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A LIMITED CHARACTERIZATION OF THE TERMINATOR POD SYSTEM
(Project Have Terminator)

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FINAL TECHNICAL INFORMATION MEMORANDUM

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14. ABSTRACT

This report documents results of the Terminator Pod System testing. Testing was requested by the 780th Test Squadron, Eglin AFB, FL. The lead developmental test organization was the Air Force Test Center, Edwards AFB, California. The executing test organization was Class 19B of the USAF Test Pilot School, Edwards AFB. Testing was conducted from 9 March 2020 to 17 March 2020 and comprised of 3 sorties totaling 6.5 flight test hours. The overall test objective was to characterize the TM signal range performance and usability of the Terminator Pod System. All test objectives were met.

15. SUBJECT TERMS

Have Terminator, Longshot II, F-15E, Sabreliner, TM, BER, PN15, ARDS, LOS, BLOS, WCS, NetView, Combiners, Antennas, Re-Radiate, SUS, Operator Comments

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EXECUTIVE SUMMARY

This report presents the results for the Have Terminator test management project. Testing was requested by the 780th Test Squadron (780 TS), Eglin AFB, FL. The lead development test organization was the Air Force Test Center, Edwards AFB, CA. Testing was conducted by members of USAF Test Pilot School (TPS) Class 19B (executing test organization) working with the 780 TS. Participating test organizations were the 40th Flight Test Squadron (40 FLTS) and 96th Range Support Squadron. Testing was conducted at Eglin AFB and the Eglin Gulf Test & Training Range (EGTTR) under JON MT19B600. The Terminator Pod System was flown in the EGTTR airspace by a Sunshine Aero Industries T-39 Sabreliner, tail number N265FT. An F-15E, tail number 86-0185, from the 40 FLTS provided a telemetry (TM) source. Three test events were executed between 9 and 17 March 2020. For each event, both aircraft flew simultaneously for approximately 2.2 hours each, for a total of 13 flight test hours. A ground checkout was conducted on 9 March 2020, prior to flight testing.

Weapon testing in the EGTTR was limited by TM signals that required line of sight (LOS) to ground stations located on the Florida Gulf Coast. A TM data stream provided real time parameters, and was often used during weapons testing. The maximum TM signal reception range was inadequate for some types of weapon testing that often required recording and relaying test data to ground stations from Beyond LOS (BLOS). An airborne test control capability might have enabled the execution of test programs that were constrained by LOS between the reception antennas and test assets, such as hypersonic or cruise missiles.

The system under test was the Terminator Pod System, which included the Terminator Pod and three equipment racks within the host aircraft; a Sabreliner business jet was used for this test. The Terminator Pod System was capable of receiving and re-radiating test aircraft and/or weapon TM signals via the Pod antennas. The system included a Flight Termination System (FTS) in the UHF-band; however, the FTS was not evaluated in this test. Because the FTS range was greater than the TM range, and weapon testing only occurred within range of TM reception, FTS signal range performance characterization was not required.

Testing was conducted with an F-15E transmitting a pseudorandom PN15 reference signal, simulating a weapon test asset transmitting TM, to characterize TM signal range performance. The signal was received by the Terminator Pod System onboard the Sabreliner aircraft and re-radiated to the Central Control Facility (CCF) at Eglin AFB. Members of the test team were in the F-15E, Sabreliner, and CCF for the test. The TM signal was analyzed using a signal measure called Bit Error Rate (BER), defined as the number of bit errors per total bits transmitted for a given time period. This was a measure of how much the signal had been altered due to noise, interference, and bit synchronization error. The F-15E and Sabreliner flew ground tracks 5-70 NM apart while the Terminator Pod received and re-radiated data at various geometries and ranges from the F-15E and shoreline. The Terminator Pod TM reception antennas were oriented directionally along the Sabreliner's 9 o'clock position (boresight).

The overall test objective was to characterize the TM signal range performance and usability of the Terminator Pod System. Overall, the Terminator Pod System exceeded predictions for maximum range and azimuth when approximately co-altitude with the TM source, demonstrating a range of 55 NM along boresight and 25 NM at 35° aft of boresight. The TM signal was successfully re-radiated to multiple ground-based receive antennas, the furthest being 97 NM away. WCS interference showed no significant impact on the performance of the Terminator Pod System when flown approximately 40 NM from the shoreline. Use of additional antennas to increase gain did not improve reception as predicted. The Terminator Pod System showed significant potential for test support, providing excellent situational awareness (SA) during test execution when the system was operating correctly. However, SA was often lost due to software and hardware failures requiring resets, which severely affected test efficiency. Additionally, overall utility was reduced due to poor Human Systems Integration (HSI). All test objectives were met; however, range and azimuth performance were only able to be characterized at one elevation.

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1.0 INTRODUCTION

1.1 General

This report presents the results for the Have Terminator test management project. Testing was requested by the 780th Test Squadron (780 TS), Eglin AFB, FL. The lead development test organization was the Air Force Test Center, Edwards AFB, CA. Testing was conducted by members of USAF Test Pilot School (TPS) Class 19B (executing test organization) working with the 780 TS. Participating test organizations were the 40th Flight Test Squadron (40 FLTS) and 96th Range Support Squadron. Testing was conducted at Eglin AFB and the Eglin Gulf Test & Training Range (EGTTR) under JON MT19B600. The Terminator Pod System was flown in the EGTTR airspace by a Sunshine Aero Industries T-39 Sabreliner, tail number N265FT. An F-15E, tail number 86-0185, from the 40 FLTS provided a telemetry (TM) source. Three test events were executed between 9 and 17 March 2020. For each event, both aircraft flew simultaneously for approximately 2.2 hours each, for a total of 13 flight test hours. A ground checkout was conducted on 9 March 2020, prior to flight testing.

1.2 Background

Weapon testing in the EGTTR was limited by TM signals that required line of sight (LOS) from the weapon test asset to ground stations located on the Florida Gulf Coast. A TM data stream provided real time parameters, and was often used during weapons testing. The maximum TM signal range was inadequate for some types of weapon testing that often required recording and relaying test data to ground stations from Beyond LOS (BLOS). An airborne test control capability might have enabled test organizations to execute test programs that were restrained by LOS, such as hypersonic or cruise missiles.

During tests involving actual weapon releases, it was normal to utilize a Flight Termination System (FTS). FTS was a signal independent of TM and was sent by the Range Safety Officer to the weapon in order to terminate the weapon should safety concerns arrive. Due to the FTS signal having a much lower bandwidth and higher power output than a received TM signal, TM was the limiting factor in range, and was the only signal used during this test.

The Terminator Pod System was previously used during the Longshot II test on 20 June 2019 by the 780 TS during the launch of an AGM-158B. For the Longshot II test, range extension was predicted to be 60 nautical miles (NM); however, the maximum range demonstrated during the flight test was only 20 NM due to interference from Wireless Communications Service (WCS) towers (reference 1). WCS filters were installed to remove this interference, which was present during this test. However, these results depended on a JASSM TM data rate of 10 Mbps. Using the updated system and a higher 20 Mbps data rate, which reduced the theoretical maximum range for test efficiency, the Adamy 1-way link equation and manufacturer-provided antenna specifications resulted in a predicted maximum range of 32 NM for this test.

1.2.1 Terminator Pod System

The System Under Test (SUT) was the Terminator Pod System, which included the Terminator Pod and three equipment racks installed inside a host aircraft. The Terminator Pod was a United States Air Force modification of the original United States Navy-designed B22 Mongoose II Pod. The Terminator Pod System included eight fixed-directional, dual-redundant S-band TM receivers that were capable of receiving test aircraft and/or weapon TM signals via the Pod antennas, as seen in Figure 1. Depending on how many antennas were configured to receive a signal, signal combiners (discussed below) were used to increase TM reception range as seen in Figure 3. The Terminator Pod boresight formed by the eight receivers could be oriented either left or right along the aircraft's 3/9 line. This configuration was set on the ground by maintenance and could not be modified airborne. For this test, the Terminator Pod was directionally configured to point left along the host aircraft's 3/9 line. Antenna specifications can be found in Appendix G.

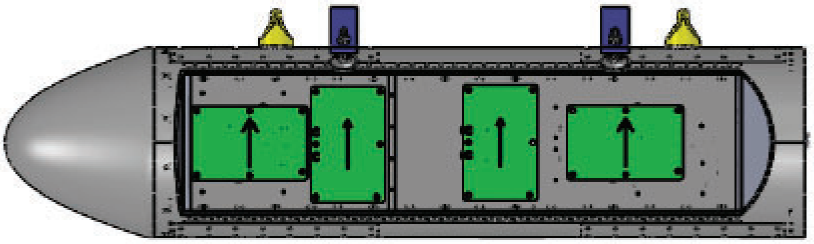


Figure 1 – Terminator Pod with Four Two-Element Azimuth-Array Antennas

The Terminator Pod was mounted to the host aircraft centerline using a pair of 30-inch spaced lug mountings 90° from vertical. Separate omnidirectional antennas mounted to the host aircraft re-radiated the TM signal to a ground station/Central Control Facility (CCF) using an L-band transmitter. By re-radiating TM from a weapon BLOS to a ground station, the Terminator Pod System increased the effective range the ground station could monitor and control weapon testing, provided the Terminator Pod System itself maintained LOS with the ground station (See figure 2 below). Time Space Position Information (TSPI) from the host aircraft's Advanced Range Data System (ARDS) plate was available to provide real-time position information of the host aircraft, TM transmitter aircraft, and the CCF. The ARDS data had an accuracy of 1.5-2.5 meters real-time/unprocessed and less than 0.5 meters post-processed for the host aircraft. Real-time TSPI from the F-15E (the source of the PN15 signal) was also available.

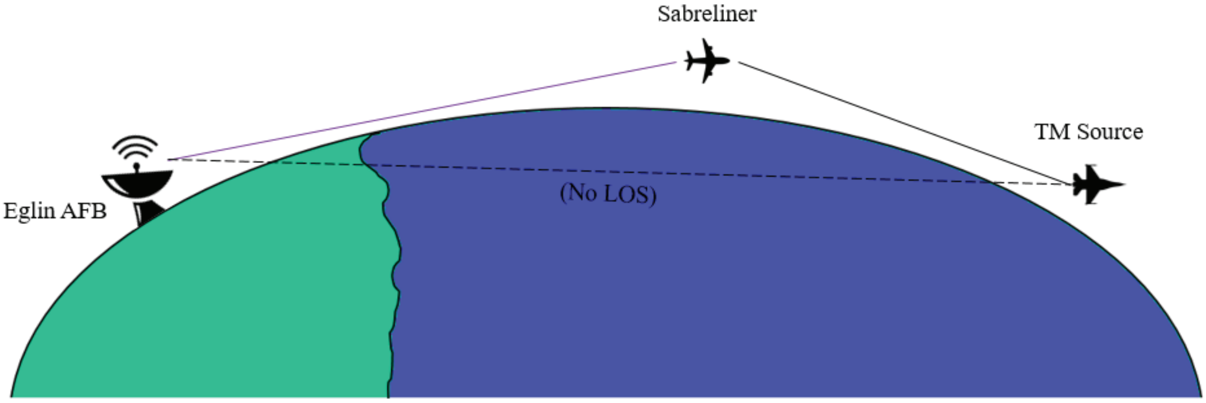


Figure 2 – Sabreliner, positioned within LOS of ground station, re-radiating TM signal from BLOS test aircraft to CCF

The Terminator Pod System also included an FTS in the UHF-band; however, the FTS was not evaluated in this test. Because the FTS range was greater than the TM range, and weapon testing only occurred within range of TM reception, FTS signal range performance characterization was not required.

For this test, PN15 TM transmissions were used as a reference signal to characterize TM signal range performance. PN15 was a repeating 32,767-bit pattern pseudorandom noise S-Band signal intended for error and jitter measurements (reference 2) that could be transmitted by 40 FLTS aircraft, providing a known data pattern highly suited to data analysis. For test analysis, received PN15 data were compared against the reference pattern, as opposed to data recorded from the PN15 source aircraft. The source of the PN15 signal for this test was a 40 FLTS F-15E. Bit Error Rate (BER) was used as a measure of received signal quality. BER was the number of bit errors per total bits transmitted for a given time period, and was a measure of how much the signal was altered due to noise, interference, and/or bit synchronization error. A BER of 1×10^{-6} or less was considered a desirable signal reception quality by the sponsoring agency for this test.

The Terminator Pod System was able to receive multiple TM streams simultaneously by dedicating a fraction of the eight receiving antennas to each signal (e.g. four antennas each for two separate weapon signals). A 3-stage signal combiner, depicted in Figure 3 below, was installed to increase the effective combined antenna gain when multiple antennas were used to receive a given signal. The Stage 1, 2, and 3 combiners could be used to increase the gain of a signal by approximately 3, 6, and 9 dBi, by dedicating 2, 4, or 8 antennas, respectively to a signal. Up to four Stage 1 combiners used a pair of antennas to add 3 dBi of gain to the system. This is shown in Figure 3, where TM receivers (RX) #1-4 each have two antennas, denoted CH1/CH2 in the figure, with a combiner in between them. The combiners from Stage 1 fed into CH1/CH2 of TM RX #5-6 via an intermediate frequency. TM RX #5-6 made up the Stage 2 combiner, which increased gain by 6 dBi. Finally, the combined outputs from the TM RX #5-6 combiners fed into CH1/CH2 of the Stage 3 combiner at TM RX #7 for a total gain increase of 9 dBi. The number of antennas needed for the “Stage n” combiner was given by the value, 2^n. For this test all antennas and combiners were configured to receive the PN15 signal.

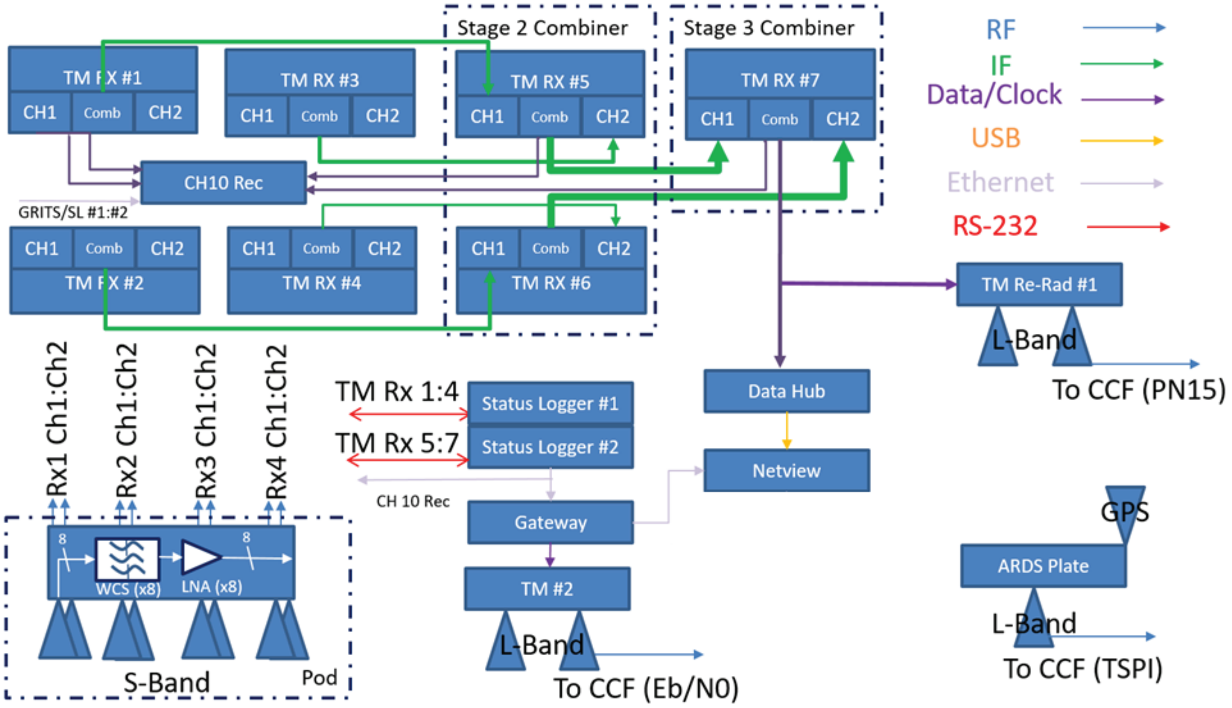


Figure 3 – Terminator Pod Telemetry Configuration

The TM received by the ground station and all the Terminator Pod antennas were saved as Chapter 10 files, which were used by NetView software to calculate BER. Chapter 10 was a common file format and digital recording standard used to provide interoperability for test range TM, flight test instrumentation, mission recorders, and flight operations (reference 3). Table 1 summarizes the signal frequencies and signal power for the Terminator Pod System.

Signal	Frequency	Power
FTS (TX)	425 MHz	200W
Re-rad (TX)	1-1.5 GHz	10W
TM (RX)	2.2 GHz	5W

Table 1 – Terminator Pod System Signal Frequencies and Power

1.2.2 NetView Software

The Terminator Pod System used NetView software (version 2.3.0.4377) to display data to the operator stations on the host aircraft. NetView provided a Graphical User Interface (GUI) that was able to fuse multiple data sources into a coherent overall interactive display to facilitate test execution. This included real-time TM received, Bit Error Rate (BER), and the 3-dimensional position/orientation of all test aircraft within the airspace (see Figure A-2). Importantly, the Terminator Pod System did not require NetView in order to transmit and re-radiate PN15 transmissions, but it greatly enhanced Situational Awareness (SA) by combining the BER information from the Terminator Pod System with a real-time 3-D map of the test assets.

Figure 4 – Terminator Pod System Left and Right Operator Stations in the Sabreliner. Tablets Running NetView are Shown (Left and Right)

Along with the Terminator Pod, three equipment racks completed the Terminator Pod System and were installed internally on the host aircraft. Each equipment rack serviced an operator station where the airborne Test Conductor (TC) monitored TM reception and weapon parameters using the NetView GUI. A PC displayed raw BER form the Terminator Pod System independently of NetView. The data from the equipment racks were displayed on laptops and tablets for the system operators in the back of the host aircraft. Airborne discipline engineers (DE) used NetView running on laptops and tablets for real-time aircraft position and data monitoring. Figure 4 shows the left and right operator stations in the back of the Sabreliner. Interfacing with the tablets and the PC in the equipment rack was achieved using traditional keyboard and mice. The PC was able to display raw BER signals independently of NetView. Interfacing with NetView itself was also achieved using a physical keyboard and mouse for each of the two tablets on board.

1.2.3 Test Aircraft

The Terminator Pod System was integrated with a T-39 Sabreliner host aircraft for this test. The T-39 Sabreliner was a twin-engine, mid-sized business jet developed by North American Aviation. The test aircraft was operated under contract by Sunshine Aero Industries and had been modified to carry a variety of different external stores, including the Terminator Pod. The Terminator Pod was mounted externally to the centerline of the aircraft and the equipment racks were installed in the midsection of the aircraft. The Terminator Pod was analyzed for an approximate gross weight of 100 lbs with a flight limit of 0.8 Mach (reference 4).The Sabreliner had two L-band antennas the Terminator Pod System could use to re-radiate TM; one on the top and one on the bottom of the aircraft, as shown in Figure 5. The aircraft had a service ceiling of 45,000 feet and a maximum speed of 450 knots. It had an endurance of up to 4 hours. The Sabreliner hosted the Terminator Pod System, but was not otherwise evaluated during this test.

Figure 5 – T-39 Sabreliner L-Band Antennas (bottom: top left / top: top right), Terminator Pod (bottom left), and Aircraft (bottom right)

The Sabreliner was operated out of Bob Sikes Airport in Crestview, FL and was operated by two contracted pilots from SAI. Two members of the 96 TW were onboard to assist with any issues with the Terminator Pod System while airborne. Two TPS students were onboard the host aircraft acting in the role of discipline engineers in order to collect data for the usability surveys, but overall test conduct remained with the qualified TC in the CCF.

1.3 Test Objectives

The overall test objective was to characterize the TM signal range performance and usability of the Terminator Pod System. The Specific Test Objectives (STOs) are listed below. All test objectives were met.

1. Demonstrate the TM reception performance of the Terminator Pod System as a function of relative range/azimuth/elevation.
2. Demonstrate TM re-radiation performance from the Terminator Pod System to a ground station.
3. Observe Wireless Communication Service interference on TM reception performance.
4. Demonstrate TM reception performance with additional gain.
5. Observe the Terminator Pod System operator station usability for test support.

All test objectives were met.

1.4 Constraints

Constraint 1: Two scheduled flight test sorties on 18 and 19 March 2020 were cancelled due to the COVID-19 global pandemic. This prevented the planned full characterization of the Terminator Pod System and limited the characterization in this report to range and azimuth performance at only one elevation.

2.0 TEST AND EVALUATION

2.1 General

Testing was conducted with an F-15E transmitting a pseudorandom PN15 test signal to simulate a weapon test asset transmitting TM. The signal was received by the Terminator Pod System onboard the Sabreliner aircraft and re-radiated to the CCF at Eglin AFB. Members of the test team were in the F-15E, Sabreliner, and CCF for the test. The TM signal was analyzed using a signal measure called BER, defined as the number of bit errors per total bits transmitted for a given time period. This was a measure of how much the signal had been altered due to noise, interference, and bit synchronization error. The F-15E and Sabreliner flew ground tracks 5-70 NM apart while the Terminator Pod received and re-radiated data at various geometries and ranges from the F-15E and shoreline. The Terminator Pod TM reception antennas were oriented to receive directionally along the Sabreliner's 9 o'clock position (boresight).

Overall, the Terminator Pod System exceeded predictions for maximum range and azimuth when approximately co-altitude with the TM source, demonstrating a range of 55 NM along boresight and 25 NM at 35° aft of boresight. The TM signal was successfully re-radiated to multiple ground-based receive antennas, the furthest being 97 NM away. WCS interference showed no significant impact on the performance of the Terminator Pod System when flown approximately 40 NM from the shoreline. Use of additional antennas to increase gain did not improve reception as predicted. When functioning, the Terminator Pod System showed significant potential for use during test support, providing excellent SA to the operator during test execution when the system was operating correctly. However, SA was often lost due to software and hardware failures requiring resets, which severely affected test efficiency. All test objectives were met; however, range and azimuth performance were only able to be characterized at one elevation.

2.2 Overall Test Methods and Conditions

The Terminator Pod System was tested in the W-151 airspace of the EGTTR. An F-15E at 12,000 feet MSL transmitted a PN15 signal from its omni-directional upper TM antenna located on top of the aircraft near the right wingroot as shown in Figure 6. PN15 was a repeating 32,767-bit pattern pseudorandom noise S-Band signal that provided a known data pattern. For test analysis, received PN15 data were compared against the reference pattern, as opposed to data recorded from the PN15 source aircraft. The PN15 signal was transmitted at 5W and 20 Mbps. The Terminator Pod was carried beneath the Sabreliner at 15,000 feet MSL and received the F-15E PN15 signal with the Terminator Pod antennas pointed along the Sabreliner's 9 o'clock position. The received PN15 data were re-radiated to the CCF at Eglin AFB via four ground antennas.

Figure 6 - F-15E Upper Antenna

Three types of test run setups were flown: a boresight range run, a constant lateral offset with overtake, and a constant lateral offset at boresight. The boresight range run was flown to demonstrate the maximum range of the Terminator Pod along antenna boresight, along the 9 o'clock level position of the Sabreliner. The F-15E began line-abreast on the left side of the Sabreliner at 5 NM slant range. The F-15E flew a diverging ground track 45° from the Sabreliner ground track while adjusting airspeed to maintain position along antenna boresight. After terminating the test run due to airspace boundaries, the next test run was setup at the slant range observed at the previous run's termination. This process was repeated until the TC observed a BER greater than $1x10^{-6}$ for ten continuous seconds. Then, the F-15E turned back into the Sabreliner for a 45° converging ground track until the TC observed a BER less than $1x10^{-6}$ for ten continuous seconds. A BER of $1x10^{-6}$ or less was considered a desirable signal reception quality by the sponsoring agency for this test.

Four runs were flown with constant lateral offset and overtake to demonstrate the azimuth limits of the Terminator Pod TM reception at different ranges. The Sabreliner established a constant heading and groundspeed at a predetermined waypoint. The F-15E then overflew its corresponding waypoint after a predetermined elapsed time in order to establish the planned lateral offset and azimuth. An example starting setup is depicted below in Figure 7. When BER received at the Terminator Pod was less than $1x10^{-6}$, the fighter held at its starting waypoint until a BER greater than $1x10^{-6}$ was observed by the TC in order to ensure the Terminator Pod limits could be determined. Once BER was greater than $1x10^{-6}$, the F-15E maneuvered to match the Sabreliner ground track with approximately 200 knots of overtake. The overtake maneuver was maintained until airspace boundaries were reached.

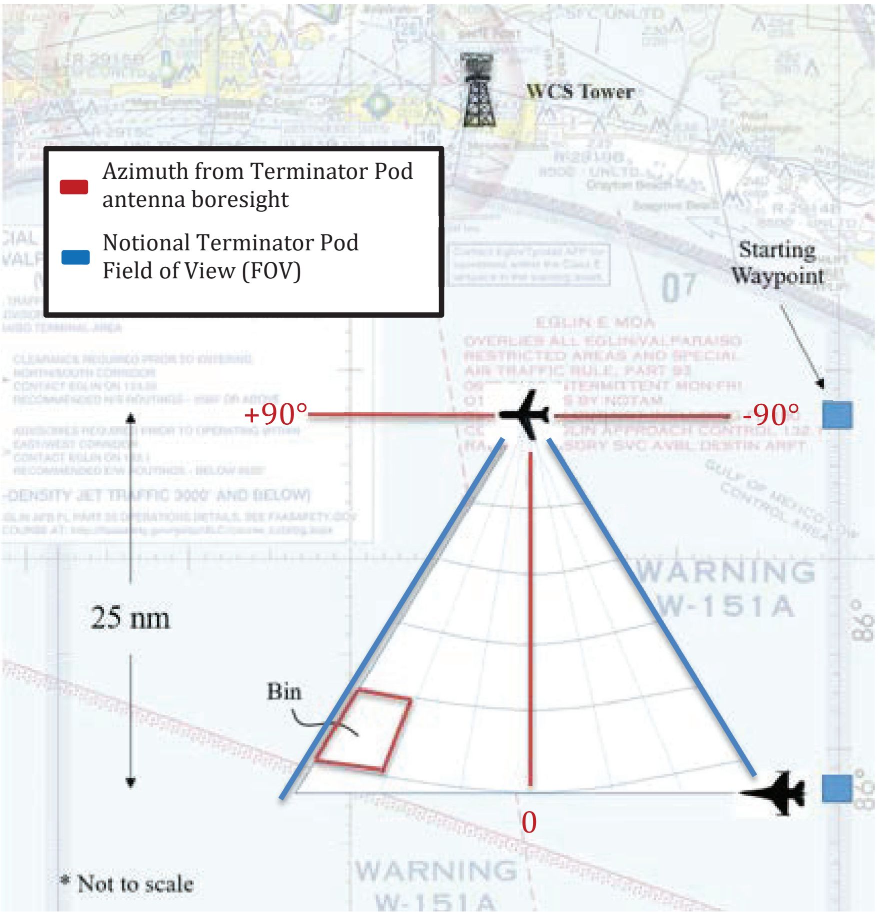


Figure 7 – Test Run Example Overhead View

A single test run was accomplished with constant lateral offset at boresight to observe the WCS interference effects on Terminator Pod TM reception. The Sabreliner was flown approximately 40 NM from the shoreline consisting of four WCS towers with the Terminator Pod antennas facing north toward the shoreline. The F-15E was flown line-abreast along antenna boresight at 20 NM range to the Sabreliner.

All test runs were designed to gather data as a function of relative range, azimuth, and elevation. To present the data in a useful manner to the sponsoring agency, three-dimensional space was divided into "bins" with dimensions of 5 NM deep (slant range), 5° wide in azimuth, and 5° tall in elevation (see Figure 8). The bin dimensions were selected to balance result fidelity and test efficiency.

2.3 TM Reception Performance

The specific test objective was to demonstrate the TM reception performance of the Terminator Pod System as a function of relative range, azimuth, and elevation. Reception from all eight antennas using the Stage 3 combiner (all eight antennas) was used for this objective.

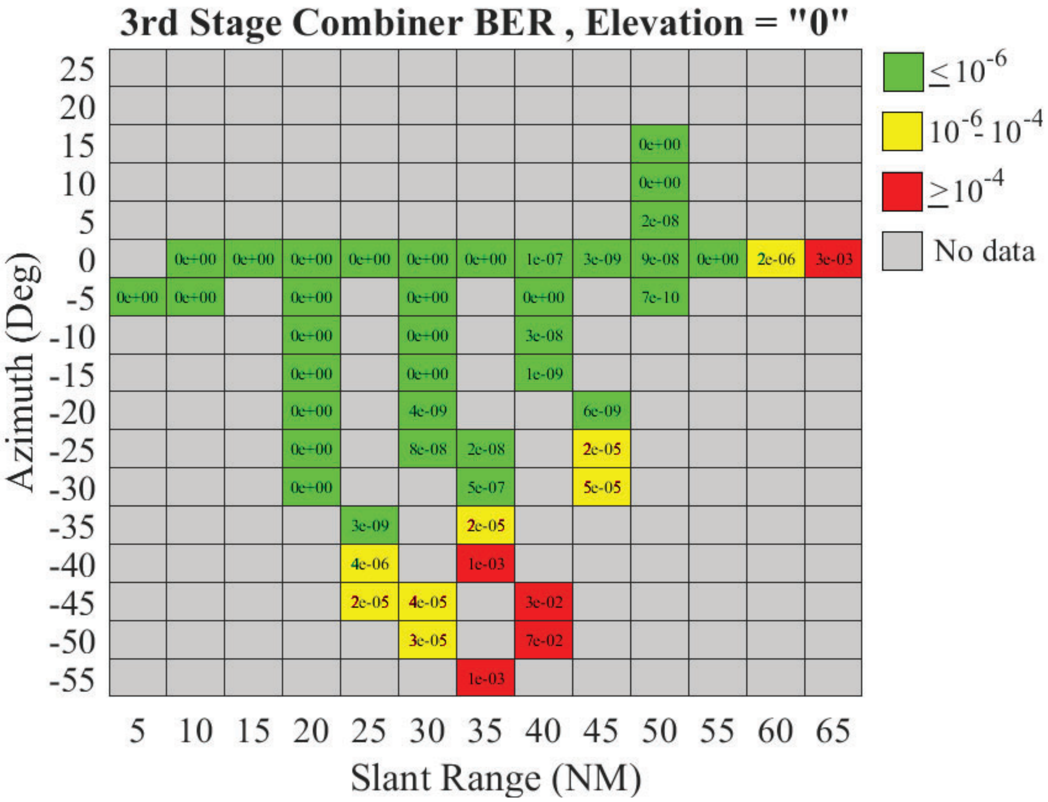
2.3.1 Test Method and Conditions

The data collected during the two max range boresight and four level lateral offset runs were used to evaluate the TM reception performance of the Terminator Pod System using the Stage 3 combiner. The boresight max range runs were accomplished from 5 NM out to 70 NM and the lateral offset runs included the data from runs at 20, 30, 40 and 50 NM. Due to airspace size restrictions, the results primarily show only the aft section through boresight of the antenna beam pattern. Rather than reset test point geometry to fully characterize boresight to the forward azimuth limit for a given range, the test team decided to characterize another aft azimuth limit to boresight beam pattern for a given range. Due to only accomplishing level offset runs during execution, the data were limited to a single 0-5° elevation bin for analysis.

2.3.2 Test Results

The data from all runs were processed through NetView and compiled through a series of MATLAB scripts to calculate the slant range, azimuth, and elevation difference between the Sabreliner and F-15E to build each bin. The bins were then populated with the average BER value based on those geometries. Heat maps were then created to show slant range verse azimuth. The BER heat map color scales are formatted such that green represents BER values less than 1x10^{-6}, yellow represents values between 1x10^{-6} and 1x10^{-4}, and red represents values that are greater than 1x10^{-4}. Values greater than 1x10^{-4} are highlighted not to represent any specific threshold, but to simply represent BERs well beyond the 1x10^{-6} threshold. The detailed analysis and code are documented in Appendix A.

The heat map for the Stage 3 combiner is shown below in Figure 8. The heat map depicts the results from the boresight max range run and the 20, 30, 40, and 50 NM lateral offset runs. Note that data at intermediate ranges is a result of the Terminator Pod receiving TM at that combined offset and azimuth or slant range between the Pod and F-15E. For example, on the 30 NM lateral offset run at -30° azimuth a BER of 5x10^{-7} was observed at 35 NM slant range.



	5	10	15	20	25	30	35	40	45	50	55	60	65
25													
20													
15										0e+00			
10										0e+00			
5										2e-08			
0		0e+00	0e+00	0e+00	0e+00	0e+00	0e+00	1e-07	3e-09	9e-08	0e+00	2e-06	3e-03
-5	0e+00	0e+00		0e+00		0e+00		0e+00		7e-10			
-10				0e+00		0e+00		3e-08					
-15				0e+00		0e+00		1e-09					
-20				0e+00		4e-09			6e-09				
-25				0e+00		8e-08	2e-08		2e-05				
-30				0e+00			5e-07		5e-05				
-35					3e-09		2e-05						
-40					4e-06		1e-03						
-45					2e-05	4e-05		3e-02					
-50						3e-05		7e-02					
-55							1e-03						

Figure 8 – Stage 3 Combiner BER Heat Map, Elevation = “0”

The Stage 3 combiner results shown in Figure 9 show the Terminator Pod System was able to receive the PN15 signal with a BER of 3×10^{-3} within the 65 NM bin, 2×10^{-6} within the 60 NM bin, and 0 within the 55 NM bin when directly off the 0° azimuth or "boresight" region. Although there was no evidence of masking shown when reviewing the raw TSPI data, the majority of the high BER values that skew the 65 NM bin are the last few seconds at the end of the maneuver; however, data were inadequate to provide higher confidence in the Terminator Pod System beyond 60 NM. **Continue testing to refine and improve confidence at the outer edge of the Terminator Pod System receive boundary. (R1)**

Off boresight, the antenna pattern at 25 NM was desirable ($\text{BER} \leq 10^{-6}$) at -35°, narrowed to -30° at 35 NM, and -20° at 45 NM. At 50 NM, the aft azimuth boundary was not characterized due to test setup geometry, but -5° aft to +15° forward azimuth were observed. Due to airspace limits, the forward reception boundary at all ranges was not characterized. **Continue testing to further characterize the forward azimuth and full elevation coverage of the Terminator Pod System. (R2)**

With the eight-antenna configuration using the Stage 3 combiner, the Terminator Pod System provided desirable BER values out to 55 NM along boresight, with gradually increasing azimuth at smaller ranges (up to 25 NM at 35° aft of boresight). The observed ranges and azimuths of desirable BER values far exceeded the 32 NM prediction. The ranges and azimuths of different data rates were unknown. This performance demonstrates a potential to extend the Terminator Pod System's range for weapons testing to 55 NM for data rates of 20 Mbps.

2.4 TM Re-radiation Performance

The specific test objective was to demonstrate TM re-radiation performance from the Terminator Pod System to a ground station.

2.4.1 Test Methods and Conditions

Data were collected while the Sabreliner flew a north to south run in the W-151 range in accordance with the 30 NM lateral offset and overtake test point, explained in Section 2.2 (Overall Test Methods and Conditions). The Sabreliner flew from W-151A5 to W-151C3, approximately 57 and 88 NM from the shoreline, respectively. The test run was designed to observe any re-radiation performance effects as the Sabreliner varied range from the CCF. Figure 9 shows the starting and ending positions of the F-15E and Sabreliner (depicted as a B-52) with respect to the shoreline (top of the image).

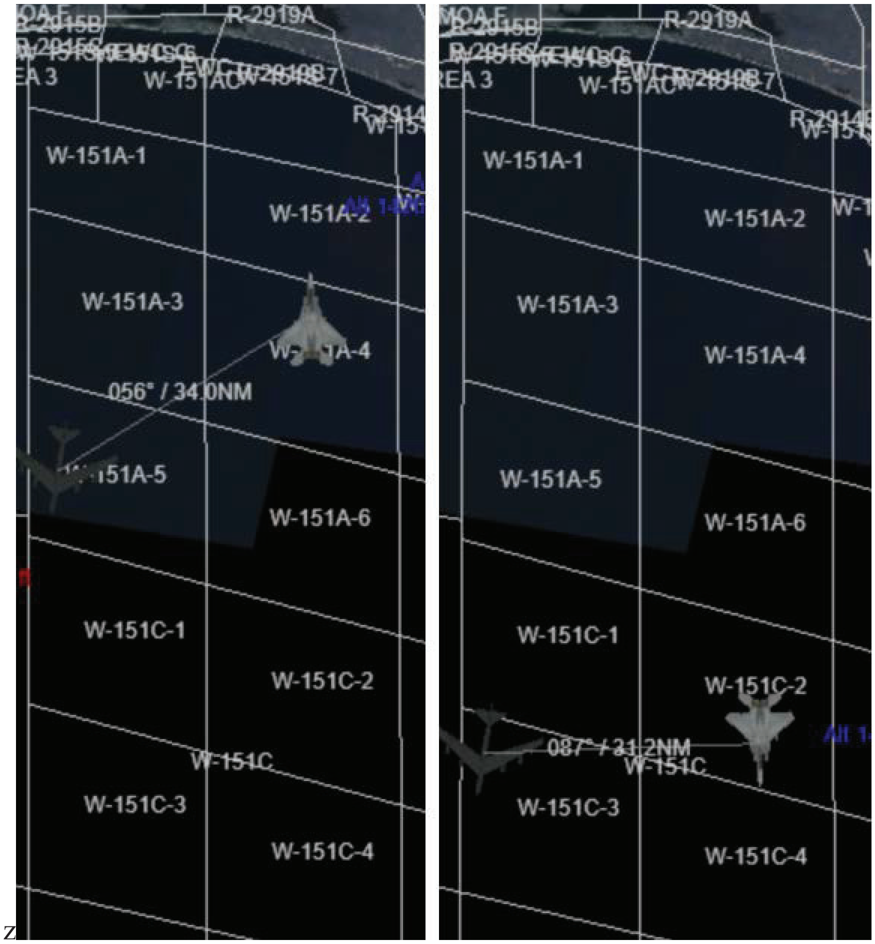


Figure 9 – Start (Left) and End (Right) Positions of the F-15E and Sabreliner Over W-151 for the Re-Radiation Performance Demonstration

The S-band PN15 signal, continuously transmitted from the F-15E, was collected by the Terminator Pod System onboard the Sabreliner and recorded from the Stage 3 combiner as a Chapter 10 file to determine the first set of BERs. The PN15 signal was re-radiated by the Terminator Pod System to the CCF via the Sabreliner's L-band antenna and collected by three ground re-rad tower antennas located around Eglin AFB. Each of the three ground re-rad tower antennas, henceforth known as ground stations, forwarded the PN15 signal it received to the CCF where NetView recorded each signal as individual Chapter 10 files. NetView also generated a unique Chapter 10 file at the CCF based on the lowest BER of the three ground stations to determine the fifth and final set of BERs. The S-band signal received by the Terminator Pod System was compared to the NetView generated L-band signal received by the CCF. Data collection of the PN15 signal used the same methodology as Section 2.3.

2.4.2 Test Results

The Chapter 10 files from the Terminator Pod System and the three ground stations located 7 NM south, 9 NM northwest, and 77 NM southeast of Eglin AFB along the Gulf Coast of Florida were used to calculate the BER for each respective location. Each BER was calculated as the number of bit errors per total bits transmitted over a period of 1 second, and was a measure of how much the signal was altered due to noise, interference, and/or bit synchronization error. The fifth Chapter 10 file, labeled "Best CCF BER", was intended to have a BER that was copied from the ground station with the lowest BER at the moment it was sampled. There were times when the "Best CCF BER" did not record the lowest BER of the ground stations. This demonstrated a delay on the part of NetView on when to switch for the best solution.

Although this fifth signal didn't always have the lowest BER, it allowed for a reasonable comparison of the signals; a bit error recorded by the Terminator Pod System carried over as a bit error recorded by the CCF. The percent change between the Terminator Pod System and the "Best CCF BER" were averaged into 1 NM blocks and is summarized in Figure 10. These data represent performance observed from the single run shown in Figure 9. Additional data is available in Appendix C.

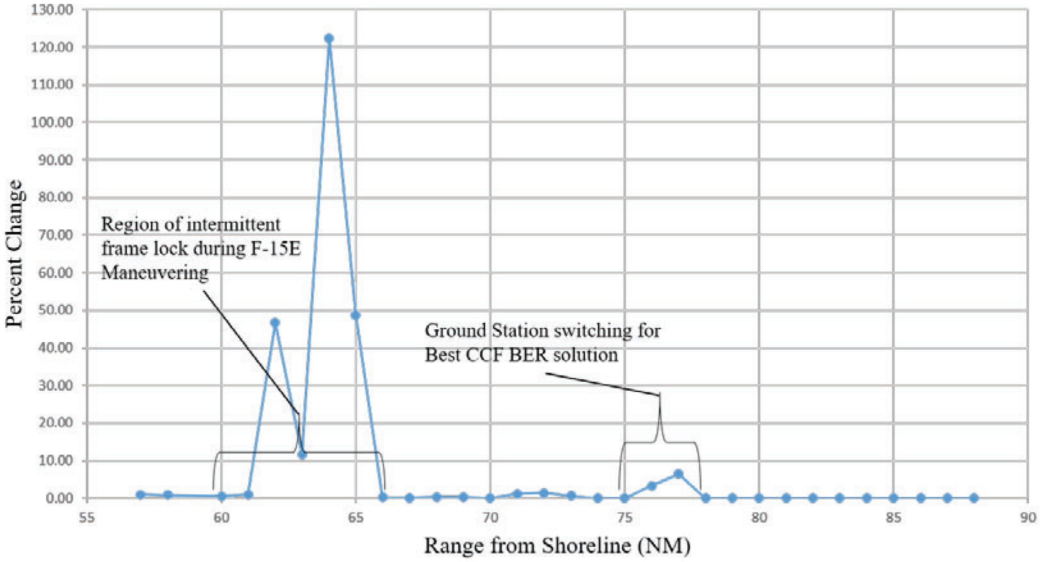


Figure 10 – Re-rad Performance of Terminator Pod System (% change of Terminator Pod BER vs Best CCF BER) as a Function of Range from Shoreline

In Figure 10, a low percent change between the two sources demonstrates low signal degradation in re-radiation. The large change observed from 62-66 NM was due to intermittent "frame lock," defined as signal synchronization between F-15E and Terminator Pod System. During the periods of intermittent frame lock, the ground stations recorded significantly fewer bits, and therefore fewer bit errors, than the Terminator Pod System, causing the large difference in BER. The difference in bits recorded during this time were between 85 and 193 million bits. The Sabreliner was not maneuvering during this period, so very little difference in BER in the L-Band (re-radiated) signal was expected. During this period of intermittent frame lock, the Terminator Pod System did not re-radiate the entire signal it received. With valid frame lock, however, the re-radiation error was very small.

F-15E maneuvering was the primary contributing factor to the intermittent frame lock. Since only the upper PN-15 antenna, rather than both the upper and lower antenna, was used for the test, body masking is a potential reason for the intermittent frame lock. Once the F-15E was on a parallel ground track heading in the same direction as the Sabreliner, valid frame lock was maintained and the re-radiated Best CCF BER started closely matching the Terminator Pod System BER. Consistent BER matching occurred at 66 NM from shore at a rate of 5.3×10^{-3} and generally improved until the run was terminated for airspace. Additionally, an increased percent change was observed in the 76-77 NM range in Figure 10 due to a delay in NetView switching to a better source signal. When comparing the BERs for each ground antenna, two of the three antennas had a very high BER compared to the Terminator Pod System, so NetView recalculated the Best CCF BER from the ground antenna with the lowest BER.

Overall, when the Terminator Pod System had valid frame lock with the F-15E, there was little difference between the PN15 signal received by Terminator Pod System and the re-radiated PN15 signal received by the CCF. The Terminator Pod System re-radiation performance demonstrated a BER of 0 (no bit errors) out to 88 NM from the shoreline and approximately 97 NM from the furthest ground antenna, which demonstrated the potential to the increase the acceptable range from shore for future weapons testing.

2.5 WCS Interference

The specific test objective was to observe Wireless Communication Service interference on TM reception performance. Longshot II showed significant interference from ground based WCS signals which decreased TM reception range. A notch filter was installed in the Terminator Pod System to mitigate that issue and data were collected to observe any remaining interference effects. Reception from all eight antennas using the Stage 3 combiner was used for this objective.

2.5.1 Test Methods and Conditions

Data were collected while the Sabreliner and F-15E flew a parallel west-to-east run over the W-151 range with the Terminator Pod antennas pointed towards the shoreline, as explained in Section 2.2. The Sabreliner and F-15E flew line-abreast and co-altitude at 12,000 feet MSL at a range of approximately 20 NM from each other. Terminator Pod System BER was recorded and compared to the 20 NM constant lateral offset run (which had the antennas pointed away from the shoreline) to determine any potential effects of WCS interference. Data collection of the PN15 signal used the same methodology as Section 2.3. Figure 11 shows the starting positions of the F-15E and Sabreliner relative to the shoreline. The red "AB Tower" depicted is an example of a known shoreline WCS tower.

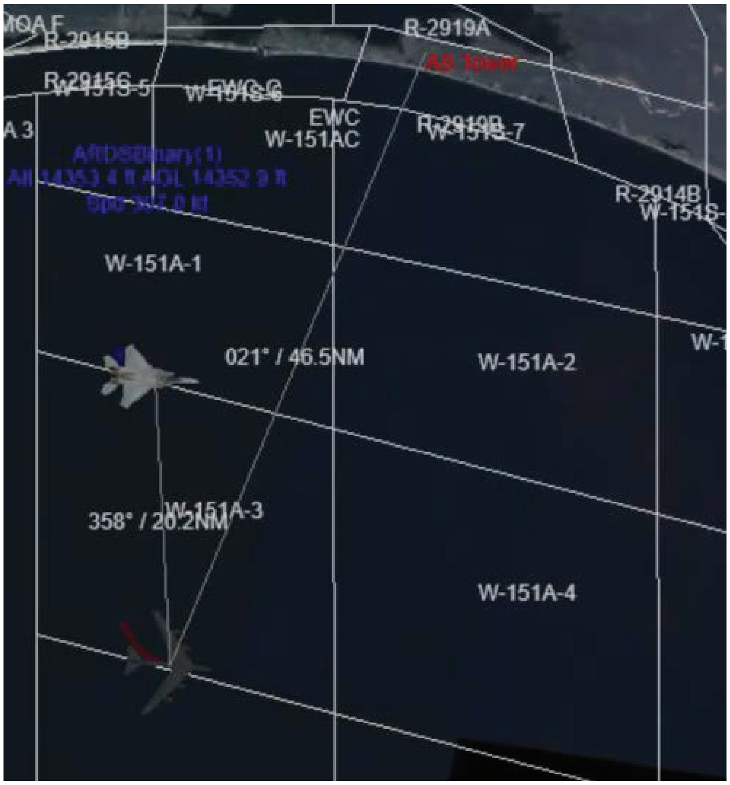


Figure 11 – Starting Positions of the F-15E and Sabreliner over W-151 for WCS Interference Observation

The 20 NM constant lateral offset run, presented in Section 2.2, was used for comparison because the Terminator Pod was not pointed towards any WCS source. Although the F-15E flew with 200 knots of overtake to characterize the shape of the antenna's main lobe, only data from similar azimuths as the WCS run were used.

2.5.2 Test Results

During the WCS run, the F-15E maintained an azimuth between 0 and 3° aft of boresight of the Terminator Pod. The Terminator Pod System maintained frame lock during the entirety of the run. Range between aircraft and BER for each azimuth are summarized in Table 2 for the WCS run.

Azimuth (deg)	Range (NM)	BER
0	19.9	0
-1	19.9	1.52×10^{-9}
-2	20.1	1.18×10^{-9}
-3	20.3	1.7×10^{-9}

Table 2 – Terminator Pod System BER While Pointed Towards WCS Sources

In Table 2, a BER of 0 represented a perfect transmission with no bit errors. The average BER was 1.1×10^{-9}, well below the desired 1×10^{-6} BER, which demonstrated desired transmissions.

Similar data were collected for the same lateral offset range while the Terminator Pod faced away from the shoreline. Data were collected from 0 to 55° aft of boresight due to the F-15E overtake maneuver. However, only the same azimuths, 0 to 3° aft of boresight, were used for comparison to the WCS data. Less data at each azimuth were collected since there was less time for the F-15E to transmit the PN15 signal before advancing. Results for the 20 NM constant lateral offset run are summarized in Table 3.

Azimuth (deg)	Range (NM)	BER
0	18.0	0
-1	18.1	0
-2	18.1	0
-3	18.1	0

Table 3 – Terminator Pod System BER While Pointed Away From WCS Sources

The BER of zero observed at all four azimuths was expected since no WCS sources were in the antenna field of view. When comparing the results from both runs, the BER showed no significant impact of WCS interference on PN15 reception performance.

2.6 TM Reception Performance with Additional Gain

The specific test objective was to demonstrate TM reception performance with additional gain. The Stage 2 combiner (with four antennas) was compared to the Stage 3 combiner which combined the signal from all eight antennas.

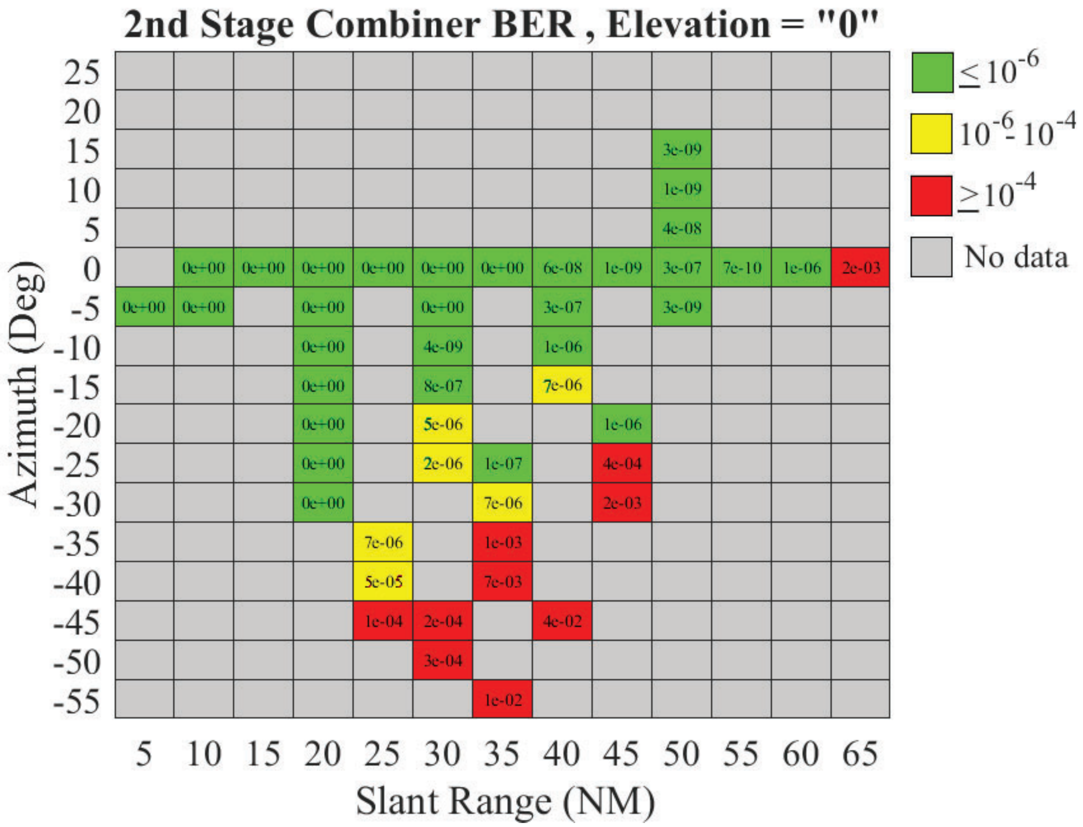
2.6.1 Test Method and Conditions

The data collected during the two max range boresight and four level lateral offset runs were used to evaluate the TM reception performance of the Terminator Pod System using the Stage 2 and 3 combiners. The data from each combiner were collected simultaneously during each test run. The max range runs were accomplished from 5 NM out to 70 NM and the lateral offset runs included the data sets at 20, 30, 40 and 50 NM.

2.6.2 Test Results

The data from all the runs were processed using the same techniques from section 2.3, except the aft Stage 2 combiner was used as the BER source. The detailed analysis and code are located in Appendix A. The Stage 2 combiner heat map in Figure 12 shows the Terminator Pod System was able to receive the PN15 signal with a BER of $2x10^{-3}$ within the 65 NM bin, $1x10^{-6}$ within the 60 NM bin, and $7x10^{-10}$ within the 55 NM bin when directly off of the 0° azimuth or "boresight" region. The majority of the high BER values within the 65 NM bin were during the last few seconds of the maneuver which resulted in the $2x10^{-3}$ BER. These Stage 2 combiner values along boresight showed a higher BER when compared to the Stage 3 combiner, although both were still well within the desirable threshold.

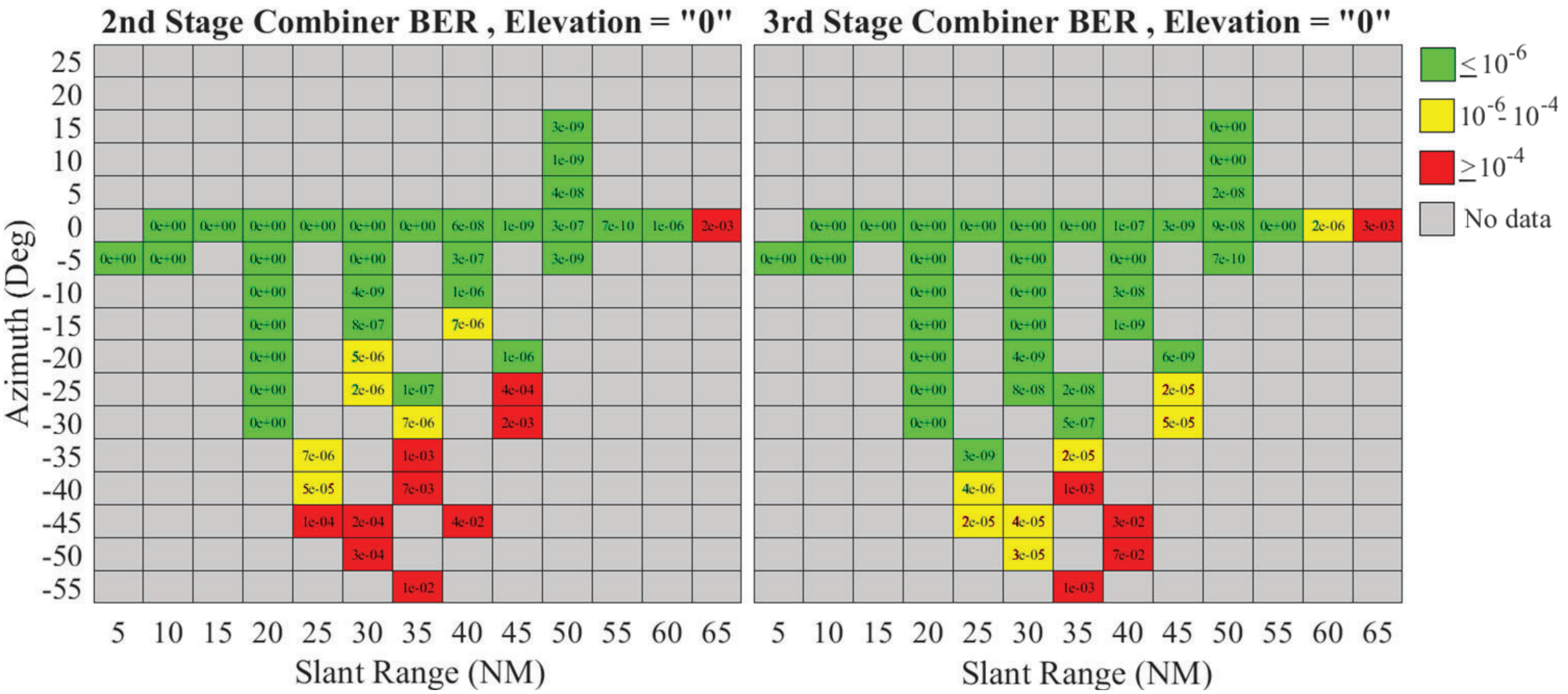
The antenna pattern at 20 NM resulted in desirable BER at -30° from boresight and narrowed to -25° at 35 NM, -20° at 45 NM, and 15° at 50 NM. Compared to the Stage 3 combiner results, the Stage 2 desirable BER region was narrower by approximately 5° azimuth at the smaller ranges but matched the desirable BER regions at 45 NM and beyond. As discussed in section 2.3.2, due to airspace limits, the forward reception boundary was not characterized.



Azimuth (Deg)	5	10	15	20	25	30	35	40	45	50	55	60	65
25													
20													
15										3e-09			
10										1e-09			
5										4e-08			
0		0e+00	0e+00	0e+00	0e+00	0e+00	0e+00	6e-08	1e-09	3e-07	7e-10	1e-06	2e-03
-5	0e+00	0e+00		0e+00		0e+00		3e-07		3e-09			
-10				0e+00		4e-09		1e-06					
-15				0e+00		8e-07		7e-06					
-20				0e+00		5e-06			1e-06				
-25				0e+00		2e-06	1e-07		4e-04				
-30				0e+00			7e-06		2e-03				
-35					7e-06		1e-03						
-40					5e-05		7e-03						
-45					1e-04	2e-04		4e-02					
-50						3e-04							
-55							1e-02						

Figure 12 – Stage 2 Combiner BER, Elevation = "0 Degrees"

While the Stage 2 BER was reduced in off boresight azimuth relative to the Stage 3 BER, the boresight BER was still within the desirable regions, matching or exceeding the measured BER for the Stage 3 combiner. With the four-antenna configuration using the Stage 2 combiner, the Terminator Pod System provided desirable BER values out to 60 NM along boresight and out to 20 NM at 30° aft of boresight. Overall, use of additional antennas to increase gain did not extend reception range as predicted. The only demonstrable improvements of Stage 3 over Stage 2 were an additional 5° of azimuth coverage at 25 NM and 35 NM. For future test missions that require two data streams (4 antennas/one Stage 2 combiner per stream) the Terminator Pod System demonstrates the potential to still provide adequate margin in range and azimuth for test setup and execution when using the Stage 2 combiners. Both Stage 2 and Stage 3 combiner heat maps are shown side by side in Figure 13 below for visual comparison.



2nd Stage Combiner BER , Elevation = "0"

Azimuth (Deg)	5	10	15	20	25	30	35	40	45	50	55	60	65
25													
20													
15										3e-09			
10										1e-09			
5										4e-08			
0		0e+00	0e+00	0e+00	0e+00	0e+00	0e+00	6e-08	1e-09	3e-07	7e-10	1e-06	2e-03
-5	0e+00	0e+00		0e+00		0e+00		3e-07		3e-09			
-10				0e+00		4e-09		1e-06					
-15				0e+00		8e-07		7e-06					
-20				0e+00		5e-06			1e-06				
-25				0e+00		2e-06	1e-07		4e-04				
-30				0e+00			7e-06		2e-03				
-35					7e-06		1e-03						
-40					5e-05		7e-03						
-45					1e-04	2e-04		4e-02					
-50						3e-04							
-55							1e-02						

Slant Range (NM)

3rd Stage Combiner BER , Elevation = "0"

Azimuth (Deg)	5	10	15	20	25	30	35	40	45	50	55	60	65
25													
20													
15										0e+00			
10										0e+00			
5										2e-08			
0		0e+00	0e+00	0e+00	0e+00	0e+00	0e+00	1e-07	3e-09	9e-08	0e+00	2e-06	3e-03
-5	0e+00	0e+00		0e+00		0e+00		0e+00		7e-10			
-10				0e+00		0e+00		3e-08					
-15				0e+00		0e+00		1e-09					
-20				0e+00		4e-09			6e-09				
-25				0e+00		8e-08	2e-08		2e-05				
-30				0e+00			5e-07		5e-05				
-35					3e-09		2e-05						
-40					4e-06		1e-03						
-45					2e-05	4e-05		3e-02					
-50						3e-05		7e-02					
-55							1e-03						

Slant Range (NM)

🟩 $\leq 10^{-6}$
🟨 10^{-6}- 10^{-4}
🟥 $\geq 10^{-4}$
⬜ No data

Figure 13 – Stage 2 and Stage 3 Combiner BER Comparison

2.7 Operator Station Usability

The specific objective was to observe the Terminator Pod System operator station usability for test support.

2.7.1 Test Method and Conditions

Two TPS students flew onboard the Sabreliner host aircraft to interface with the Terminator Pod System during test execution. This allowed observations to be made regarding the operator station's usability for test support. The observations from each flight were recorded in a survey packet. Page 2 of the survey packet recorded comments on the operator station usability and page 3 recorded the ratings from the System Usability Survey (SUS) (reference 5). Overall test safety was provided by a qualified TC in the CCF during test execution. The left-hand operator station is show below in Figure 15.

Figure 14 – Left-Hand Operator Station. Two Keyboards (Center and Left), Two Mice (Bottom Right) and the PC Screen (Center) are Shown. Tablets Not Shown

In addition to the left-hand operator station shown in Figure 15, the Terminator Pod System was fitted with two portable tablets running NetView software. This provided each discipline engineer with their own NetView tablet, mouse and keyboard during the test, which was the primary method of interfacing with the Terminator Pod System.

2.7.2 Test Results

To evaluate the system, operator comments were collected and fell into two main categories: Human Systems Integration (HSI) and software.

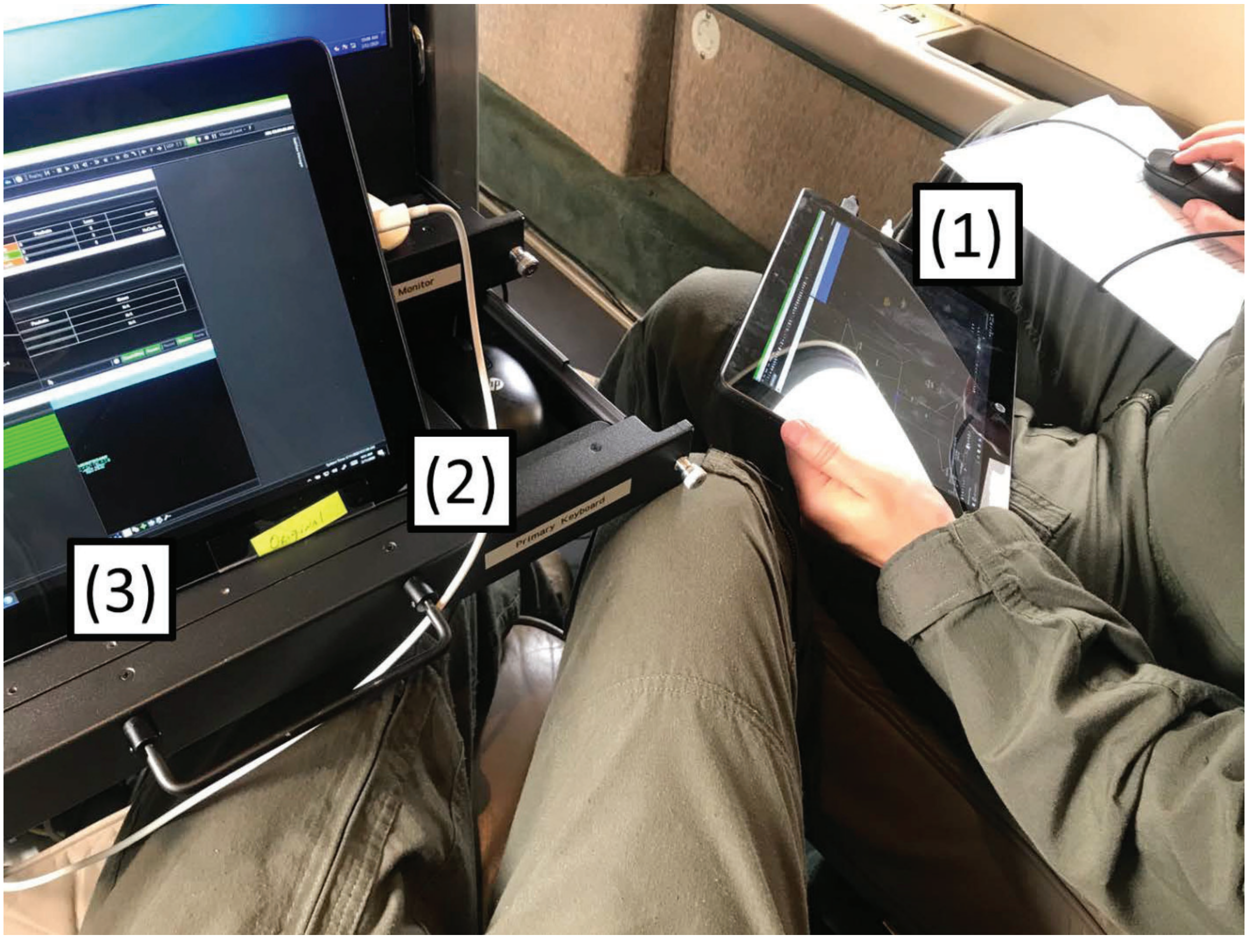
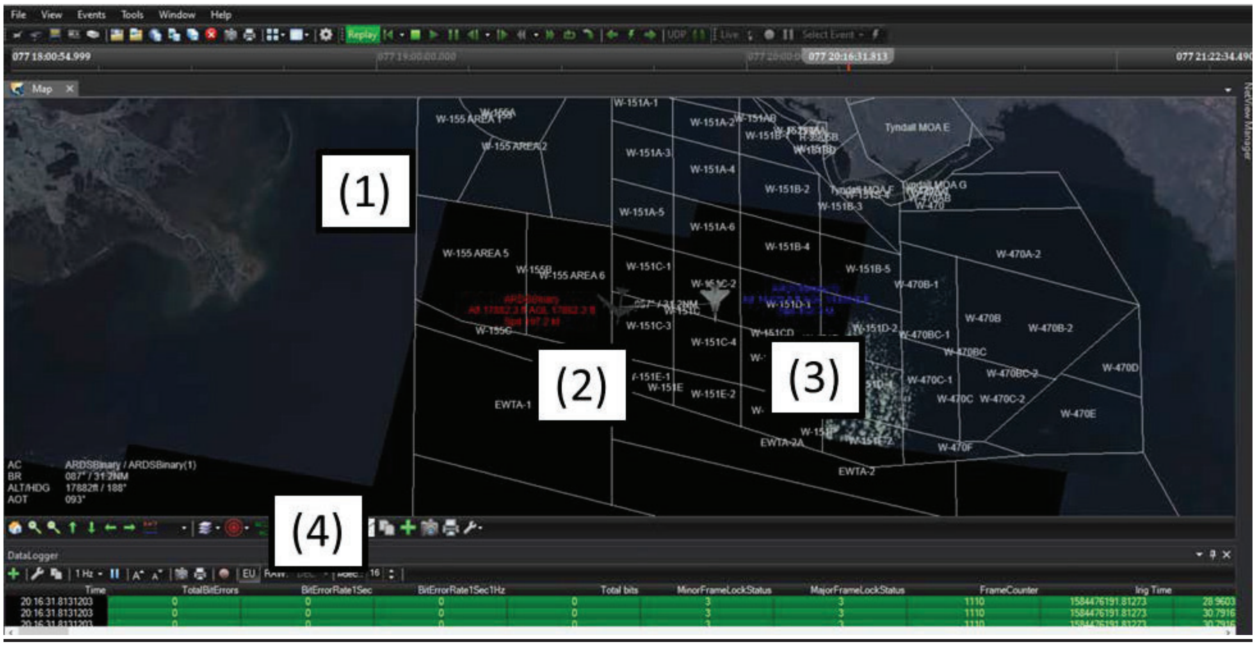


Figure 15 – Operator Station HSI Issues: (1) No desk space for right-hand operator, (2) Very little desk space for the left-hand operator, (3) Keyboard stowed away to provide space for tablet

Overall, the user comments highlighted that the HSI of the operator stations was generally poor. The lack of desktop space at the operator station reduced the utility of the Terminator Pod System as it made interacting with the system and running the test cards difficult. To interface with the system, there were two tablets, two computer mice, two keyboards, and an additional PC situated in the equipment rack. The tablets were running NetView software and the PC within the equipment rack was processing and displaying raw ARDS and BER data. The tablets were hardwired to the equipment racks so any potential portability was lost, and were also difficult to operate when balanced on the operator's lap due to the lack of horizontal desktop workspace. One keyboard was hardwired to the rack-mounted PC, which consumed almost all of the available desktop space when in use. When not required for data entry, the keyboard had to be stowed away in order to use the space to position one of the tablets (Figure 15 (3)). The second keyboard had to be used on the operator's lap due to the lack of space (Figure 15 (2)). The right-hand operator station had no desk space at all. The two mice were mainly used on the operators' laps due to a lack of space (Figure 15 (1)). This reduced the usability of the Terminator Pod System for test support due to an increased workload on the operator when trying to prioritize and physically manipulate multiple displays and devices during execution.

When NetView was operational, it was able to provide an extremely clear plan-view of the airspace, complete with airspace boundary lines and real-time position and velocity data from both of the aircraft. This provided extremely good SA to the operators, such as real-time aircraft geometry, PN15 data quality, and SA to aid the aircraft during maneuver set-ups and maintenance of the airspace (Figure 16).



AC ARDSBinary / ARDSBinary(1)
BR 087° / 31.2NM
ALT/HDG 17882ft / 188°
AOT 093°

Time	TotalBitErrors	BitErrorRate1Sec	BitErrorRate1Sec1Hz	Total bits	MinorFrameLockStatus	MajorFrameLockStatus	FrameCounter	Irig Time	
20:16:31.8131203	0	0	0	0	3	3	1110	1584476191.81273	28.9603
20:16:31.8131203	0	0	0	0	3	3	1110	1584476191.81273	30.7916

Figure 16 – NetView Software: (1) White airspace boundaries, (2) Real-time Sabreliner position, altitude and speed (depicted with B-52 icon), (3) Real-time F-15Eposition, altitude and speed. Note, paired data between aircraft shown in text between aircraft symbols, (4) Real-time BER

Unfortunately, the NetView software used on the two tablets was highly prone to failures which required shutting down and restarting the software. The first sortie experienced six failures. The third and final sortie experienced two failures. Total failures of this nature were highly undesirable and significantly reduced test efficiency. On the first sortie, approximately five minutes were lost during each reset in order to reconfigure NetView to be ready for data collection. By the final test sortie, the creation of a project file (a type of software configuration 'preset' loaded from a single file) had reduced the time lost during a NetView reset to approximately thirty seconds.

The biggest impact of a NetView failure was when it failed during a test point. While the Terminator Pod continued to receive and re-radiate PN15 data during NetView failures, for test efficiency it was preferable to continue data collection and revert to the raw PN15 data stream. While this provided the same measure of signal quality from the same source as NetView, all positional SA was lost (Figure 17). This was a compromise between test efficiency and operator SA that was nonexistent when NetView worked properly.

NetView, in the software version tested, was far too unstable to be relied upon for data collection. Most weapon tests consist of one of a kind, expensive assets. Additionally if this system is to be used for safety of test with an FTS, then no down time can be tolerated. The creation of a project file 'preset' greatly reduced the time lost to a full NetView reset, but any time spent without NetView resulted in greatly decreased SA onboard the Sabreliner, as the operators were forced to fall back on the raw BER measurement of signal quality without any aircraft or airspace position data being displayed. Decreased SA while a cruise missile is in flight could be detrimental to a test, especially if the missile is BLOS from the CCF. **Improve reliability of NetView software. (R3)**

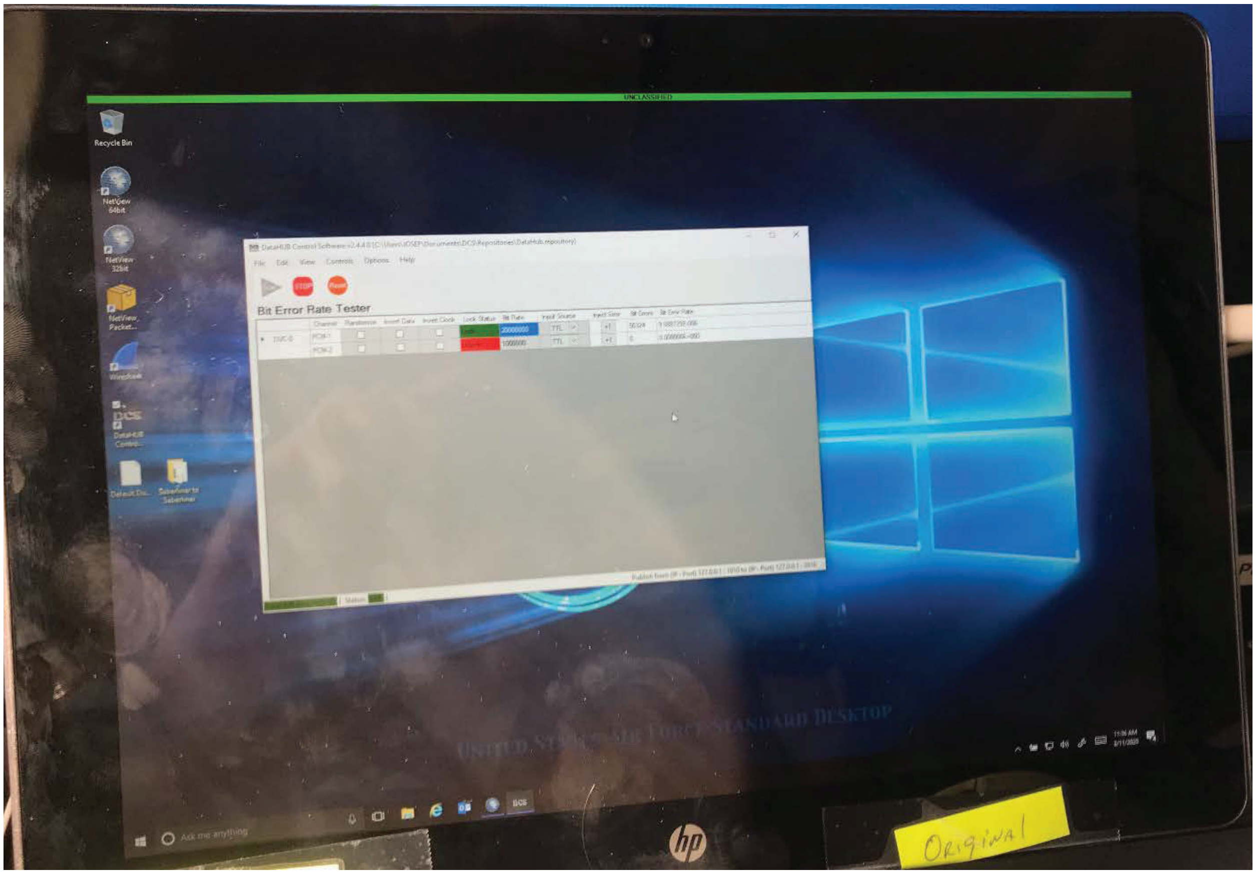


Figure 17 – DCS Software Showing Raw BER (Depicted in Green)

The software version of NetView used a typical desktop GUI. This required a dedicated mouse and keyboard to interact with the software. Because space at the operator station was at a premium, trying to find desk space to use the mice and keyboards resulted in poor HSI and increased operator workload. In addition, the use of tablets also meant that not only were an additional mouse and keyboards required for each tablet, accidental touches of the screen would sometimes register as a mouse click and perform operations within NetView that were not desired by the operator. A screen orientation lock was also required to prevent numerous reorientations of NetView when the tablets were placed on a horizontal surface.

The multiple displays and interface methods required to operate NetView resulted in difficulties managing all of the computer hardware at the operator station. **Improve the method of interfacing with NetView to reduce operator workload. (R4)**

The SUS results collected from page 3 of the survey are shown below (Figure 18). The data were collected over the four Sabreliner flights. 13 March 2020 had a planned sortie that resulted in an F-15E ground abort after the Sabreliner had already launched. On this sortie, the TC had sufficient exposure to the Terminator Pod System to provide answers to the survey, but there were no data from the DE since the F-15E ground abort prematurely ended the sortie. The completed surveys are shown in Appendix B.

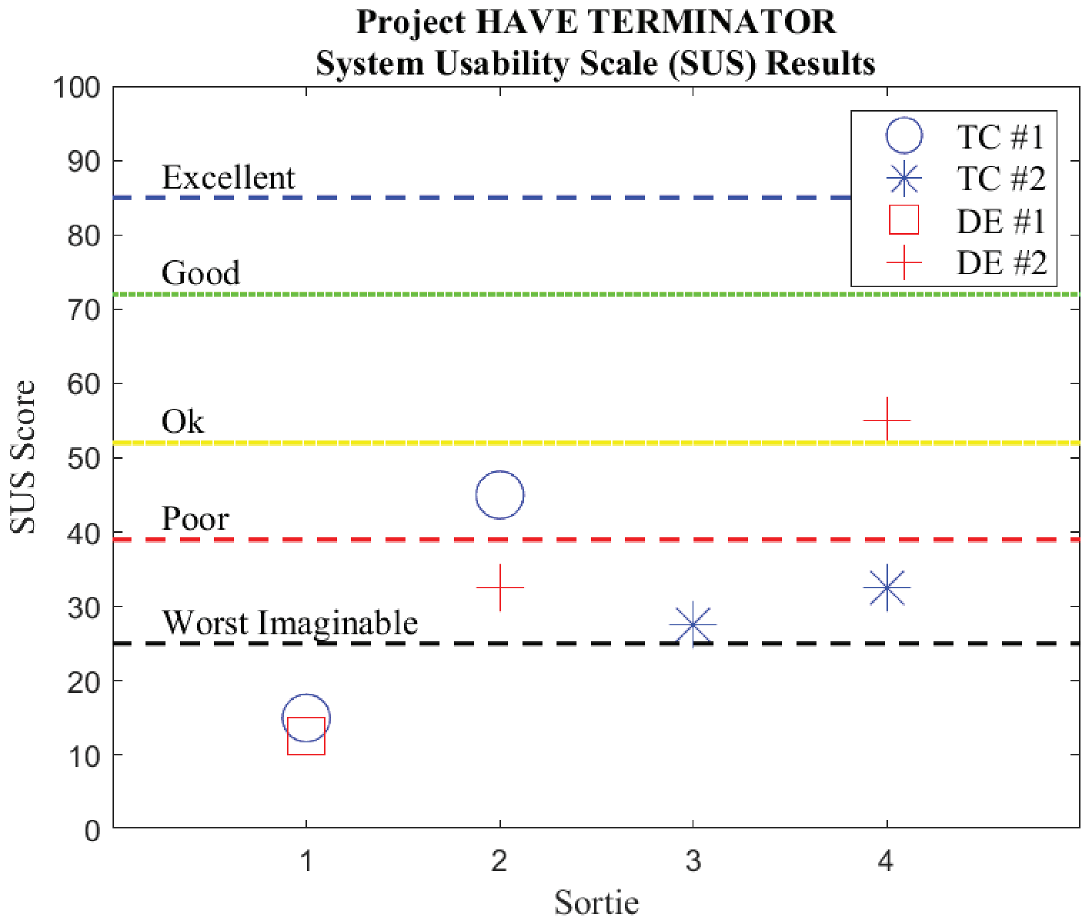


Figure 18 – System Usability Survey Results

The SUS outputted numerical scores on a 0 to 100 scale. The raw SUS scores were useful in providing an overall metric of the System's usability, backed up by operator comments. Overlaying the "adjective rating statements" (Poor, Ok, Good, etc.) provided a meaning to the raw SUS scores.

The data showed that the Terminator Pod System generally performed poorly, with sortie 1 performing in the 'Worst Imaginable' region. This low score is due to both the frequent NetView software resets as well as the steep initial learning curve encountered during sortie 1, where no previous experience in operating the Terminator Pod System was available. Sortie 2 achieved higher scores than sortie 1, with one score inside the 'Ok' region. This was due to keeping one team member on the Sabreliner from the previous sortie to provide much-needed continuity in System operation, and the creation of the project file 'preset' to reduce the time lost during NetView resets. This 'Marginal' score was the only score during the test that fell above the 'Not Acceptable' range. The score for sortie 3 was from a new TC on their first flight operating the Terminator Pod System, explaining why the score was back down on the 'Poor'- 'Worst

Imaginable' boundary. Sortie 4 had the same team as sortie 3 and showed an upward trend with the ratings. Most apparent was the increase in score from sortie 2 to sortie 4 from DE #2.

The poor HSI and unstable NetView software combined to increase operator workload, decrease test efficiency, and reduce operator SA. The overwhelming majority of operator comments and SUS scores suggest the Terminator Pod System operator station performed poorly as a test support asset.

Overall the operator station utility for test support had the potential to be effective. This was demonstrated during test execution during those times when NetView was operational and excellent SA was provided to the operator and was reflected in the operator comments. Some of the HSI shortcomings could be mitigated with training and experience, but the nature of weapon testing required consistent and reliable software especially for future test safety elements such as FTS. This would require significant NetView reliability improvements if used for future testing.

3.0 REFERENCES

1. AKZE0021, *Longshot II*, 780 TS, Eglin AFB, FL, 24 June 2019.

2. ITU-T Recommendation O.150, *General Requirements for Instrumentation for Performance Measurements on Digital Transmission Equipment*, International Telecommunication Union, May 1996.

3. M. Glass, *IRIG 106 Chapter 10 Standardizes MIL-STD-1553B Data Recording*, 2007 IEEE/AIAA 26th Digital Avionics Systems Conference, Dallas TX, 2007.

4. B22TRM-RPT-STR-001, *B22TRM Mongoose 2 Pod Structural Analysis*, 96 RANSS/RNRE, Eglin AFB, FL, 20 March 2019.

5. Bangor, Aaron, Kortum, Philip T. and Miller, James T., *An Empirical Evaluation of the System Usability Scale,* International Journal of Human-Computer Interaction, January 2008

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APPENDIX A – DATA ANALYSIS

STO 1: TM Reception Performance

MOP 1.1: Aircraft TM PN15 Bit Error Rate

1.1.1: Required Data

Four files were required to complete data reduction and data analysis for MOP 1.1. The required data parameters, organized by data groups, are shown below in Table A-1. The two primary platforms for gathering the required data were the Sabreliner and F-15E. The Sabreliner files were recorded through the onboard Terminator Pod System Chapter 10 recorder for the PN15 data signal and the ARDS plate recorded the Sabreliner TSPI data. The F-15E had the ARDS pods on station 8A and 2B that provided the TSPI data required for the F-15E, but only one source was used for processing due to no difference in data collected.

The TSPI data from both the Sabreliner and the F-15E were required so that the geometry between the platforms could be calculated to provide slant range, azimuth, and elevation. The TSPI geometry was then used to code the BER values to the physical dimensions between the platforms to show the range, azimuth, and elevation where the Terminator Pod System could be employed with an acceptable level of error. The BER values were derived from the computer application NetView, which took in the raw bit errors and total bits for the PN15 signal and calculated the BER over a one second sample at one Hz update frequency.

Data Grouping	Parameter	Platform	Data Source	Engineering Units
	Time	NetView	NetVew Time Sync	HH:mm:ss.sssssss
Sabreliner 3rd Stage Combiner	TotalBitErrors	Sabreliner	Sabreliner PN15 Data .CH10 files: "File002_17032020_18185300.ch10" & "File003_17032020_20421000.ch10"	Double
	BitErrorRate1Sec			Double
	BitErrorRate1Sec1Hz			Double
	Total bits			Double
	MinorFrameLockStatus			Binary
	MajorFrameLockStatus			Binary
	FrameCounter			Double
	Irig Time			Seconds
Sabreliner TSPI	TSPI_LAT_1	Sabreliner	Sabreliner Ards.DAT file: "5822 pod 957 FSSRDATA.dat"	Degrees.Decmial
	TSPI_LON_1			Degrees.Decmial
	TSPI_ALT_1			Feet
	TSPI_SPEED_1			Knots
	TSPI_ROLL_1			Degrees
	TSPI_PITCH_1			Degrees
	TSPI_HEADING_1			Degrees
F15E TSPI	TSPI_LAT	F-15E	F-15E Station 8A Ards.DAT file: "6497 0185 906 8A 17MAR20 FSSRDATA.dat"	Degrees.Decmial
	TSPI_LON			Degrees.Decmial
	TSPI_ALT			Feet
	TSPI_SPEED			Knots
	TSPI_ROLL			Degrees
	TSPI_PITCH			Degrees
	TSPI_HEADING			Degrees

Table A-1 – Data Parameters MOP 1.1

Additional data from hand-written test logs and notes, generated from the TC and DE in the CCF were collected. The test log documents the start and end times for each run, comments, and initial quality of data gathered during the mission. The sequential start and end times for each run that included data for MOP 1.1 are shown in Table A-2 below. The Scanned Logs are included in Appendix H.

Card #	Start Time	End Time	Description	STO
1.1A	18:33:00	18:43:00	Max range run #1, out to 35nm	1,4
1.1B	18:51:10	19:00:55	Max range run #2, 33nm out to 70nm	1,4
6	19:29:50	19:35:53	50nm offset	1,4
5	19:52:18	19:56:49	40nm offset	1,4
4	20:06:01	20:16:28	30nm offset	1,2,4
3	20:30:27	20:38:12	20nm offset	1,3,4
7	20:45:30	20:48:30	WCS	3

Table A-2 – Run Times

1.1.2: Data Media and Data Format

The two ARDS TSPI files and the two Sabreliner Chapter 10 files were collected post-sortie and downloaded for processing in NetView. The three groups of data were saved to the Have Terminator Hewlett-Packard (HP) laptops and were backed up on two hard drives. The files used for MOP 1.1 are listed above in Table A-1 in the Data Source column. The Sabreliner Chapter 10 file containing the PN15 data for card 7 for the WCS run was split into the second file listed in Table A-1 due to data recorder convenience. The data for the previous 6 cards are contained in the first file noted. Additional information on other data files collected (not discussed here), file structure and folder locations are included in the Digital Appendix, Appendix C.

1.1.3: Data Reduction

For simplicity in exporting the data from NetView, the first six data runs were processed using the first Chapter 10 file and the two TSPI sources, and then the export process documented below, was repeated using the final Chapter 10 file for the WCS data run. The data required for MOP 4.1 was included in export process for MOP 1.1 to improve efficiency and reduce redundant export processing. Additional details for MOP 4.1 are included in section 4.1.

1.1.3.1: NetView Data Export Process

- In NetView, File>Open>ARDS Binary>ARDS Binary File and open the Sabreliner ARDS file and then open the F-15E ARDS file. In NetView Manager, the Sabreliner will be listed as “ARDSBinary” and the F-15E will be “ARDSBinary(1).”

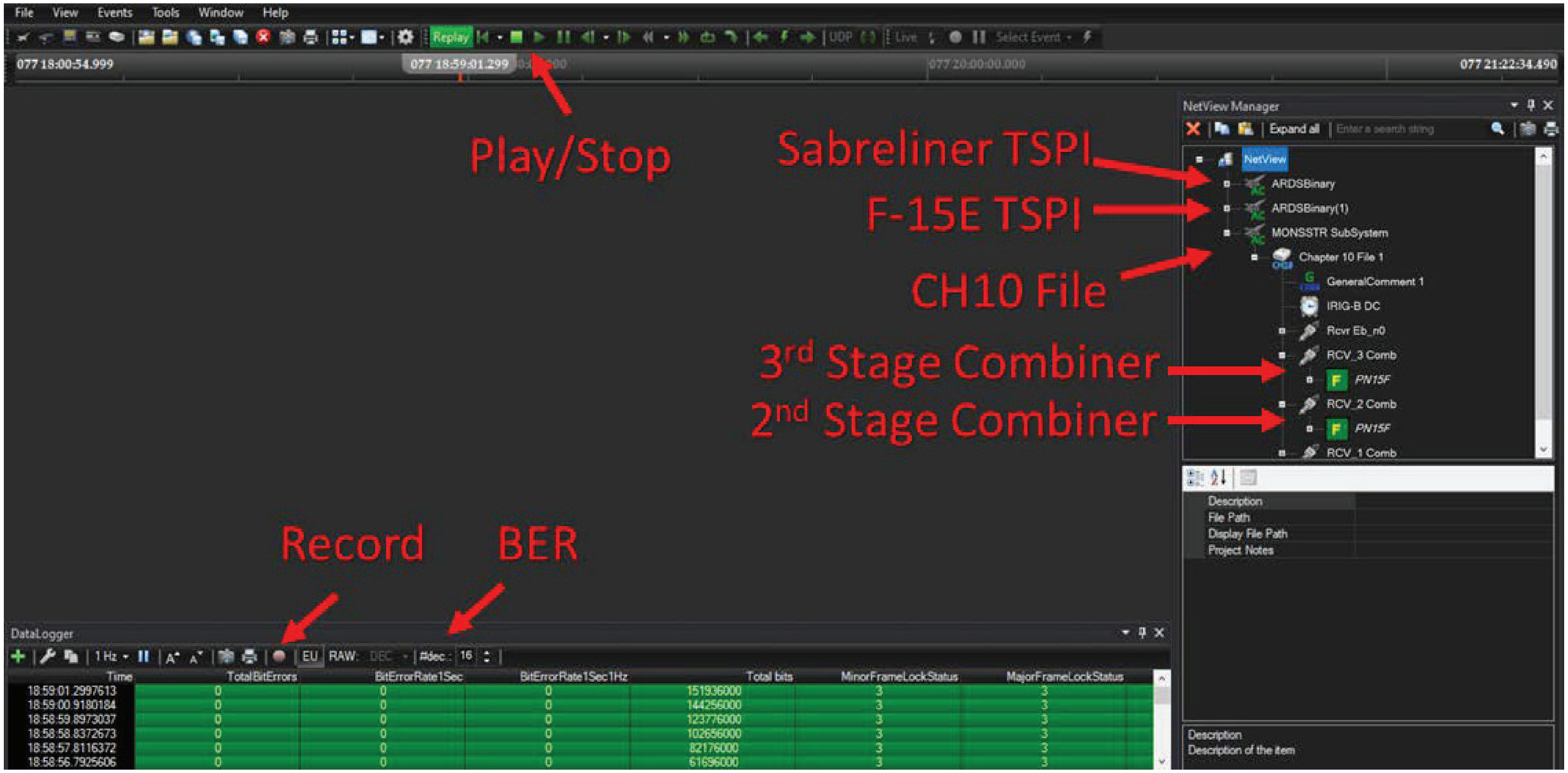
- Next, File>Open>Chapter 10 Sources>File and open the Sabreliner Chapter 10 file. In NetView Manager, the Sabreliner Chapter 10 file will be “MONSSTR SubSystem.”

- On NetView Manager, expand the “MONSSTR SubSystem” to show the “RCV_3 Comb” and “RCV_2 Comb” data blocks with a green “F”. Right click each block and select “PN15F” under the Decoder Setup option. RCV_3/RCV_2 Comb are the Stage 2 and 3 combiners.

- Open the custom display file named “BER_TSPI_Display_31mar20.DisplayFile” with the built-in data labels, listed in Table A-1. The Display should look like Figure A-1 below.
- *Optional* Add the Map Display with EGTTR lines and bearing pair between the Sabreliner and F-15E. Go Window>Create New Display>Map. Show/Hide Overlays>Drawing File>Add File>”EGLIN.mil_special_use_airspace_area(ALL POLYGONS).kml”. Pairings>Define…> ARDSBinary as first object and ARDSBinary(1) as second object, change display type to “Text and Line” and select AOT container. Last, on NetView Manager change the model to B52 to represent the Sabreliner and the F-15E to represent itself. The Display should look like Figure A-2 below. ** Having the Map display while exporting may cause NetView to crash, thus optional recommendation**

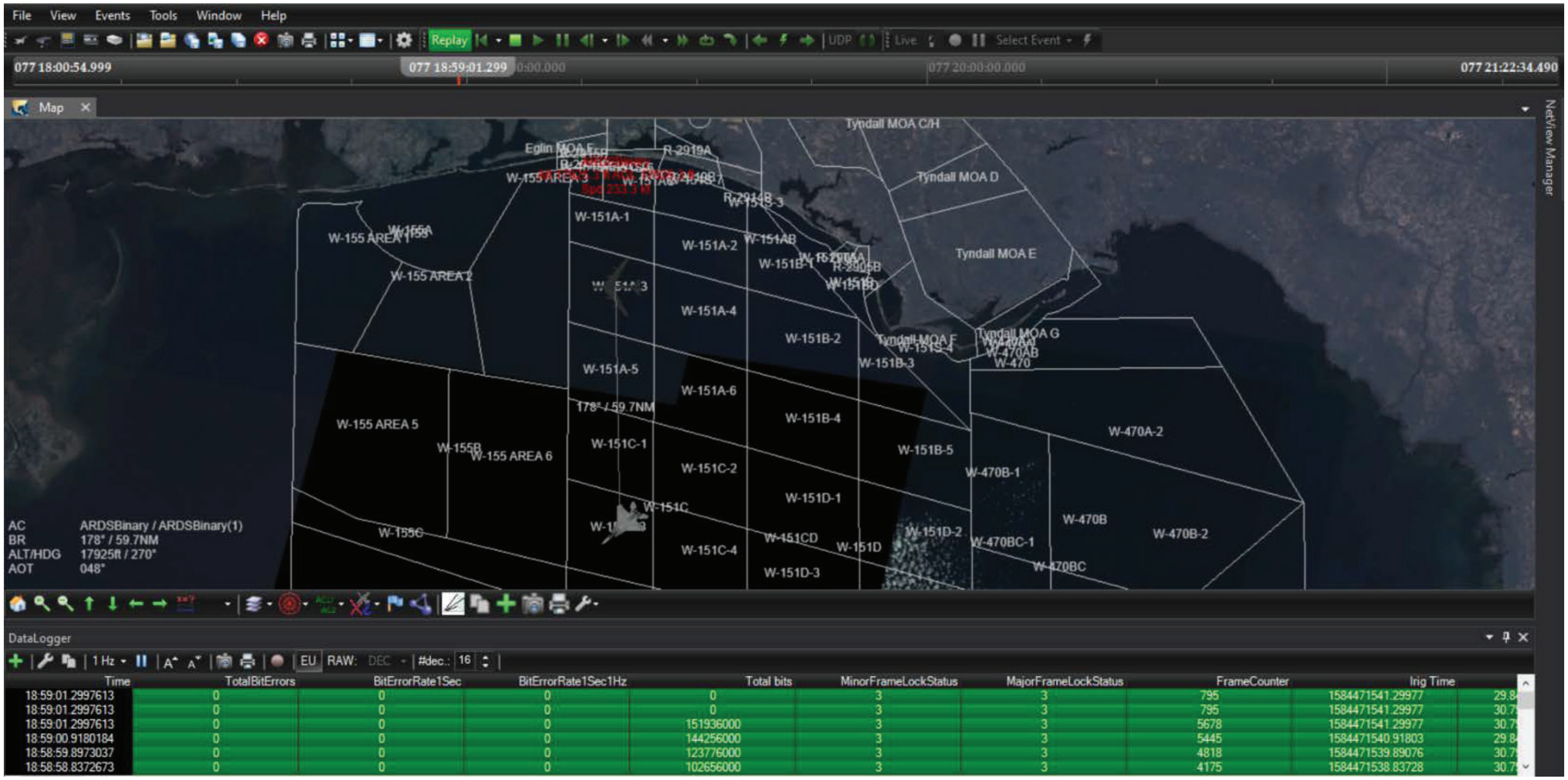
- Set the start time for the data export using the time scroll bar at the top of the window. Select the red record button on the Data Logger display and press play. The Data logger exports the data at a 1 Hz rate and you can see the outputs at the mission is played at real time speed (it was not tested exporting at any speed other than real time).

- At the end of the run time, press the stop button to end the Data logger recording. The data were written to a .txt file located in the Documents/ NetView Datalogs folder under the timestamp for the run.



Time	TotalBitErrors	BitErrorRate1Sec	BitErrorRate1Sec1Hz	Total bits	MinorFrameLockStatus	MajorFrameLockStatus
18:59:01.2997613	0	0	0	151936000	3	3
18:59:00.9180184	0	0	0	144256000	3	3
18:58:59.8973037	0	0	0	123776000	3	3
18:58:58.8372673	0	0	0	102656000	3	3
18:58:57.8116372	0	0	0	82176000	3	3
18:58:56.7925606	0	0	0	61696000	3	3

Figure A-1 - NetView Default Display



AC ARDSBinary / ARDSBinary(1)
BR 178° / 59.7NM
ALT/HDG 17925ft / 270°
AOT 048°

Time	TotalBitErrors	BitErrorRate1Sec	BitErrorRate1Sec1Hz	Total bits	MinorFrameLockStatus	MajorFrameLockStatus	FrameCounter	Irig Time	
18:59:01.2997613	0	0	0	0	3	3	795	1584471541.29977	29.8
18:59:01.2997613	0	0	0	0	3	3	795	1584471541.29977	30.7
18:59:01.2997613	0	0	0	151936000	3	3	5678	1584471541.29977	30.7
18:59:00.9180184	0	0	0	144256000	3	3	5445	1584471540.91803	29.8
18:58:59.8973037	0	0	0	123776000	3	3	4818	1584471539.89076	30.7
18:58:58.8372673	0	0	0	102656000	3	3	4175	1584471538.83728	30.7

Figure A-2 - NetView Map Display

Once the data were exported from NetView, the .txt file was renamed for ease of future data processing in MATLAB and record keeping. The exported data parameter order (provided in the project display file) does matter for processing in MATAB and leads to incorrect data processing during Data Analysis if not abided by. The files exported from NetView for MOP 1.1 are listed below in Table A-3. The Card 4 data set was processed using the modified process described in MOP 2.1, but included below for ease of reference.

Files Exported From NetView
MSN3_Card1_1A_Export_31Mar20.txt
MSN3_Card1_1B_Export_31Mar20.txt
MSN3_Card3_Export_31Mar20.txt
MSN3_Card4_Export_31Mar20_Full.txt
MSN3_Card5_Export_31Mar20.txt
MSN3_Card6_Export_31Mar20.txt
MSN3_Card7_Export_31Mar20.txt

Table A-3

1.1.4: Data Analysis

The MATLAB script "STO1_4_Terminator_Processing_xxApril20.m" was used for simultaneously processing the data used for both MOP 1.1 and 4.1. This script was used to calculate the geometry differences between the Sabreliner and the F-15E. Once the azimuth, elevation and range were calculated, a .mat file was exported that combined the geometry data in a matrix with the Stage 2 and 3 combiners, along with the MajorFrameLock parameters for a quick binary data quality check.

The pseudo-code highlighting the major functions of the script is shown below. Once the script has completed running, a gut check "heat map" was displayed showing the BER values across all elevation cuts, azimuth, and range. However, this data were not used for the final plot that includes all data sets from each run and therefore was just a sanity check that the run matched the initial results viewed from the CCF that were noted in the TC and DE logs.

STO1_4_Terminator_Processing_2April20.m pseudo-code:

```
- Declare and read in NetView exported .txt file
- Establish Navigation constants and correct a NetView export sign error
- Calculate difference vector in Cartesian coordinate system (ΔU, ΔV, ΔW)
- Convert to local coordinates (ΔNorth, ΔEast, ΔHeight)
- Calculate azimuth/elevation angles and range
- Plot azimuth vs range (BER) **Gut Check**
- Save data in .mat file
- End Script
```

Each data set from Table A-3 was processed using the script above and the data were exported in .mat files under the same originating name. The card 4 data set was processed using the modified process described later in MOP 2.1, however, it was able to be run through this script to generate the required data sets in the same order.

Once the individual .mat files were generated, the MATLAB script "Terminator_Final_DataPlot_PartA_2Apr2020.m" was run to consolidate the data sets and remove any data points that did not have a valid MajorFrameLock. This script processes both the MOP 1.1 and 4.1 data for frame lock independently and then exports the consolidated data sets to Excel files for manual "binning" of the data.

Terminator_Final_DataPlot_PartA_2Apr2020.m pseudo-code:

```
- Declare and read in all .mat files
- Consolidate data into one matrix (one matrix for 3rd Stage and one matrix for 2nd Stage)
- Remove rows where MajorFrameLock was invalid
- Plot azimuth vs range (BER) **Gut Check**
- Save data in .xls file
- End Script
```

With the two Excel files (Have_Term_Level_Latoffset_3Stage_31Mar20.xls and Have_Term_Level_Latoffset_2Stage_31Mar20.xls) exported from the above script they were then opened in Excel to calculate the average BER in each bin. For the data collected and processed, all elevations were within 5° of boresight and as such all runs were considered "level" at 0 elevation. First, the range was rounded to the nearest 5, then the azimuth was rounded to the nearest 5. The range, azimuth and corresponding BER were then sorted from lowest to highest in range then sorted again in azimuth. With these groupings, the BER average was taken for each 5 NM range and 5° azimuth bins. Additionally, the number of samples (representing 1 sec BER) were counted.

The average BER and number of samples were then mapped to their corresponding spot in the Range vs Azimuth matrix. For the data set gathered, the range was from 5 to 65 NM and -55 to 25° in azimuth. Both the Stage 2 and 3 combiner files were processed this way and saved under "Have_Term_Level_Latoffset_2Stage_31Mar20_sorted_plots.xlsx"and "Have_Term_Level_Latoffset_2Stage_31Mar20_sorted_plots.xlsx" that show the process documented above in each tab.

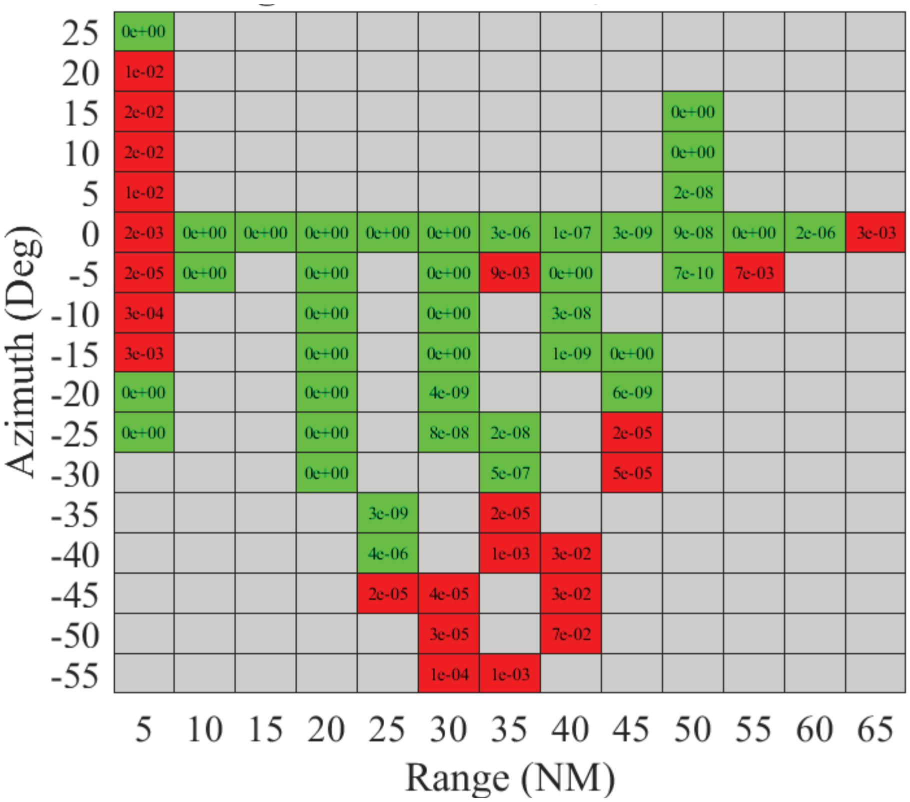
The binned Excel files were imported into MATLAB, saved as .mat files for repeatability, and the final heat maps for both the Stage 2 and 3 combiners were generated using the script "Terminator_Final_DataPlot_PartB_2Apr2020.m".

Terminator_Final_DataPlot_PartB_2Apr2020.m pseudo-code:

```
- Declare and read in all BER/BIN .mat files for 3rd Stage and 2nd Stage
- Plot Heat Map for all data sets
- Save .png image
- End Script
```

1.1.5: Data Analysis Products

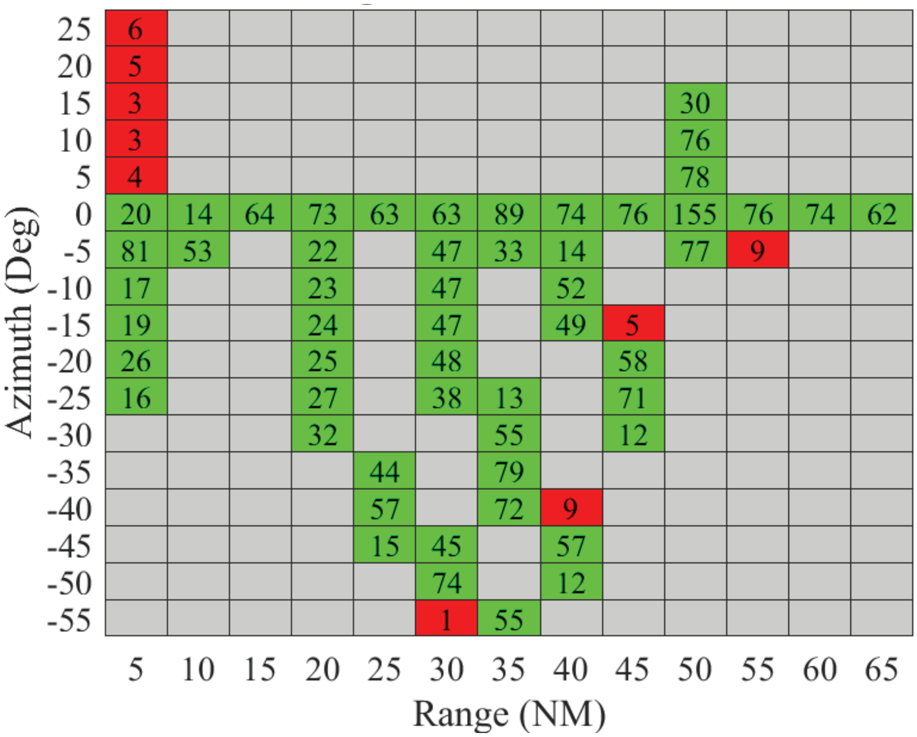
The initial heat maps for MOP 1.1 are shown below in Figures A-3 and A-4. The BER heat map (Figure A-3) color scales are formatted such that the green represents BER values less than the $1x10^{-6}$, yellow represents values between $1x10^{-6}$ and $1x10^{-4}$, and red represents values that fall below $1x10^{-4}$. The Bin Counter (Figure A-4) heat map color scale is simply green and red to show green when the desired 10 samples per bin were collected and red for when there were less than 10 samples. The 10 sample requirement was derived from previous test experience for the minimum level of samples for a valid BER. These color scales are reused for each of the data products presentation throughout the analysis sections.



Azimuth (Deg)	5	10	15	20	25	30	35	40	45	50	55	60	65
25	0e+00												
20	1e-02												
15	2e-02									0e+00			
10	2e-02									0e+00			
5	1e-02									2e-08			
0	2e-03	0e+00	0e+00	0e+00	0e+00	0e+00	3e-06	1e-07	3e-09	9e-08	0e+00	2e-06	3e-03
-5	2e-05	0e+00		0e+00		0e+00	9e-03	0e+00		7e-10	7e-03		
-10	3e-04			0e+00		0e+00		3e-08					
-15	3e-03			0e+00		0e+00		1e-09	0e+00				
-20	0e+00			0e+00		4e-09			6e-09				
-25	0e+00			0e+00		8e-08	2e-08		2e-05				
-30				0e+00			5e-07		5e-05				
-35					3e-09		2e-05						
-40					4e-06		1e-03	3e-02					
-45					2e-05	4e-05		3e-02					
-50						3e-05		7e-02					
-55						1e-04	1e-03						

Range (NM)

Figure A-3 – Initial Stage 3 Combiner BER Heat Map, Elevation = "0"

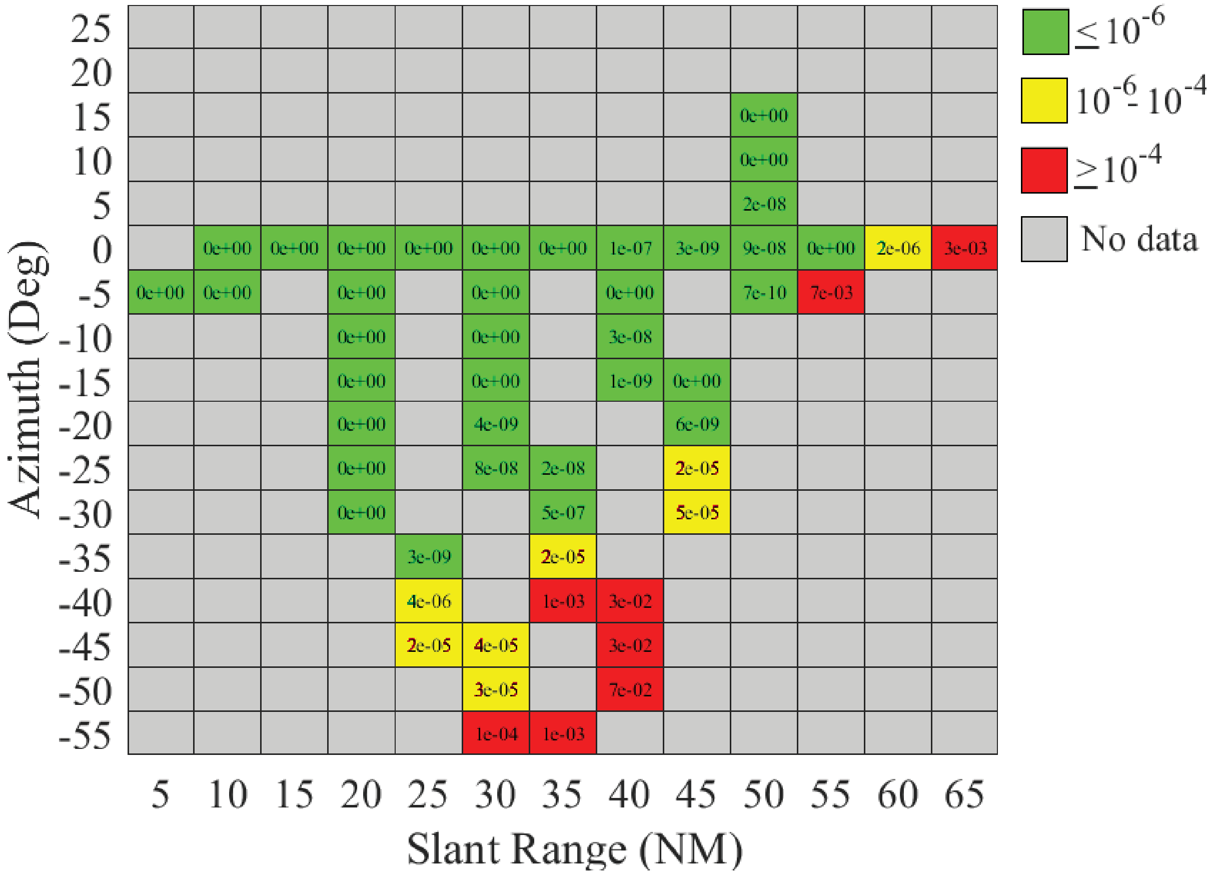


Azimuth (Deg)	5	10	15	20	25	30	35	40	45	50	55	60	65
25	6												
20	5												
15	3									30			
10	3									76			
5	4									78			
0	20	14	64	73	63	63	89	74	76	155	76	74	62
-5	81	53		22		47	33	14		77	9		
-10	17			23		47		52					
-15	19			24		47		49	5				
-20	26			25		48			58				
-25	16			27		38	13		71				
-30				32			55		12				
-35					44		79						
-40					57		72	9					
-45					15	45		57					
-50						74		12					
-55						1	55						

Range (NM)

Figure A-4 – Initial Stage 3 Combiner Bin Heat Map

After generating the two figures above with all the combined runs, there were apparent high levels of BER that corresponded to the 5, 35, and 65 NM bins for the start and end of the max range runs. After reviewing the geometry during the setup and comparing the BER to the Sabreliner and F-15E, Roll/Pitch/Heading TSPI data points were removed due to masking at the 5 and 35 NM bins. However, upon inspection, there was no apparent maneuvering or masking shown in the data at 65 NM bin, so the higher BER values remained. The detailed plots and walk through is documented in the MATLAB script "High_BER_Investigation_3Apr20.m". After removing the corresponding data points the final heat maps for MOP 1.1 were generated and shown below in Figures A-5 and A-6.

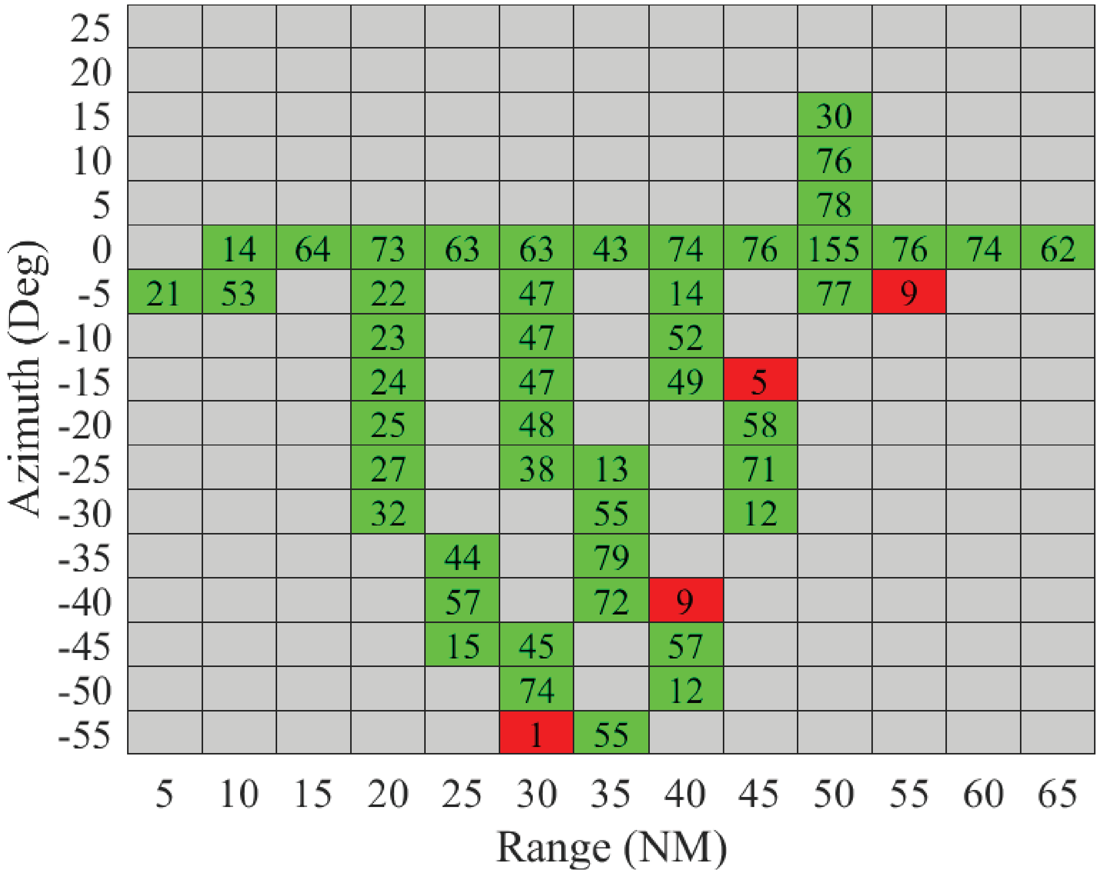


Azimuth (Deg)	5	10	15	20	25	30	35	40	45	50	55	60	65
25													
20													
15										0e+00			
10										0e+00			
5										2e-08			
0		0e+00	0e+00	0e+00	0e+00	0e+00	0e+00	1e-07	3e-09	9e-08	0e+00	2e-06	3e-03
-5	0e+00	0e+00		0e+00		0e+00		0e+00		7e-10	7e-03		
-10				0e+00		0e+00		3e-08					
-15				0e+00		0e+00		1e-09	0e+00				
-20				0e+00		4e-09			6e-09				
-25				0e+00		8e-08	2e-08		2e-05				
-30				0e+00			5e-07		5e-05				
-35					3e-09		2e-05						
-40					4e-06		1e-03	3e-02					
-45					2e-05	4e-05		3e-02					
-50						3e-05		7e-02					
-55						1e-04	1e-03						

Figure A-5 – Final Stage 3 Combiner BER Heat Map, Elevation = "0"

The Stage 3 combiner results shown in Figure A-5 show the Terminator Pod System was able to receive the PN15 signal with a BER of 3x10^{-3} within the 65 NM bin, 2x10^{-6} within the 60 NM Bin, and 0 within 55 NM bin when directly along the 0 azimuth or "boresight" region. Although there was no evidence of masking shown when reviewing the raw TSPI data, the majority of the high BER values that skewed the 65 NM bin were the last few samples at the end of the maneuver and more information would be required to provide higher confidence in the Terminator Pod System beyond 60 NM.

Along boresight, the antenna pattern at 25 NM was in the desirable region at -35° and then narrowed to -30° at 35 NM, -20° at 45 NM, and 15° at 50 NM. Due to only one sortie of useful data, the symmetric nature of the antenna pattern was not observed.



Azimuth (Deg)	5	10	15	20	25	30	35	40	45	50	55	60	65
25													
20													
15										30			
10										76			
5										78			
0		14	64	73	63	63	43	74	76	155	76	74	62
-5	21	53		22		47		14		77	9		
-10				23		47		52					
-15				24		47		49	5				
-20				25		48			58				
-25				27		38	13		71				
-30				32			55		12				
-35					44		79						
-40					57		72	9					
-45					15	45		57					
-50						74		12					
-55						1	55						

Figure A-6 – Final Stage 3 Combiner Bin Heat Map

Figure A-6 shows the number of BER one second samples collected in each bin. Only four bins did not meet the 10-sample threshold. Although the correspond BERs were not removed from Figure A-5 the only results that show concern was the BER values at the 55 NM and -5° azimuth since it was a clear drop off in BER compared to the surrounding bins. The final heat mat provided in the main body of the report will exclude these bins.

Overall, with the eight-antenna configuration using the Stage 3 combiner, the Terminator Pod System provided desirable BER values out to 55 NM at azimuths ranging from -35 to +15°. This envelope should provide an adequate margin in range and azimuth for test setup and execution for tracking future weapons testing.

1.1.6: Data Distribution

There are no data distribution limitations. All data collected is available upon request, and contents are outlined in the Digital Appendix, Appendix C.

1.1.7: Hardware and Software Requirements

The post-processing software used consisted of standard Microsoft Office products, MATLAB R2019b, and NetView version 2.3.0.4377. All applications and data processing occurred on a HP ProBook 450 G6, Windows 10 Pro, Version 1903, OS Build 18362.720 that was provided by the 96 RANSS office. As mentioned in the export steps above, it appeared NetView would crash when large amounts of data were being exported with the MAP display up. The HP laptops have only 16 GB of RAM which may have been the limiting factor.

STO 2: TM Re-radiation Performance

MOP 2.1: Aircraft TM PN15 Bit Error Rate

2.1.1: Required Data

Data requirements for MOP 2.1 were the same as MOP 1.1 with the addition of a Chapter 10 data file that was recorded at the CCF that included the re-rad PN15 data, as shown below in Table A-4. For MOP 2.1, the data collected during card 4, the 30 NM lateral offset, was used since it was a north to south flow that ended around 88 NM from the shoreline. This was also the farthest south test point during sortie and was the best data set to demonstrate the re-radiation performance of the Terminator Pod System.

In addition to the required data described in Section 1.1.1, the data from each ground tower was required for re-radiation performance and comparison. Antennas A5, D3 and B4B were three ground re-rad tower antennas that received the L-band signal transmitted from the Sabreliner. The Penthouse antenna located on top of King Hangar at Eglin AFB received the direct S-Band PN15 signal from the F-15E, and although included in the data export process, it was not used for our analysis. A final “Best” Data source was also created in NetView that selected the best BER at any given time and consolidated into a single source. Each BER was calculated as the number of bit errors per total bits transmitted over a period of 1 second, and was a measure of how much the signal was altered due to noise, interference, and/or bit synchronization error.

Data Grouping	Parameter	Platform	Data Source	Engineering Units
CCF Receivers	TotalBitErrors_A5	A5 Tower	CCF PN15 Data .CH10 file: "SiAW MSN 5822 17 MAR 20_file0009_17032020_13412260_16145092.ch10"	Double
	BitErrorRate1Sec_A5			Double
	BitErrorRate1Sec1Hz_A5			Double
	Total bits_A5			Double
	MinorFrameLockStatus_A5			Binary
	MajorFrameLockStatus_A5			Binary
	FrameCounter_A5			Double
	Irig Time_A5			Seconds
	TotalBitErrors_D3	D3 Tower		Double
	BitErrorRate1Sec_D3			Double
	BitErrorRate1Sec1Hz_D3			Double
	Total bits_D3			Double
	MinorFrameLockStatus_D3			Binary
	MajorFrameLockStatus_D3			Binary
	FrameCounter_D3			Double
	Irig Time_D3			Seconds
	TotalBitErrors_PH	Pent House Tower		Double
	BitErrorRate1Sec_PH			Double
	BitErrorRate1Sec1Hz_PH			Double
	Total bits_PH			Double
	MinorFrameLockStatus_PH			Binary
	MajorFrameLockStatus_PH			Binary
	FrameCounter_PH			Double
	Irig Time_PH			Seconds
	TotalBitErrors_BEST	"Best" Tower		Double
	BitErrorRate1Sec_BEST			Double
	BitErrorRate1Sec1Hz_BEST			Double
	Total bits_BEST			Double
	MinorFrameLockStatus_BEST			Binary
	MajorFrameLockStatus_BEST			Binary
	FrameCounter_BEST			Double
	Irig Time_BEST			Seconds
	TotalBitErrors_B4B	B4B Tower		Double
	BitErrorRate1Sec_B4B			Double
	BitErrorRate1Sec1Hz_B4B			Double
	Total bits_B4B			Double
	MinorFrameLockStatus_B4B			Binary
	MajorFrameLockStatus_B4B			Binary
	FrameCounter_B4B			Double
	Irig Time_B4B			Seconds

Table A-4 – Additional Data Parameters for MOP 2.1

2.1.2: Data Media and Data Format

The two ARDS TSPI files, the Sabreliner Chapter 10 file and the CCF Chapter 10 file were collected post-sortie and downloaded for processing in NetView. The files used for MOP 2.1 are listed above in Table A-1 and Table A-4 in the Data Source column. Additional information on other data files collected (not discussed here), file structure and folder locations are included in the Digital Appendix, Appendix C.

2.1.3: Data Reduction

All four files were imported into NetView and the data export process described below was used for MOP 2.1. The process is identical to the data export process described in section 1.1.3.1 with the addition of the ground re-rad tower PN15 data words included in the display file for export. This data export process was used to generate all the required data for MOP 1.1, MOP 2.1, and MOP 4.1 using the Card 4 data set.

2.1.3.1: NetView Data Export Process

- In NetView, File>Open>ARDS Binary>ARDS Binary File and open the Sabreliner ARDS file and then open the F-15E ARDS file. In NetView Manager, the Sabreliner will be listed as “ARDSBinary” and the F-15E will be “ARDSBinary(1).”
- Next, File>Open>Chapter 10 Sources>File and open the Sabreliner Chapter 10 file. In NetView Manager, the Sabreliner Chapter 10 file will be “MONSSTR SubSystem.”
- On NetView Manager, expand the “MONSSTR SubSystem” to show the “RCV_3 Comb” and “RCV_2 Comb” data blocks with a green “F”. Right click each block and select “PN15F” under the Decoder Setup option. RCV_3/RCV_2 Comb are the Stage 2 and 3 combiners.
- Next, File>Open>Chapter 10 Sources>File and open the CCF Chapter 10 file. In NetView Manager, the CCF Chapter 10 file will be “Wyle TDS IMUX G2.”
- On NetView Manager, expand the “Wyle TDS IMUX G2” to show the “A5 RERAD”, “D3 RERAD”, “PH DIRECT(1)”, “RERAD BEST”, and “B4B RERAD” data blocks with a green “F”. Right click each block and select “PN15F” under the Decoder Setup option.
- Open the custom display file named “card4_rerad_display.DisplayFile” with the built-in data labels, listed in Table C-1 and Table C-2. The Display should look like Figure A-1.
- *Optional* Add the Map Display with EGTTR lines and bearing pair between the Sabreliner and F-15E. Go Window>Create New Display>Map. Show/Hide Overlays>Drawing File>Add File>”EGLIN.mil_special_use_airspace_area(ALLPOLYGONS).kml”. Pairings>Define…> ARDSBinary as first object and ARDSBinary(1) as second object, change display type to “Text and Line” and select AOT container. Last, on NetView Manager change the model to B52 to represent the Sabreliner and the F15E to represent itself. The Display should look like Figure A-2. ** Having the Map display while exporting may cause NetView to crash, thus optional recommendation**
- Set the start time for the data export using the time scroll bar at the top of the window. Select the red record button on the Data Logger display and press play. The Data logger exports the data at a 1 Hz rate and you can see the outputs at the mission is played at real time speed (it was not tested exporting at any speed other than real time).
- At the end of the run time, press the stop button to end the Data logger recording. The data were written to a .txt file located in the Documents/ NetView Datalogs folder under the timestamp for the run.
- Once the data were exported from NetView, the .txt file was renamed to “MSN3_Card4_Export_31Mar20_Full.txt” for ease of future data processing in MATLAB and record keeping.

2.1.4: Data Analysis

The MATLAB script “STO2_Terminator_Processing_2April20.m” was used for processing the data used for MOP 2.1 for the Card 4 data set. This script was used to calculate the same geometry information as described in section 1.1.4 with the addition of the PN15 data from the re-rad towers.

The pseudo-code highlighting the major functions of the script is shown below and only differs from the STO1_4 script by including the additional data parameters.

STO2_Terminator_Processing_2April20.m pseudo-code:

```
- Declare and read in NetView exported .txt file *Expanded data set*
- Establish Navigation constants and correct a NetView export sign error
- Assign Shoreline reference point
- Calculate difference vector in Cartesian coordinate system ($\Delta U$, $\Delta V$, $\Delta W$) to reference point
- Convert to local coordinates ($\Delta$North, $\Delta$East, $\Delta$Height)
- Calculate range to reference point
- Save data in .mat  and .xls files
- End Script
```

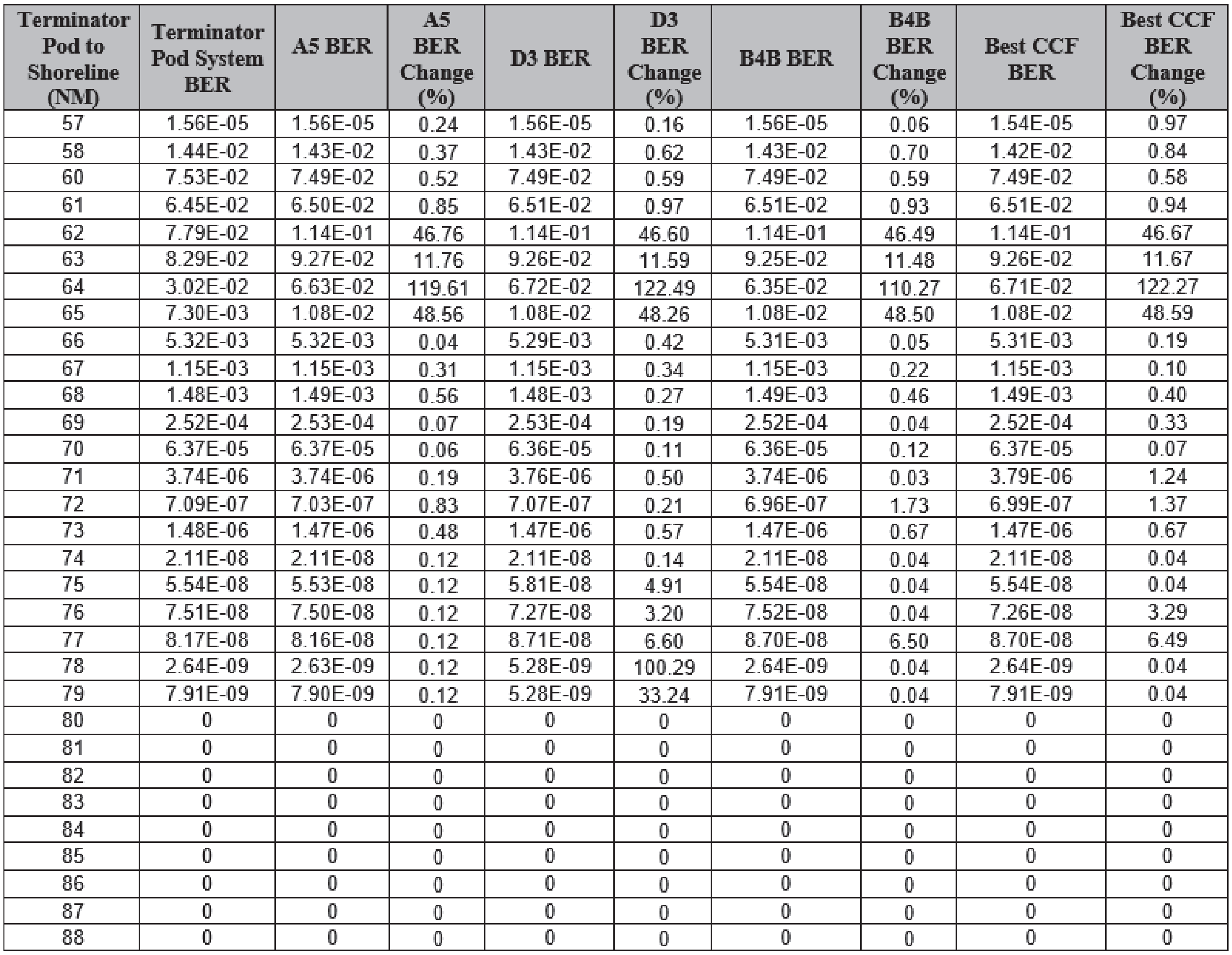
The Excel file “HaveTerminator_ReRad_Comparison_31Mar20.xls” was then opened and manually binned using the same process described in section 1.1.4. Finally, the BER from the Sabreliner was then compared to the BER values for each of the re-rad towers.

2.1.5: Data Analysis Products

Only BER data from the Sabreliner and each of the re-rad towers was processed if there was good frame lock, otherwise that data were thrown out as being erroneous. The remaining 530 entries of the original 609, representing 10 minutes of data, were averaged based on range between the Sabreliner and the shoreline. The percent change between each of the ground re-rad antennas BER vs the Terminator Pod System BER was determined as the basis for comparison. Table A-5 shown on the following page shows the average BER values at 1 NM intervals for the Sabreliner with the Terminator Pod System and re-rad antennas and corresponding percent change. The percent change for each of the ground re-rad antennas was calculated by:

$$Antenna\ BER\ \%\ Change = \frac{|Ground\ Antenna\ BER - Terminator\ BER|}{Terminator\ BER}$$

It was evident that the BER data recorded from all the sources are not in perfect time sync, such that a ground-based antenna occasionally reported having received more total bits than the Terminator Pod system in the same 1 Hz sample block. Since the antenna cannot look forward in time and the BER differences were so minute, times when Best CCF BER was better than the Terminator Pod System were considered inconsequential for the analysis.



Terminator Pod to Shoreline (NM)	Terminator Pod System BER	A5 BER	A5 BER Change (%)	D3 BER	D3 BER Change (%)	B4B BER	B4B BER Change (%)	Best CCF BER	Best CCF BER Change (%)
57	1.56E-05	1.56E-05	0.24	1.56E-05	0.16	1.56E-05	0.06	1.54E-05	0.97
58	1.44E-02	1.43E-02	0.37	1.43E-02	0.62	1.43E-02	0.70	1.42E-02	0.84
60	7.53E-02	7.49E-02	0.52	7.49E-02	0.59	7.49E-02	0.59	7.49E-02	0.58
61	6.45E-02	6.50E-02	0.85	6.51E-02	0.97	6.51E-02	0.93	6.51E-02	0.94
62	7.79E-02	1.14E-01	46.76	1.14E-01	46.60	1.14E-01	46.49	1.14E-01	46.67
63	8.29E-02	9.27E-02	11.76	9.26E-02	11.59	9.25E-02	11.48	9.26E-02	11.67
64	3.02E-02	6.63E-02	119.61	6.72E-02	122.49	6.35E-02	110.27	6.71E-02	122.27
65	7.30E-03	1.08E-02	48.56	1.08E-02	48.26	1.08E-02	48.50	1.08E-02	48.59
66	5.32E-03	5.32E-03	0.04	5.29E-03	0.42	5.31E-03	0.05	5.31E-03	0.19
67	1.15E-03	1.15E-03	0.31	1.15E-03	0.34	1.15E-03	0.22	1.15E-03	0.10
68	1.48E-03	1.49E-03	0.56	1.48E-03	0.27	1.49E-03	0.46	1.49E-03	0.40
69	2.52E-04	2.53E-04	0.07	2.53E-04	0.19	2.52E-04	0.04	2.52E-04	0.33
70	6.37E-05	6.37E-05	0.06	6.36E-05	0.11	6.36E-05	0.12	6.37E-05	0.07
71	3.74E-06	3.74E-06	0.19	3.76E-06	0.50	3.74E-06	0.03	3.79E-06	1.24
72	7.09E-07	7.03E-07	0.83	7.07E-07	0.21	6.96E-07	1.73	6.99E-07	1.37
73	1.48E-06	1.47E-06	0.48	1.47E-06	0.57	1.47E-06	0.67	1.47E-06	0.67
74	2.11E-08	2.11E-08	0.12	2.11E-08	0.14	2.11E-08	0.04	2.11E-08	0.04
75	5.54E-08	5.53E-08	0.12	5.81E-08	4.91	5.54E-08	0.04	5.54E-08	0.04
76	7.51E-08	7.50E-08	0.12	7.27E-08	3.20	7.52E-08	0.04	7.26E-08	3.29
77	8.17E-08	8.16E-08	0.12	8.71E-08	6.60	8.70E-08	6.50	8.70E-08	6.49
78	2.64E-09	2.63E-09	0.12	5.28E-09	100.29	2.64E-09	0.04	2.64E-09	0.04
79	7.91E-09	7.90E-09	0.12	5.28E-09	33.24	7.91E-09	0.04	7.91E-09	0.04
80	0	0	0	0	0	0	0	0	0
81	0	0	0	0	0	0	0	0	0
82	0	0	0	0	0	0	0	0	0
83	0	0	0	0	0	0	0	0	0
84	0	0	0	0	0	0	0	0	0
85	0	0	0	0	0	0	0	0	0
86	0	0	0	0	0	0	0	0	0
87	0	0	0	0	0	0	0	0	0
88	0	0	0	0	0	0	0	0	0

Table A-5 –Terminator Pod System and Re-Rad Tower BER Data Table

The percent change between the Terminator Pod System and each of the ground re-rad antennas from Table A-5 were plotted in excel for a graphical depiction. The ground stations A5, D3, B4B, and Best CCF BER percent change plots are summarized in Figures A-7 through A-10 below. Percent change spikes from 61-66 NM were due to intermittent frame lock. Figure A-10 demonstrates NetView switching from a poor BER recorded at D3 and B4B to a lower BER at ground station A5. This explicitly demonstrates that the "Best CCF BER" does not have the lowest BER of all incoming sources at all times. Ground station A-5 consistently produced a low BER compared to D3 and B4B.

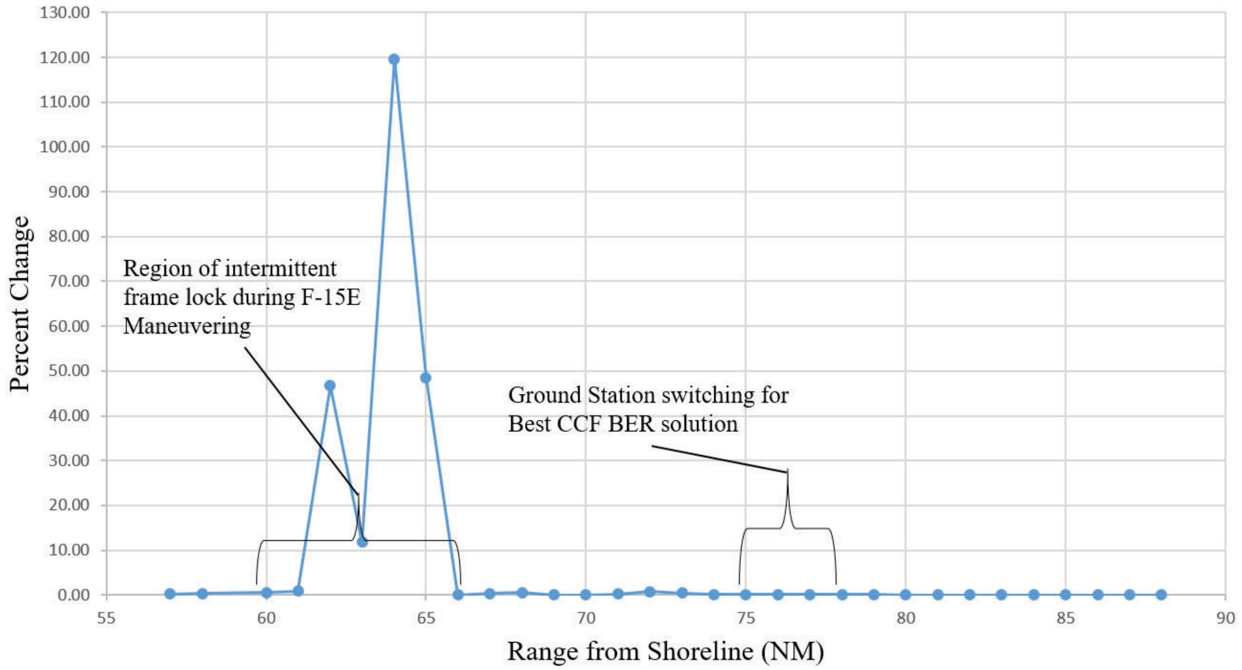


Figure A-7 – Re-rad Performance of Terminator Pod System (% change of Terminator Pod BER vs A5 BER) as a Function of Range From Shoreline

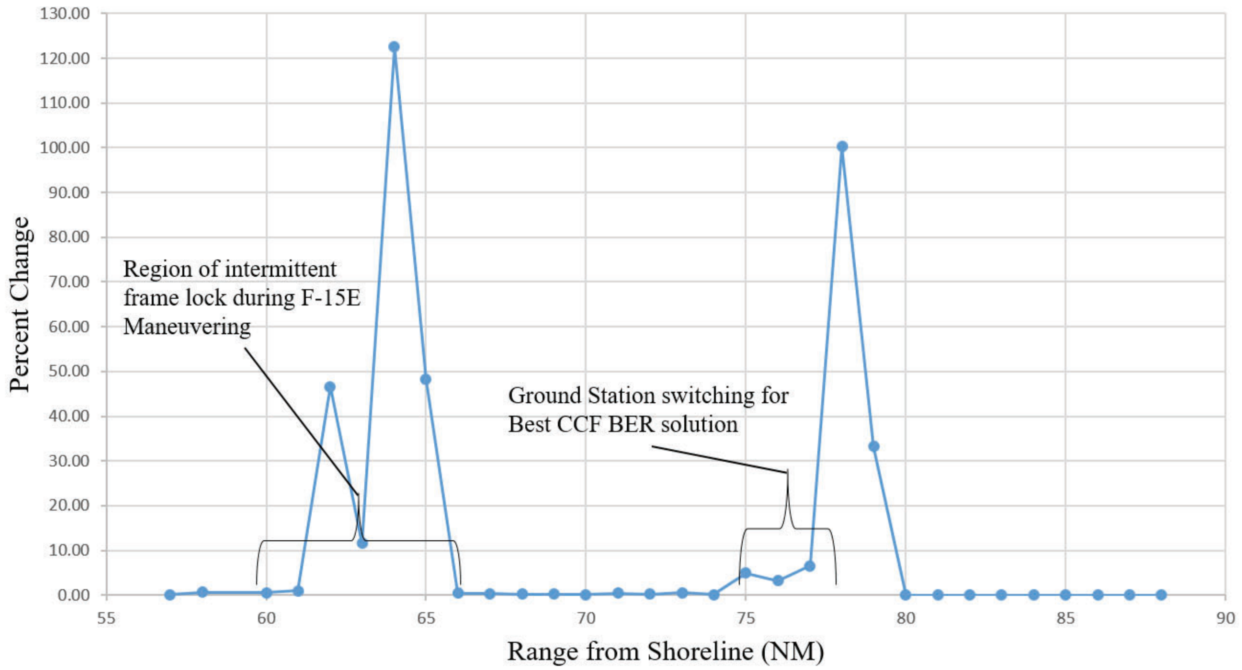


Figure A-8 – Re-rad Performance of Terminator Pod System (% change of Terminator Pod BER vs D3 BER) as a Function of Range From Shoreline

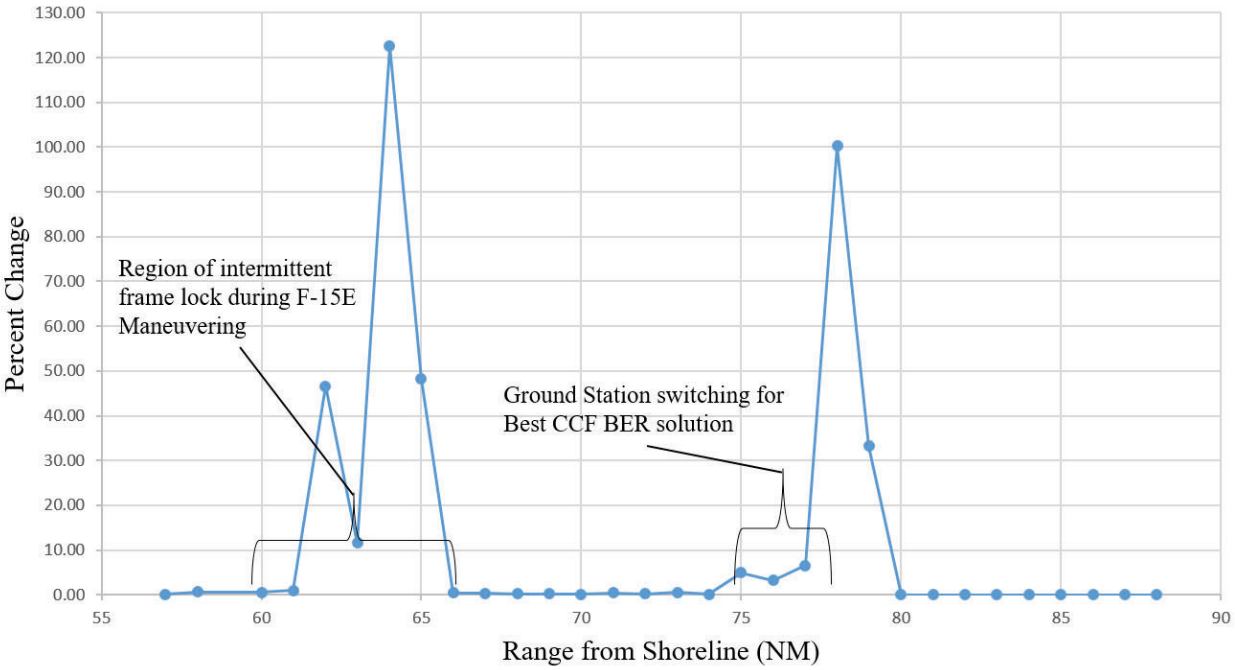


Figure A-9 – Re-rad Performance of Terminator Pod System (% change of Terminator Pod BER vs B4B BER) as a Function of Range From Shoreline

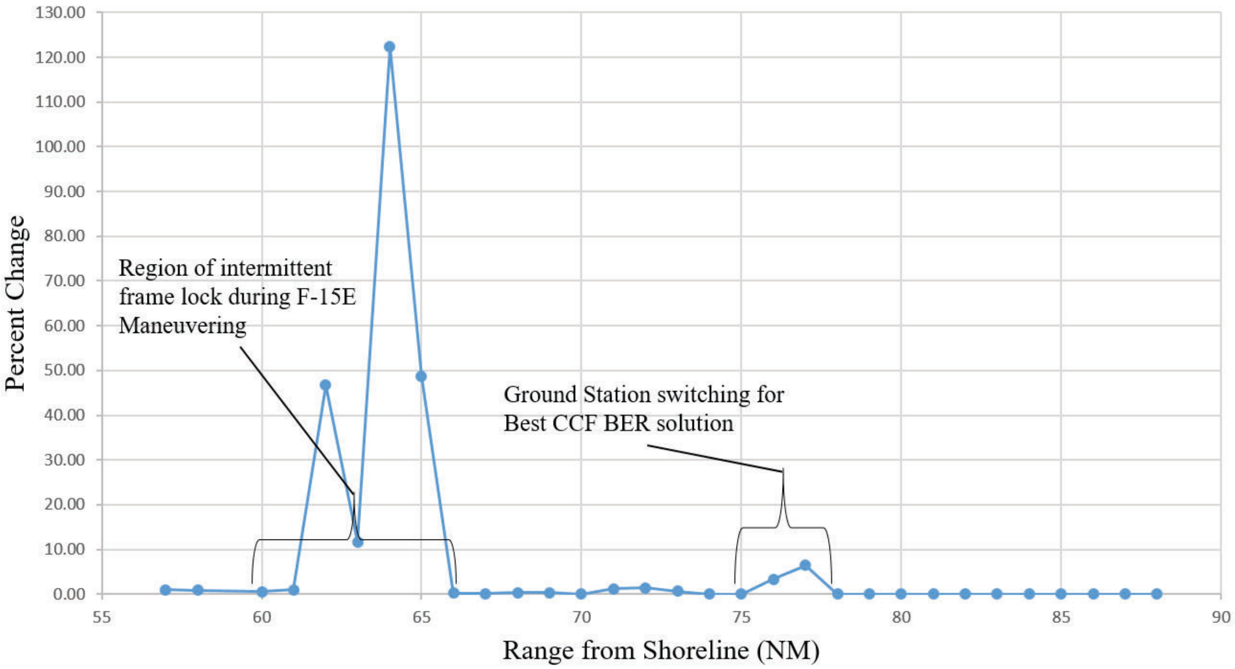


Figure A-10 – Re-rad Performance of Terminator Pod System (% change of Terminator Pod BER vs Best CCF BER) as a Function of Range From Shoreline

Percent change spikes from 61-66 NM, seen in Figures A-7 through A-10, were due to intermittent frame lock while the F-15E was maneuvering. Figure A-10 demonstrates NetView switching from a poor BER recorded at D3 and B4B to a better BER at A5.

2.1.6: Data Distribution

Same as section 1.1.6.

2.1.7: Hardware and Software Requirements

Same as section 1.1.7.

STO 3: WCS Interference

MOP 3.1: Aircraft TM PN15 Bit Error Rate

3.1.1: Required Data

Data requirements were the same as listed in Table C-1 in section 1.1.1. Two data sets were used from Card #3, the 20 NM lateral offset and Card #7 the WCS. The Card #7 data set had the Sabreliner facing the Eglin shoreline with the F-15E in-between and Card #3 was a south to north run that faced out to sea. These two runs were required to compare difference in BER data to observe any WCS interference on the Terminator Pod System TM reception performance.

3.1.2: Data Media and Data Format

Same as section 1.1.2.

3.1.3: Data Reduction

The NetView data export process described in section 1.1.3.1 was used to export both Card #3 and Card #7 data sets for comparison. Once the .txt files were exported and renamed, the MATLAB script “STO3_Terminator_Processing_31Mar2020.m” was used to consolidate the data sets and export to Excel for comparison and data analysis.

The pseudo-code highlighting the major functions of the script is shown below.

STO3_Terminator_Processing_31Mar2020.m pseudo-code:

```
- Declare and read in NetView exported .txt files for Card #3 and #7
- Consolidate Azimuth, Range, BER and MajorFrameLock a matrix for each data set
- Export to two .xls files for binning in Excel
- End Script
```

3.1.4: Data Analysis

The Excel files "STO3_20nmData_31Mar20.xls" and "STO3_WCSData_31Mar20.xls" were opened and manually binned using the same process described in section 1.1.4. Next, the BER from the two runs was compared for similar azimuths to observe any WCS effects when facing the shoreline. Of the 455 samples taken from the sea facing run, only 17 entries had similar azimuths as those collected from the shore facing run. Those 17 samples all had a BER of 0, representing perfect transmission and thus no interference. All of the samples from the shore facing run were used in the analysis.

3.1.5: Data Analysis Products

Two tables, Tables A-6 and A-7, were generated showing the difference between the shore and sea facing runs.

Azimuth (deg)	Range (NM)	BER	Samples
0	19.9	0	5
-1	19.9	1.52E-09	33
-2	20.1	1.18E-09	85
-3	20.3	1.7E-09	59

Table A-6 –Terminator Pod System BER While Pointed Towards WCS Sources

Azimuth (deg)	Range (NM)	BER	Samples
0	18.0	0	4
-1	18.1	0	4
-2	18.1	0	4
-3	18.1	0	5

Table A-7 –Terminator Pod System BER While Pointed Away From WCS Sources

A comparison with a BER heat map similar to those presented in section 1.1.5 was not used, as only 4° of azimuth were captured. The BER heat map would only show a single bin, defined as 5° of azimuth, so tables were used for comparison as an alternative.

3.1.6: Data Distribution

Same as section 1.1.6.

3.1.7: Hardware and Software Requirements

Same as section 1.1.7.

STO 4: TM Reception Performance with Additional Gain

MOP 4.1: Aircraft TM PN15 Bit Error Rate

4.1.1: Required Data

Data requirements were the same as MOP 1.1.1 with the addition of the Stage 2 combiner BER values from the Sabreliner Chapter 10 file, shown below in Table A-8.

Data Grouping	Parameter	Platform	Data Source	Engineering Units
Sabreliner 2nd Stage Combiner	TotalBitErrors_2	Sabreliner	Sabreliner PN15 Data .CH10 files: "File002_17032020_18185300.ch10" & "File003_17032020_20421000.ch10"	Double
	BitErrorRate1Sec_2			Double
	BitErrorRate1Sec1Hz_2			Double
	Total bits_2			Double
	MinorFrameLockStatus_2			Binary
	MajorFrameLockStatus_2			Binary
	FrameCounter_2			Double
	Irig Time_2			Seconds

Table A-8 – Additional Data Parameters for MOP 4.1

4.1.2: Data Media and Data Format

Same as section 1.1.2.

4.1.3: Data Reduction

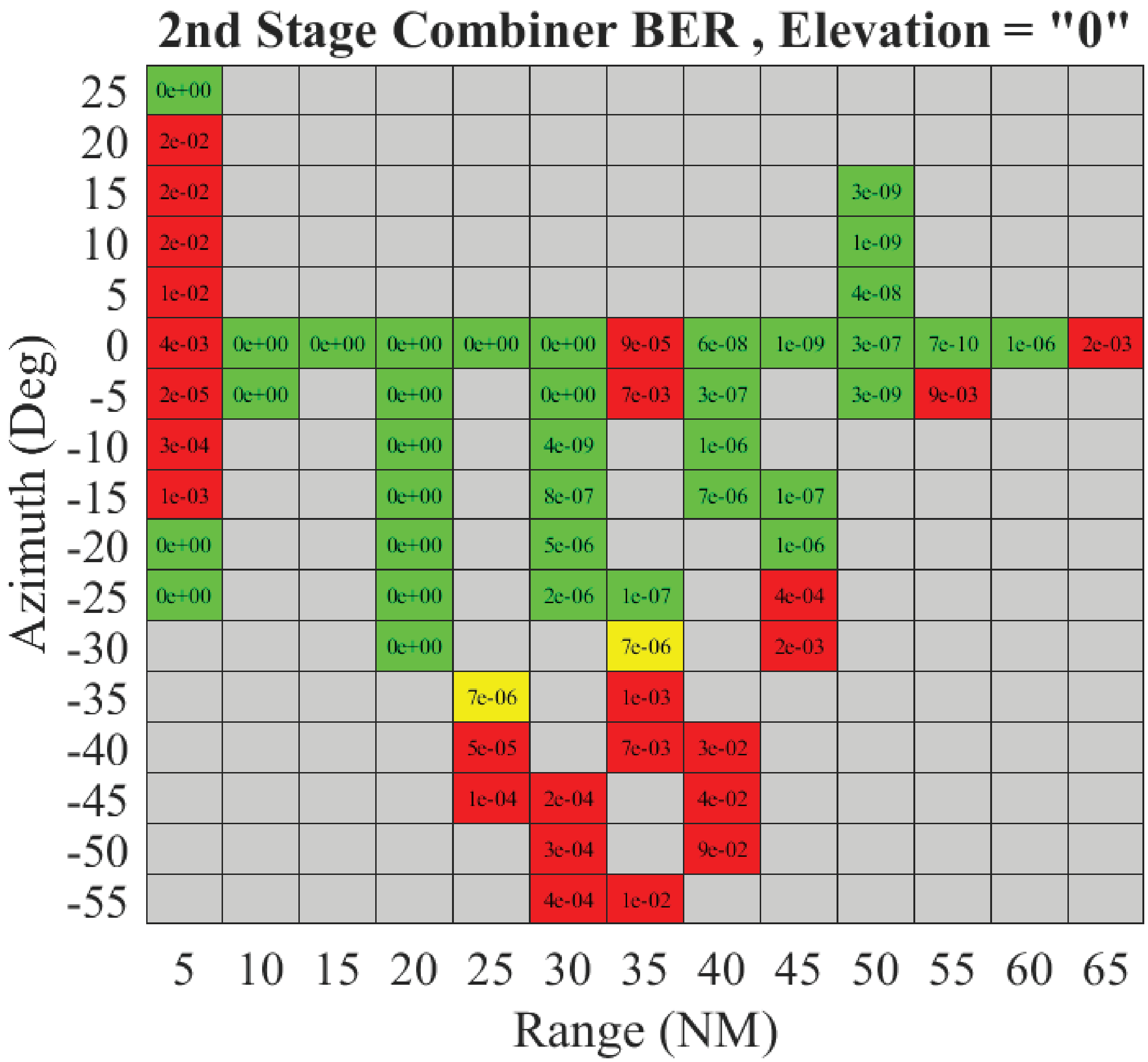
Same as section 1.1.3.

4.1.4: Data Analysis

The MATLAB scripts listed in section 1.1.4 were used to calculate the geometry and BER value heat map for both the Stage 2 and 3 combiners. The initial and final heat map plots for the Stage 2 combiner were generated using the steps listed in section 1.1.4. The comparison of the differences between the 2 and 3 Stage combiners are discussed with each corresponding plot.

4.1.5: Data Analysis Products

The initial heat maps showed the same high BER due to masking as discussed in section 1.1.5 and are only shown for completeness. The data sets for the Stage 2 combiner were recut as discussed in that section and the plots for the initial findings are only shown for completeness and will not be discussed further. The initial and final heat map plots for the Stage 2 combiner are shown below in Figures A-11, A-12, A-13, and A-15

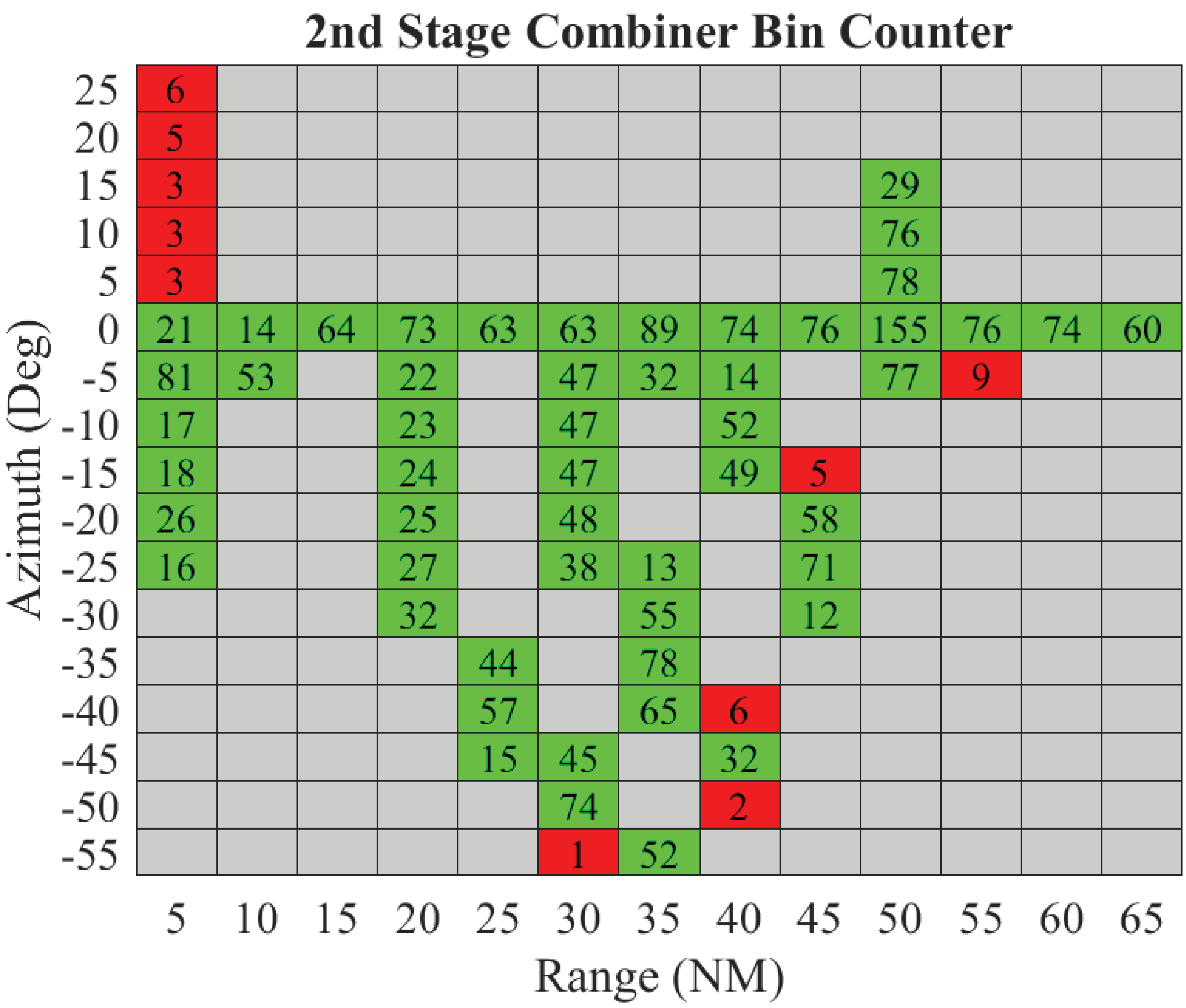


2nd Stage Combiner BER , Elevation = "0"

Range (NM)

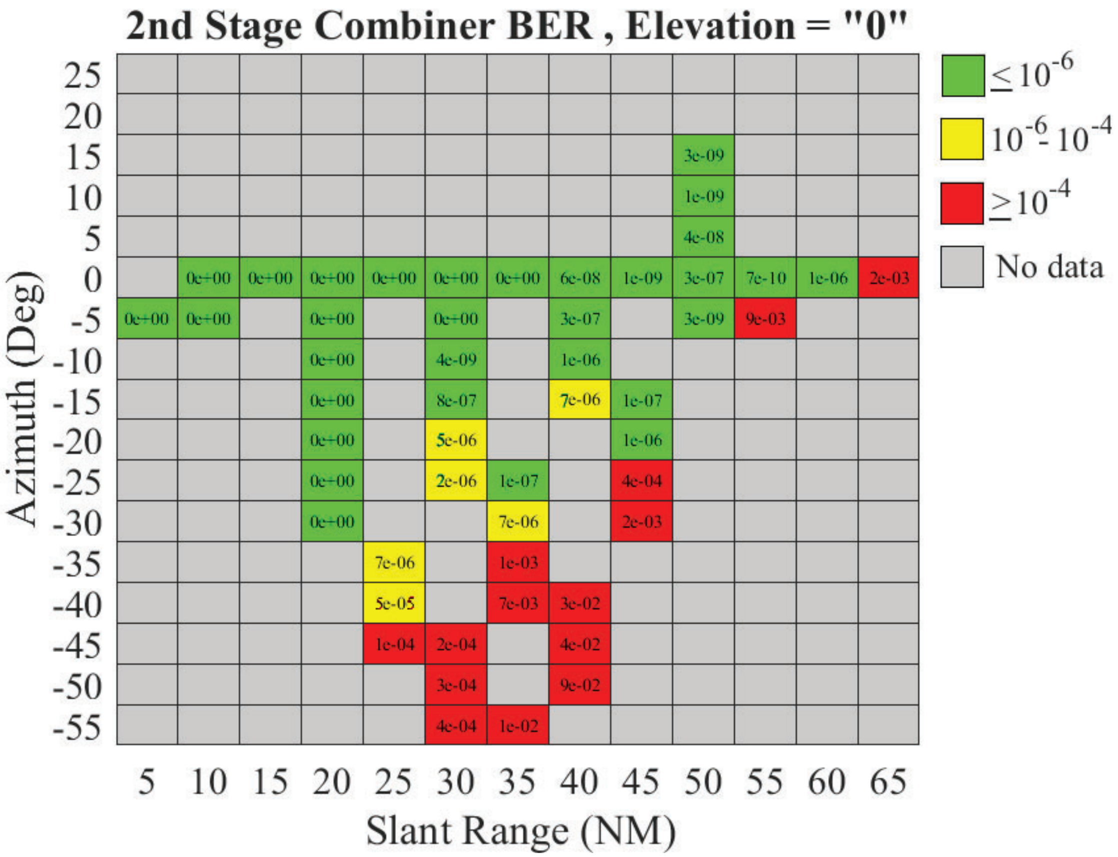
Azimuth (Deg)	5	10	15	20	25	30	35	40	45	50	55	60	65
25	0e+00												
20	2e-02												
15	2e-02									3e-09			
10	2e-02									1e-09			
5	1e-02									4e-08			
0	4e-03	0e+00	0e+00	0e+00	0e+00	0e+00	9e-05	6e-08	1e-09	3e-07	7e-10	1e-06	2e-03
-5	2e-05	0e+00		0e+00		0e+00	7e-03	3e-07		3e-09	9e-03		
-10	3e-04			0e+00		4e-09		1e-06					
-15	1e-03			0e+00		8e-07		7e-06	1e-07				
-20	0e+00			0e+00		5e-06			1e-06				
-25	0e+00			0e+00		2e-06	1e-07		4e-04				
-30				0e+00			7e-06		2e-03				
-35					7e-06		1e-03						
-40					5e-05		7e-03	3e-02					
-45					1e-04	2e-04		4e-02					
-50						3e-04		9e-02					
-55						4e-04	1e-02						

Figure A-11 – Initial Stage 2 Combiner BER Heat Map



Azimuth (Deg) \ Range (NM)	5	10	15	20	25	30	35	40	45	50	55	60	65
25	6												
20	5												
15	3									29			
10	3									76			
5	3									78			
0	21	14	64	73	63	63	89	74	76	155	76	74	60
-5	81	53		22		47	32	14		77	9		
-10	17			23		47		52					
-15	18			24		47		49	5				
-20	26			25		48			58				
-25	16			27		38	13		71				
-30				32			55		12				
-35					44		78						
-40					57		65	6					
-45					15	45		32					
-50						74		2					
-55						1	52						

Figure A-12 – Initial Stage 2 Combiner Bin Heat Map



Azimuth (Deg)	5	10	15	20	25	30	35	40	45	50	55	60	65
25													
20													
15										3e-09			
10										1e-09			
5										4e-08			
0		0e+00	0e+00	0e+00	0e+00	0e+00	0e+00	6e-08	1e-09	3e-07	7e-10	1e-06	2e-03
-5	0e+00	0e+00		0e+00		0e+00		3e-07		3e-09	9e-03		
-10				0e+00		4e-09		1e-06					
-15				0e+00		8e-07		7e-06	1e-07				
-20				0e+00		5e-06			1e-06				
-25				0e+00		2e-06	1e-07		4e-04				
-30				0e+00			7e-06		2e-03				
-35					7e-06		1e-03						
-40					5e-05		7e-03	3e-02					
-45					1e-04	2e-04		4e-02					
-50						3e-04		9e-02					
-55						4e-04	1e-02						

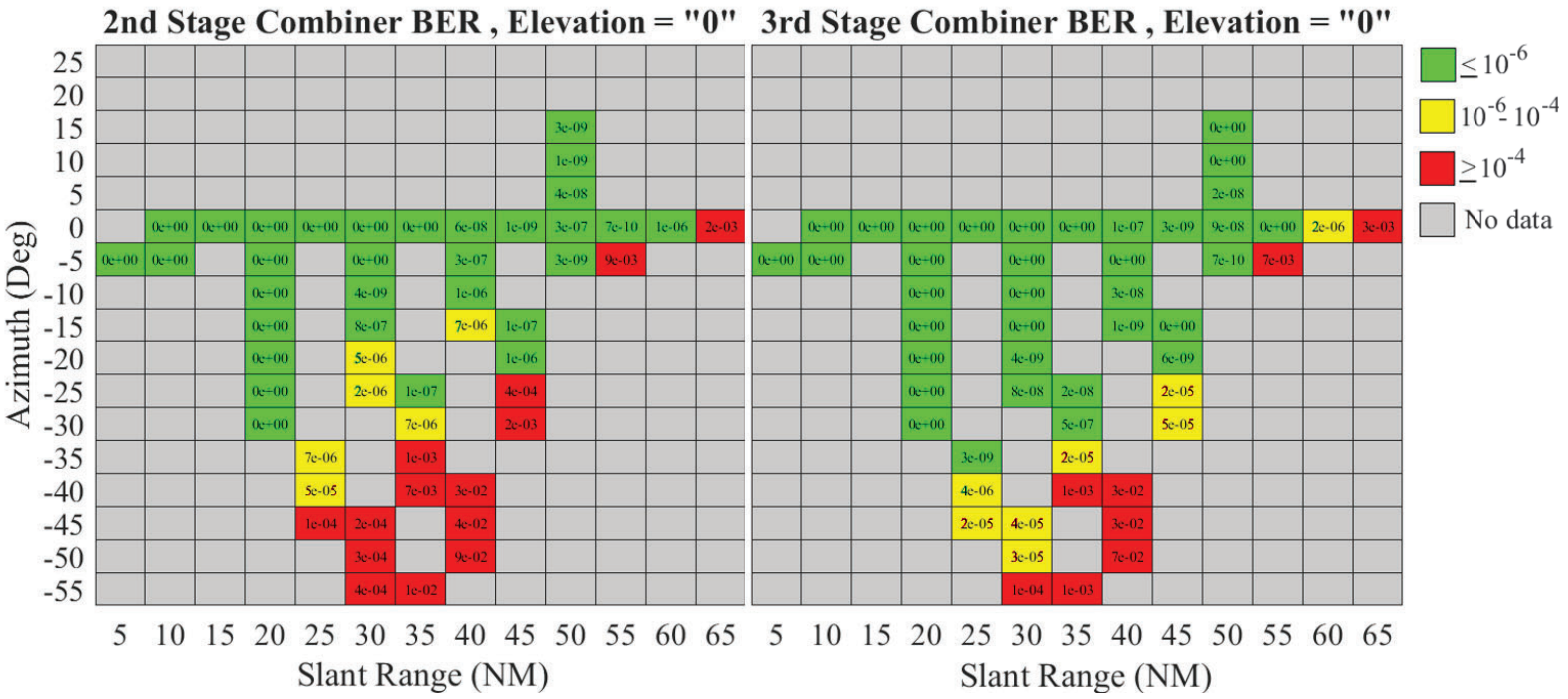
Figure A-13 – Final Stage 2 Combiner BER Heat Map

The Stage 2 combiner results in Figure A-13 show the Terminator Pod System was able to receive the PN15 signal with a BER of 2x10^{-3} within the 65 NM bin, 1x10^{-6} within the 60 NM Bin, and 7x10^{-10} within the 55 NM bin when directly along the 0° azimuth or "boresight" region. Since there was no evidence of masking shown when reviewing the raw TSPI data, the majority of the high BER values that skew the 65 NM bin were the last few samples at the end of the maneuver. These Stage 2 combiner values along boresight did show a higher BER when compared to the Stage 3 combiner, although both were still well within the desirable threshold.

Along boresight, the antenna pattern at 20 NM was in the desirable region at -30°, narrowed to -25° at 35 NM, -20° at 45 NM, and 15° at 50 NM. Compared to the Stage 3 combiner results, the Stage 2 was narrower by approximately 5° azimuth at the closer distances but then equally matched the desirable regions at 45 NM and beyond.

While the BER was diminished more off of boresight, the boresight BER was still within the desirable regions matching or exceeding the measured BER for the Stage 3 combiner. With the four-antenna configuration using the Stage 2 combiner, the Terminator Pod System provided desirable BER values out to 60 NM at azimuths ranging from -30 to +15°. For future test missions that require a FTS signal that would require the use of only Stage 2 combiners to receive the data signals from a test asset, the Terminator Pod System should still provide adequate margin in range and azimuth for test setup and execution.

Both Stage 2 and Stage 3 combiner heat maps are shown side by side in Figure A-14 below for visual comparison.



2nd Stage Combiner BER , Elevation = "0"

Azimuth (Deg)	5	10	15	20	25	30	35	40	45	50	55	60	65
25													
20													
15										3e-09			
10										1e-09			
5										4e-08			
0		0e+00	0e+00	0e+00	0e+00	0e+00	0e+00	6e-08	1e-09	3e-07	7e-10	1e-06	2e-03
-5	0e+00	0e+00		0e+00		0e+00		3e-07		3e-09	9e-03		
-10				0e+00		4e-09		1e-06					
-15				0e+00		8e-07		7e-06	1e-07				
-20				0e+00		5e-06			1e-06				
-25				0e+00		2e-06	1e-07		4e-04				
-30				0e+00			7e-06		2e-03				
-35					7e-06		1e-03						
-40					5e-05		7e-03	3e-02					
-45					1e-04	2e-04		4e-02					
-50						3e-04		9e-02					
-55						4e-04	1e-02						

Slant Range (NM)

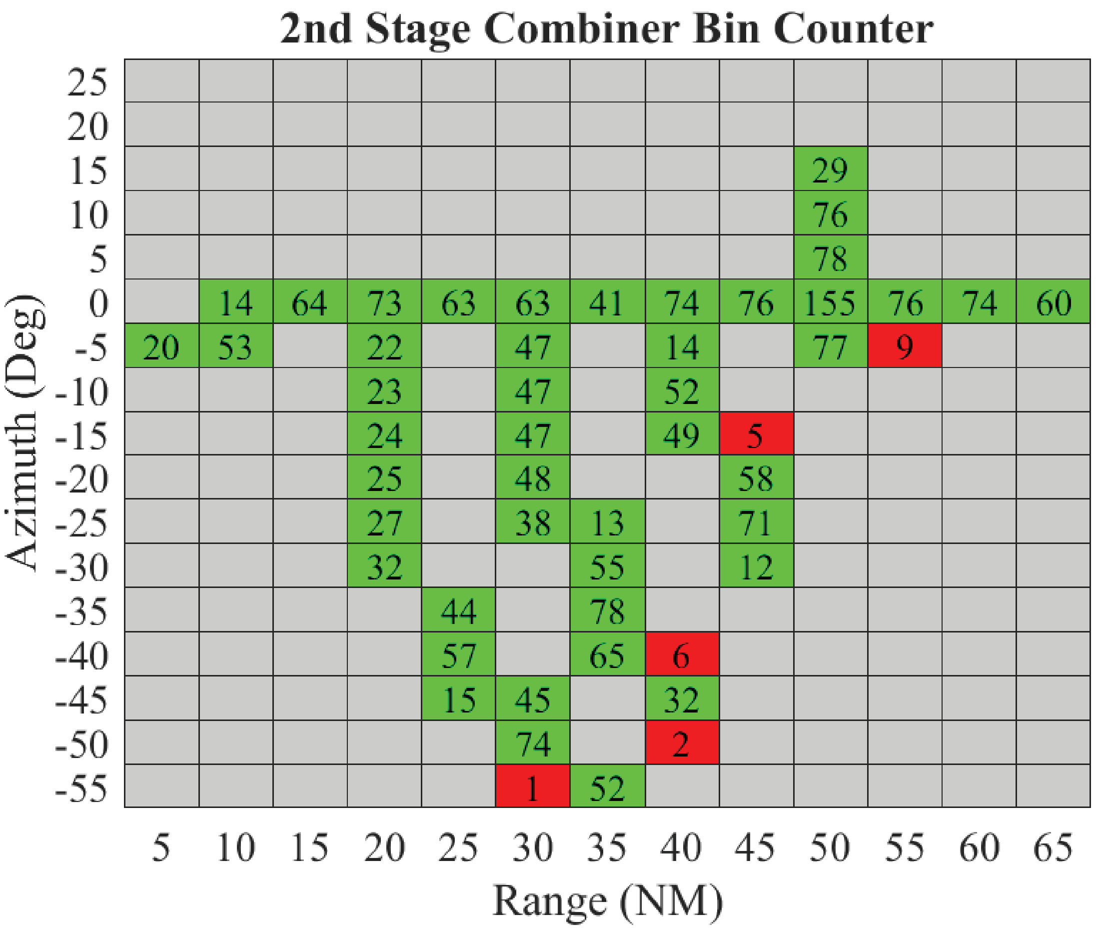
3rd Stage Combiner BER , Elevation = "0"

Azimuth (Deg)	5	10	15	20	25	30	35	40	45	50	55	60	65
25													
20													
15										0e+00			
10										0e+00			
5										2e-08			
0		0e+00	0e+00	0e+00	0e+00	0e+00	0e+00	1e-07	3e-09	9e-08	0e+00	2e-06	3e-03
-5	0e+00	0e+00		0e+00		0e+00		0e+00		7e-10	7e-03		
-10				0e+00		0e+00		3e-08					
-15				0e+00		0e+00		1e-09	0e+00				
-20				0e+00		4e-09			6e-09				
-25				0e+00		8e-08	2e-08		2e-05				
-30				0e+00			5e-07		5e-05				
-35					3e-09		2e-05						
-40					4e-06		1e-03	3e-02					
-45					2e-05	4e-05		3e-02					
-50						3e-05		7e-02					
-55						1e-04	1e-03						

Slant Range (NM)

🟩 ≤ 10^{-6}
🟨 10^{-6}- 10^{-4}
🟥 ≥ 10^{-4}
⬜ No data

Figure A-14 – Stage 2 and 3 Combiner BER Comparison



2nd Stage Combiner Bin Counter

Azimuth (Deg) \ Range (NM)	5	10	15	20	25	30	35	40	45	50	55	60	65
25													
20													
15										29			
10										76			
5										78			
0		14	64	73	63	63	41	74	76	155	76	74	60
-5	20	53		22		47		14		77	9		
-10				23		47		52					
-15				24		47		49	5				
-20				25		48			58				
-25				27		38	13		71				
-30				32			55		12				
-35					44		78						
-40					57		65	6					
-45					15	45		32					
-50						74		2					
-55						1	52						

Figure A-15 – Final Stage 2 Combiner Bin Heat Map

Figure A-15 shows the number of BER one second samples collected in each bin. The same four bins did not meet the 10-sample threshold. Although the correspond BERs were not removed from Figure A-13, the only results that show concern is the BER values at 55 NM and -5° azimuth since it is a clear drop off in BER compared to the surrounding bins. The final heat mat provided in the main body of the report will exclude these bins.

4.1.6: Data Distribution

Same as section 1.1.6

4.1.7: Hardware and Software Requirements

Same as section 1.1.7

STO 5: Operator Station Usability

MOP 5.1: Operator Comments

5.1.1: Required Data

Page 2 of the Survey Packet filled in with comments were collected and consolidated from each TC and DE on the Sabreliner over the course of the four sorties flown during the test execution window. Due to the F-15E mission cancel soon after the Sabreliner was airborne, sortie 3 only has data from TC2.

5.1.2: Data Media and Data Format

The paper copy of the Survey Packet was collected post-flight and scanned into Appendix B.

5.1.3: Data Reduction

All comments for each question in the survey packet were reviewed, and follow-up questions or clarifications to comments were pursued.

5.1.4: Data Analysis

Consolidated comments were qualitatively evaluated with respect to the Terminator Pod System usability and its ability to be used as a test support asset. Images taken of the Terminator Pod System during test were included to support the comments.

5.1.5: Data Analysis Products

A data analysis summary, as well as results and conclusions were provided.

5.1.6: Data Distribution

Same as section 1.1.6.

5.1.7: Hardware and Software Requirements

Same as section 1.1.7.

MOP 5.2: Operator System Usability Survey (SUS) Ratings

5.2.1: Required Data

Page 3 of the Survey Packet filled in with comments were collected and consolidated from each TC and DE on the Sabreliner over the course of the four sorties flown during the test execution window.

5.2.2: Data Media and Data Format

The paper copy of the Survey Packet was collected post-flight and scanned for into Appendix B.

5.2.3: Data Reduction

The raw SUS values were consolidated in MATLAB for analysis.

5.2.4: Data Analysis

The raw SUS values were consolidated and plotted in MATLAB using the script "STO5_Terminator_SUS_Analysis_24Mar20.m". The script calculated each operator's score independently and plotted the final SUS score sorted by sortie number and crew position. The raw SUS scores are converted from the raw survey to a 100-point scale through the process described in reference 5.

The pseudo-code highlighting the major functions of the script is shown below.

STO5_Terminator_SUS_Analysis_24Mar20.m pseudo-code:

```
- Consolidate data collected from the SUS survey
- Calculate the SUS score for each person
- Plot the Overall SUS scores collected
- End Script
```

There were no data for the DE during sortie 3 as no testing was conducted in this role after the F-15E ground abort prematurely ended the Sabreliner sortie. The SUS outputted numerical scores on a 0 to 100 scale. The raw SUS scores were useful in providing an overall metric of the System's usability, backed up by operator comments. Overlaying the "adjective rating statements" (Poor, Ok, Good, etc.) provided a meaning to the raw SUS scores.

The data showed that the Terminator Pod System generally performed poorly, with sortie 1 performing in the 'Worst Imaginable' region. This was attributable to the initial learning curve encountered during sortie 1, where no previous experience in operating the Terminator Pod System was available within the group. Sortie 2 achieved higher scores than sortie 1, with one score inside the 'Ok' region. This was due to keeping one team member on the Sabreliner from the previous sortie to provide much-needed continuity in System operation, and the creation of the project file 'preset' to reduce the time lost during NetView resets. This 'Marginal' score was the only score during the test that fell above the 'Not Acceptable' range. The score for sortie 3 was from a new TC on their first flight operating the Terminator Pod System, explaining why the score was back down on the 'Poor'- 'Worst Imaginable' boundary. Sortie 4 had the same team as sortie 3 and showed an upward trend with the ratings. Most apparent was the increase in score from sortie 2 to sortie 4 from DE #2.

5.2.5: Data Analysis Products

The final SUS results are shown below in figure A-16.

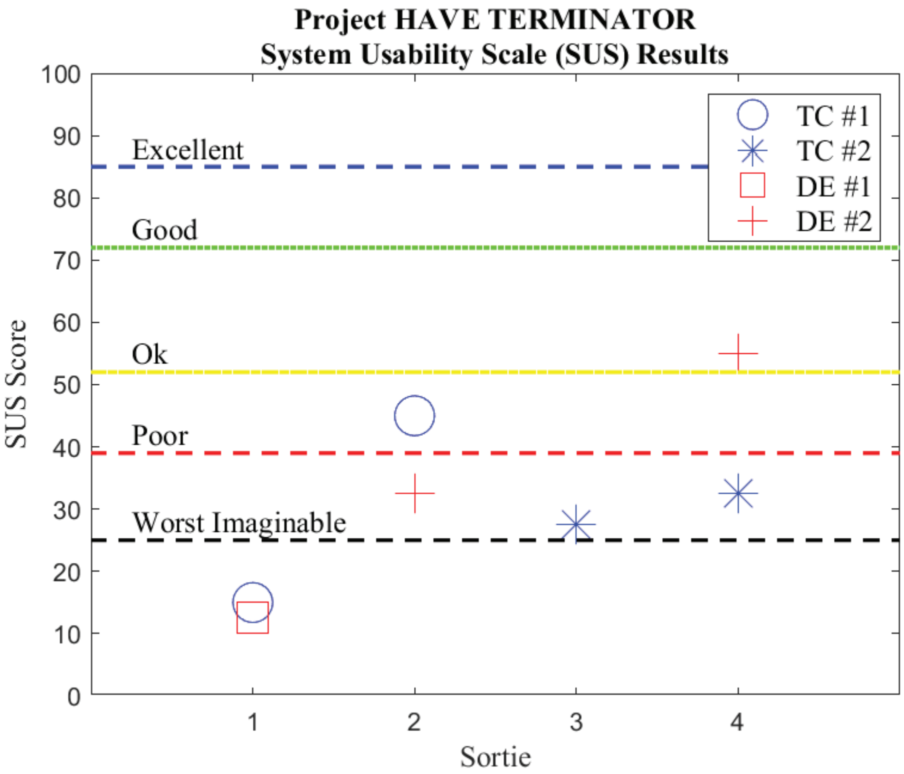


Figure A-16 –Summary Plot for SUS Results

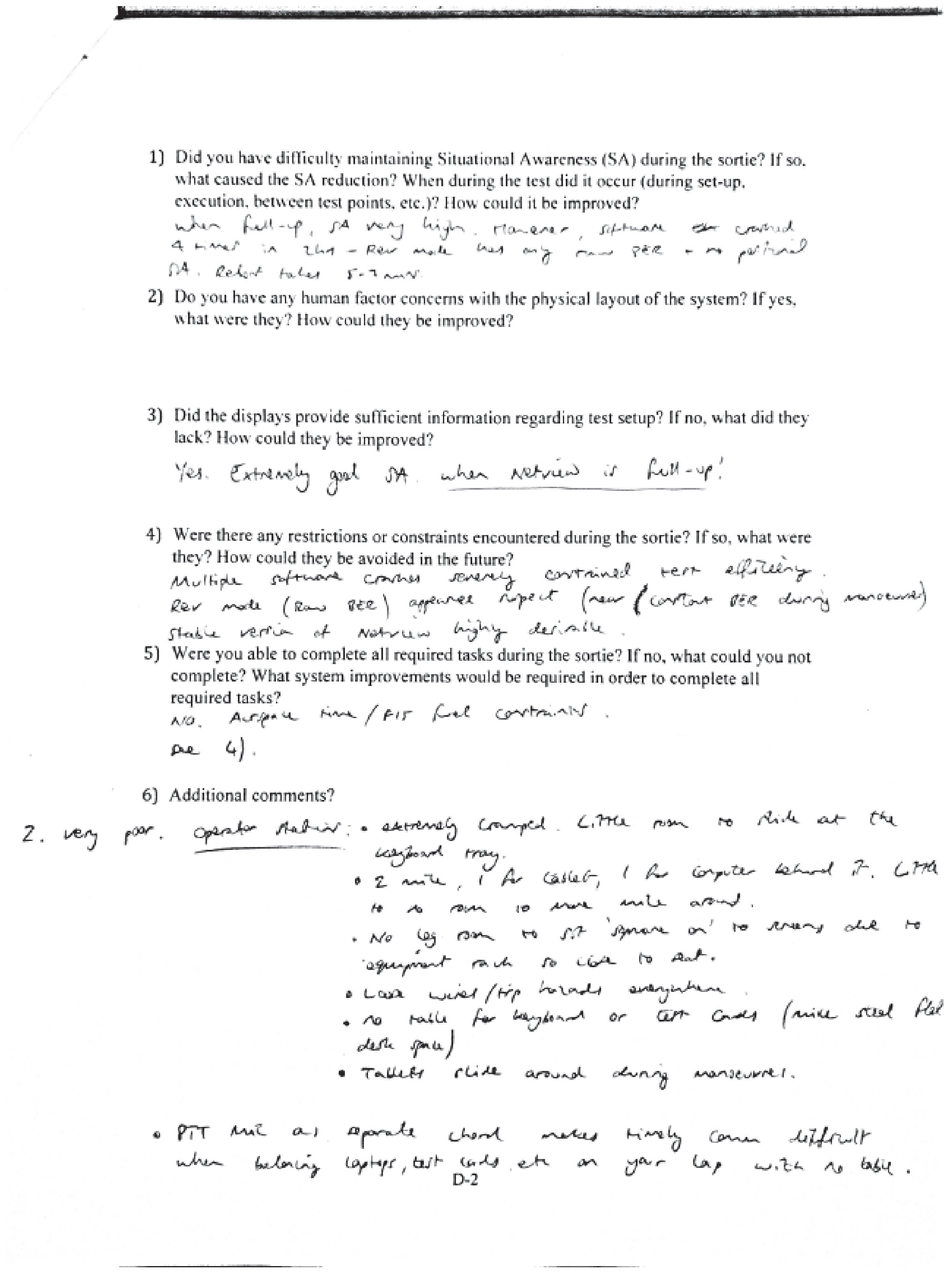
5.2.6: Data Distribution

Same as section 1.1.6.

5.2.7: Hardware and Software Requirements

Same as section 1.1.7.

APPENDIX B – COMPLETED SYSTEM USABILITY SURVEYS



1) Did you have difficulty maintaining Situational Awareness (SA) during the sortie? If so, what caused the SA reduction? When during the test did it occur (during set-up, execution, between test points, etc.)? How could it be improved?

when full-up, SA very high. However, software crashed 4 times in 2hr - Rev mode has only raw BER + no positional SA. Reboot takes 5-7 min.

2) Do you have any human factor concerns with the physical layout of the system? If yes, what were they? How could they be improved?

3) Did the displays provide sufficient information regarding test setup? If no, what did they lack? How could they be improved?

Yes. Extremely good SA when Netview is full-up!

4) Were there any restrictions or constraints encountered during the sortie? If so, what were they? How could they be avoided in the future?

Multiple software crashes severely constrained test efficiency. Rev mode (Raw BER) appeared suspect (near (constant BER during manoeuvres) Stable version of Netview highly desirable.

5) Were you able to complete all required tasks during the sortie? If no, what could you not complete? What system improvements would be required in order to complete all required tasks?

No. Airspace time / F15 fuel constraints.

See 4).

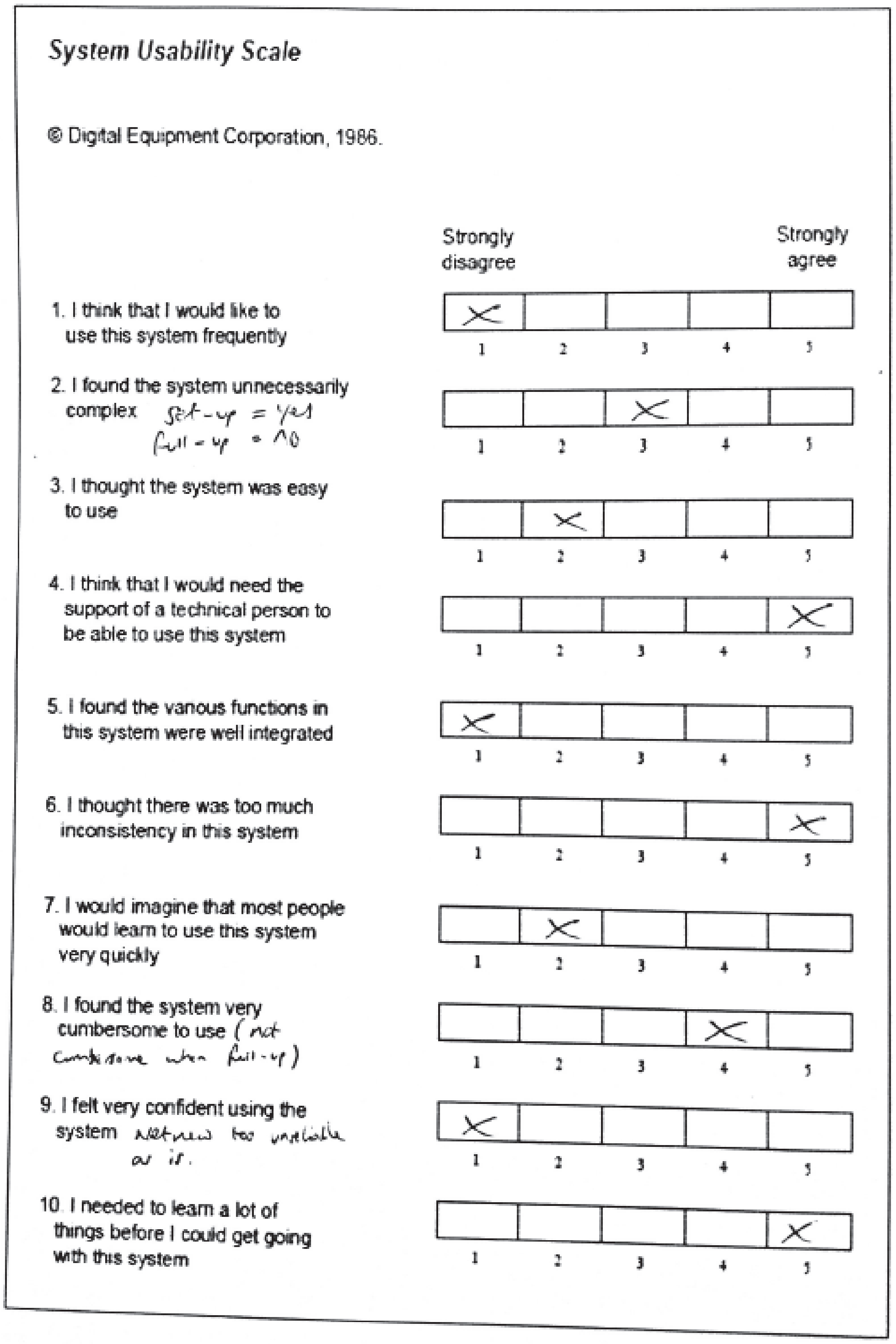
6) Additional comments?

2. very poor. Operator station:
- extremely cramped. Little room to write at the keyboard tray.
- 2 seats, 1 for cables, 1 for computer behind it. Little to no room to move seats around.
- No leg room to sit 'square on' to [illegible] due to equipment rack so close to seat.
- Loose wires / trip hazards everywhere.
- no table for keyboard or test cards (need steel flat desk space)
- Tablets slide around during manoeuvres.

- PTT mic as separate chord makes timely comm difficult when balancing laptops, test cards etc on your lap with no table.

D-2

Figure B-1 – Sortie 1 DE1 comments



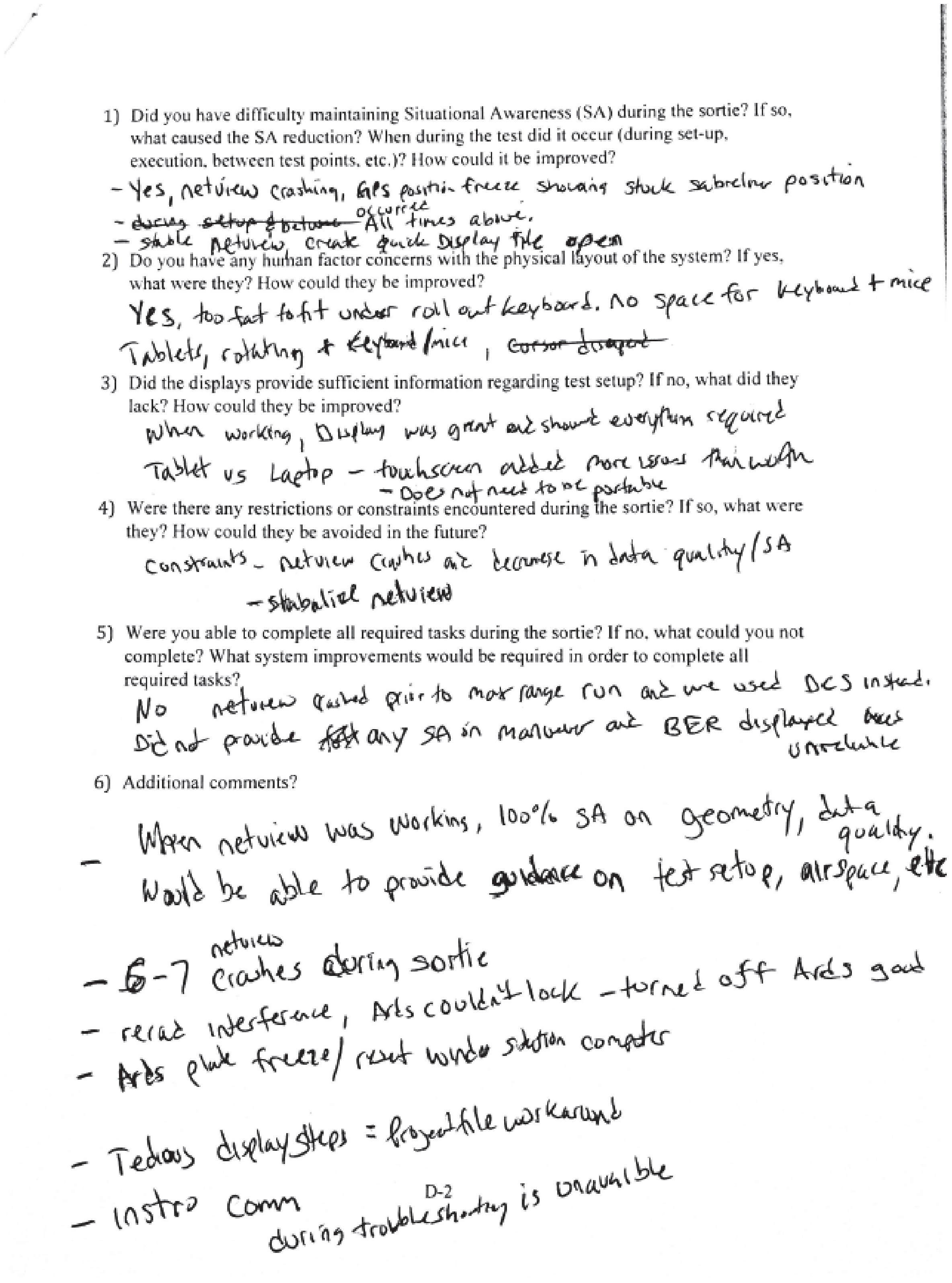
System Usability Scale

© Digital Equipment Corporation, 1986.

	Strongly disagree				Strongly agree
	1	2	3	4	5
1. I think that I would like to use this system frequently	☒	☐	☐	☐	☐
2. I found the system unnecessarily complex set-up = yes full-up = no	☐	☐	☒	☐	☐
3. I thought the system was easy to use	☐	☒	☐	☐	☐
4. I think that I would need the support of a technical person to be able to use this system	☐	☐	☐	☐	☒
5. I found the various functions in this system were well integrated	☒	☐	☐	☐	☐
6. I thought there was too much inconsistency in this system	☐	☐	☐	☐	☒
7. I would imagine that most people would learn to use this system very quickly	☐	☒	☐	☐	☐
8. I found the system very cumbersome to use (not cumbersome when full-up)	☐	☐	☐	☒	☐
9. I felt very confident using the system network too unreliable as is.	☒	☐	☐	☐	☐
10. I needed to learn a lot of things before I could get going with this system	☐	☐	☐	☐	☒

D-3

Figure B-2 – Sortie 1 DE1 ratings



1) Did you have difficulty maintaining Situational Awareness (SA) during the sortie? If so, what caused the SA reduction? When during the test did it occur (during set-up, execution, between test points, etc.)? How could it be improved?

- Yes, netview crashing, GPS position freeze showing stuck sabreliner position
- ~~during setup & between~~ occurree All times above.
- stable netview, create quick Display file open

2) Do you have any human factor concerns with the physical layout of the system? If yes, what were they? How could they be improved?

Yes, too fat to fit under roll out keyboard. No space for keyboard + mice

Tablets, rotating + keyboard/mice, ~~Cursor [illegible]~~

3) Did the displays provide sufficient information regarding test setup? If no, what did they lack? How could they be improved?

When working, Display was great and showed everything required

Tablet vs Laptop – touchscreen added more issues than worth

– Does not need to be portable

4) Were there any restrictions or constraints encountered during the sortie? If so, what were they? How could they be avoided in the future?

Constraints – netview crashes and decrease in data quality/SA

– stabalize netview

5) Were you able to complete all required tasks during the sortie? If no, what could you not complete? What system improvements would be required in order to complete all required tasks?

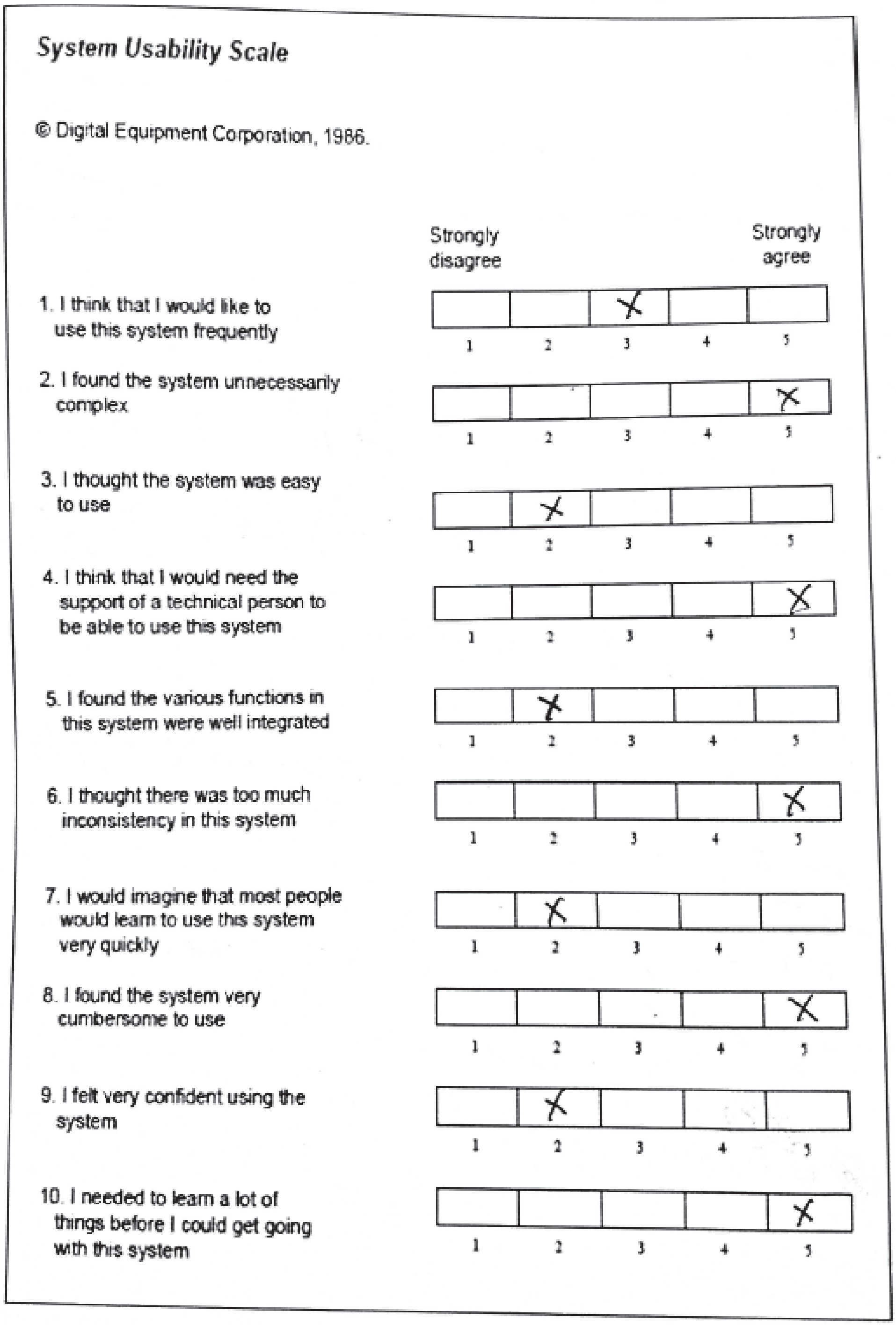
No netview crashed prior to max range run and we used DCS instead. Did not provide ~~fast~~ any SA in maneuver and BER displayed was unreliable

6) Additional comments?

- When netview was working, 100% SA on geometry, data quality. Would be able to provide guidance on test setup, airspace, etc
- 6-7 netview crashes during sortie
- reread interference, Ards couldn't lock – turned off Ards good
- Ards plate freeze/ reset window station computer
- Tedious display steps = project file workaround
- instro comm during troubleshooting is unavailable

D-2

Figure B-3 – Sortie 1 TC1 comments



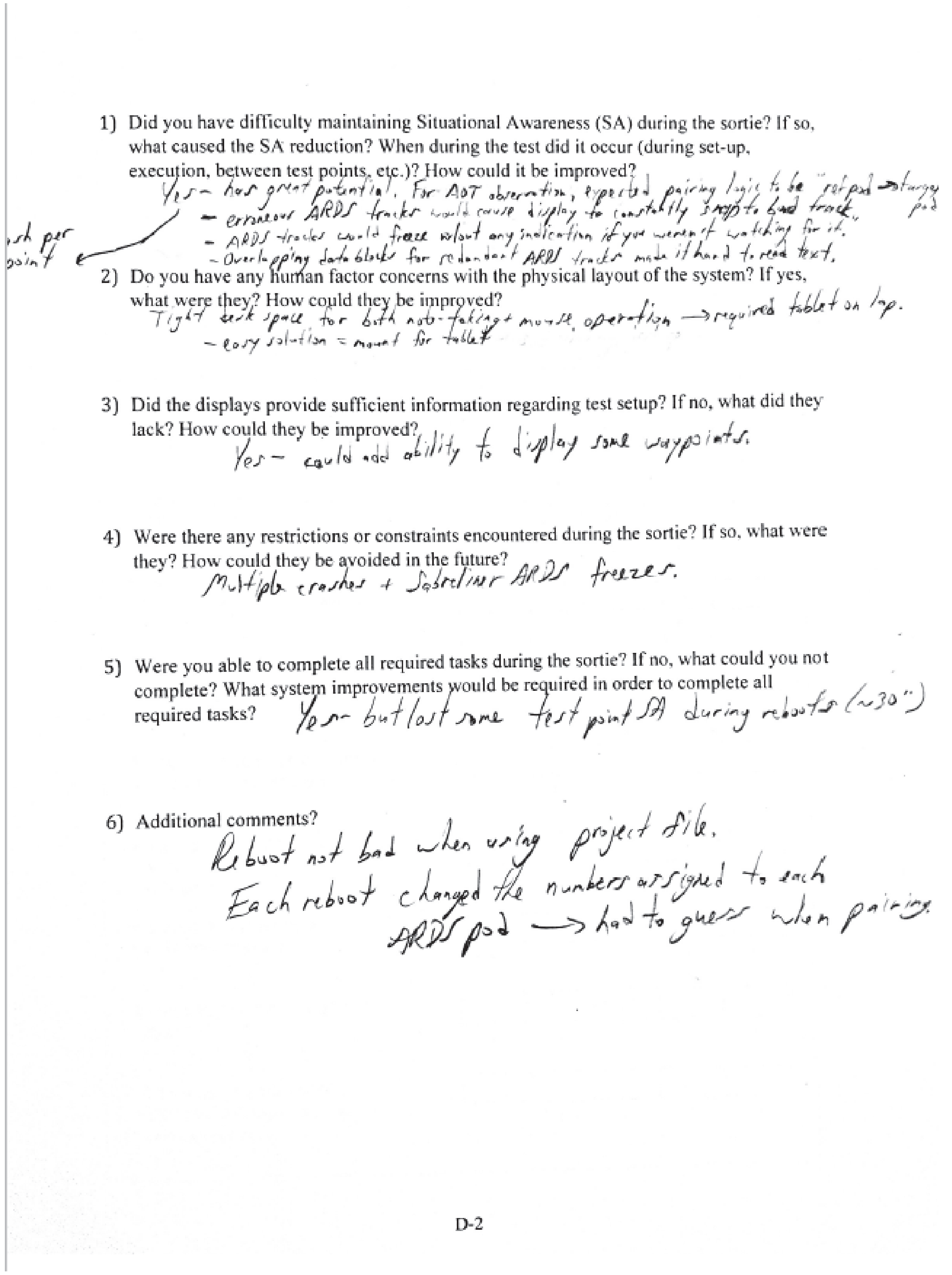
System Usability Scale

© Digital Equipment Corporation, 1986.

	Strongly disagree				Strongly agree
	1	2	3	4	5
1. I think that I would like to use this system frequently	☐	☐	☒	☐	☐
2. I found the system unnecessarily complex	☐	☐	☐	☐	☒
3. I thought the system was easy to use	☐	☒	☐	☐	☐
4. I think that I would need the support of a technical person to be able to use this system	☐	☐	☐	☐	☒
5. I found the various functions in this system were well integrated	☐	☒	☐	☐	☐
6. I thought there was too much inconsistency in this system	☐	☐	☐	☐	☒
7. I would imagine that most people would learn to use this system very quickly	☐	☒	☐	☐	☐
8. I found the system very cumbersome to use	☐	☐	☐	☐	☒
9. I felt very confident using the system	☐	☒	☐	☐	☐
10. I needed to learn a lot of things before I could get going with this system	☐	☐	☐	☐	☒

D-3

Figure B-4 – Sortie 1 TC1 ratings



1) Did you have difficulty maintaining Situational Awareness (SA) during the sortie? If so, what caused the SA reduction? When during the test did it occur (during set-up, execution, between test points, etc.)? How could it be improved?

Yes – has great potential. For ADT observation, expected pairing logic to be "tgt pod → target pod"
- erroneous ARDS tracks would cause display to constantly snap to bad track.
- ARDS tracks would freeze w/out any indication if you weren't watching for it.
- Overlapping data blocks for redundant ARDS tracks made it hard to read text.

ch per
point

2) Do you have any human factor concerns with the physical layout of the system? If yes, what were they? How could they be improved?

Tight desk space for both note-taking + mouse operation → required tablet on lap.
- easy solution = mount for tablet

3) Did the displays provide sufficient information regarding test setup? If no, what did they lack? How could they be improved?

Yes – could add ability to display some waypoints.

4) Were there any restrictions or constraints encountered during the sortie? If so, what were they? How could they be avoided in the future?

Multiple crashes + Sabreliner ARDS freezes.

5) Were you able to complete all required tasks during the sortie? If no, what could you not complete? What system improvements would be required in order to complete all required tasks?

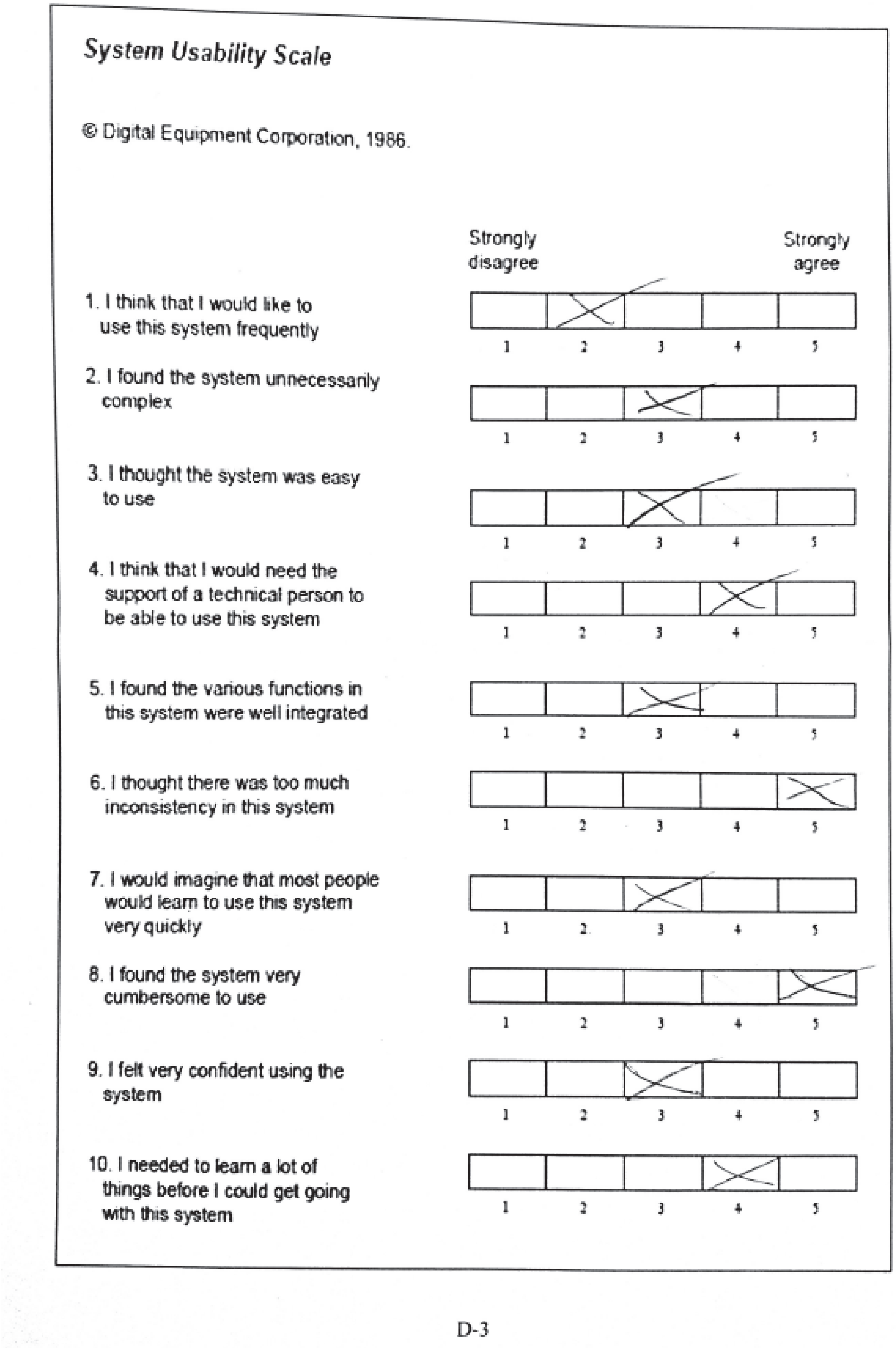
Yes – but lost some test point SA during reboots (~30")

6) Additional comments?

Reboot not bad when using project file.
Each reboot changed the numbers assigned to each ARDS pod → had to guess when pairing.

D-2

Figure B-5 – Sortie 2 DE2 comments



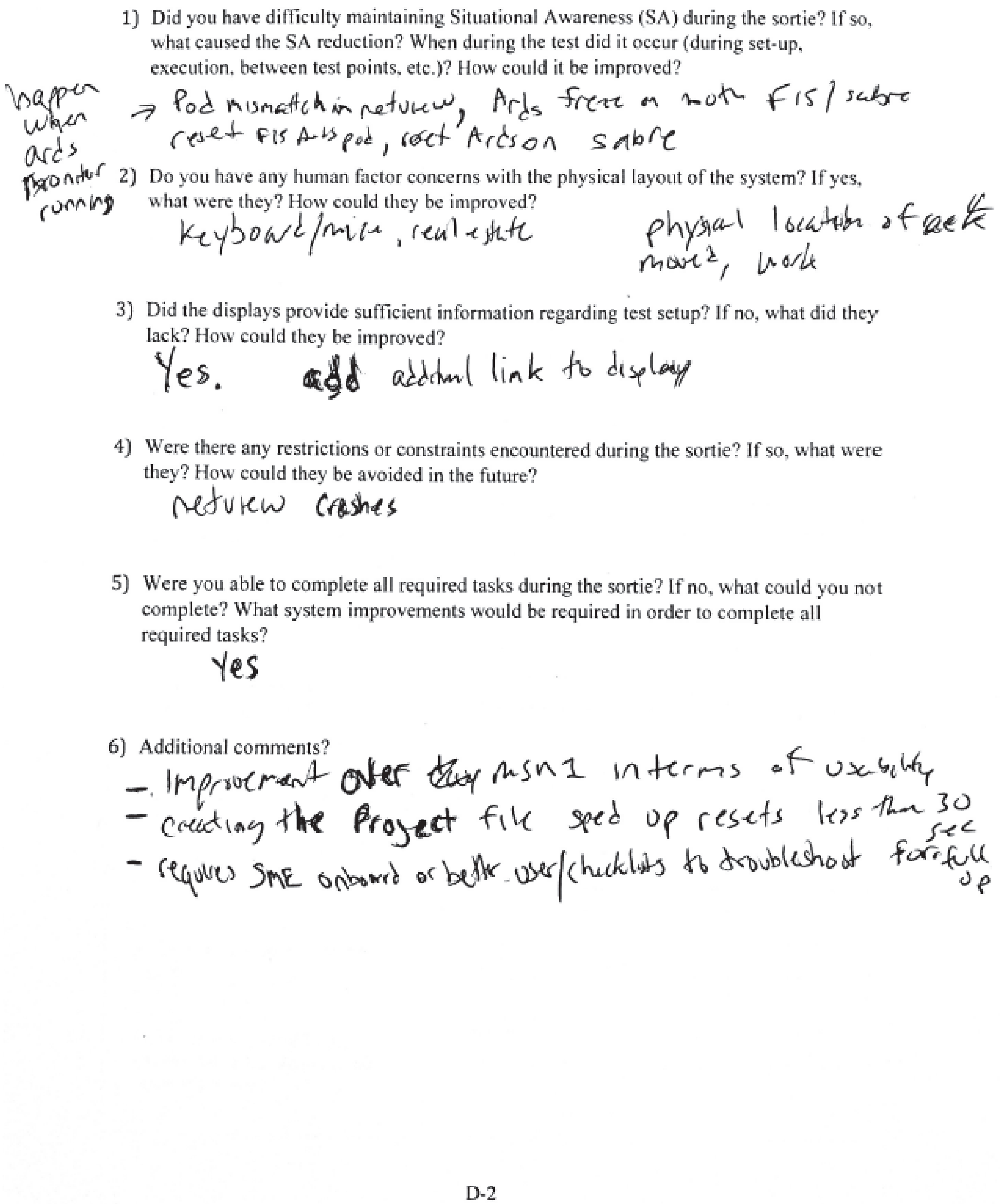
System Usability Scale

© Digital Equipment Corporation, 1986.

	1	2	3	4	5
	Strongly disagree				Strongly agree
1. I think that I would like to use this system frequently	☐	☒	☐	☐	☐
2. I found the system unnecessarily complex	☐	☐	☒	☐	☐
3. I thought the system was easy to use	☐	☐	☒	☐	☐
4. I think that I would need the support of a technical person to be able to use this system	☐	☐	☐	☒	☐
5. I found the various functions in this system were well integrated	☐	☐	☒	☐	☐
6. I thought there was too much inconsistency in this system	☐	☐	☐	☐	☒
7. I would imagine that most people would learn to use this system very quickly	☐	☐	☒	☐	☐
8. I found the system very cumbersome to use	☐	☐	☐	☐	☒
9. I felt very confident using the system	☐	☐	☒	☐	☐
10. I needed to learn a lot of things before I could get going with this system	☐	☐	☐	☒	☐

D-3

Figure B-6 – Sortie 2 DE2 ratings



1) Did you have difficulty maintaining Situational Awareness (SA) during the sortie? If so, what caused the SA reduction? When during the test did it occur (during set-up, execution, between test points, etc.)? How could it be improved?

happen when ards thronder running

→ Pod mismatch in netview, Ards freeze on both F15/sabre reset F15 Ards pod, reset Ards on sabre

2) Do you have any human factor concerns with the physical layout of the system? If yes, what were they? How could they be improved?

keyboard/mice, real estate

physical location of rack mount, work

3) Did the displays provide sufficient information regarding test setup? If no, what did they lack? How could they be improved?

Yes. add additional link to display

4) Were there any restrictions or constraints encountered during the sortie? If so, what were they? How could they be avoided in the future?

netview crashes

5) Were you able to complete all required tasks during the sortie? If no, what could you not complete? What system improvements would be required in order to complete all required tasks?

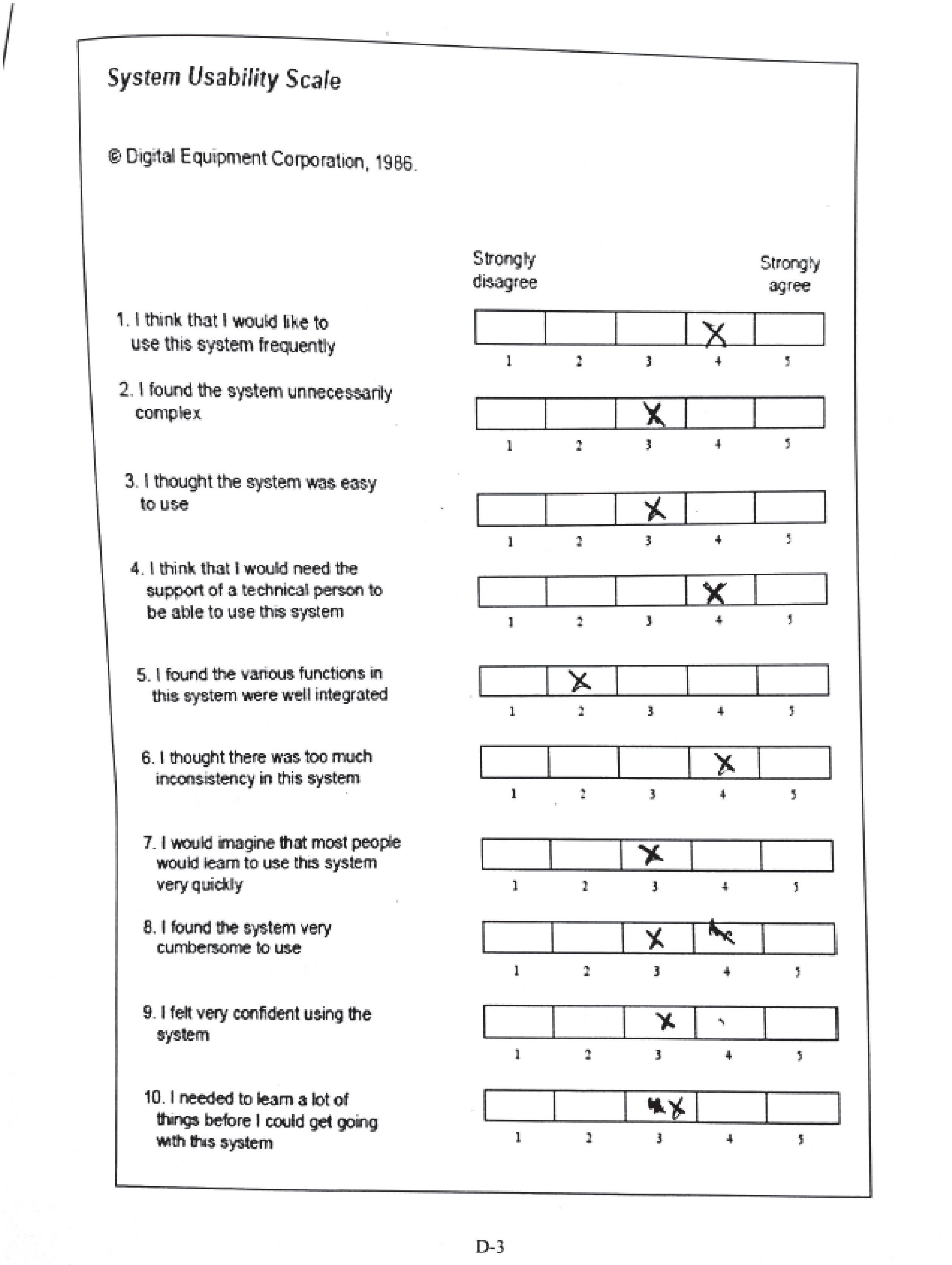
Yes

6) Additional comments?

- Improvement over ~~the~~ msn 1 in terms of usability
- creating the Project file sped up resets less than 30 sec
- requires SME onboard or better user/checklists to troubleshoot for full op

D-2

Figure B-7 – Sortie 2 TC1 comments



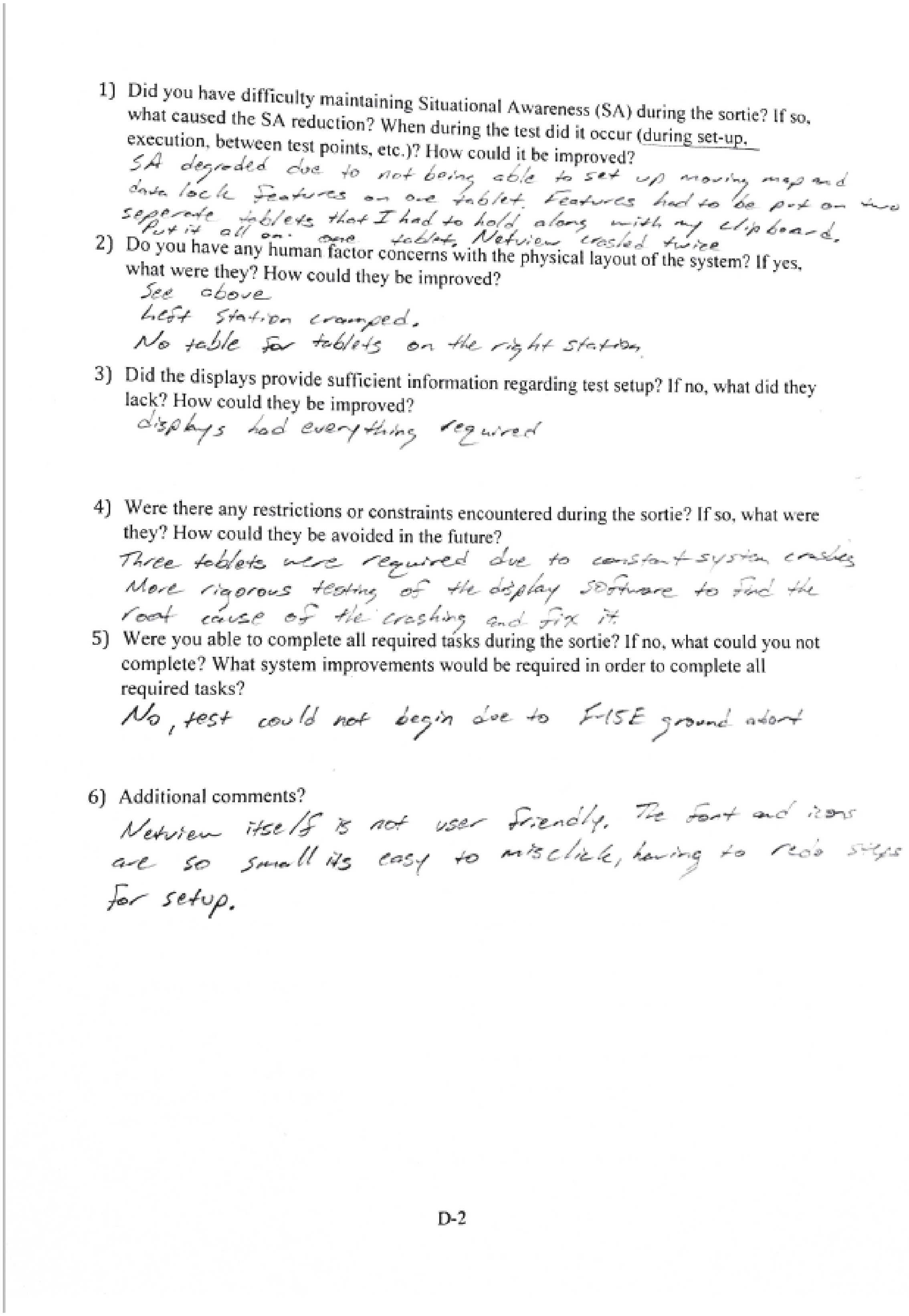
System Usability Scale

© Digital Equipment Corporation, 1986.

	Strongly disagree				Strongly agree
1. I think that I would like to use this system frequently	☐ 1	☐ 2	☐ 3	☒ 4	☐ 5
2. I found the system unnecessarily complex	☐ 1	☐ 2	☒ 3	☐ 4	☐ 5
3. I thought the system was easy to use	☐ 1	☐ 2	☒ 3	☐ 4	☐ 5
4. I think that I would need the support of a technical person to be able to use this system	☐ 1	☐ 2	☐ 3	☒ 4	☐ 5
5. I found the various functions in this system were well integrated	☐ 1	☒ 2	☐ 3	☐ 4	☐ 5
6. I thought there was too much inconsistency in this system	☐ 1	☐ 2	☐ 3	☒ 4	☐ 5
7. I would imagine that most people would learn to use this system very quickly	☐ 1	☐ 2	☒ 3	☐ 4	☐ 5
8. I found the system very cumbersome to use	☐ 1	☐ 2	☒ 3	☐ 4	☐ 5
9. I felt very confident using the system	☐ 1	☐ 2	☒ 3	☐ 4	☐ 5
10. I needed to learn a lot of things before I could get going with this system	☐ 1	☐ 2	☒ 3	☐ 4	☐ 5

D-3

Figure B-8 – Sortie 2 TC1 ratings



1) Did you have difficulty maintaining Situational Awareness (SA) during the sortie? If so, what caused the SA reduction? When during the test did it occur (during set-up, execution, between test points, etc.)? How could it be improved?

SA degraded due to not being able to set up moving map and data lock Features on one tablet. Features had to be put on two seperate tablets that I had to hold along with my clipboard. Put it all on one tablet. Netview crashed twice

2) Do you have any human factor concerns with the physical layout of the system? If yes, what were they? How could they be improved?

See above

Left Station cramped.

No table for tablets on the right station.

3) Did the displays provide sufficient information regarding test setup? If no, what did they lack? How could they be improved?

displays had everything required

4) Were there any restrictions or constraints encountered during the sortie? If so, what were they? How could they be avoided in the future?

Three tablets were required due to constant system crashes More rigorous testing of the display software to find the root cause of the crashing and fix it.

5) Were you able to complete all required tasks during the sortie? If no, what could you not complete? What system improvements would be required in order to complete all required tasks?

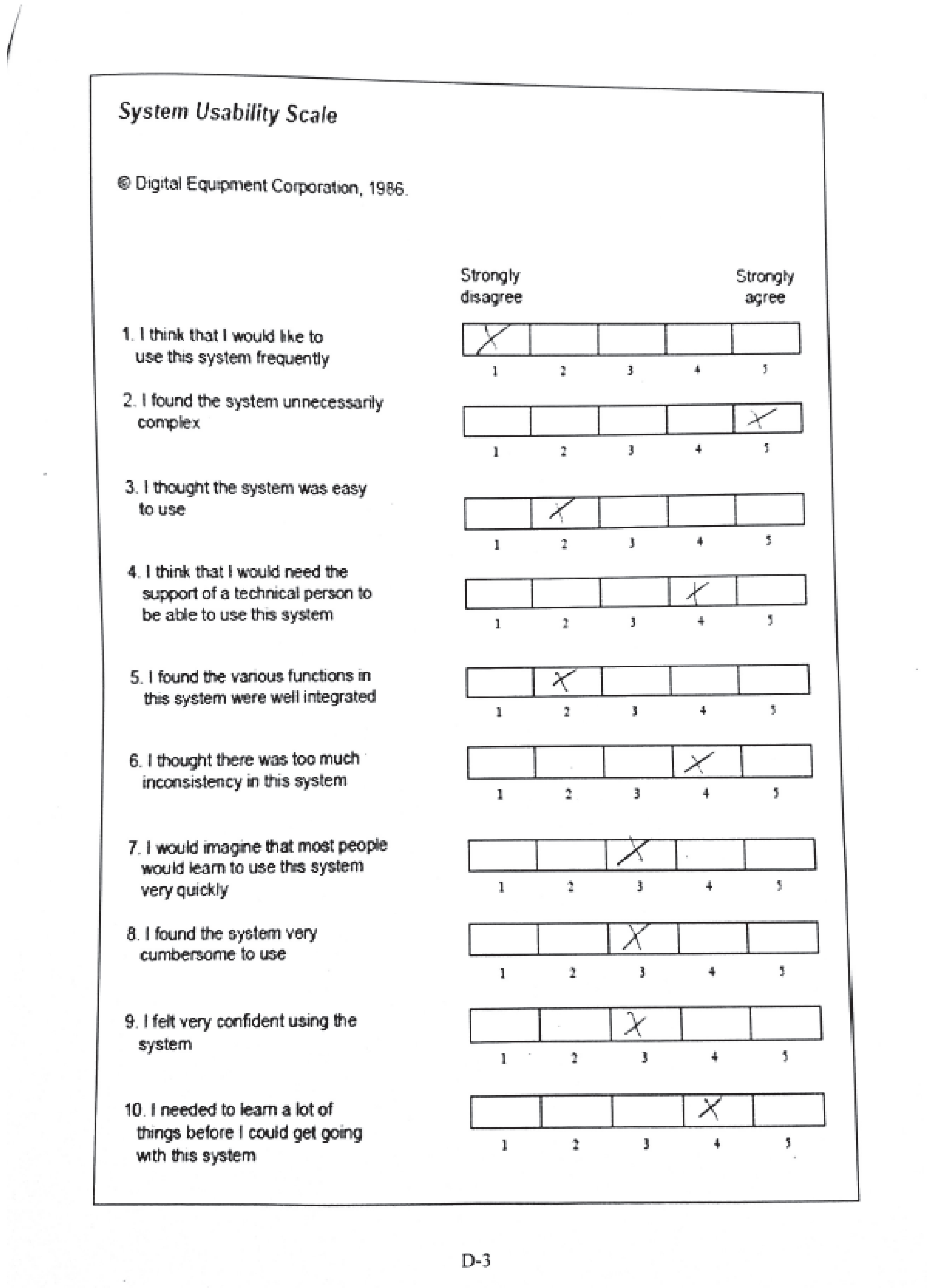
No, test could not begin due to F-15E ground abort

6) Additional comments?

Netview itself is not user friendly. The font and icons are so small its easy to misclick, having to redo steps for setup.

D-2

Figure B-9 – Sortie 3 TC2 comments



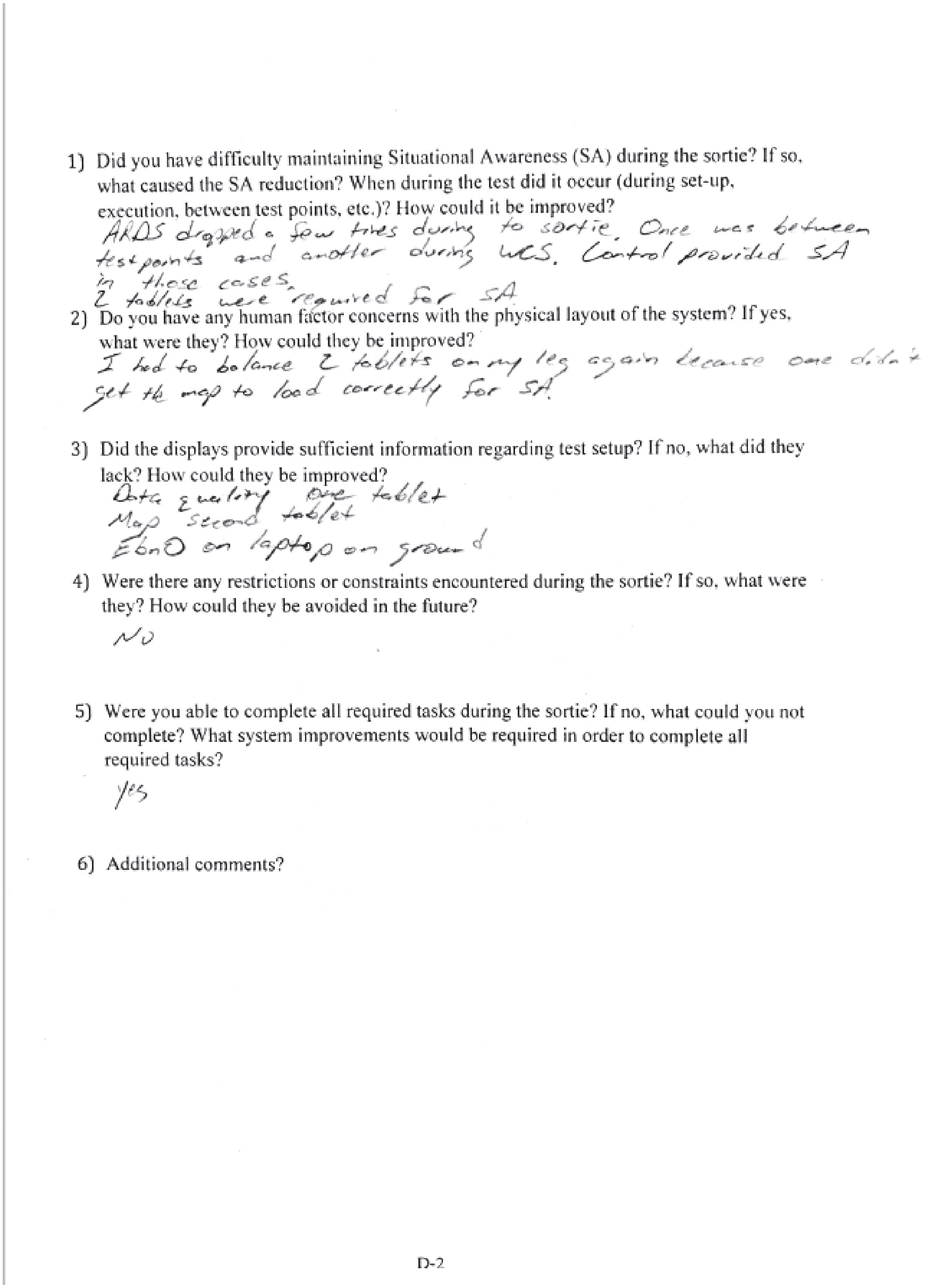
System Usability Scale

© Digital Equipment Corporation, 1986.

	Strongly disagree 1	2	3	4	Strongly agree 5
1. I think that I would like to use this system frequently	☒	☐	☐	☐	☐
2. I found the system unnecessarily complex	☐	☐	☐	☐	☒
3. I thought the system was easy to use	☐	☒	☐	☐	☐
4. I think that I would need the support of a technical person to be able to use this system	☐	☐	☐	☒	☐
5. I found the various functions in this system were well integrated	☐	☒	☐	☐	☐
6. I thought there was too much inconsistency in this system	☐	☐	☐	☒	☐
7. I would imagine that most people would learn to use this system very quickly	☐	☐	☒	☐	☐
8. I found the system very cumbersome to use	☐	☐	☒	☐	☐
9. I felt very confident using the system	☐	☐	☒	☐	☐
10. I needed to learn a lot of things before I could get going with this system	☐	☐	☐	☒	☐

D-3

Figure B-10 – Sortie 3 TC2 ratings



1) Did you have difficulty maintaining Situational Awareness (SA) during the sortie? If so, what caused the SA reduction? When during the test did it occur (during set-up, execution, between test points, etc.)? How could it be improved?

ARDS dropped a few times during to sortie. Once was between testpoints and another during WCS. Control provided SA in those cases.
2 tablets were required for SA

2) Do you have any human factor concerns with the physical layout of the system? If yes, what were they? How could they be improved?

I had to balance 2 tablets on my leg again because one didn't get the map to load correctly for SA.

3) Did the displays provide sufficient information regarding test setup? If no, what did they lack? How could they be improved?

Data quality one tablet
Map second tablet
EbnO on laptop on ground

4) Were there any restrictions or constraints encountered during the sortie? If so, what were they? How could they be avoided in the future?

NO

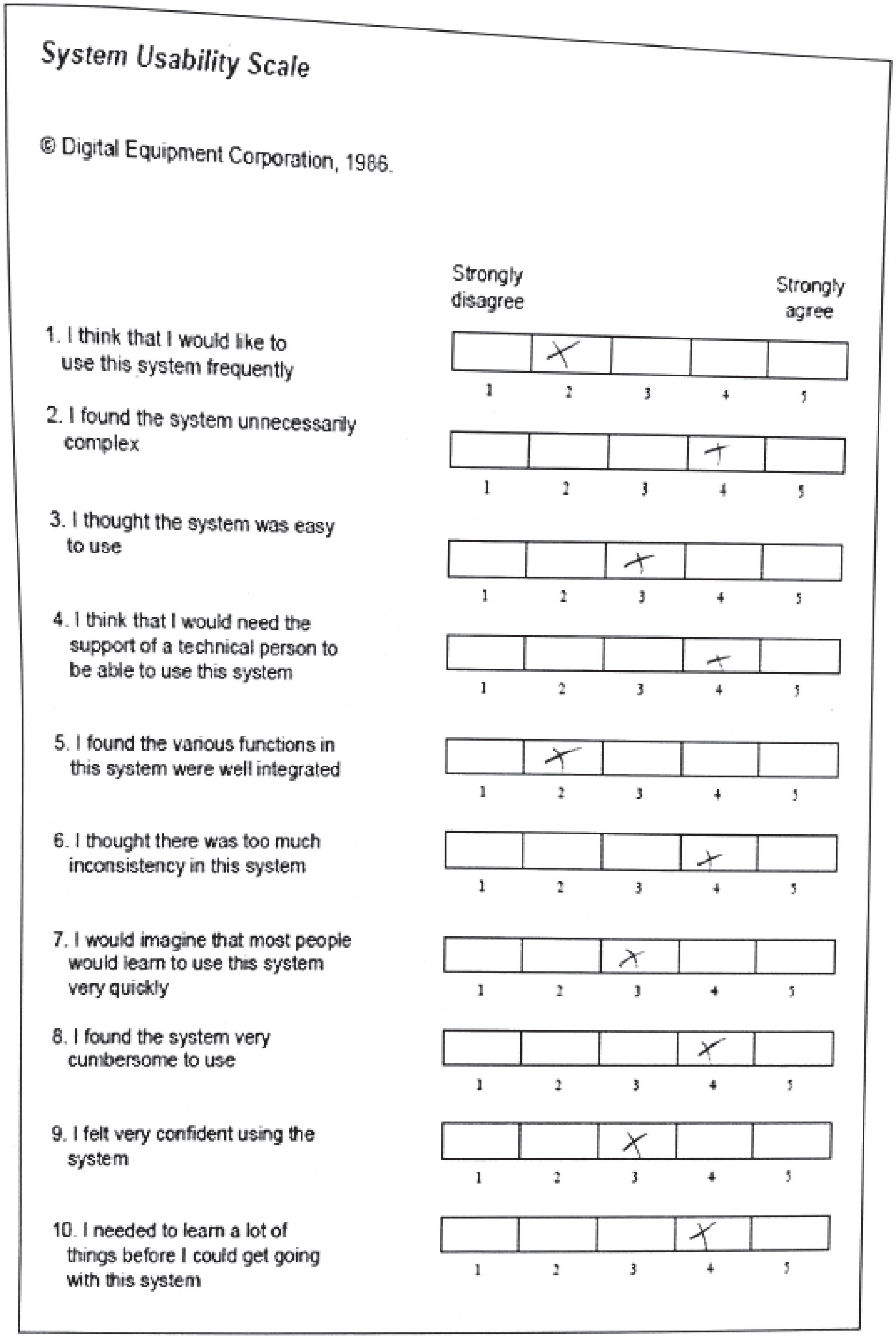
5) Were you able to complete all required tasks during the sortie? If no, what could you not complete? What system improvements would be required in order to complete all required tasks?

yes

6) Additional comments?

D-2

Figure B-11 – Sortie 4 TC2 comments

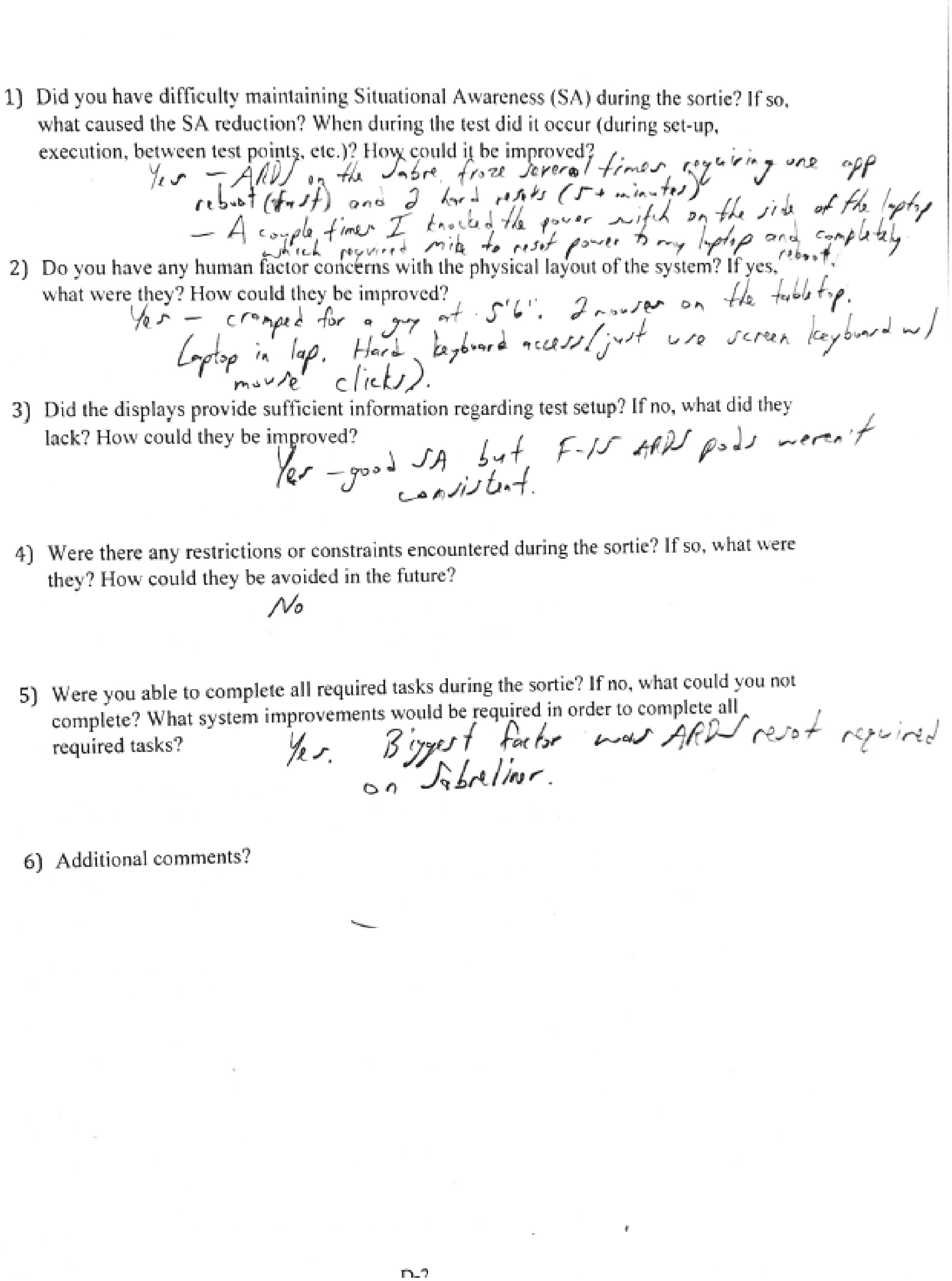


System Usability Scale

© Digital Equipment Corporation, 1986.

	Strongly disagree 1	2	3	4	Strongly agree 5
1. I think that I would like to use this system frequently		X			
2. I found the system unnecessarily complex				X	
3. I thought the system was easy to use			X		
4. I think that I would need the support of a technical person to be able to use this system				X	
5. I found the various functions in this system were well integrated		X			
6. I thought there was too much inconsistency in this system				X	
7. I would imagine that most people would learn to use this system very quickly			X		
8. I found the system very cumbersome to use				X	
9. I felt very confident using the system			X		
10. I needed to learn a lot of things before I could get going with this system				X	

Figure B-12 – Sortie 4 TC2 ratings



1) Did you have difficulty maintaining Situational Awareness (SA) during the sortie? If so, what caused the SA reduction? When during the test did it occur (during set-up, execution, between test points, etc.)? How could it be improved?

Yes – ARDS on the Sabre froze several times requiring one app reboot (fast) and 2 hard resets (5+ minutes).
– A couple times I knocked the power switch on the side of the laptop which required mike to reset power to my laptop and completely reboot.

2) Do you have any human factor concerns with the physical layout of the system? If yes, what were they? How could they be improved?

Yes – cramped for a guy at 5'6". 2 mouses on the table top. Laptop in lap. Hard keyboard access (just use screen keyboard w/ mouse clicks).

3) Did the displays provide sufficient information regarding test setup? If no, what did they lack? How could they be improved?

Yes – good SA but F-15 ARDS pods weren't consistent.

4) Were there any restrictions or constraints encountered during the sortie? If so, what were they? How could they be avoided in the future?

No

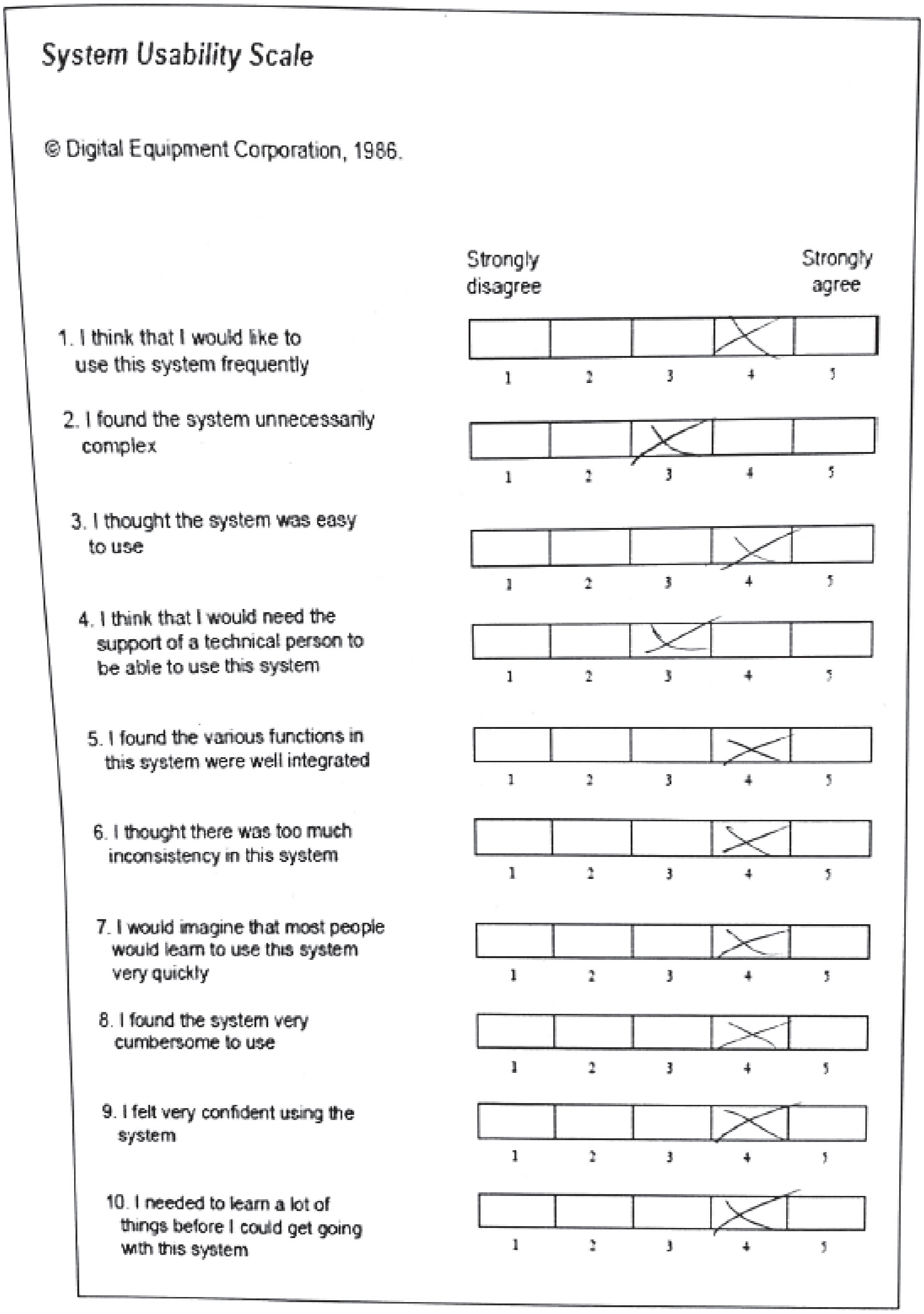
5) Were you able to complete all required tasks during the sortie? If no, what could you not complete? What system improvements would be required in order to complete all required tasks?

Yes. Biggest factor was ARDS reset required on Sabreliner.

6) Additional comments?

–

Figure B-13 – Sortie 4 DE2 comments



System Usability Scale

© Digital Equipment Corporation, 1986.

	Strongly disagree				Strongly agree
1. I think that I would like to use this system frequently	☐ 1	☐ 2	☐ 3	☒ 4	☐ 5
2. I found the system unnecessarily complex	☐ 1	☐ 2	☒ 3	☐ 4	☐ 5
3. I thought the system was easy to use	☐ 1	☐ 2	☐ 3	☒ 4	☐ 5
4. I think that I would need the support of a technical person to be able to use this system	☐ 1	☐ 2	☒ 3	☐ 4	☐ 5
5. I found the various functions in this system were well integrated	☐ 1	☐ 2	☐ 3	☒ 4	☐ 5
6. I thought there was too much inconsistency in this system	☐ 1	☐ 2	☐ 3	☒ 4	☐ 5
7. I would imagine that most people would learn to use this system very quickly	☐ 1	☐ 2	☐ 3	☒ 4	☐ 5
8. I found the system very cumbersome to use	☐ 1	☐ 2	☐ 3	☒ 4	☐ 5
9. I felt very confident using the system	☐ 1	☐ 2	☐ 3	☒ 4	☐ 5
10. I needed to learn a lot of things before I could get going with this system	☐ 1	☐ 2	☐ 3	☒ 4	☐ 5

Figure B-14 – Sortie 4 DE2 ratings

APPENDIX C – DIGITAL APPENDIX

The Folder structure and contents listed below are for mission data collected on 17 March 2020 and the subsequent post processing files used to create the analysis in the Have Terminator TIM. There are additional files that were collected during the mission included in the folders, however, only files specifically mentioned during data analysis are annotated.

Main Project Folder: 2020.03.17 HT Day 4 (folders in bold)

SiAW MSN 5822 17 MAR 20_file0009_17032020_13412260_16145092.ch10
(Consolidated CCF data for ground Re-Rad towers)

1. **ARDS** ***(****Contains the ARDS TSPI for both Sabreliner and F-15E)*
    a. 5822 pod 957 FSSRDATA.dat *(Sabreliner TSPI)*
    b. 6497 0185 906 8A 17MAR20 FSSRDATA.dat *(F-15E sta 8A TSPI)*
2. **SH1** ***(****Contains the Sabreliner Stage 2, Stage 3 and Ebn0 CH10 files)*
    a. File002_17032020_18185300.ch10 *(Sabreliner CH10, max range to card 3 data)*
    b. File003_17032020_20421000.ch10 *(Sabreliner CH10, WCS data)*
3. **Processed Files** *(Contains the raw NetView displays & exports, MATLAB scripts, excel data summaries and final data product .mat files)*
    a. BER_TSPI_Display_31mar20.DisplayFile *(NetView display file STO 1,3,4)*
    b. card4_rerad_display.DisplayFile *(NetView display file STO 2)*
    c. MSN3_Card1_1A_Export_31Mar20.txt *(NetView data export STO 1,4)*
    d. MSN3_Card1_1B_Export_31Mar20.txt *(NetView data export STO 1,4)*
    e. MSN3_Card3_Export_31Mar20.txt *(NetView data export STO 1,4)*
    f. MSN3_Card4_Export_31Mar20_Full.txt *(NetView data export STO 1,2,4)*
    g. MSN3_Card5_Export_31Mar20.txt *(NetView data export STO 1,4)*
    h. MSN3_Card6_Export_31Mar20.txt *(NetView data export STO 1,4)*
    i. MSN3_Card7_Export_31Mar20.txt *(NetView data export STO 3)*
    j. MSN3_Card1_1A_Export_31Mar20.mat *(MATLAB data export STO 1,4)*
    k. MSN3_Card1_1B_Export_31Mar20.mat *(MATLAB data export STO 1,4)*
    l. MSN3_Card3_Export_31Mar20.mat *(MATLAB data export STO 1,4)*
    m. MSN3_Card4_Export_31Mar20_Full.mat *(MATLAB data export STO 1,2,4)*
    n. MSN3_Card5_Export_31Mar20.mat *(MATLAB data export STO 1,4)*
    o. MSN3_Card6_Export_31Mar20.mat *(MATLAB data export STO 1,4)*
    p. MSN3_Card7_Export_31Mar20.mat *(MATLAB data export STO 3)*
    q. Stage2_BIN_NAN_3Apr20.mat *(Final Stage 2 Bin counter matrix)*
    r. Stage2_BER_NAN_3Apr20.mat *(Final Stage 2 BER matrix)*
    s. Stage3_BIN_NAN_3Apr20.mat *(Final Stage 3 Bin counter matrix)*
    t. Stage3_BER_NAN_3Apr20.mat *(Final Stage 3 BER matrix)*
    u. STO1_4_Terminator_Processing_2Apr2020.m *(STO 1,4 Processing script)*
    v. STO2_Terminator_Processing_2Apr2020.m *(STO 2 Processing script)*
    w. STO3_Terminator_Processing_31Mar2020.m *(STO 3 Processing script)*
    x. STO5_Terminator_SUS_Analysis_24mar2020.m *(STO 5 Processing script)*
    y. Terminator_Final_DataPlot_PartA_2Apri2020.m *(Heatmap Processing script A)*
    z. Terminator_Final_DataPlot_PattB_3April2020.m *(Heatmap Processing script B)*
    aa. High_BER_Investigation_3Apr20.m *(Data reduction script)*
    bb. Have_Term_Level_Latoffset_2Stage_31Mar20_sorted_plots_analysis.xlxs *(excel analysis method for bin creation, stage 2 combiner)*
    cc. Have_Term_Level_Latoffset_3Stage_31Mar20_sorted_plots_analysis.xlxs *(excel analysis method for bin creation, stage 3 combiner)*

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APPENDIX D – LESSONS LEARNED

Ignoring the impact of COVID-19 on the execution of the program, the test plan and initial execution laid the foundations for success. That said, there were lessons learned that should be accounted for in subsequent tests.

Antenna selection on PN15 source aircraft was crucial to operation of the SUT

The F-15E aircraft of the 40 FLTS were previously modified with an upper and lower antenna capable of transmitting PN15 signals. When both antennas are operated together, the total signal power available to each one was halved compared to when only one antenna was in use, greatly reducing signal range. Due to this, standard procedure was to transmit from only one antenna at a time. The lower antenna was used initially as this was the most operationally representative of a downward facing antenna of an underwing store and the most likely future use-case for the sponsoring agency.

The antenna configuration was set prior to flight and could not be changed during flight. Two test sorties (11 and 12 March 2020) were flown with the F-15E transmitting from the lower antenna located behind the nose gear below the fuselage as seen in Figure 6 below. Data collected on the two sorties using the lower antenna fell significantly short of the mathematical predictions. The position of the lower antenna may have resulted in masking effects from the F-15E airframe and stores that reduced the observed ranges. Because the overall test objective was to characterize the Terminator Pod System, not perform an operational evaluation for weapon test, the final sortie (17 March 2020) was flown using the upper antenna and the range issues observed previously were eliminated. As a result, only data from the final sortie was used for analysis and reporting.

Figure D-1 - F-15E Lower Antenna

Conduct ground checks of all assets involved, not just the SUT

The test plan required two separate aircraft and a ground station. While the SUT was the Terminator Pod System hosted on the Sabreliner, it was crucial to conduct ground testing on all assets involved to capture potential issues prior to first flight. For the execution of this test, this may have captured the high potential for signal masking when using the lower antenna. Future testing should conduct ground testing on all assets individually before attempting to execute as a whole package.

Always fly with an Instrumentation Expert on the Sabreliner to conduct ARDS resets as required

Positional data were provided to the SUT via ARDS data. During execution it was found that the ARDS sub-system was temperamental. This failure of ARDS led to a loss of positional SA at the operator stations. In almost all cases, a full reset of the ARDS sub-system was required and was only possible due to the timely assistance from the Instrumentation Expert.

Create a NetView project file to mitigate against software failures

The NetView software was highly prone to failures. Software updates were continuously published, which reduced the number of failures, but they continued to occur throughout testing. Creating a project file preset was able to drastically reduce the reset times, which greatly increased test efficiency. Additionally, having two separate computers running NetView was a good way in mitigating these failures. Future testing should continue to fly with independent computers running NetView and with project files pre-saved.

The CCF can run the test during System failures or loss of SA in the Sabreliner

When SA was lost at the operator stations onboard the host aircraft, the ground-based CCF was able to assume Test Conductor duties using alternative data sources such as positional information from radar feeds. This improved test efficiency during periods of other system failures such as during loss of positional data from ARDS. This greatly improved test efficiency and was found to be something that should be utilized during future testing.

Conduct NetView training prior to flight execution

NetView had a steep learning curve for operators that had never used the program before. Crews should be thoroughly trained on software operation, especially how to respond to malfunctions and crashes.

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APPENDIX E – ABBREVIATIONS, ACRONYMS, AND SYMBOLS

Abbreviation	Definition
AFB	Air Force Base
ARDS	Advanced Range Data System
BER	Bit Error Rate
BLOS	Beyond Line-of-Sight
CCF	Central Control Facility
DE	Discipline Engineer
EGTTR	Eglin Gulf Test & Training Range
FLTS	Flight Test Squadron
FTS	Flight Termination System
GUI	Graphical User Interface
HSI	Human Systems Integration
JON	Job Order Number
LOS	Line Of Sight
MSL	Mean Sea Level
NM	Nautical Miles
RF	Radio Frequency
RX	Receive
SA	Situational Awareness
SAI	Sunshine Aero Industries
SOP	Standard Operating Procedure
STO	Specific Test Objective
SUS	System Usability Survey
SUT	System Under Test
TC	Test Conductor
TIM	Technical Information Memorandum
TM	Telemetry
TPS	Test Pilot School
TS	Test Squadron

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APPENDIX F – DISTRIBUTION LIST

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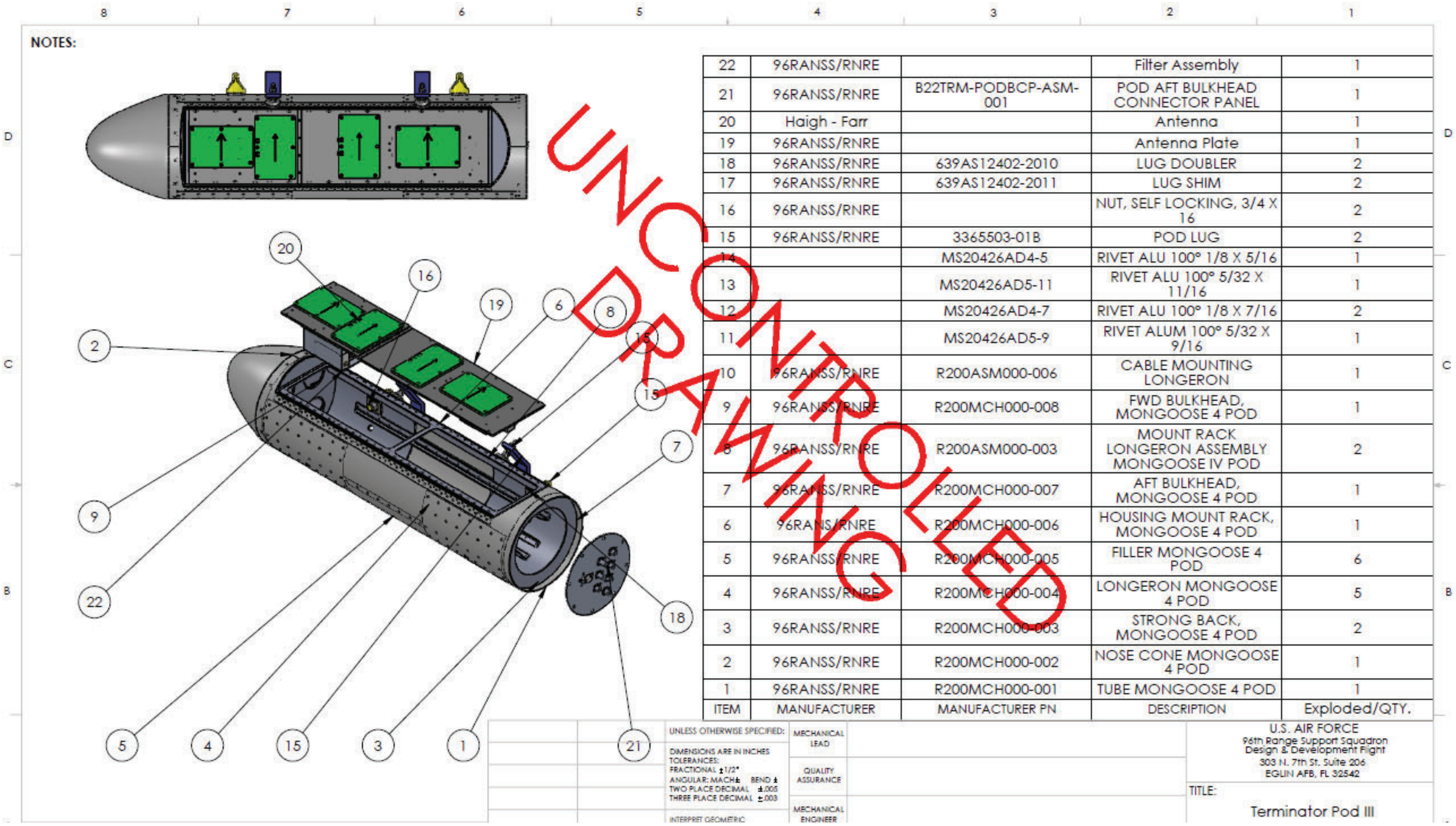
APPENDIX G – ANTENNA SPECIFICATIONS



22	96RANSS/RNRE		Filter Assembly	1
21	96RANSS/RNRE	B22TRM-PODBCP-ASM-001	POD AFT BULKHEAD CONNECTOR PANEL	1
20	Haigh - Farr		Antenna	1
19	96RANSS/RNRE		Antenna Plate	1
18	96RANSS/RNRE	639AS12402-2010	LUG DOUBLER	2
17	96RANSS/RNRE	639AS12402-2011	LUG SHIM	2
16	96RANSS/RNRE		NUT, SELF LOCKING, 3/4 X 16	2
15	96RANSS/RNRE	3365503-01B	POD LUG	2
14		MS20426AD4-5	RIVET ALU 100° 1/8 X 5/16	1
13		MS20426AD5-11	RIVET ALU 100° 5/32 X 11/16	1
12		MS20426AD4-7	RIVET ALU 100° 1/8 X 7/16	2
11		MS20426AD5-9	RIVET ALUM 100° 5/32 X 9/16	1
10	96RANSS/RNRE	R200ASM000-006	CABLE MOUNTING LONGERON	1
9	96RANSS/RNRE	R200MCH000-008	FWD BULKHEAD, MONGOOSE 4 POD	1
8	96RANSS/RNRE	R200ASM000-003	MOUNT RACK LONGERON ASSEMBLY MONGOOSE IV POD	2
7	96RANSS/RNRE	R200MCH000-007	AFT BULKHEAD, MONGOOSE 4 POD	1
6	96RANSS/RNRE	R200MCH000-006	HOUSING MOUNT RACK, MONGOOSE 4 POD	1
5	96RANSS/RNRE	R200MCH000-005	FILLER MONGOOSE 4 POD	6
4	96RANSS/RNRE	R200MCH000-004	LONGERON MONGOOSE 4 POD	5
3	96RANSS/RNRE	R200MCH000-003	STRONG BACK, MONGOOSE 4 POD	2
2	96RANSS/RNRE	R200MCH000-002	NOSE CONE MONGOOSE 4 POD	1
1	96RANSS/RNRE	R200MCH000-001	TUBE MONGOOSE 4 POD	1
ITEM	MANUFACTURER	MANUFACTURER PN	DESCRIPTION	Exploded/QTY.

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±1/2"
ANGULAR: MACH± BEND ±
TWO PLACE DECIMAL ±.005
THREE PLACE DECIMAL ±.003
INTERPRET GEOMETRIC

MECHANICAL LEAD
QUALITY ASSURANCE
MECHANICAL ENGINEER

U.S. AIR FORCE
96th Range Support Squadron
Design & Development Flight
303 N. 7th St. Suite 206
EGLIN AFB, FL 32542

TITLE:
Terminator Pod III

Figure G-1 - Terminator Pod Engineering Drawing

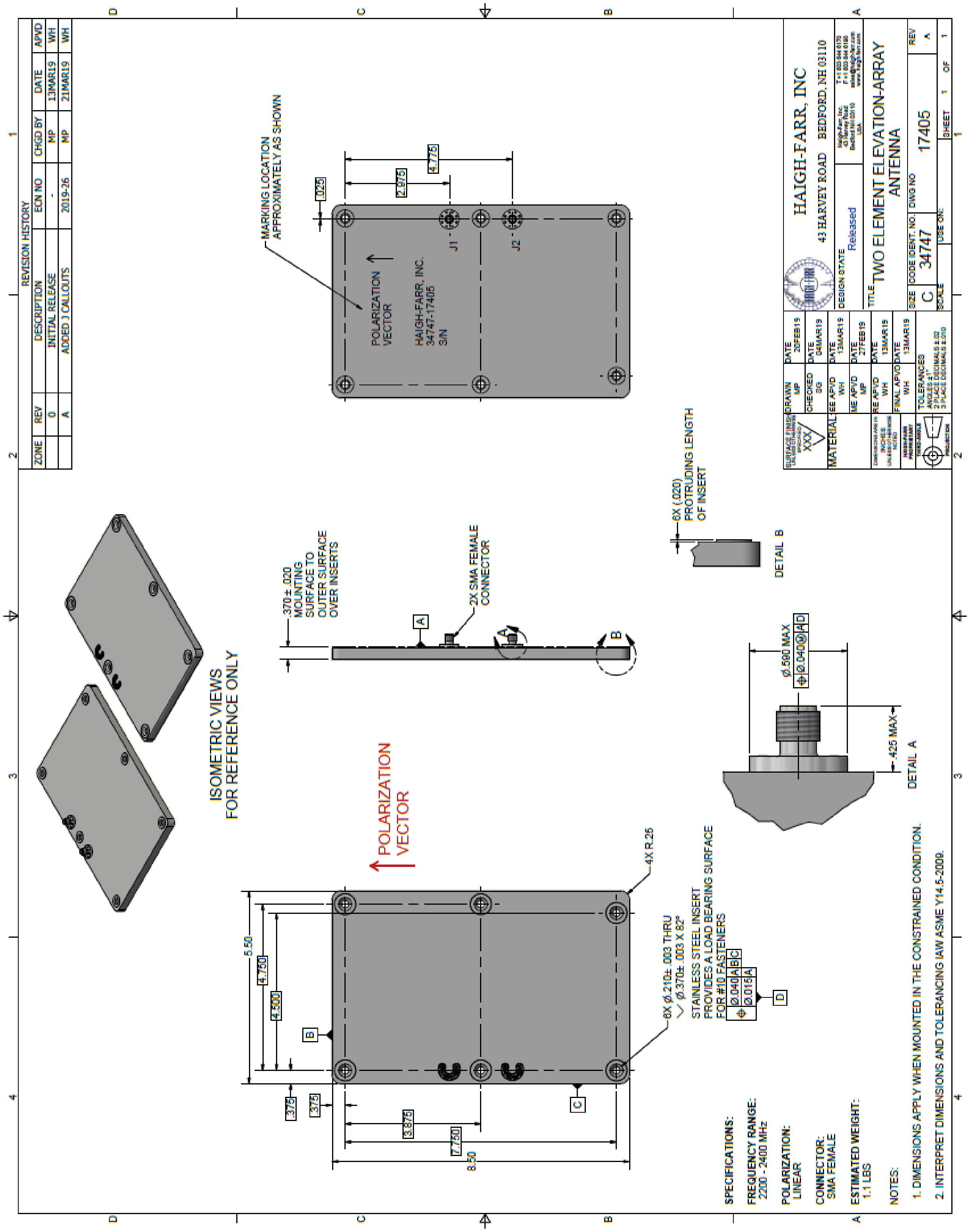
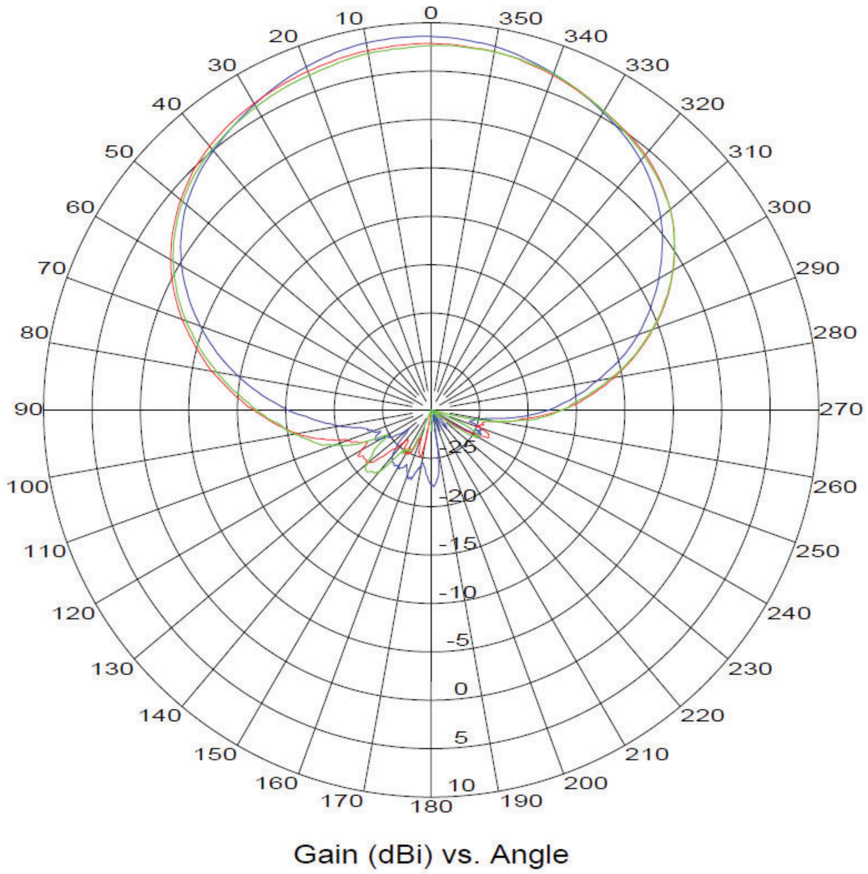


Figure G-2 - Terminator Pod Vertical Antenna Enginnering Drawing



Operator: BAH

Test: Acceptance Patterns

Part Number: 17405

Serial Number: 1

Frequency Overlays

Freq: 2.20000 GHz —
Freq: 2.30000 GHz —
Freq: 2.40000 GHz —

Polarization: Vertical

Pattern Cut: (J1)

Phi = 0 Deg
Theta = Variable

Figure G-3 - Terminator Pod Vertical Antenna Gain vs. Angle Pattern

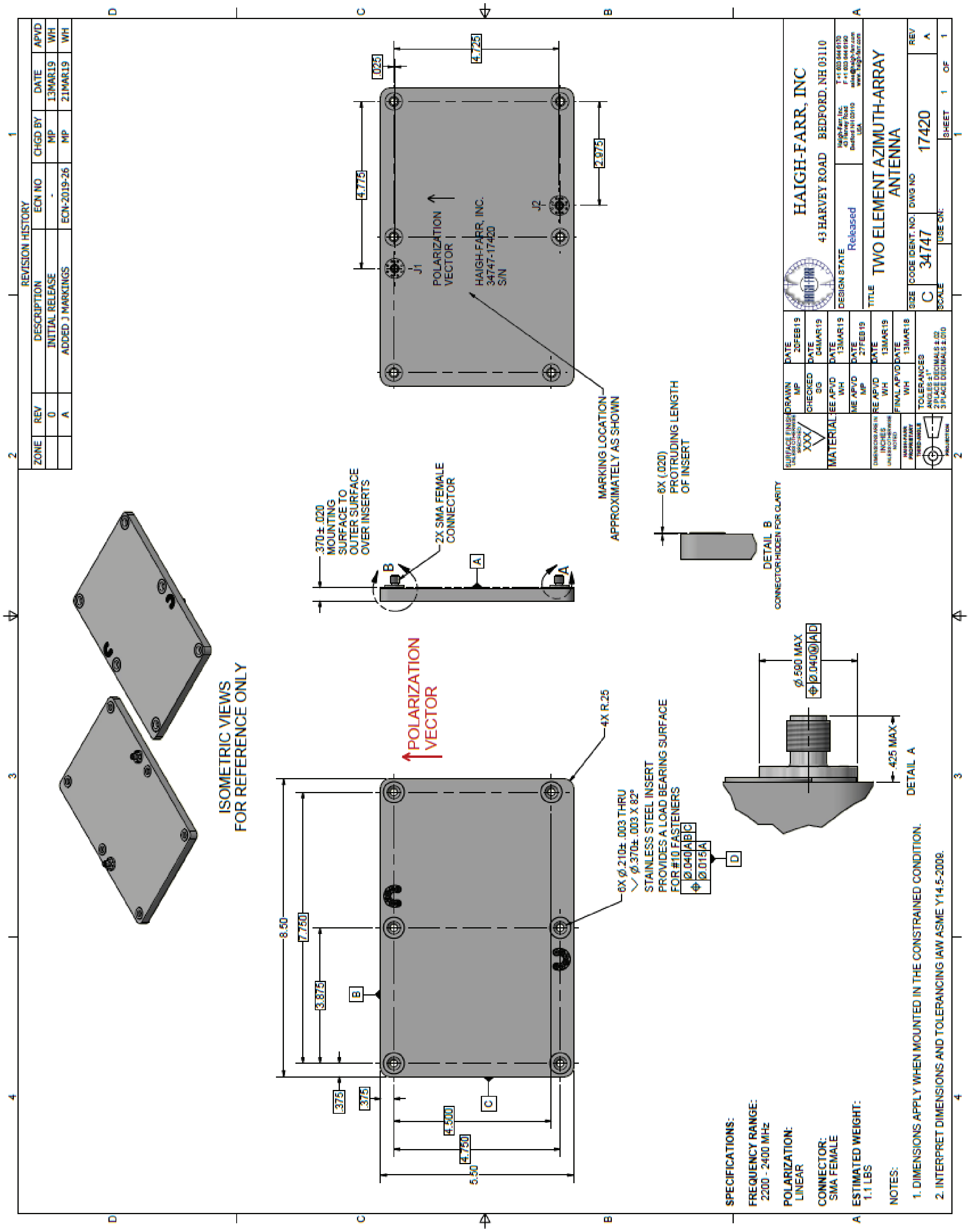
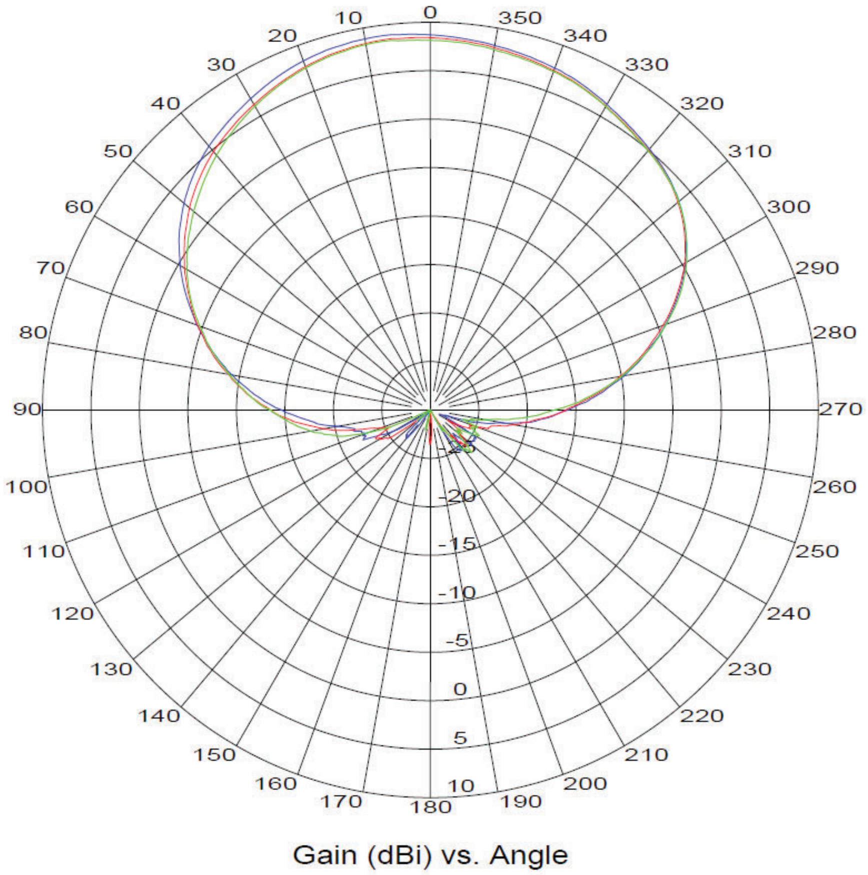


Figure G-4 - Terminator Pod Horizontal Antenna Enginnering Drawing



Operator: BAH

Test: Acceptance Patterns

Part Number: 17420

Serial Number: 1

Frequency Overlays

Freq: 2.20000 GHz —
Freq: 2.30000 GHz —
Freq: 2.40000 GHz —

Polarization: Vertical

Pattern Cut: (J1)

Phi = 0 Deg
Theta = Variable

Figure G-5 - Terminator Pod Horizontal Antenna Gain vs. Angle Pattern

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APPENDIX H – QUICKLOOKS & SCAN LOGS

QUICKLOOK / INITIAL FLIGHT TEST REPORT	1. AIRCRAFT TYPE F-15E	2. SERIAL NUMBER 185

3. CONDITIONS RELATIVE TO TEST

A. PROJECT / MISSION NO Have Terminator	B. FLIGHT NO / DATA POINT 1	C. DATE 11 Mar 2020
D. FRONT COCKPIT *(Left Seat)* Smith, K	E. FUEL LOAD 23500 lb	F. JON
G. REAR COCKPIT *(Right Seat and rest of crew)* Berggren	H. START UP GR WT 65000 lb	I. WEATHER Alt 30.22, Winds aloft 200/20, ISA+4°C
J. TO TIME / SORTIE TIME 1000L / 2.2 hrs	K. CONFIGURATION / LOADING Clean/ 120D / AAIS x2 / ASQ-236 / 9X, Lower Antenna	L. SURFACE CONDITIONS T/O: Winds 230/8, 17°C
M. CHASE OR TARGET ACFT / SERIAL NO Sabreliner 01	N. CHASE OR TARGET CREW Brad Colquitt	O. CHASE OR TARGET TO TIME / SORTIE TIME 0950L

4. PURPOSE OF FLIGHT / TEST POINTS

First sortie for HAVE Terminator (characterize TM range performance and system usability). Attempting to demo a cross-section of all our planned maneuvers for Sabreliner practice and assessment, gather boresight range run data for initial max range indications, and accomplish as many test points up to the max range as possible.

5. RESULTS OF TESTS *(Continue on reverse if needed)*

All test points adhered to published databands and tolerances. No significant atmospheric conditions were encountered that affected the test points. Light winds from the northwest aloft, not a factor. No processed data available as of this writing.

Ground Block: The ground block was uneventful, but the F-15E was held in chocks for about 10 minutes awaiting words that the Sabreliner had taxied. The Sabreliner could not establish comms with control, so the first contact was made after they were airborne. No further F-15E delays happened on the ground. There was confusion about whether video should be pushed from the F-15, so the decision was made to use "Data on" only (video off) as this provided good PN15 at the CCF. The config was not correct, as two external fuel tanks were expected. The steerpoints also were not loaded on the DTM so the IP had to handjam the critical points for the mission but this did not cause delay.

Card 2 (10nm Level): There was no delay in beginning the first run after the F-15 got in the airspace as the Sabreliner was already established. The good data seemed to occur at roughly 10 degrees aft of boresight, which was way inside predictions. The TOT was easy to shack and worked out well and accurately as an azimuth setup tool. After establishing the correct ground speed and track, ground track and altitude hold autopilot was engaged and aided in reducing workload, which was already quite low. However, the GT autopilot did not work per the Dash-1 and would only hold the current groundtrack when engaged (Dash-1 indicates you can set a ground track to hold via the CRS rocker). Initial data indications were that there was a gap in good data within 10 degrees of boresight, with good data a couple degrees around 10 degrees on either side of boresight.

Card 21 (5.5nm Symm Banks/Level): The 5.5nm point resulted in significantly better antenna coverage at about 35 degrees aft at 6.9nm slant range (about 11000' altitude offset, F-15 high). The Sabreliner did not understand the plan and ended up beginning its maneuver late (approaching line-abreast).

6. RECOMMENDATIONS

Continue testing in accordance with the test matrix. Repeat today's test points with the safety cover removed to observe differences and re-arrange points to maximize observation of masking effects (fly points with opposite headings instead of the same headings?). Investigate the potential use of the upper antenna on the F-15 instead.

COMPLETED BY Smith, K	SIGNATURE	DATE 11 Mar 2020

5. RESULTS OF TEST (CONTINUED):

1.1 (Boresight Range Run): Due to seeing good data at 10nm and the limited airspace, the boresight range run was started at 10nm. The Sabreliner FTE (Mongoose) thought they had good data all the way out, so much that we did several runs…stepping out the range until we hit Bingo fuel/range end time at 50nm+. The plan for Mongoose to calculate groundspeed worked out well and kept us within 2 degrees of line-abreast. However, it seems that there was actually never good data, even at 10nm, because the bit errors essentially froze due to a bad lock throughout that the FTEs weren't aware of. It was interesting to note that there was a brief period of good data when setting up at about 35nm and both aircraft were about co-altitude and showing each other a forward aspect. Perhaps this indicates some sort of masking effects from the Sabreliner and/or F-15.

It was revealed during the debrief that there was a safety cover over the F-15 transmitting antenna that has never been tested for effects, so that may have also contributed to the poor performance. That is planned to be removed for subsequent sorties.

QUICKLOOK / INITIAL FLIGHT TEST REPORT

QUICKLOOK / INITIAL FLIGHT TEST REPORT	1. AIRCRAFT TYPE F-15E	2. SERIAL NUMBER 185

3. CONDITIONS RELATIVE TO TEST

A. PROJECT / MISSION NO Have Terminator	B. FLIGHT NO / DATA POINT 1	C. DATE 12 Mar 2020
D. FRONT COCKPIT *(Left Seat)* Smith, J	E. FUEL LOAD 31500 lb	F. JON
G. REAR COCKPIT *(Right Seat and rest of crew)* Turner	H. START UP GR WT 72500 lb	I. WEATHER Alt 30.07, Winds aloft 300/14
J. TO TIME / SORTIE TIME 0945L / 2.1 hrs	K. CONFIGURATION / LOADING 2-Bag/ 120D / AAIS x2 / 9X, Lower Antenna, safety cover removed	L. SURFACE CONDITIONS T/O: Winds 250/5, 12°C, Bkn 700
M. CHASE OR TARGET ACFT / SERIAL NO Sabreliner 01	N. CHASE OR TARGET CREW Brad Colquitt	O. CHASE OR TARGET TO TIME / SORTIE TIME 0910L

4. PURPOSE OF FLIGHT / TEST POINTS

Second sortie for HAVE Terminator (characterize TM range performance and system usability). Due to airspace limitations (20NMx85NM) and low reception ranges from the first sortie, 6 North/South test points (pts 2, 12, 20, 11, 18, 19) and 1 East/West (pt 7) test points were planned.

5. RESULTS OF TESTS *(Continue on reverse if needed)*

All test points flown adhered to published databands and tolerances with the exception of a 1 minute late TOT due to an F-15E TOT clock glitch that did not affect the data. Due to a later takeoff than planned, only 5 test points were accomplished. No significant atmospheric conditions were encountered that affected the test points. Light winds from the northwest aloft, not a factor. Data from previous sortie showed intermittent data at various ranges, shorter than predicted, but airspace limitations dictated the test points flown.

Ground Block: The ground block was uneventful, after a weather hold and slight MX issue that delayed start. The steerpoints were not loaded on the DTM so the IP had to manually input the critical points for the mission but this did not cause delay.

Card 2 (10NM Level, 15,000’): No issues with setup. The good data seemed to occur at roughly 10 degrees aft of boresight, which was inside predictions. After establishing the correct ground speed and track, ground track and altitude hold autopilot was engaged and aided in reducing workload. Initial data look showed good lock +/- 10 degrees on either side of boresight.

Card 12 (5.5NM Symm Banks/Level, Sabreliner 15K’, F-15E 14K’): The 5.5nm point resulted in significantly better antenna coverage at about 35 degrees aft at 6.9nm slant range (about 11000’ altitude offset, F-15 high).

Card 20 (10NM Symm Banks/Level, Sabreliner 15K’, F-15E 13K’): Software glitch in the F-15E delayed the TOT by 1 minute – the F-15E was flying outbound and TOT instantaneously jumped by 1 minute. To resolve the issue, the F-15E simple accelerated until at the predicted azimuth for start (Mongoose was able to call the decrease to “on conditions” speed). No good data.

Card 19 (15NM Symm Banks/Level, Sabreliner 3K’, F-15E 20K’): No issues with setup, no good data observed.

Card 7 (WCS Level, 20NM separation, 15K’): Due to nose-on data on sortie 1 showing brief good lock at long ranges (37NM), this test point was modified for the aircraft to fly in opposite direction (left to left pass). No good data observed.

a6. RECOMMENDATIONS

Continue testing in accordance with the test matrix, but investigate the potential use of the upper antenna on the F-15 in case the less-than-predicted reception is due to aircraft masking.

COMPLETED BY Smith, J	SIGNATURE // SIGNED //	DATE 12 Mar 2020

QUICKLOOK / INITIAL FLIGHT TEST REPORT

1. AIRCRAFT TYPE F-15E	2. SERIAL NUMBER 86-0185

3. CONDITIONS RELATIVE TO TEST

A. PROJECT / MISSION NO Have Terminator	B. FLIGHT NO / DATA POINT 3	C. DATE 17 Mar 2020
D. FRONT COCKPIT *(Left Seat)* Hughes, Brett M	E. FUEL LOAD 31,500 lb	F. JON 96TW(AFMC)/FTFA
G. REAR COCKPIT *(Right Seat and rest of crew)* Loiacono, Francis X	H. START UP GR WT 73,000 lb	I. WEATHER Alt 30.21, Winds aloft 239/18
J. TO TIME / SORTIE TIME 1326L / 2.7 hrs	K. CONFIGURATION / LOADING 2 Tanks/ 120D / AAIS x2 / 9X, Upper Antenna	L. SURFACE CONDITIONS T/O: Winds 160/6, 26°C
M. CHASE OR TARGET ACFT / SERIAL NO T-39 Sabreliner / N265FT	N. CHASE OR TARGET CREW Brad Colquitt, Bryan Williams	O. CHASE OR TARGET TO TIME / SORTIE TIME 1308L

4. PURPOSE OF FLIGHT / TEST POINTS

This was the third sortie for Have Terminator, but the first using the upper antenna on the F-15E to transmit PN15 TM. The previous two sorties used the lower antenna, but due to worse-than-predicted results from suspected masking, the upper antenna was used for this sortie. With the possibility (and reality) that this would be the last sortie due to COVID-19, all the test points chosen were of the highest priority.

5. RESULTS OF TESTS *(Continue on reverse if needed)*

All test points adhered to published databands and tolerances. No significant atmospheric conditions were encountered that affected the test points. Light winds aloft from the southwest were not a factor. No processed data available as of this writing.

Ground Block: The ground block was uneventful. The Sabreliner took off at 1308 to get to the airspace on time. The F-15E tookoff one minute late. The correct steerpoints were found loaded in Sortie A.

After Takeoff: Good initial reception for both ARDS and PN15 from Mongoose and Control.

Card 1.1A&B (Boresight Range Run): The runs began with 5 NM spacing between aircraft and continued with the F-15E checking 45 degrees away until Mongoose lost PN15 reception. Because this did not happen before the end of the airspace boundary, the run was reset starting at the lateral offset the previous run was terminated. This continued until signal loss, at a range of 69 NM, was observed. The F-15E then checked into the Sabreliner until signal reception was observed, which occurred at 50 NM. Initial observations show a difference in maximum range depending on if a lock is initially established or not. This and all subsequent test points were flown with the autopilot ground track and altitude hold modes engaged. All test points except Card 7 were flown with the Terminator Pod facing away from shore.

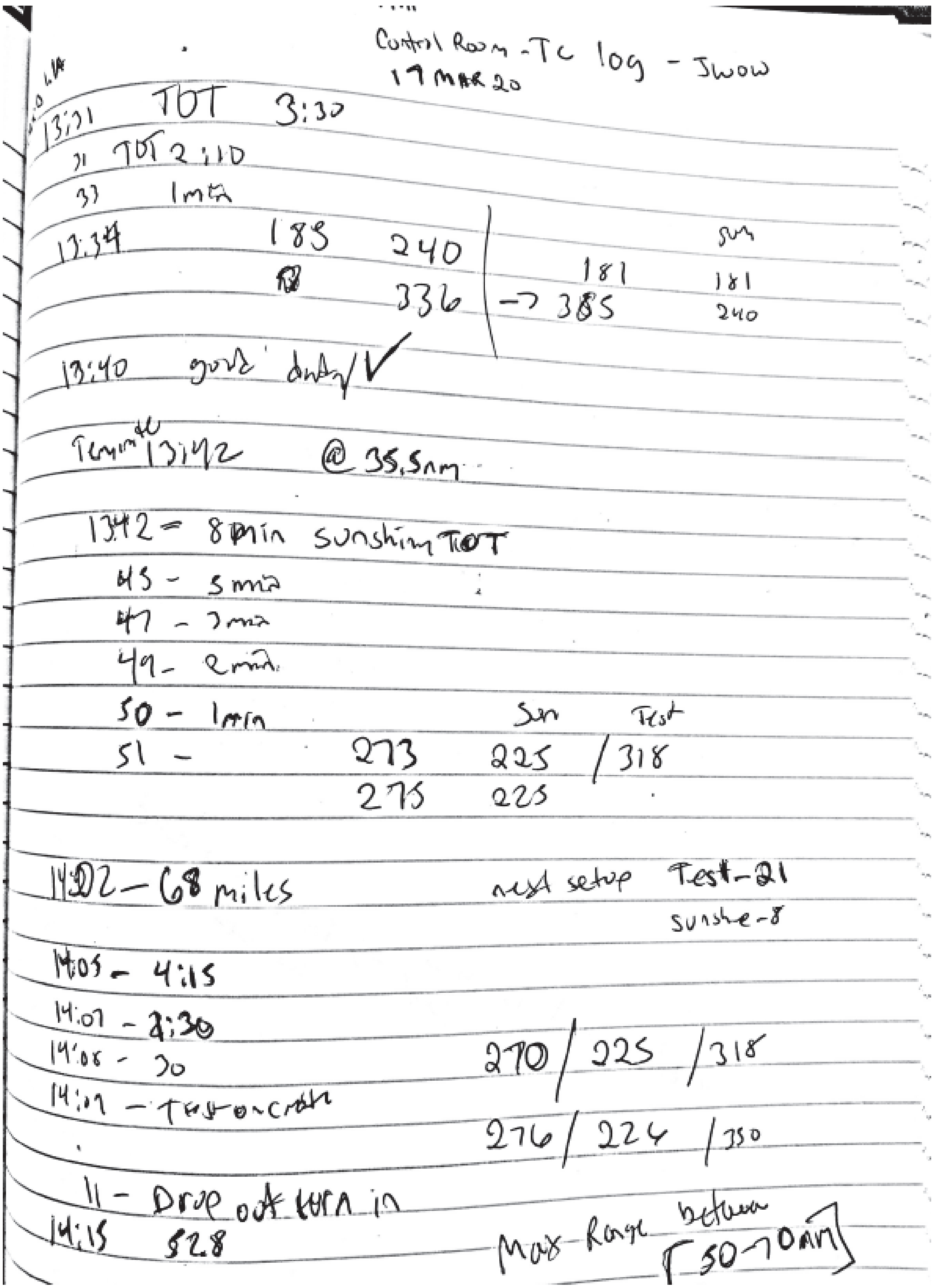
Card 6, 5, 4, 3 (50, 40, 30, 20 NM Level): These test points were all flown under the same conditions except points 6 and 5 were flown east to west and points 4 and 3 were flown north to south/south to north, respectively. This was done because of airspace limitations. The F-15E had to perform numerous spins before overtaking the Sabreliner because of better than predicted results for Terminator Pod azimuth reception. The F-15E began the overtake outside of good reception, then flew parallel to the Sabreliner to observe what azimuths the Termintor Pod received good data. Because of the better-than-predicted results, the F-15E was not able to find the maximum azimuth in front of the Sabreliner before running out of airspace. Since symmetry cannot be assumed, these test points would have been completed on the next sortie.

Card 7 (WCS Level): This test point was flown just like the 20 NM Level run, except the Terminator Pod was facing the shore and the F-15E was between the Sabreliner and shore. The purpose of this card was to observe any interference from cellular towers. Initial observations show the same results as the 20 NM Level run, indicating no interference.

a6. RECOMMENDATIONS

The plan for the next sortie would have been to clean up the test points from 40 to 70 NM where we were lacking data, specifically in the front half of the pod's view. Also observe the difference in maximum range when a lock is established and the transmitter increases its distance versus not having a lock and flying towards the Terminator Pod.

COMPLETED BY Loiacono, Francis X	SIGNATURE	DATE 18 Mar 2020



Control Room - TC log - JWOW
17 MAR 20

13:31 TOT 3:30
31 TOT 2:10
33 1min
13:34 189 240 | sum
[illegible] 336 | 181 181
→ 385 240
13:40 good data ✓

Terminate 13:42 @ 35.5nm

1342 = 8min sunshine TOT
45 - 5min
47 - 3min
49 - 2min
50 - 1min Sun Test
51 - 273 225 / 318
275 225

14:02 - 68 miles next setup Test-21
sunshine-8

14:05 - 4:15
14:07 - 2:30
14:08 - 30 270 / 225 / 318
14:09 - Test on crate
276 / 224 / 350
11 - Drop out turn in
14:15 528 Max Range between
[50-70nm]

Cd 6: 8 14:30

OPS Check
19k 14:20

14:21 - 6 min TOT
14:22 - Ards 957 dead
14:25 - working rect - 2 min TOT
14:27 - cleared to maneuver
27. 30 sec

		GS	GT	W
S	273	167	275	17
	8			

14:29 test on condition
14:36 terminate

Cd 5
14:39 cleared to maneuver
14:38 TOT 4:30
14:43 - 30 sec

GT	GS
273	171
278	175

45 - spin #1
47 - spin #2
spin #3

14:52 .151 ~ 36° back [25°]
155 lock up
14:56 Terminate

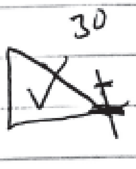
Cd 4:
14:58 Cleared to maneuver

updated IPs

T	S
7	45

14:59 6 min
2848

GS	GT
183	187
190	



46° up 060 backin

15:16 term

Card 3:

15:19 3min TOT

GT	GS
001	208
006	207

15:24

15:21 2 min

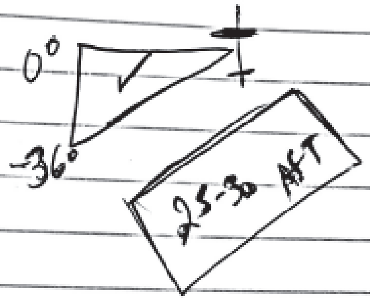
15:24 SPIN #1

15:28 SPIN #2

15:30 ~~test~~ on Condition

15:32 - good data ~36° Aft

15:37 - terminate



Card 7:

15:39 - Cleared to maneuver

15:40 - 5 min TOT

15:41 - Ards rqst mongoose

15:43 - 1:30 TOT

15:45 S | 094 | 340

boresight
20nm WCS

15:47 - 957 Ards Fail

15:48 - terminate

BORESIGHT RANGE

18:34:10 185 240.

35:00 45° away

42:05 Terminate @ 35.5nm.

51.00 SL attack. Immediate lock.

51:39

19:00:30 Terminate + 68nm.

09.22 SL hack.

09 46 Test on condition.

10.40 Lost lock. 178°.

11:00 Test turn in. 70 nm approx

13:08 65nm. good lock, then dropped.

15.05 good lock 55nm intermittent.

16:00 52.8nm good lock. turned away then in. good data on turning in.

17:32 50nm. turned away, good data.

18:56 good lock 55.5nm Terminate for airspace.

204529. on condition } WCS card. 20nm
204845 terminate

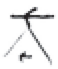
CARD 6 50nm

19:28:18 SL @ IP

29:41 Test @ IP. was this correct?

35:45 Terminate airspace.

Not enough space for finding fast side



#5 40nm

278/175kn.

19:43:54 SL @ IP

Good data → spin.

168° good data

Spin @ 47:30

After Spin 2:

19:49:43 Spin 3 begins. 159° good data.

19:52:00 bad data. @ 157°.

19:56:35 terminate 155 – 156° ⇒ good data.

#4: 30nm

20:02:30 SL @ IP.

052° emm start. 050° AT

unlock 20:06:28

20:10:53 good lock

20:11:10 good data

20:16:28 Terminate

060° AT

i.e.

#3 20nm

202350 SL @ IP.

2025:06 lock, good data, spin.

2027 26 lock ✓.

2028 00 spin 2.

2030 00 Bad data.

2032:08 Good data

203245 Bad data.
good data 235° ≈ 33°.