it is able to deploy both conventional and nuclear weapons. The bomber has a crew of two and can drop up to eighty 500 lb (230 kg)-class JDAM GPS guided bombs, or sixteen 2,400 lb (1,100 kg) B83 nuclear bombs. The B-2 is the only aircraft that can carry large air-to-surface standoff weapons in a stealth configuration.

Development originally started under the "Advanced Technology Bomber" (ATB) project during the Carter administration, and its performance was one of his reasons for the cancellation of the supersonic Rockwell B-1 Lancer. Development continued during the Reagan administration, but worries about delays in its introduction led to the reinstatement of the B-1 program as well. The winding-down of the Cold War in the latter portion of the 1980s dramatically reduced the need for the aircraft, which was designed with the intention of penetrating Soviet airspace and attacking high-value targets. During the late 1980s and 1990s, Congress slashed plans to purchase 132 bombers to 21. In 2008, a B-2 was destroyed in a crash shortly after takeoff, though the crew ejected safely. Twenty B-2s remain in service with the United States Air Force, who plans to operate the B-2 until 2058.

The B-2 is capable of all-altitude attack missions up to 50,000 feet (15,000 m), with a range of more than 6,000 nautical miles (11,000 km) on internal fuel and over 10,000 nautical miles (19,000 km) with one midair refueling. Though originally designed primarily as a nuclear bomber, it was first used in combat dropping conventional ordnance in the Kosovo War in 1999 and saw further service in Iraq and Afghanistan.

What is not known by very many people is that Sperry Univac (later Unisys, Loral and Lockheed Martin) in Eagan, Minnesota made major contributions to the success of this program while at the same time accomplishing some rather amazing computer engineering feats.

Jim Inda, a retired senior system engineer, reports that sometime in the early 1980's a group of Air Force and Northrop Aircraft people came to Univac Plant 8 to set up a meeting. Jim, one of the top system engineers at Sperry Univac with a unique knowledge of nuclear attack resistant hardware, said that in addition to himself, the meeting included Paul Kruelle, his engineering boss at the time, Daryl Kulenkamp from contracts, a Univac Vice-President, and a marketer were the only Univac people

[1] The first three paragraphs on this paper are copied from Wikipedia.

invited to be present at the meeting. The attendees at this meeting were told to sign some papers that indicated they could not disclose anything said at this meeting. This secrecy included everyone and even the wives and families were excluded from any knowledge of these discussions. They were told that if they told anyone what was discussed at this meeting, they would be subjected to fines and possible imprisonment by the federal government.

Naturally the group became very interested in what they had to say. We signed the papers. The Northrop representatives then proceeded to explain that they were designing and proposing to build 132 new technology bombers. Each of the 132 bombers would require 13 General Purpose computers. With spares this would mean our company would sell the Air Force more than 2,000 computers. At $50 K per computer, that would be a sale of at least $100 Million. Were they interested? You betcha, they were interested!

One of the requirements for the computer was that it was required to be nuclear hardened. Nuclear hardened meant it had to have the capability in its design to withstand exposure to the gamma dot pulse from a nuclear weapon explosion detonated nearby. Jim suspects that he was invited to this first meeting at Sperry Univac for the B-2 Program because of his background and knowledge of how to counteract the effects of nuclear radiation on a computer. Up to that time in his career, he had met and had many nuclear hardening discussions with a civilian Air Force research and developer at the Wright-Patterson Air Force Base in Dayton, Ohio. His name is Bob Conklin. Bob had funded a number of studies that had to do with nuclear hardening of computers. Jim is reasonably sure when he was approached by the bomber developers in the Air Force, he would have brought my name up as a specific person at Sperry Univac to be involved with the radiation hardening of airborne computers. As it turned out not only was he knowledgeable in nuclear hardening, but he also had enough experience and a proven track record at Sperry Univac to also be named as project engineer for the B-2 Computer Development Program.

Obviously, to this day, the radiation levels that radiation hardened computers are designed to are still classified. However, if one wanted to estimate what the levels probably are, it is a straightforward exercise. Generally, a good physics book would contain enough information to allow a knowledgeable person to make reasonable estimates. When a nuclear weapon goes off, a number of different bad news environments are generated. Depending on the location of the computer, different parameters could be the primary cause of failure. In the case of a space borne environment, the level of the low energy X-ray exposure is the driving parameter. It can cause severe and near instantaneous overheating of materials used in semiconductors that could in turn cause them to blow themselves apart via the creation of thermal shock waves. In the case of an atmospheric environment, overpressure is the driving requirement for the survivability of an aircraft. An aircraft can only withstand a certain amount of overpressure. Once that level occurs, the wings of the aircraft are damaged or basically are torn off of the aircraft. At ground level, EMP (Electro Magnetic Pulse) exposure to the input/output circuitry would be the driving parameter. Exposure of long lines to strong electric fields will burn out the interface circuits. In a below ground environment, the secondary gamma dot level is normally the failure driver. In the case of the B-2, the maximum overpressure to be withstood is the driver for all the rest of the parameters. Note that the physical shape and design of the B-2 wings are already very hard to overpressure effects.

Another area of concern for a manned aircraft is the total gamma dose and dose rate levels that emanate from a nuclear burst. It turns out that humans are affected at very low total gamma dose levels while the electronics are not affected at this level of gamma dose. Conversely the electronics can be totally affected or even destroyed by minimal gamma dose rate levels, while a human being sitting next to the equipment would hardly even notice the passing of the prompt gamma dot pulse through their body.

Northrop and the Air Force asked us if they were willing to bid on this project, and explain in our proposal how we planned to meet each of their very specific requirements. Naturally the group said yes, and we were off and running. Jim says that this was the beginning of some of the best times of his life as an engineer. The bad news was he could not say a word to his wife or anyone else about working on the project.

In the early 1980's, computer development technology was evolving at an ever-increasing rate. When you proposed to do something technically, you needed to have reasonable assurance that you could actually do it in the proposed time frame of the efforts. To fit a computer into a standard LRU (Line Replaceable Unit) size was a very difficult task. At the time, magnetic core-memory modules were about the only main memory technology available that could be hardened to the required radiation levels. Standard core memory modules were 1.2 inches thick and they needed four modules. At the time, Quadri, a newly formed company from Tempe, Arizona, was making claims for a 0.9-inch thick 6" x 9" memory module, The savings in the thickness of the module would allow us to have a few more Integrated Circuit Printed Circuit modules in the LRU. The use of cache memory architecture would help us meet performance (processing speed) requirements, but it was a brand new and untried technology at the time. The cache memory card also gave us some room for some of the radiation-hardened devices they would need, and also gave us space for Varistors needed to protect the I/O devices from the effects of EMP.

The Mil-Std-1750A Instruction Set Architecture (ISA) logic required for implementing the processor consisted of some bipolar gate arrays UNIVAC had previously developed using IRAD (Independent Research and Development) funding. The gate arrays allowed the processor electronics to fit on two PC (Printed Circuit) cards. The team proposed developing some special MIL-STD-1553B Gate array arrays to implement the 4 redundant 1553 I/O channels that were required. With the newly developed 1750A gate arrays, memories from Quadri, the use of a cache memory, and the use of the 1553 gate arrays, the team was able, we thought, to meet the primary specified requirements, and fit within the LRU maximum size requirements.

It is very difficult for Jim as an engineer to explain how they came up with the total design. The ACU (Airborne Control Unit) was of a complexity that no single individual would know everything about the design. At best, the team of about 20 engineers each individually knew their parts of the design, but no one individual knew it all. The proposed solution the group of engineers came up with was reviewed, and they all agreed they should be able to build it in the time period required. They submitted the bid and won. I believe our only competition was from IBM in Owego, New York. By the way, at Sperry Univac, IBM was always considered as our archenemy. We refereed to their company acronym as the Itsy Bitsy Machine Company.

Because of the tight security requirements, it was difficult if not impossible to discuss technical details over the telephone. Jim and other team members flew to Los Angeles many, many times. Again, because of security requirements they could not physically stay in hotels close to Northrop. They usually ended up staying at an Embassy Suites in Anaheim, California. This was close to Disney land and also close to some excellent restaurants. Early in the program, Northrop used an unnamed innocuous facility located about a mile from the Los Angeles Airport (LAX). Northrop at the time was engaged in a massive hiring program.

One of the funnier stories Jim remembers was how they would walk through the Northrop facility to get to a meeting room. Security has two parameters. The first is having a valid level of clearance appropriate to the material being discussed, and the second is to have a need to know. As they walked through the facility, they were normally in a single file with a Northrop person in the lead and another Northrop person at the end of our group. They had the proper security level clearances, but they did not necessarily have the need to know as they passed through different aircraft design areas. As they walked the lead person would announce in a loud voice: "Un-cleared personnel". This was done to warn the people in that area that un-cleared personnel were coming through their work area. After a while they would say "unclean personnel' and laugh about it. The visitors did feel like they were being treated as lepers in their area. Again after a while as they walked in single file, one or more of them would start to say under their breath, Baaaa, just like a bunch of sheep. Meanwhile people they passed would shut any papers on their desk into folders, put them in a drawer, or cover their computer screen. After a while you did feel as of you were unclean.

In order to perform on the project they had to hire a number of newly graduated electrical and mechanical engineers. What Jim found interesting is that the engineering department would only interview engineers that had greater than 3.5 GPA (Grade Point Average). When he was graduated, he just made a 2.0 GPA and here he was interviewing the cream of the graduating crop. It's funny how some things in life work out.

Jim says his job as Project Engineer was to keep things on schedule, keep within budget, and settle technical differences of opinion in design approaches. One advantage I had was that I was also the technical lead engineer for all of the nuclear hardening aspects of the design. At one point, he thinks he had an engineering staff of about 40 people reporting to him on the project. Jim says he was lucky enough to have access to a large number of very experienced and state of the art leaders in many different design areas that had to be implemented into the computer design. A number of engineers that directly reported to him were state of the art leaders in their specific technical area. Rick Pliml was the leader on MI-STD-1750A CPU (Central Processing Unit), and Daryl Hamlin was the leader on MIL-STD-1553B Serial I/O (Input/Output). Jim says he could probably name another 10 engineers that were tops in their fields at that time, but you get the point on how lucky he felt he was to have a power house of exceptional engineers working on the B-2 ACU development project.

The ACU had some very demanding mechanical and environmental requirements. These were significant cost drivers. They generated a proposal to design and deliver an emulator of the ACU they called the ACUE (Avionics Control Unit Emulator). This computer would be rack mounted, meet commercial environmental conditions, and would run the identical software that was run in the ACU with the exact same results. It would save the Air Force a lot of money for the computers used in the B-2 Aircraft simulator being designed and built by Link. Northrop and Link accepted our approach, so they we were able to design the ACUE meeting commercial requirements rather than the more costly nuclear hardened airborne requirements.

Once we started to deliver prototype ACU's, Northrop started to use them to check out their software designs. Now Northrop had a new problem they had not foreseen. For years, software developers had written their code at what they would call machine level coding. The now hired software developers more experienced in writing code at a much higher level. For example using C and C plus coding techniques. This allowed software to be developed faster, but it created operational programs that required a much larger amount of main memory space to perform the same task. Jim says that the original memory size requirements that Northrop specified to us, were excessively small for the software code being developed by their software engineers.

During that same time frame, integrated circuit manufacturers were starting to come out with memory chips that could contain 2 to 4K bytes of memory on a single device. Now 30 years later, chips can hold gigabytes of memory in one device. Back then, they proposed to change the main memory design from core memories to semiconductor memories. That would increase the main memory capacity by a factor of 4, and it would also increase the processing speed of the CPU twenty to forty percent. Of course, Northrop accepted our offer. Our semiconductor design approach really saved them big time from a near disaster. Of course they had to pay us additional funding for redesigning the ACU to host semiconductor memories.

Jim says that one thing you have to remember is that back in those days, computer technology and in particular available semiconductor memory sizes and types were changing very rapidly. They had to select technical approaches that had a high degree of success during the period they bid to do the job. You cannot deliver technology that is still being designed in somebody's back room. That was the toughest part of computer design in that you could not and should not bite off more then you could chew at that point in time. Jim remembers a few years later when a Northrop engineer claimed Sperry Univac ripped Northrop off by selling them core memory based computers first, and then semiconductor based units later at additional expense. The problem was he did not understand that usable size semiconductor memory chips did not exist when the core-based units were bid.

Once the ACU's were changed to a larger size memory, the ACUE's also had to change to accommodate larger memories. Again to reduce recurring costs, they designed the ACUE to use DRAM (Dynamic Random Access Memory) chips instead of the SRAM (Static Random Access

Memory) used in the ACU. SRAM devices could meet the radiation requirements; DRAM devices could not - DRAM chips are also typically twice the density of SRAM chips and usually half the cost. Therefore their use in the ACUE was a big cost saving for the government.

By far the mechanical vibration requirements were the toughest requirement to meet. The problem actually was created very early in the aircraft design program. The original B-2 requirement was that of a high altitude bomber. At that point in the program some of the ACU's were located aft of the bomb bay doors. Later in the program the flight requirements were changed such that the B-2 had to also fly at high speeds at very low altitudes using terrain following radar. When the bomb bay doors were opened, the ACU's located aft of the doors were subjected to very high shock and vibration levels from the wind coming into the rear of the open doors. At that point in the program, Northrop could not relocate those ACU's. So they could not get a reduction in the vibration requirements. After many months of testing, redesign, and retesting, they finally changed the PC (Printed Circuit) card designs such that the PC cards were screwed down to the back panel. This kept the back panel from flexing which in turn allowed the PC card connectors to continue to make good electrical contact under very severe vibration conditions. A lot of time, money, and energy were spent on resolving how to meet the high vibration requirements.

Until the problem was fixed, Jim had to attend more and more meetings with our CEO (Chief Operating Officer of Sperry Univac DSD. The pressure to resolve the problem was very intense. In the long run, the test and retest efforts paid off in terms of achieving a highly reliable ACU design implementation.

Jim says that one of the advantages of being the Project Engineer was the many times he had to go to meetings in California for the ACU, and to Binghamton, New York for the ACUE. He was in the B-2 Aircraft assembly area at Edwards Air Force Base a number of times. He was able to climb into a B-2 cockpit area and he sat in both the Pilot's seat and the weapons Officer's seat. He was able to closely look into the open bomb bay area, and also got to fly the B-2 Simulator a couple of times at the Link Binghamton, New York facility.

It took a lot of time and effort to pass the very tough combined temperature/vibration requirements. In doing this, the seemingly minor changes they made along the way, greatly improved the overall reliability of the ACU. The original contract requirement of meeting a 300-hour MTBF (Mean Time Between Failure) was easily met, and the last Jim heard the measured MTBF was in the thousands of hours. At this point Jim would like to include the story about the proudest moment that occurred in his life. The reason he wants tell the story at this point is because the story relates to the very high MTBF they were able to achieve for the ACU. By the way, very late in the B-2 Program, the Air Force decided to change the name of the ACU (Airborne Control Unit) to the ACC (Avionics Control Computer). The names and acronyms are interchangeable.

One of the down sides of working on the project was the very tight security requirement on the program. Jim could not tell his wife or family what project he was working on. When Jim's daughters, Diane and Gail, were in their early teens, they hosted a foreign exchange student from

Nicaragua. While Jim was working on the B-2 program, the student's mother tried to make contact with us (Sperry) since their family was on the wrong side of a revolution going on in their country. Because of security requirements, he could not have any contact with any foreign nationals. That could jeopardize his security clearance. Jim was sorry they could not help them, but he did not think it was wise for him to jeopardize a job and a career.

- *EPILOG* –

A STORY ABOUT THE PROUDEST MOMENT IN THE LIFE OF A GREAT COMPUTER ENGINEER – JIM INDA

As each completed B-2 aircraft was sold by Northrop to the Air Force, a naming ceremony was held in the state that the particular aircraft was named after. The transfer of ownership (called a DD250) of the B-2 named "Spirit of New York" was held at an airbase in upstate New York. I was lucky enough to be invited to attend the ceremony. Since I had accrued an enormous amount of frequent flier miles, I was also able to take my wife Babs on the trip with me. They flew out to New York and were able to attend a number of functions and take a number of tours while they were out there. They had a tour of the campus at West Point and learned a lot about its history including the fact that for a period of time General Douglas Macarthur was the Commandant of West Point. They did not know that. By the way, his mother stayed just off campus during his time at West Point to "help her son do good". The evening before the aircraft naming ceremony, we attended a semiformal dinner at the main dining room at West Point. With the long history of West Point, attending a dinner there was simply outstanding. Many of the people that attended the dinner were contractors and their wives or husbands that had supplied some equipment or service on the B-2 aircraft. As a remembrance of the dinner and naming ceremony, both Babs and I received a one once silver B-2 Spirit of New York commemoration coin.

The following day after the banquet, Babs and I drove out to the Air Base and were led to and seated in a VIP (Very Important Person) grandstand area facing a very large hanger. What was fun was the fact that they had really good viewing seats in the grandstand, while there was a host of people behind us standing behind a chain link security fence. They both felt really special, seated along with Generals, Colonels, and other civilian Honchos. The ceremonies started with all the speeches that the various dignitaries normally give. The door of the hanger was opened, and a B-2 aircraft was rolled out for all to see. Naturally as a part of the ceremony, a bottle of champagne was broken on the front of the aircraft. During the ceremony two other B-2 aircraft flew over our grand stand. One flew over at a very low level and then roared away flying virtually straight up. A short time later the second B-2 aircraft flew over in level flight and you could hardly hear it as it flew by. The overall ceremony was fun to watch.

We were invited to a luncheon at the Air Force base cafeteria after the ceremony. At the luncheon we were given a large photograph of the B-2 aircraft. An announcement was made that if we wished, two of the B-2 pilots would autograph the photo for each of us. At first I did not want to wait in the line that formed, but Babs convinced me that as long as they were here, we should get the photo autographed. We got into the line and the wait was short. When we reached the pilot, he asked what I would like to have him write on the photograph. I told him to put down "the ACC's are working fine". He looked up at me and asked, "What is your relationship to the ACC's?" I told him I was the Project Engineer for the design of the ACC's.

He immediately stood up and reached out to shake my hand. He then said, ***"I thank you, my family thanks you, and my crew thanks you. When they fly into harm's way, it's great to have some equipment aboard that they can really count on."*** His complimentary comment just bowled me over. Ever since then, tears of pride come to my eyes whenever I think about his comment.

In talking to him for a little while, he said he was the pilot that was training the other pilots in how to load the OFP's (Operational Flight Programs) into the ACC's before each flight mission. That is why he was very familiar with the ACC's. From his point of view, he confirmed to me the reliability that was being seen in the operational life of the equipment for which I was in charge of the design. I really feel that that moment in time was the proudest moment in my lifetime. Not only that, but it occurred with my wife standing next to me listening to the entire conversation. It doesn't get any better than that. On second thought, I suppose it could have been better if my mother was also standing next to my wife and me.

I really enjoyed working on the B-2 program. It was technically very challenging, I flew in the B-2 simulator twice at Link as they were building the first two B-2 simulators. The simulator was fun because it operated like a big Atari toy. On one occasion, I came in for a landing in the simulator and I sunk into the runway. It was like being in a swimming pool. The engineers at Link had not yet installed the limit switches to prevent flying under the runway.

A number of times I was at the Northrop facility at Edwards Air Force Base. I got to climb into a couple of B-2 aircraft. I got to sit in both the pilot's seat and the weapons officer's seat. The airplane itself is an amazing piece of machinery. It actually contains 132 separate computers. Our 13 General Purpose computers in each aircraft are the largest and highest processing powered units. If you are familiar with the history and evolution of the processing chips used in personal computers, our CPU had roughly the processing power of the 386 vintage chips. Note that the four Mil-Std-1553B channels each had a processing power roughly equivalent to 286 chips.

Thanks to Mike Wold for coordinating this paper – Mike was one of several B-2 program managers at Sperry. His career summary is section 4.7 of http://vipclubmn.org/people7.html. A few excerpts are:
"At the time I came on the program it was still a black program and we lived in a "tank" in the basement. ..It was a small high performance team of talented people. Since the top management was not "read in" to the program they could not come into our space and they could not be told what we were doing. Unisys became a poster child for good performance at Northrop and we won their supplier of the year award. I remember getting calls from program managers of other Northrop subs thanking me and our great mechanicals for proving that the stress scenario was in error. I felt we saved the B-2 program millions of dollars because of our engineering expertise." *LABenson*, editor.