“The SA-2 and SR-71”
By John A. Schell
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On July 4, 1956 a CIA operated airplane departed Wiesbaden West Germany on the first and only U-2 overflight of Moscow. It carried the A-2 camera system. Reconnaissance targets included a Bison bomber plant, an IRCM missile development facility, a research flight test facility, a rocket production facility, and several bomber bases.

We knew in advance that the Soviets had deployed their first surface to air (SAM) network, SA-1, around the capital city. But we lacked specific knowledge on the acquisition radar or the SA-1 missile capability to intercept a U-2 at altitude.

The mission was a huge success. It produced more intelligence in one flight than the CIA interpreters typically saw in a year. The Soviet early warning and acquisition radars did detect the U-2, but no missiles were launched. That was because the missiles were not being stored at the SA-1 launch sites! Also, there was mass confusion at different Soviet echelons on exactly what was happening.

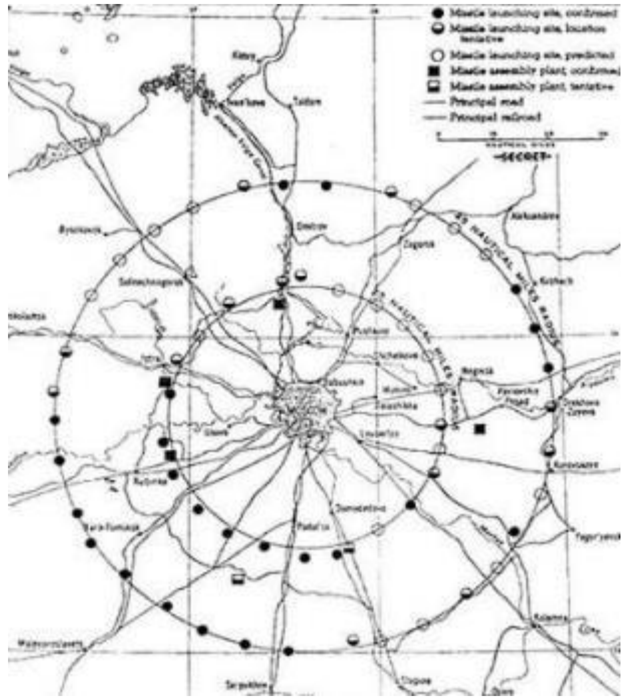

Figure 1 - SA-1 Sites Around Moscow

Figure 2 - SA-1 Missiles on Launch Pads

After three more U-2 overflights on different targets, the Soviets made an official protest to the U.S. embassy. It began “On July 4 of this year at 0818 Moscow time a twin-engine medium-bomber of the USAF appeared from the direction of West Germany and invaded the airspace of the Soviet Union …”[i]. Their radars indeed had tracked the U-2s almost from origin, but the Soviet high command could not believe a single engine plane could get to 65,000 ft altitude. They assumed it was a bomber, which only escalated the tension.

President Eisenhower directed that he must personally approve all future U-2 overflights and that the CIA should immediately commence radar signature reduction of the U-2. According to Eisenhower, the U-2 needed to become “invisible” to radar which prompted the CIA to initiate Project Rainbow in August of 1956. About the same time, the USSR began the development of a SAM with mobile launchers – the SA-2. U-2 radar signature reduction was marginal, and Rainbow was terminated. In January 1958 they initiated Project Gusto to develop a survivable replacement for the U-2. This led to the A-12 and SR-71 airplanes.

The SA-2

The Soviets introduced the SA-2 Guideline (S-75 DVINA) SAM system in December 1957 and began deployment within the USSR in early 1958. They also exported the SA-2 system to China, which, at the time, was an ally.

The SA-2 SAM vastly surpassed the SA-1 in capability. It had mobile erector-launchers; improved early warning radar; a search/track/missile guidance radar; a new missile with a guidance system; and improved operator controls. The Soviets deployed the SA-2 to defend major cities (> 200,000), and critical industrial/military sites. Eventually there were over 1,000 SA-2 missile batteries in the USSR. It became the common air defense weapon for the Soviet Union and Warsaw pact nations. On May 1, 1960, a SA-2 shot down the U-2 flown by Francis Gary Powers; thus, ending all U-2 overflights of the USSR. However, the shootdown over Russia was not the first. Seven months earlier the Chinese used a SA-2 to down an RB-57 over their airspace[ii].

SA-2 system exports to North Vietnam began in 1965. After seven years of operation, the Soviets had made several improvements. Most notably, the Guideline missile could now fly much longer and higher. But the Soviets were only willing to send the early versions which the Chinese already had. They were concerned that the Chinese, who were no longer allies, might sneak across the border and snatch a few of the improved systems. Nonetheless, North Vietnamese received a powerful SAM capability. The missile could reach 88,735 ft altitude with a command guided range of 18.5 nm. The Soviets also sent thousands of troops to man the systems and train the North Vietnamese. Numbers grew to 95 SA-2 SAM sites and 7,500 missiles which were used to effectively defend Hanoi and Haiphong from U.S. bombing. Late in the war (1971), the Soviets exported a SA-2 version that used optical tracking instead of radar tracking. Even with the newer optical tracking systems, radar tracking units remained in use[iii].

At the SAM regiment HQ, the North Vietnamese used the Bar Lock (P-35) radar for aircraft early warning. A regiment would have two or more missile batteries (battalions) in proximity. Bar Lock rotated 360 degrees with multiple simultaneous beams at S-band (2.6-3.1 GHz). It had high power and could detect a small reflection such as a SR-71 nearly 100 nautical miles away. (Assuming clear line of sight and no jamming) Early warning information was sent to a missile battalion for acquisition.

Figure 3 - Bar Lock Radar

At the SAM batteries (launch sites), the North Vietnamese used the Spoon Rest (P-12 Yenisei) radar for target acquisition. They later added the Flat Face and Side Net radars which were more accurate. Spoon Rest had four operator selectable frequency bands near 70MHz. It rotated, providing 360-degree coverage to over 100nmi range. It had two rows of YAGI antennas to provide an estimate of the target elevation. Target elevation was displayed on an elevation display and target azimuth and range was displayed on a PPI (plan position indicator). Target range and bearing information was sent to the SA-2 search radar.

Figure 4 - Spoon Rest Radar

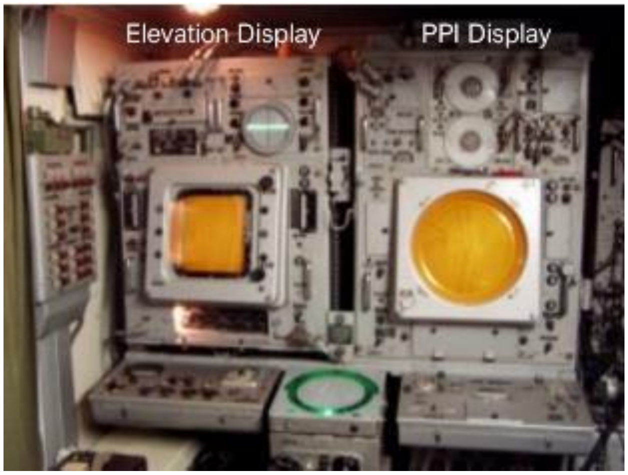

Figure 5 - Spoon Rest Operator's Displays

The SA-2 search radar was the Fan Song (RSNA-75M). It would rotate to the azimuth bearing provided by Spoon Rest. Target detection was provided by two large antennas, which had a folded lens with a rotating feed horn on the end. Its “fan shaped” beams moved back and forth with the rotation of the feed. This type of antenna, known as a Lewis Scanner, had been invented in the U.S. The antenna assembly tilted upward in elevation to center the incoming aircraft. As configured for Vietnam, Fan Song operated near 3GHz frequency (S-Band) and searched (scanned) an area of 20 degrees in both azimuth and elevation.

Figure 6 - Fan Song Radar Used in Vietnam

Figure 7 - Fan Song Operator's Van

Once detected, Fan Song would begin target tracking. For tracking, it increased its center frequency and used a different waveform. Because both the frequency and waveforms were different, the Fan Song scanners could simultaneously perform single target tracking while continuing to scan.

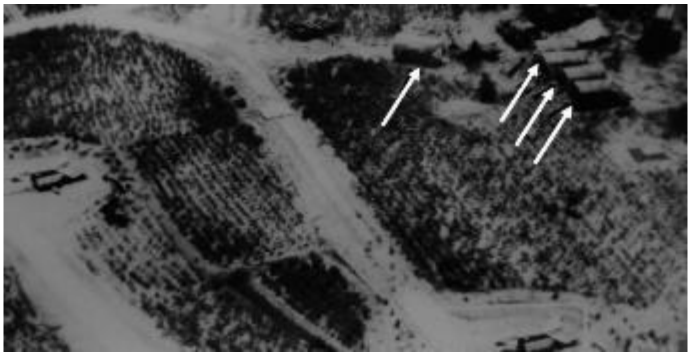

Figure 9 - SA-2 Site with Bamboo Camouflage

Each site had six erector-launchers which could rotate 360 degrees. The Vietnamese learned how to make locating the sites from the air more difficult by using the jungle as camouflage.[iv] Sometimes the missiles were in revetments.[v] The Vietnamese used SA-2 mobility to add an element of surprise.

Figure 8 - SA-2 Site with Revetments

Operators would select an erector launcher and manually issue a launch command. It is reported that up to three missiles could be tracked and controlled by one Fan Song.[vi] Launches were required to be spaced at least five seconds apart. Salvos of one or two missiles were more common during the War.

The Guideline used in Vietnam was a two-stage missile consisting of a 4-5 sec first stage solid fuel burn followed by a second-stage liquid fuel burn. It could achieve a maximum altitude of roughly 88,000 feet flying at Mach 3. It had a proximity fuse, which was manually armed by Fan Song operators for warhead detonation. At 55-63 seconds after launch if the missile did not intercept a target, the warhead would automatically self-destruct.

Figure 10 - Launch from Revetment

Fan Song used a computer to calculate the intercept point and missile guidance commands. The receive antenna for missile guidance was in in the base of the second stage. The proximity fuse used a radio beacon to trigger detonation. Its antennas were two strips in the nose of the missile. The second stage was 1.5 feet in diameter and 35 feet long. Looking out an aircraft window, upcoming Guidelines appeared as “flying telephone poles”. But the guidance system prevented it from turning quickly, and a sharp turn by the pilot was often an effective countermeasure.

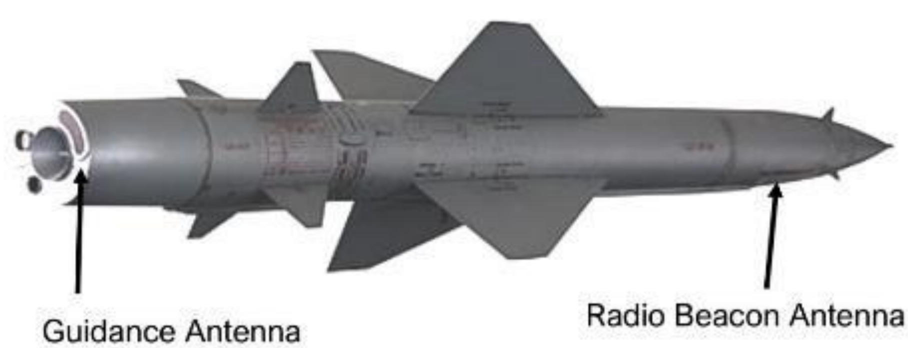

Figure 11 - Guideline Second Stage

The SA-2 system operated as follows.[vii]

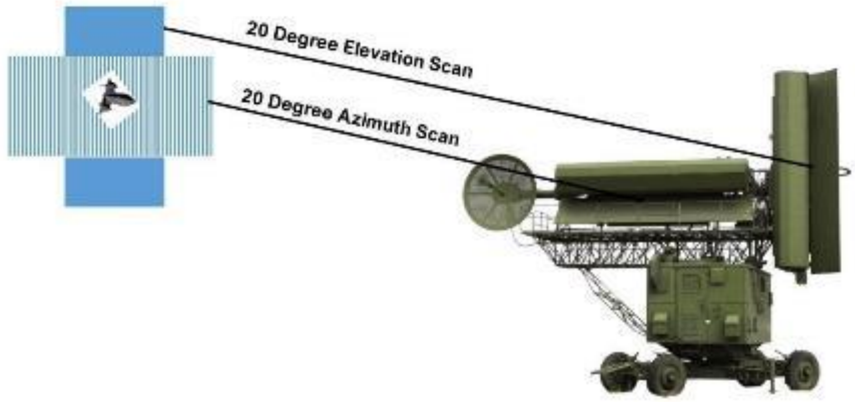

Figure 12 - Target Search with Fan Song

Fan Song rotated and tilted upward toward the incoming aircraft. The two scanners searched an area of sky in elevation and azimuth. Operators could see the range and azimuth/elevation bearing on console displays. Fan Song search had about 450ft range accuracy. Azimuth and elevation accuracy depended on range. At 40 nm range, the 1.1-degree beam width resulted in about 4,400 ft accuracy in azimuth and elevation.

Using the displays, operators would designate the target to initiate tracking. Although manual tracking was possible, automated tracking was commonly used. (The exceptions were Fan Songs using manual optical trackers.) The system's computer determined when intercept conditions were met alerting operators who could then command a launch. After boost stage separation, the second stage emitted a beacon signal which along with target radar return provided the data necessary to compute guidance commands. The Fan Song missile guidance commands were uplinked from the dish antenna.

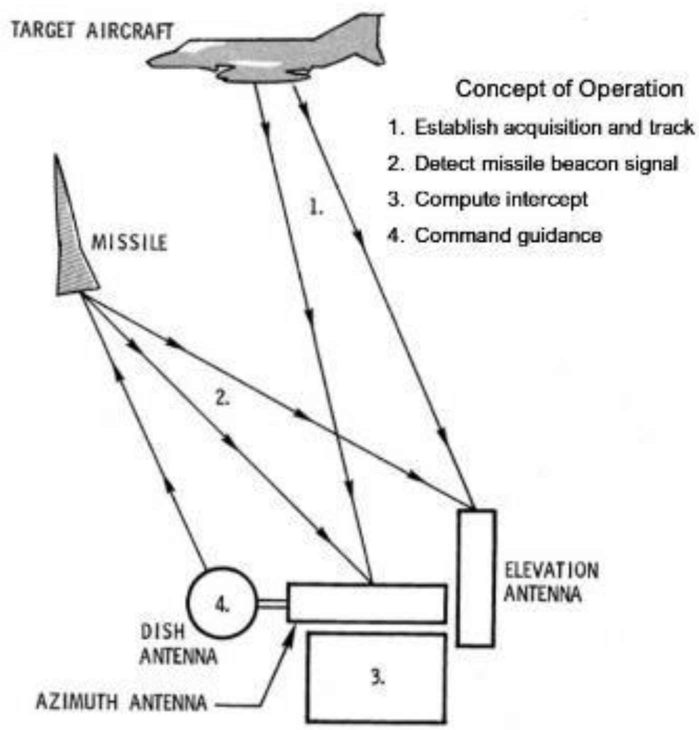

Figure 13 - Concept of Operation

The operators could see the missile, the target, and closure on their radar scopes. As a final step, operators would arm the warhead which had a proximity fuse for detonation.

The lethality distance was about 800 feet at an altitude of 80,000 feet. It decreased to about 200-400 feet at lower altitudes. The armed warhead would self-destruct about a minute after launch.

The SR-71a

On 21 March 1968 at noon local, a SR-71 Blackbird rose from Runway 05 Kadena AB Japan. It was the first operational mission for our nation's premier reconnaissance asset. And one that would take the "Habu"[viii] into the "Mouth of the Dragon." It was to overfly North Vietnam's SA-2 missile sites where it would encounter the Fan Song and Guideline. On board was the Operational Objective Camera (OOC) which would continuously sweep a 72 mi wide area below the aircraft looking for SAM sites. The Habu's Electronic Intelligence (ELINT) receivers would continuously collect radar signals from within a 350 mi radius below the aircraft. Any radiation from SA-2 radars would be recorded. Both the imagery and radar signals received immediate post flight processing and analysis.

Figure 14 - DEF B Receiver

In the rear cockpit was the Reconnaissance Systems Officer (RSO) who monitored the navigation/route progress, sensors, and defensive (DEF) systems operation. The DEF systems provided both threat warning and electronic countermeasures (ECM) to protect the SR-71 from its only known threat at the time, the SA-2. No North Vietnamese MIG interceptor could get high enough or fast enough to launch an air-air missile that could engage the SR-71. Anti-aircraft Artillery (AAA) was completely ineffective at high altitude. SR-71 collections provided unmatched intelligence throughout the Vietnam War. These overflights provided the vital information to maintain threat data bases with current SA-2 locations and operational status.

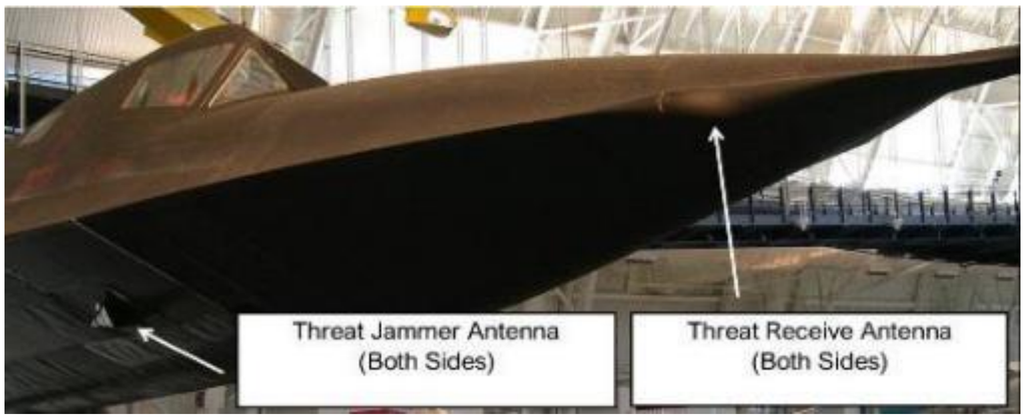

Figure 15 - SR-71 DEF System Antennas

The DEF systems consisted of multiple receivers and jammers. In the early years, DEF B was the SA-2 receiver and DEF G was the jammer. The receivers and jammers used a common set of transmit and receive antennas located on each side which provided forward hemispherical coverage.

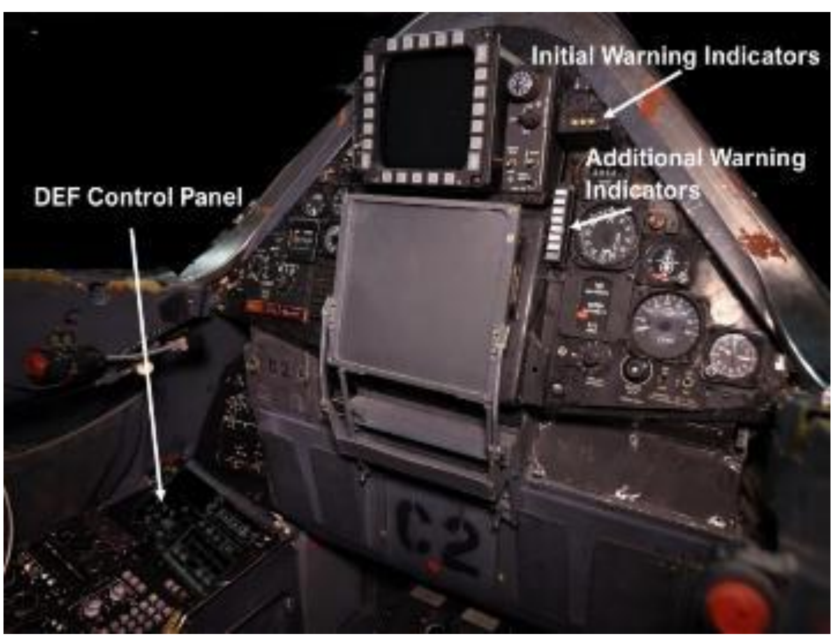

Figure 16 - RSO Cockpit Threat Warning

Only the RSO cockpit contained DEF system warning lights and controls. The initial three threat warning lights were just to the right of the view sight. These lights indicated; 1) right light on - Fan Song was in search mode, 2) middle light on - Fan Song was now tracking, and 3) left light on – a missile launch had occurred.[ix.] Because there were different frequencies and waveforms for search, track, and guidance, DEF B could separately detect each signal and initiate appropriate ECM. For example, noise jamming, range gate deception, and angle deception to disrupt tracking and missile guidance.

The RSO, using the control panel, had limited interaction because DEF systems were primarily automated. After take-off, he would turn on the DEF systems and initiate a Go/No Go test. He would sometimes repeat this test just before entering a hostile area. It was standard operating procedure to abort if the DEF systems tested No Go. Just an added safety measure for an airplane that was built to outfly the threat.

Figure 17 - Universal Defensive Control Panel (UDCP)

As threats changed and grew in number, there were corresponding DEF system changes. The three warning lights grew to ten with the addition seven additional warning lights. With added threat bands, each warning light now instructed the RSO to immediately look down at the Control Panel and possibly make selections. While the waveforms were programmed into the software and response was still automated, there was now increased operator involvement. A highly complex system, but one which was necessary to maintain the safety of the nation's premier reconnaissance airplane.

DEF system hardware and software underwent constant upgrades. Not always, but often, the response to a new or changed threat was developed, tested, and in operation on the SR-71 before the rest of the USAF inventory.

There was nearly zero probability that a SA-2 missile could intercept an SR-71. At the nominal cruise altitude, an increase in speed, the use of ECM, or a slight turn would negate the SA-2.

This chart[x] shows that an SR-71 traveling at Mach 3 and an altitude of 80,000 ft and being tracked at maximum range would prove very difficult for Guideline to intercept. With optimum launch condition, the SR-71 speed does not for allow missile guidance. Guideline would have to intercept within 5-9 nm from the launch on a straight and very lucky shot.

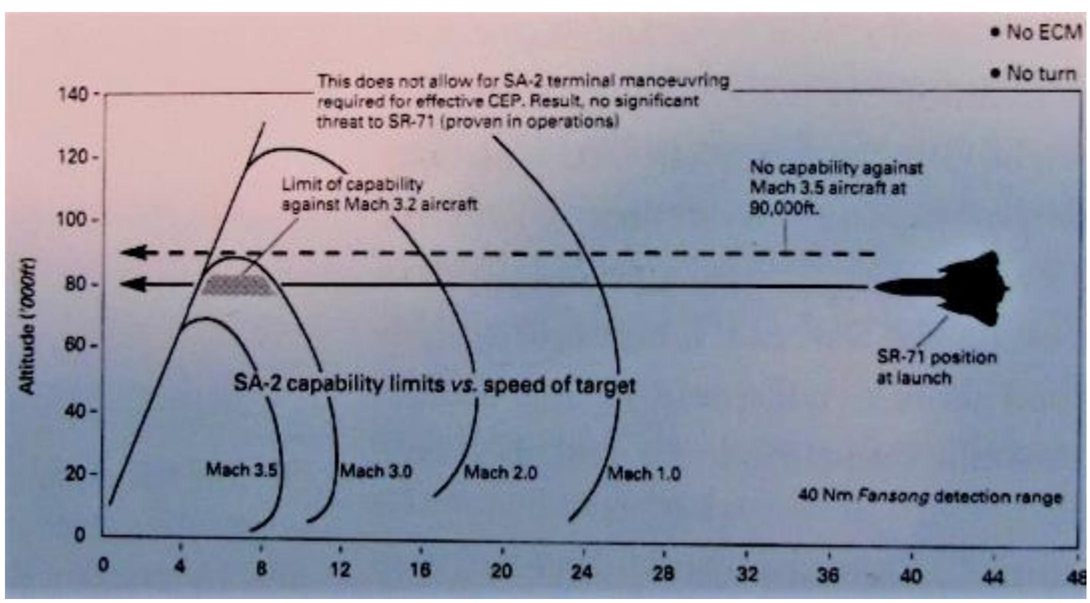

Figure 18 - Effects of Speed and Altitude Against SA-2 Guideline

To overcome even the luckiest of shots, SR-71 pilots were taught to increase speed whenever the DEF systems indicated SA-2 track warning. Crews might also initiate a turn. DEF B would automatically begin jamming the tracking and guidance signals. Any mid-course guidance would slow the missile, allowing the SR-71 to safely overfly.

Prior to flying the Blackbird, many aircrews had flown other aircraft against the SA-2. Their first overflight in the SR-71 often proved extremely stressful. They had Kelly Johnson and his team of engineers and technicians to thank for a magnificent airplane that could avoid the lethality of the SA-2. And sometimes they captured a picture of an off-course missile underneath with the Terrain Objective Camera (TROC) in the belly.

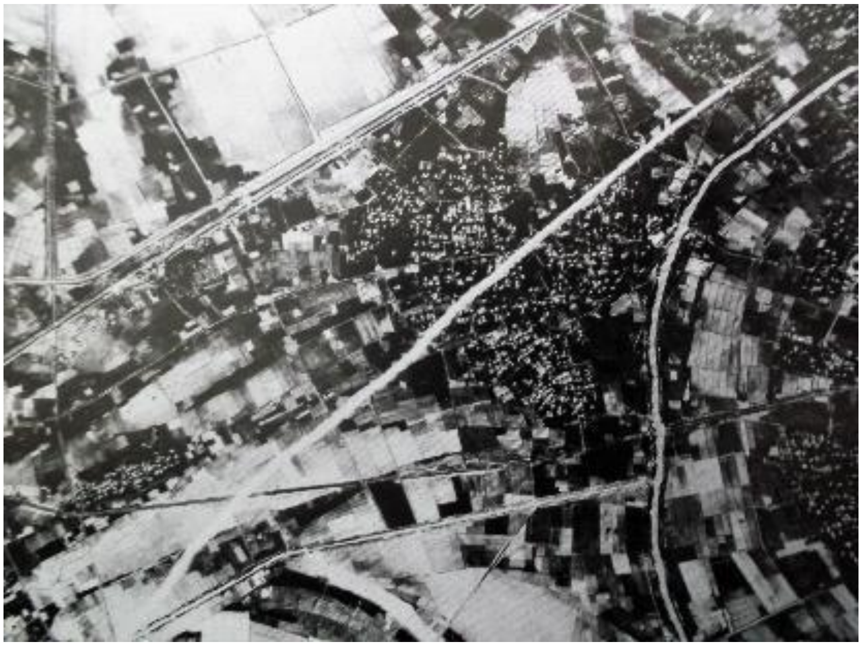

Figure 19 - SA-2 Missile Recorded by TROC

With the extensive air threat – counterthreat, what was the score during the Vietnam War? No one knows. General estimates are a few hundred to zero in favor of the SR-71. It is reported. that both the U.S. and the Soviets inflated SA-2 estimates during the War.[xi] The U.S. estimated a total of 9,000 SA-2 launches. Post war analysis revised the number to about 5,800 launches. The Soviets claimed the SA-2 shot down six times more aircraft than actual. We know for sure none was an SR-71!!

The SA-2 and C-124 – My First Assignment

In April 1970, I entered active duty in the USAF assigned to the Air Force Avionics Lab, Wright Patterson AFB. It introduced me to the SA-2 Fan Song. My boss tasked me on a F-4D radar Quick Reaction Capability (QRC) Project for Vietnam. He figured a young engineer fresh out of college would provide the energy and zeal needed. Thus, I got my “Baptism of Fire” as engineer on the Search and Destroy Radar Attack Modification (SADRAM) Project.

I had Georgia Tech Research Institute (GTRI) engineering support. They had developed a breadboard circuit for locating Fan Song’s unique scanning signature. It exploited retro-reflection from the rotating feed horn at the end of the folded lens antenna. The F-4’s radar signal would enter the scanner and travel to the end. There it received a 16 Hz amplitude modulation as the feed passed by. The now modulated radar signal would be reflected out the scanner and back to the F-4. A neat feature was this could work even if Fan Song was tracking another target. At the F-4, the SADRAM circuit

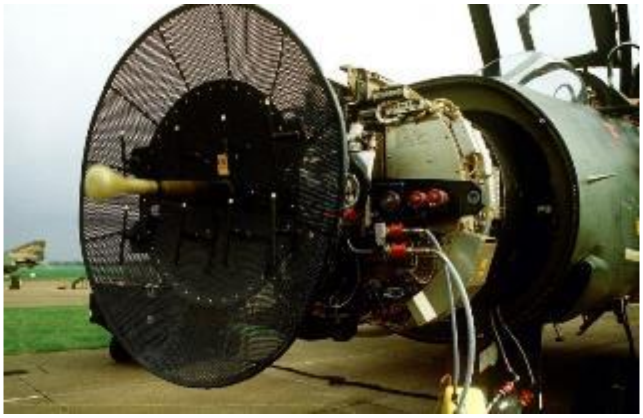

Figure 20 - F-4D Radar

would detect the modulation, produce a tone to alert the pilot, and provide range and bearing on the pilot's display. The objective was a useful range of at least 20 nm from the Fan Song. This required an airborne test.

For the airborne test, we could not use an actual F-4 because the circuit board was not hardened and there was no room for engineers with test equipment. The team searched for a suitable platform and found an Air Force Reserve C-124 unit at Dobbins AFB, GA. The Globemaster navigator station had plenty of room for the test equipment and engineers. And the AFRES Wing was thrilled to support a QRC project for Vietnam.

Figure 21 - C-124 Navigator Station

We used the Eglin AFB Test Range where there was a Fan Song simulator located on Santa Rosa Island—a site which was kept busy testing Wild Weasel improvements. Weasels such as the F-100, F-105, and F-4's routinely screamed in at high speed toward the simulator from the Gulf of Mexico. Now we were about to introduce a lumbering C-124!

My job was to determine the test conditions and pass/fail criteria. We had to determine the range and bearing where this technique would positively identify the Fan Song. And it had to be a strong and continuous signal. If successful, a brass-board circuit would be immediately built and tested in an F-4.

Most of the plan fell into place quickly. Except for the C-124 flight altitude over the Gulf. To avoid radar multipath from the water (which could give false range readings), I calculated that 50 ft altitude should do it. That low had never been done before. After some spirited discussion, the Eglin test range and Dobbins pilots accepted the challenge to fly some very low approaches.

Repeated attempts in the C-124 revealed that the SADRAM technique would never reach the operational stand-off range of 20 nm; and the project was terminated. Fan Song had won – this time.

Figure 22 - That's Not A Weasel!

I was soon re-assigned to a new high-resolution radar research project which eventually took me to work radar on the SR-71. But that's for another story for another time …

Acknowledgements

I'd like to thank those who generously reviewed this paper and supported me in this work.

David Brog (Col. USAF, Ret) provided an excellent review of SA-2 capabilities. During his service, Colonel Brog conducted some of the early SA-2 signal intelligence collection. He later flew the Wild Weasel mission in Vietnam.

Mike Hull (MSgt USAF, Ret) provided outstanding information and materials on the SR-71 defensive systems. During his 27-year career, Mike performed U-2 and SR-71 defensive system maintenance and management.

Joe Matis (SMSgt, USAF, Ret) made skillful edits that greatly improved the readability and enjoyability of this paper. He also conducted additional research on SAM capabilities. During his USAF career, Joe served as an F-106 and F-4 aircraft maintainer.

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At the Air Force Avionics Lab, I supported the SA-2 SADRAM QRC, research on airborne active element phased array radar, spotlight mode radar technology, and spotlight technology transition. Later I became the ASARS lead engineer and Chief Avionics Engineer for the U-2/SR-71. With industry, I supported multiple ISR projects including ASARS fielding, SR-71 program re-start, U-2 rapid targeting system, and RQ-4 Interoperability. Since 2017, I have been retired and a volunteer at the National Museum of the USAF.

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[i] Chris Pocock, "50 Years of the U-2, The Complete Illustrated History of the Dragon Lady" Schiffer Publishing LTD, p 40

[ii] On Oct 7th1959, a SA-2 scored the first destruction of an enemy aircraft by a SAM. It shot down a Taiwanese RB-57D over China at 65,600 ft. It was credited to Chinese fighter aircraft at the time in order to keep the SA-2 program secret from the West.

[iii] Steven J. Zaloga "Red SAM: The SA-2 Guideline Anti-Aircraft Missile". Osprey Publishing, 2007

[iv] Larry Davis "Wild Weasel, The SAM Suppression Study" Squadron/Signal Publications, 1993 p. 7

[v] Tactics and Techniques of Electronic Countermeasures in the Air War Against North Vietnam 1967-1973, Bernard C. Nalty

[vi] Steven J. Zaloga "Red SAM: The SA-2 Guideline Anti-Aircraft Missile". Osprey Publishing, 2007

[vii] Tactics and Techniques of Electronic Countermeasures in the Air War Against North Vietnam 1967-1973, Bernard C. Nalty

[viii] When the SR-71 arrived at Kadena AB, the locals began calling it "Habu" because it reminded them of their local snake, a pit viper. The name stuck and both aircrews and the SR-71 were referred to as "Habu".

[ix] Richard H. Graham, "SR-71 Blackbird, Stories, Tales, and Legends" Zenith Press, 2002, pp 76-77

[x] Paul F. Crickmore, "Lockheed SR-71 Blackbird, Beyond the Secret Missions, Osprey Publishing, 2016, p 196

[xi] Steven J. Zaloga "Red SAM: The SA-2 Guideline Anti-Aircraft Missile". Osprey Publishing, 2007