VHF-DF Testing for Rescue 21

Project Report

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Projects in Electrical & Computer Engineering
United States Coast Guard Academy
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ABSTRACT

The Coast Guard Headquarters Acquisition directorate (G-AND) has tasked the Coast Guard Academy with developing a testing device for the modernized National Distress and Response System. The testing system will assess the very high frequency (VHF) direction finding system built by General Dynamics. The testing system consists of two VHF modem radios, one transmitting position information from a mobile station and one receiving the information at a base station. The position information received at the base station is translated into a bearing by a MATLAB program using the known position of the base station and compared to the bearing received from the direction finder.

The difference in the bearing calculated from wide area augmentation system (WAAS) position information and the bearing from the direction finder ranged from 0.00152 degrees to 175.95 degrees, but the average difference was 0.04081 degrees. These results lead me to conclude the testing system works. However, there are still minor problems with the MATLAB program and the Windows operating system on the laptop to fix before the testing system can be widely used. When the testing system is completely finished, it will provide a quick and user-friendly way to test direction finders to ensure that they are operating correctly and are providing sufficient coverage for areas of operation.

INTRODUCTION

On an average day, the Coast Guard saves 15 lives, assists 117 people in distress and conducts 90 search and rescue cases [1]. The Coast Guard needs a radio direction finding system that works as efficiently as the organization does. The Coast Guard's legacy National Distress and Response System (NDRS) is outdated, has many coverage gaps, and does not provide full coverage out to 20 nautical miles across the United States' waterways. NDRS consists of 300 VHF-FM (very high frequency - frequency modulated) antenna sites along the coasts and inland waters of the United States [6]. However, unless the distressed vessel states its position in the distress call, the location cannot normally be obtained. Therefore, the Coast Guard expends many of its resources searching for vessels with unknown locations. Also, the current system can only monitor one communication channel at a time. So, when that channel is being used, other distress calls cannot be heard. The inadequacies of NDRS in today's environment create a high risk that lives will be lost.

The Coast Guard's Headquarters Acquisition directorate (G-AND) has proposed the solution: Rescue 21. Rescue 21 is the modernization that will enable the National Distress and Response System (NDRS) to adequately perform to today's expectations. The Rescue 21 system will update the 300 legacy VHF-FM antenna sites by replacing the outdated equipment with more capable hardware. The modernization will provide coverage and automation in areas where they presently do not exist. The Rescue 21 system will link systems along the coasts; this will allow information received in one area to be available in another area, increasing situational awareness. The new system will increase the number of channels monitored from one to six. Rescue 21 will also have digital recording and playback of the messages received. Digital recording will allow the Coast Guard to slow down the message or decrease the noise to better understand the transmission [7].

The recapitalization of the system will provide the Coast Guard with a direction finding (DF) system with a claimed accuracy of plus or minus 2 degrees, enabling search and rescue teams to search smaller areas and locate distressed boaters faster. The update will also enable the Coast Guard to distinguish between legitimate and false distress calls by analyzing the voice, background noises and the direction of the

signal. The improved system will allow the Coast Guard to work efficiently with limited resources and provide a quicker response.

The Coast Guard needs a way to verify that the direction finders are accurate. In 2002, the Coast Guard awarded General Dynamics the contract to build a system that will meet the requirements to update NDRS and the Rescue 21 program office asked the Coast Guard Academy to design and produce a device that will test the new VHF-DF for its geolocation capabilities and accuracy [8]. The testing device must be able to assess the direction finding capability of a VHF-DF site and be easy to use. In order to accurately verify the ability of the VHF-DF system to locate transmissions in real-world situations, the testing device must be portable to allow the Coast Guard to test multiple VHF-DF systems along the United States' coast, in different weather conditions, and on different vessels. In addition to being used to verify the accuracy of the Rescue 21 direction finder, the testing device can be used by the Coast Guard to test any direction finder.

During the 2002-2003 academic year, the cadet working on this project determined the specifications that the transmitted signal should meet for testing the Rescue 21 direction finder. He also researched radios that would be useful to test the direction finder and concluded two types of modem radios, Frequency Shift Keying Modulation (FFSK) and Gaussian Minimum Shift Keying (GMSK), would be sufficient for the tests [2]. During the 2003-2004 school year, the cadet working on the project researched FFSK and GMSK radios and found the necessary bit rates to be comparable to FM. Then, she bought two sets of VHF radios, a Teledesign Radio that uses GMSK and a Key Radio Systems radio that uses FFSK. She began constructing a system using the Teledesign radios, but due to time constraints was unable to finish the construction and testing [3]. For the 2004-2005 school year, the cadet working on this project continued constructing and testing the system using Teledesign radios. She created MATLAB code to receive and analyze data from the receiver and direction finder. Then, she tried fine-tuning the MATLAB code to accurately test the direction finder [4]. The previous work by cadets provides a solid foundation for this project.

Building on previous work, I first clarified the objective for this project. Then, I designed and built the test system. After building the system, it was time to test the system to ensure it was working correctly. Tests were conducted to ensure that the direction finder worked and then tests were conducted to evaluate the testing system. Tests to evaluate the testing system were conducted on land and on the water. After conducting the tests, I processed the data and concluded that the testing design would work to test direction finders for the Coast Guard.

OBJECTIVE

The goal of this project is to create a testing system that will validate the General Dynamics direction finding system. The specifications of the direction finding system include being able to receive distress communications sent with 1 Watt from an antenna 2 meters above sea level, 20 nautical miles from the coast and being able to provide at least one line of bearing to the transmission with an accuracy within plus or minus two degrees [5]. The testing system needs to be mobile, weatherproof, functional using AC/DC or battery power, accurate, and able to simulate a voice transmission from a vessel with an antenna 2 meters above sea level transmitting with 1 Watt from 20 nautical miles from the coast. In order to be weatherproof, the system needs to be unaffected by water, wind, sun, heat, and cold. To be mobile, the device needs to be small enough to be deployed on small boats, helos, and cutters. It is important for the testing device to be functional using alternating current (AC), direct current (DC) or battery power so that the device can operate on a variety of platforms using a variety of available power options. The testing apparatus needs to be able to provide an efficient way to transmit position information to compute an accurate bearing to the transmitted signal because the bearing from the Rescue 21 direction finder will be compared to the signal from the testing equipment.

SYSTEM DESIGN

The VHF-DF testing system consists of a base station and a mobile test bed. The mobile test bed transmits a signal to test the direction finder. This test bed is made up of a Novatel ProPak-G2 Wide Area Augmentation System (WAAS) receiver and a Teledesign packet modem transmitter. The Teledesign radio uses Gaussian Minimum Shift Keying (GMSK) to transmit the WAAS data. The mobile test bed is powered by 12 V DC power. If only AC power is available, a power converter will be included. The mobile test bed is deployed on a vessel. See Figure 1 for a picture of the mobile test bed.

Figure 1: Mobile Test Bed

The base station consists of a direction finder, a Teledesign modem radio, and a computer. The antennas for the direction finder and the Teledesign modem radio are mounted on the roof of the building or on a tower. Figure 2 is a picture of the base station showing the direction finder, the radio and the computer.

Figure 2: Base Station

A block diagram of the testing system is shown in Figure 3. The Teledesign modem radio receives the WAAS information from the transmitter on the mobile unit and sends the information to the computer through a serial-to-USB port connection. The bearing information from the direction finder is sent to the computer via a serial-to-USB port connection. The computer has a MATLAB program running that captures the WAAS position information from the receiver and the bearing information from the direction finder. Then, MATLAB calculates the actual bearing from the WAAS receiver and will compare that bearing to the direction finder bearing. The Novatel ProPak-G2 WAAS receiver is rated at an accuracy of less than 1.2 meters [4]. Due to the accuracy of the WAAS receiver, the bearing calculated by MATLAB is accurate to plus or minus 0.001719 degrees at 20 NM from the coast and plus or minus 0.0344 degrees at 1 NM from the coast. These errors are negligible for the purpose of the tests.

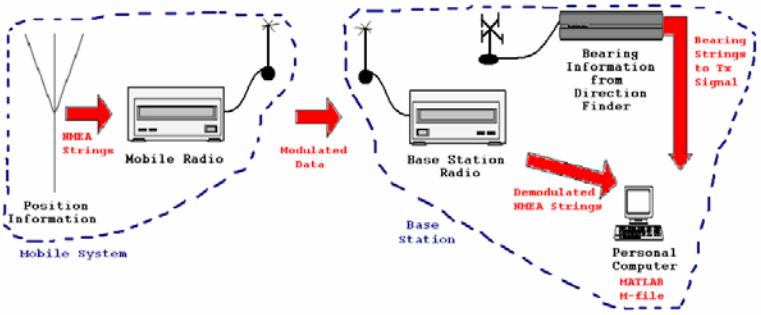

Figure 3: Test System Setup

The MATLAB code interprets the National Marine Electronics Association (NMEA) strings received from the Teledesign receiver and from the direction finder. The NMEA strings received from the Teledesign receiver are the same as the NMEA strings output by the Novatel WAAS receiver. The position information NMEA string has a format as shown in Figure 4.

```
$GPGGA,160707.00,4122.3471891,N,07205.987
0379,W,1,08,0.9,40.117,M,,,,*17
```

Figure 4: NMEA Position String

The $GPGGA distinguishes this as a position string. The next number, 160707, is the time in Greenwich Mean Time (GMT) which is converted into hours, minutes and seconds by MATLAB. The time in the NMEA string is 16 hours, 7 minutes, and 7 seconds. The latitude, in degrees, is read in next. The next number is the longitude [4]. The MATLAB software converts the latitude and longitude into degrees and minutes. The time, latitude, and longitude are the only parts of the GPGGA NMEA string used for my testing device.

The direction finder used during development is a SIMRAD TD-L1550A. The bearing information from the direction finder is sent using a proprietary string made by SIMRAD, which follows the example in Figure 5.

```
$DFBRG,S81,,1,292,R,
```

Figure 5: DF Bearing String

The $DFBRG means that it is a bearing string. The first number, S81, is the channel that the signal was received on. In this example, the signal was received on channel 81. The next number, 1, is the signal to noise ratio (SNR) value of the signal received by the direction finder. The SNR values range from 1 to 5

with 5 being the strongest signal. The third number, 292, is the bearing to the signal. The last part of the string, R, means that the direction is in degrees relative to the North plate of the DF antenna [4].

When testing the Rescue 21 direction finder, it will be very important to determine the format of the string output by the Rescue 21 direction finder because the SIMRAD direction finder is not being used in the Rescue 21 tests and the string formats will be different. The MATLAB code will be adjusted to read the Rescue 21 bearing string. Then, the Rescue 21 direction finder can be tested in the same manner as the SIMRAD DF by having its bearing compared to the exact bearing calculated by MATLAB from the WAAS information.

The General Dynamics (GD) testing system being used to evaluate the Rescue 21 direction finder is different than the testing system that I designed. The GD testing system outputs a tone and the computer system on the boat logs the position of the vessel and the time that the tone was sent. Then, the computer system at the direction finder site logs the time and bearing of each signal received. When the test is completed, the data from both computers is sent out for post processing. This process of testing takes a long time because of the time it takes to compile and post process all of the data. My testing system transmits modulated data. The data has the position information and the time that it was sent in it. Then, the computer at the direction finder site collects the data and calculates the bearing to the vessel and the difference between that bearing and the direction finder bearing. The information is then sent to an output file. With this testing system, the results are available as soon as the test is completed.

RESULTS

The first goal of the project was to recreate the results obtained by the cadet working on this project last year. To do this, I had to learn how to program the radios and ensure that the direction finder and radios were compatible with the personal computer. I used the same MATLAB code and instrument settings that she used last year and observed how they operated together. While analyzing the testing system, I observed some problems with the system. The MATLAB program would shut down regularly about every 5 minutes and the bearings from the direction finder and from the WAAS were very different. I decided before I tested how well the testing system worked, I would test the direction finder to ensure that it was accurate.

Testing the Direction Finder

To test the direction finder, there was a person in a car with a GPS receiver and a VHF handheld radio on channel 81 and another person in the base station with a VHF handheld radio. The person in the car would drive to a spot and read off the GPS information from the GPS. The person in lab would write down the bearing from the direction finder and the GPS position along with the general area where the position was taken. Later, the bearing would be calculated from the GPS position information and compared the bearing from the direction finder (DF). I used channel 81 to test the direction finder because that is the channel that the mobile radio transmits on for the VHF-DF testing device. However, the direction finder and the testing device can operate on any channel.

For the first direction finder test, the tester drove around New London, CT and read the positions to me in lab. The results from this test can be seen in Appendix D.
The average difference in the DF bearing and the GPS bearing was 28.85 degrees. I attributed this to multipath because of the location of the tests. So, I decided to test the direction finder from Groton. For the second test, I had someone stay in the lab and write down the bearings from the DF and the GPS information that I would relay to him while driving around Groton, CT. The results from the 2nd test are in Appendix E.

The average difference in the DF bearing and the GPS bearing during the 2nd test was 20.46 degrees. Due to the terrain of our tests and the fact that the SIMRAD DF we are using to verify our DF testing system is not the Rescue 21 DF that I will be testing, I concluded that the SIMRAD DF was accurate enough to determine if our testing system is operating correctly. The actual tests of the Rescue 21 DF will be conducted on the water and not in a terrestrial environment so multipath and other factors, such as hilly terrain limiting the ability of VHF communications, will be less relevant.

Correcting MATLAB Script

The next obstacle of the project was to correct the MATLAB code so the program would run continuously without having an operator standing by to restart it. After analyzing when MATLAB shut down, I concluded that the program could not handle incomplete or incorrect NMEA strings. To fix the MATLAB code, I added error checking commands to disregard the incomplete or incorrect strings. To view the improved MATLAB code, refer to Appendix A.

Adjusting Transmission Time

After ensuring that MATLAB would work continuously, the next goal was to increase the transmit time of the radio to at least 4 seconds so that the direction finder could lock on to the signal and produce an accurate bearing. First, I investigated changing the settings on the radios to increase the transmit time. I increased the timeout time of the radio to 500 characters and this lengthened the signal a little bit, but not enough for the DF to get an accurate bearing. The timeout time is the amount of time that the radio transmits after it stops receiving a message from the WAAS receiver. Then, I changed the transmitter from data activation mode to hardware handshake mode. This configured the radio for constant transmission. I watched the operation of the radio and it was transmitting every NMEA position string from the WAAS receiver and the DF was able to provide a bearing to it, but operating continuously is not good for the transmitter because it creates a risk that the radio will burn out. Also, I concluded that it would not be an accurate representation of a distress call if the radio was transmitting continuously because a distress call could possibly be only a few seconds long. A distress call is usually not continuous.

Next, I investigated increasing the signal length by increasing the NMEA strings from the WAAS receiver. I reconfigured the WAAS receiver to output a longer string followed by the GPGGA NMEA string with the position information in it. I changed the transmitter back to data activation and analyzed how it worked with the WAAS receiver with the longer string. This modification increased the transmission time to about 4 seconds. I concluded that this configuration would work well for testing. This process of changing the transmission time of the signal can be used to test any type of direction finder.

Field Tests

Once the transmission time was increased, I tested my system. The stationary base station remained in lab with the antennas mounted on the roof, while the mobile unit was driven around Groton, CT in a van. The purpose of the test was to verify that the testing system was working correctly, the WAAS receiver was outputting GPGGA NMEA position strings every second and that the receiver was receiving all of them. Also, the test was designed to verify that MATLAB would run continuously while the testing system was mobile.

During the testing, MATLAB would shut down randomly for a few different reasons. When the receiver was not receiving a signal from the transmitter, the MATLAB code would time out. Also, MATLAB would return error messages and shut down if the M-file was started in the middle of a NMEA string, if MATLAB did not receive all the components of the position string, or if it received pieces of different strings inside the position string and other anomalies. A watch stander is still needed to stand by to restart MATLAB during testing. A short list of the errors received and the NMEA strings received in MATLAB prior to the error are included in Appendix B. The results of the test were promising because the errors between the GPS bearing and the DF bearing are relatively small and MATLAB ran for a longer amount of time before returning an error message. The errors between the GPS bearing and the DF bearings are less than 15 degrees except for a few outliers. To view a short sample of the results refer to Table 1.

Table 1: Excerpt of Results from First Field Test

RESULTS TAKEN ON01-Dec-2005					
ZULU Tim	Lat	Long	GPS Brg	DF Brg	Difference
23:07:33	41.38045	-72.0852	52.67734	48	4.677336
23:07:34	41.38045	-72.0854	52.42651	60	7.573495
23:07:35	41.38045	-72.0855	52.16504	66	13.834959
23:07:36	41.38049	-72.0856	51.83727	66	14.162726
23:07:38	41.3805	-72.0858	51.33451	49	2.334508

To view more results from the first field test of the testing system refer to Appendix C.

After testing the system on land, I corrected the MATLAB code and ensured that it would work without shutting down. Also, I changed the code to output the SNR value of the received signal into the output file. The SNR value is the Signal to Noise Ratio of the signal received by the direction finder. The SNR value is output by the SIMRAD DF and ranges from 1 to 5 with 5 being the best. Knowing the SNR value helps the tester to know when the signal received by the DF is the signal that is being tested and not a random value output by the SIMRAD DF. It will also help in future tests to determine the quality of the signal used during the test. Then, I tested the system while it was deployed on a 41' Utility boat. For the three underway tests that were conducted, the base station was located in the yellow FAA van and the mobile station was deployed on the 41' boat. The base station was located on Avery Point because it has good line of sight to the vessel and the vessel would transit between predetermined waypoints between New London Channel and Fishers Island. To see a picture of the base station during the underway tests, view Figure 6 and Figure 7.

Figure 6: Base Station on Avery Point

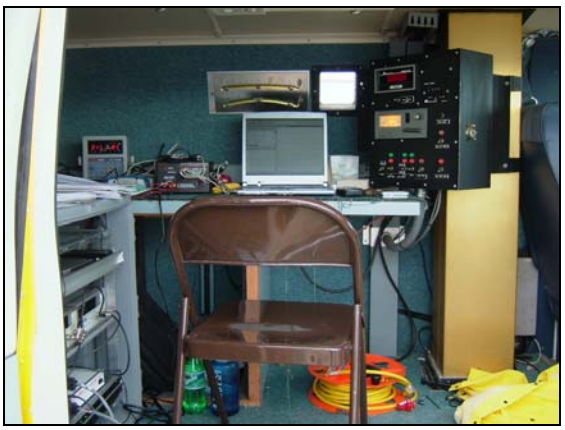

Figure 7: Base Station Setup in Van

The mobile lab setup on the 41' Utility Boat can be seen in Figure 8, Figure 9, and Figure 10.

Figure 8: 41' Utility Boat used for Testing

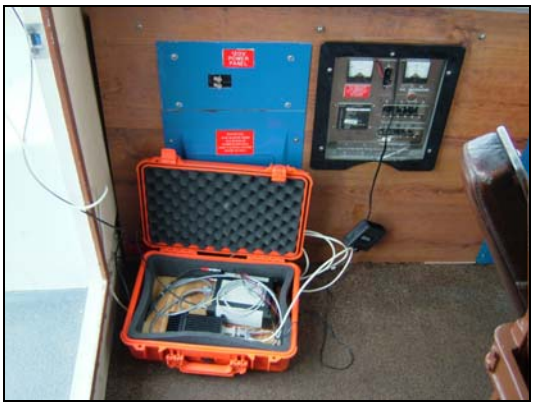

Figure 9: Mobile Test Setup

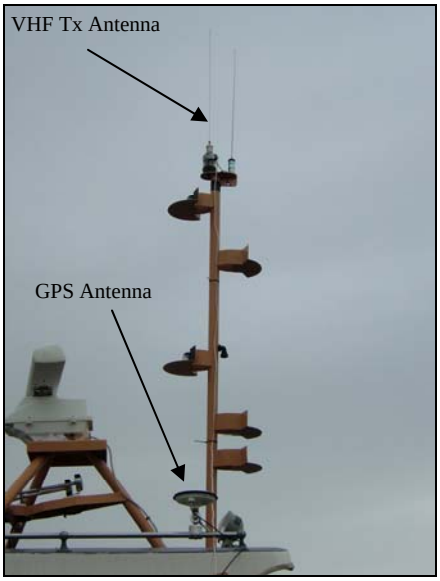

Figure 10: Antennas used for Testing on 41' Boat

The first underway (U/W) test occurred on 02MAR06. After getting the mobile test bed and the base station set up, the laptop hard drive crashed. So, data collection was impossible. U/W test number one was stopped early and it was time to try to retrieve all of the project files off of the broken hard drive. Before the next U/W test could happen, I needed to get a new hard drive and make the laptop functional again.

After transferring all of the files off of the old hard drive and installing the necessary programs on the new hard drive, I conducted another underway test of my system. This three and a half hour test occurred on 24MAR06 and provided some good data. The test plan for the second underway test is provided in Appendix F. During the second U/W test, MATLAB experienced five runtime errors and had to be restarted each time.

This resulted in data not being collected during the time that MATLAB was not working correctly. These gaps in data collection are shown on the graph of the received bearings in Figure 11. A short excerpt of the output file is shown in Appendix H. The average difference between the bearings for this U/W test was 21.79 degrees when analyzing all of the data collected. Figure 11 illustrates the results from the test graphically and shows the difference. The difference can be caused by an error in the orientation of the DF antenna and variation. It can also be caused by other communications on Channel 81 and the use of the VHF handheld radios on Channel 69 inside the van. The use of the VHF handheld radios was observed to cause a change in the direction finder. For the second

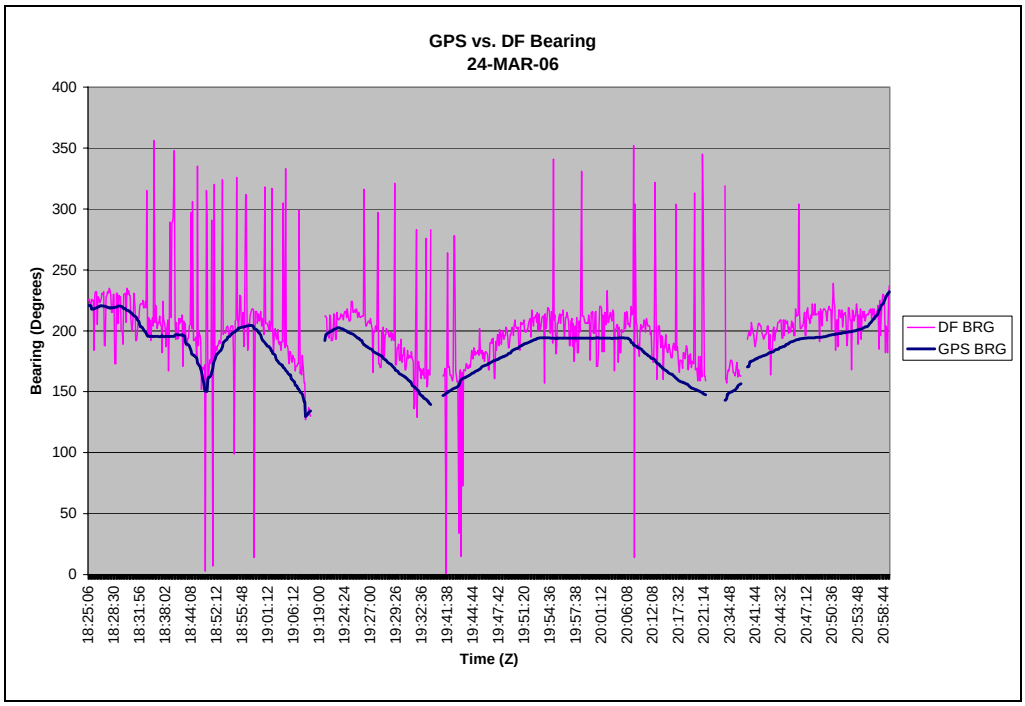

Figure 11: GPS vs. DF Bearing for 24MAR06

underway test, a log of communications and observations on the channels was not kept.

After the test, the data was post-processed. A trend was found to exist in the SNR value and the accuracy of the signal. The data with SNR 5 was found to have an average difference of 124.58 degrees. Data with SNR 4 had an average difference of 17.9 degrees and data with SNR 3 had a difference of 20.92 degrees. Data with SNR 2 had an average difference of 30.5 degrees. A graph in Figure 12 shows that the difference of bearings is very bad for SNR 5, improves for SNR 4 and decreases as the SNR decreases. Because of the quality of the results based on SNR, only SNR values of 3 and 4 were used to evaluate the system. I decided not to use the SNR values of 5 because I concluded that they were so strong that they could not be from the signal from the testing system. The SNR values of 5 could be attributed to either our communications on the handheld VHF-FM radios or other communications. When the system was evaluated using only SNR values of 3 and 4, the average difference in bearing was 15.37 degrees. The reason for this difference is that I aligned the DF antenna to North using a magnetic compass and the magnetic variation for Avery Point is 15 degrees west. After applying the correction for variation, the difference between the GPS bearing and DF bearing is 0.37 degrees. Figure 13 shows the GPS bearing, original DF bearing and adjusted DF bearing. It shows that the GPS bearing and DF bearing are very similar. The reason for the differences is the fact that the SIMRAD direction finder that we are using to evaluate the testing system outputs data even when it is not receiving a signal and is also rated for an accuracy of plus or minus 5 degrees.

The same MATLAB code was being used for the second U/W test as was used for the first test. The MATLAB code was proven to operate without shutting down prior to conducting the first underway test.

Therefore, I believe that the runtime error that MATLAB was experiencing in the second U/W test was caused by a setting in Windows. The reason for this is that Windows had to be reinstalled after the hard drive crashed and would have been restored to its default settings.

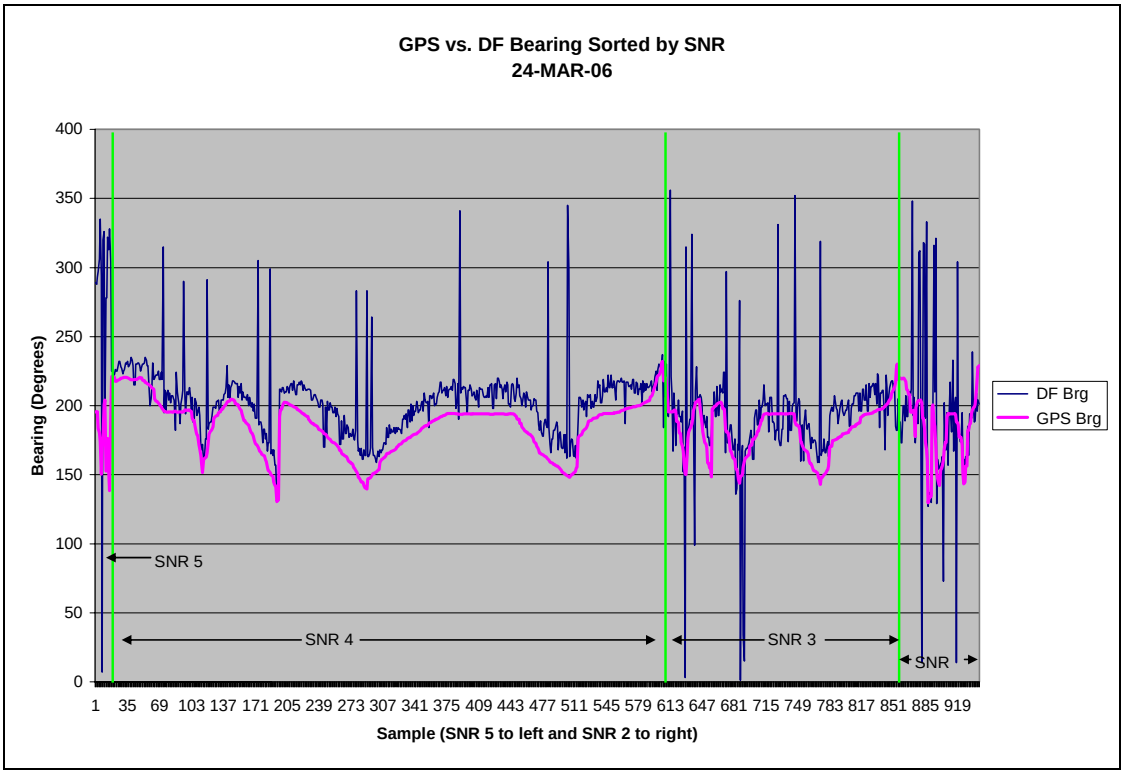

Figure 12: GPS vs. DF Bearing Sorted by SNR for 24MAR06

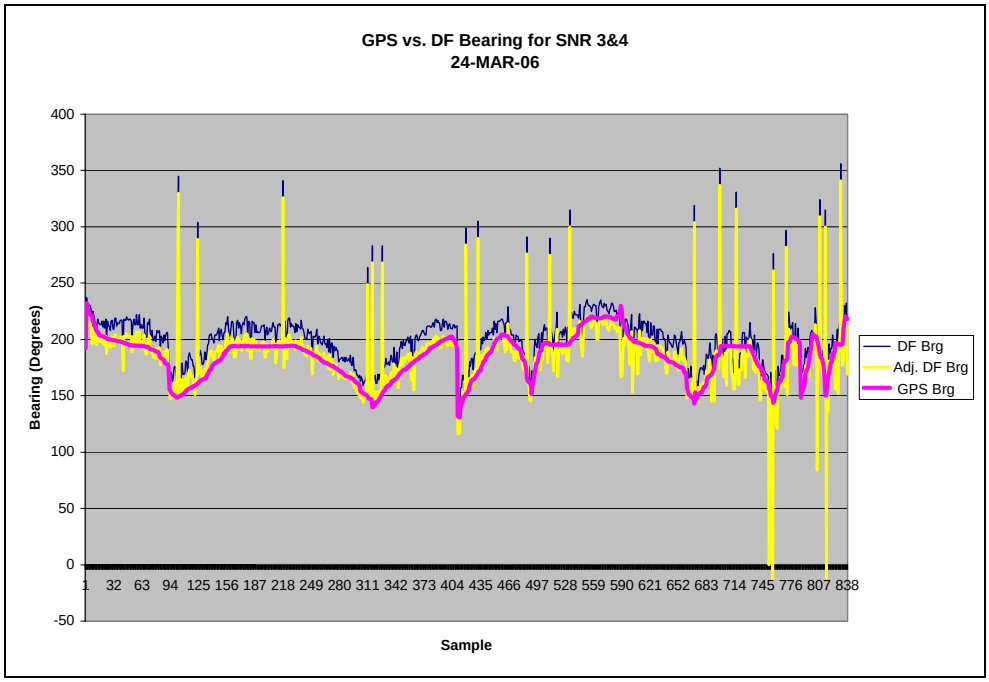

Figure 13: GPS vs. DF Bearing for SNR 3 & 4 for 24MAR06

The third U/W test was conducted on 05APR06 and was conducted differently than the first two. The purpose of the third test was to investigate the behavior of the system while using VHF voice communications and VHF data communications. During this test, the mobile test setup was used and so were the VHF-FM handheld radios. The test plan for the third underway test can be viewed in Appendix G. The 41' Utility boat would transit between set waypoints and would transmit using the mobile test bed and the VHF-FM handheld radios on Channel 69 and Channel 81 depending on their position and the point in the test. By calculating the difference between the known position of the vessel and the bearing displayed on the direction finder, the use of the VHF-FM handheld radios provided us with a correction factor for the direction finder calculated by taking the average difference of the direction finder bearing and the bearing to the known location of the vessel using fixed navigation aids, such as Ledge Light, and the GPS receiver onboard the vessel. The average direction finder difference was 22.7188 degrees to the West. Also, the MATLAB M-file was changed for the third underway test to show whether the direction finder bearing was larger or small than the GPS bearing. Prior to the change, the difference between the two bearings was an absolute value. The MATLAB code can be seen in Appendix K. After applying the correction factor to adjust for the error in the direction finder, the average difference between the GPS bearing and the DF bearing was 0.04081 degrees. To see a short section of the data collected during the third underway test, view Appendix I. A graphical representation of the data is shown in Figure 14.

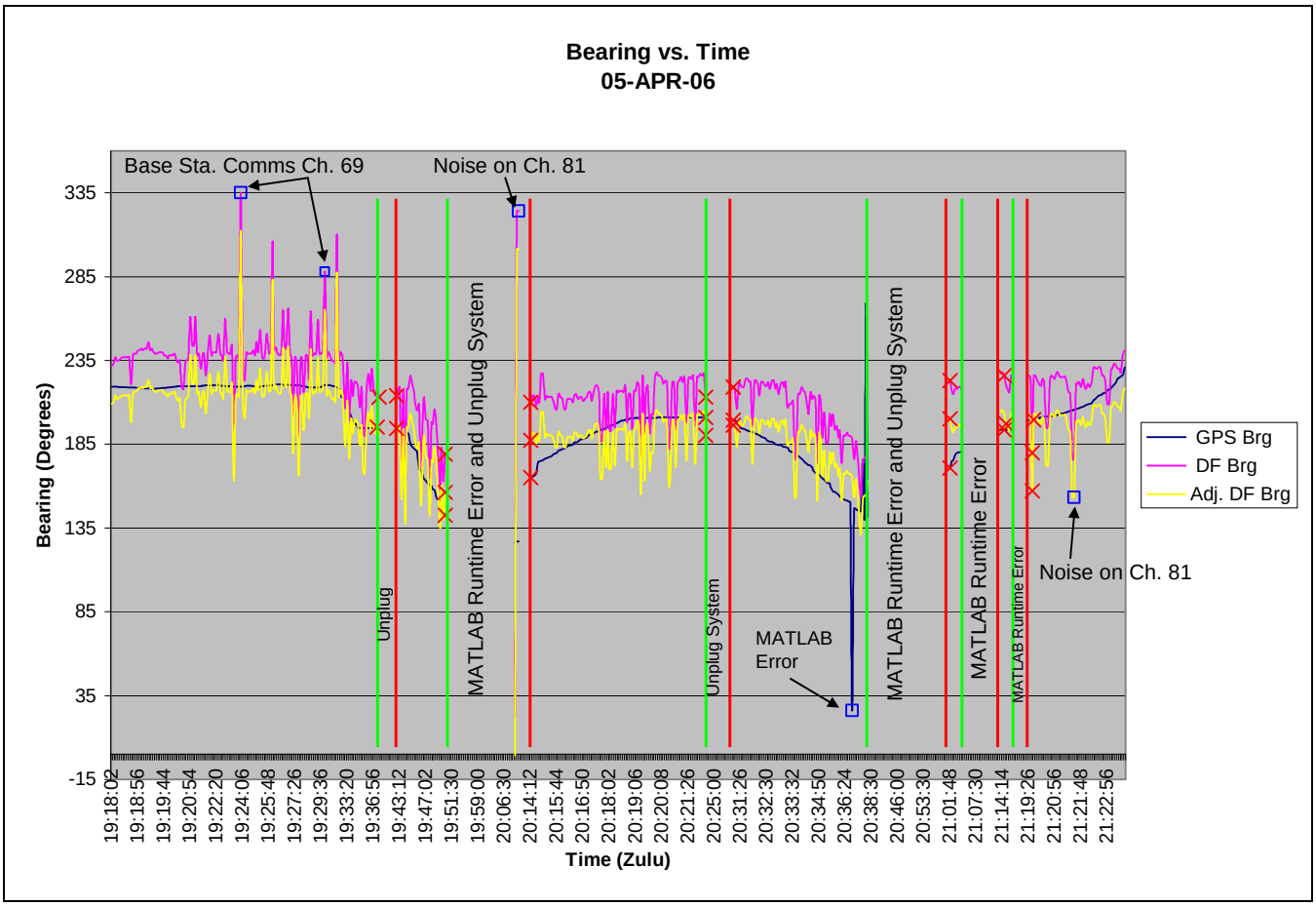

Figure 14: Adjusted DF vs. GPS Bearing for 05APR06

The graph shows the GPS bearing, the original DF bearing and the adjusted DF bearing. The gaps in the graph are caused by the MATLAB runtime errors and the VHF-FM handheld tests that were conducted. Figure 15 shows the graph with explanations for the gaps and for the outliers. Figures 14 and 15 analyze data for all SNR values. The outliers on the graph can be attributed to other communications and noise on Channel 81. Also, the direction finder was noted to react when the handheld radio was used inside the van

on Channel 69. So, some of the difference in bearings can be attributed to that. During the third underway test, a communications log was kept to note any communications or noise observed during the testing.

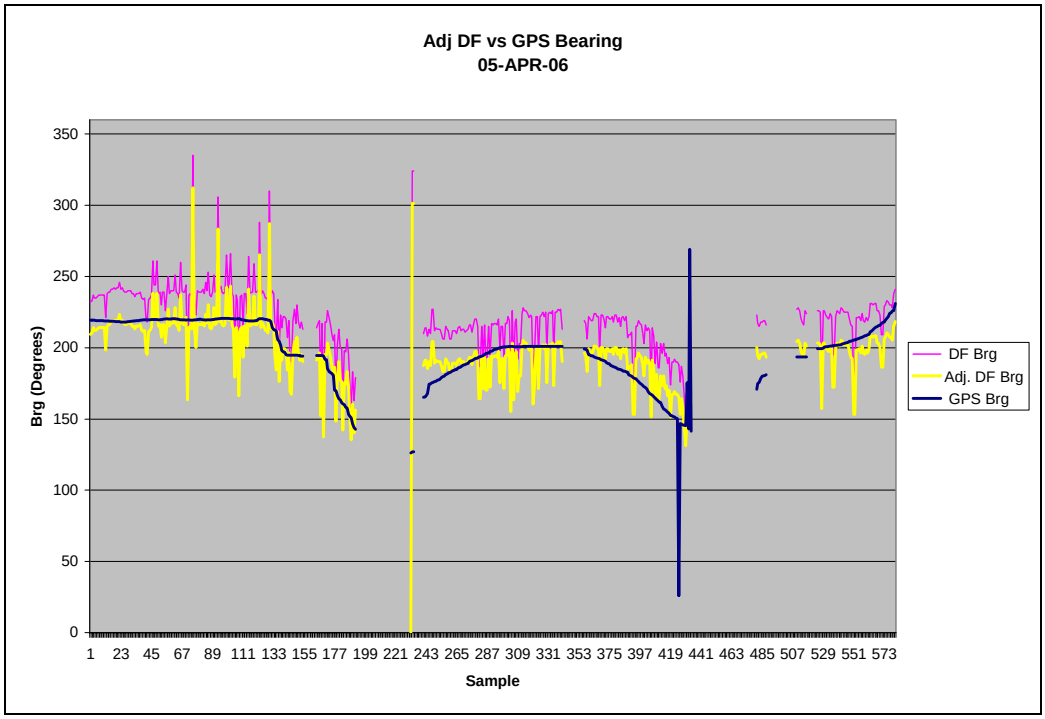

Figure 15: Bearing vs. Time for 05APR06

The communications log is in Appendix J. This provides enough data to conclude that the testing system is working the way that it was designed to.

During this two hour test, MATLAB experienced 12 runtime errors and had to be restarted 12 times. The amount of time that MATLAB worked got progressively shorter as the test went on. I believe that this is caused by a setting in Windows, specifically that the Comm Ports are not configured correctly and that is causing errors. Even though MATLAB created problems during the test, the data collected showed that the testing system is sufficient to test direction finders.

CONCLUSIONS

The biggest challenges faced during this project were adjusting the transmission time of the signal and making MATLAB operate correctly for longer periods of time. I have accomplished making the signal length long enough for the direction finder to provide a bearing to the signal by adjusting the settings on the WAAS receiver. I have also succeeded in providing the MATLAB code with more error checking in it to account for anomalies encountered during testing such as incomplete strings and not receiving a signal. However, after the laptop hard drive crashed, MATLAB began experiencing Runtime Errors and shutting down. This resulted in a lot of downtime during testing and subsequently a lot of data that was not collected. It also created a need for a watchstander to monitor the base station to ensure that it was still collecting data and restart the system if it was not.

The data collected during the tests supports that the direction finder testing system works correctly and could be used for testing any direction finder. The system needs a minor amount of work before it could be widely used to test direction finders. The testing system can be used to test the Rescue 21 direction finder. Prior to testing the DF, the MATLAB M-file needs to be changed to read in the output string from the direction finder. Also, the transmission time and the transmission channel can be changed for the tests.

In the future of this project, the MATLAB M-file needs to be corrected and changed for ease of operation and to allow for testing of various direction finders. Also, Windows needs to be configured to minimize the amount of runtime errors encountered during testing. During the evaluation of this testing system, the output power was not monitored. Future projects can design a

system to monitor and change the output signal power to accurately test direction finders. Also, a testing system made with Key Radio Systems radios should be built and investigated.

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APPENDICES

[A] MATLAB Code

[B] Errors Encountered During Field Test 1

[C] Results from Field Test 1

[D] Results from the First DF Testing

[E] Results from the Second DF Testing

[F] Test Plan for 24MAR06

[G] Test Plan for 05APR06

[H] Results taken on 24MAR06

[I] Results taken on 05APR06

[J] Communications Log

[K] MATLAB M-file used for U/W test 3