Improving Developmental Test Using HFE Concepts

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Introduction

There is a final balance that exists between quality and cost, which is never overlooked in the Aerospace and Defense Industry. For many Aerospace companies, government oversight and regulation is a standard mode of business, which typically requires customer or regulatory agency witnessing of the development and product verification activities. The Aerospace and Defense industry is known to provide products that are extremely advanced, but typically at very low quantities. Within many large Aerospace and Defense contracts, the detailed product and system requirements may be larger than ten thousand requirements. Cost problems often occur when customers desire large product volumes of complex systems.

The sheer volume of requirements desired by Aerospace and Defense customers typically requires long periods of product verification cycles. For example, the Ground-Based Midcourse Defense Program of the Boeing Company has over fifty thousand requirements. The program has been in the development phase of verifying requirements since 2000, and the current design validation program is expected to continue another 10 years. Many design and verification cycles have to occur with complex military systems, in order to generate a product that satisfies the large variety of customers and requirements. Consequently, the additional oversight by many different Government offices and agencies may also prolong a lot of the verification activities, because much of the testing is required to be performed using step-by-step test procedures. It is often difficult and expense to develop test automation for high-complex products, especially when product volumes are low. When product volumes are high, the industry typically migrates towards automated test applications to reduce cost.

Many Aerospace and Defense companies generate manual testing until it is time to cut cost or schedule out of the product lifecycle. At those phases of the program, automation of testing and product verification is greatly considered. However, since most of the advanced and complex products require high level of engineering expertise to understand and interpret data, automation is difficult at any stage of the product lifecycle. For complex systems, engineers are typically developing test software that they understand, and there is often little consideration for the end user, which is often a technician or operator of less understanding than the engineer. This is not an uncommon problem in the Aerospace and Defense Industry. The purpose of this investigation is to demonstrate how Human Factors Engineering (HFE) can be used to improve test software and test station design/development.

Current Problem

For several years, I have been on the Joint Tactical Radio System (JTRS) program, which is a development program for a software-defined radio, designated for the U.S. Army. As the project manager for product assurance, I am responsible for assuring all products conform to product requirements, as well as assure that all quality requirements are defined and implemented throughout Boeing and its subcontractors.

The concept of the radio is very complex. There are twenty-three existing communication systems (a.k.a. radios) that are commonly being utilized by the U.S. military. Each one of these radios operates at different frequencies and has different modes of communication (data, encryption, voice, networking, etc). Further complexity lies in that each of the legacy (current) radios are hardware driven. The meaning of hardware driven is that most of the radio frequency waveforms and signals are generated through a large portion of the hardware device. The purpose of a software defined military radio is to create software emulation of each of the legacy waveforms, and run them on a single hardware source. This simplifies the procurement of communication systems for the Government because is introduces one common design and more robustness to the modes of communications that a military vehicle can use. In addition to this requirement, the U.S. Army has levied new and complex networking and data requirements, which require the development of Internet based service for the Armed Services. Furthermore, the new communication system needs to provide the same or better performance than the legacy radio it replaces. Each of the legacy radios contains over three thousand requirements in amongst themselves. In total, the software and hardware architecture has culminated in over forty thousand requirements for this new tactical software defined radio.

Of these new requirements, most of them need to be tested or demonstrated to U.S. government agencies prior to be implemented to the warfighter (current military forces). A lot of system engineering and architecture design is required to define common interfaces with the new hardware and software. The current problem faced withy my team is how to support product qualification and product testing, in order to reduce test time and cost, while verifying all requirements. The problem that we are facing is that it takes nearly a week to perform standard acceptance testing on the radio system, which is a test to verify the high-level system requirements. The procurement plan for this radio will exceed fifty thousand units, which means it would take fifty thousand weeks of testing, with no issues, to deliver all products in the required procurement cycle.

Because of this, our program managers have set up a test improvement team, to find out what the issues are related to testing and to improve the program's cost, schedule, and product quality. In addition, the program is planning a very complex Production Qualification Test (PQT) event with the U.S. Army, which will require thorough testing of over forty thousand requirements. In recent discussions with the test team and the U.S. Army customers, there is a great concern on how this can be achieved on time and on budget. It is recognized by all parties that the test software that is going to be developed has to be both easy to operate, as well as provide automation to allow for repeatability and improvements in test time.

My team of Quality Engineers and Quality Inspectors currently perform "over-the-shoulder" inspections of tests and product demonstrations. It is the intent of our test improvement team to identify alternatives for developing test software implementations that will allow less trained labor to perform the acceptance testing, while maintaining the same level of testing quality. Much of the testing is mature enough to address the product requirements, but the implementation is still at a level requiring a higher-level knowledge in both radio frequency (RF) and networking design. The next following sections will itemize the HFE problems found the current testing of the Joint Tactical Radio System.

Figure 1 - Joint Tactical Radio (Public Release Image)

Testing time is too long

Until recently, it was not apparent to me that many of the issues that we are facing with the current test program are HFE related. Our program had recently completed the contract milestone testing. The Design Verification Test and Contractor Developmental Testing events took over three months to perform at a headcount of 17 people per week. Over ten thousand requirements were being tested at three facilities during that time. Much of the testing was performed simultaneously, from the component level, all the way up to the System level. A rough total of 6000 man-hours were spent performing the test. That averages out to 1.6 requirements verified per hour. If the same concept were being used for the Production Qualification Testing (PQT), where over forty thousand (40,000) requirements need to be verified, the testing time would take roughly nine months to complete. This is a big program concern with our program managers.

Several HFE arise out of the long testing cycles. The first HFE issue identified related to the prolonged hours and work schedules that have been seen in current testing. This has caused several complaints from personnel. In some cases, test personnel have quit or asked for re-assignment because the time demands and stress levels are extremely high. The HFE issue observed is related to poor interactions with the work environment, and the identification of Overuse Disorders (ODs). Unfortunately, there are a large variety of tests to be performed and it has been difficult to arrange the testing in a way that is not intrusive to individual lives.

Another known HFE problem is that we are required to have Electro-Static Sensitive (ESD) approved chairs in the laboratories, which are not ergonomically designed for long periods of use. Most of the chairs are flat, and have no armrest or lumbar support. A lot of the testing is performed sitting down in front of a test station computer, inputting and changing test code to run testing for the radio system. Most engineers are not looking at how they can make the test more convenient or better designed for users, but rather on if they can simply create a test to verify specific requirements. The excessive hours in the chairs has caused some complaints from personnel. Most of the testing is designed not to have breaks because the schedule to complete the test in intense. There is no split shift being used currently in the test program, which results in many engineers and quality personnel working an excess of 10 to 12 hours a day, six days a week.

In many of the program personnel opinion, the future looks grim for the test program. There are many different types of test events still to be performed, which are designed to provide different levels of product verification. The current poor design of the test equipment, laboratory, and test process will continue to generate HFE problems to the workforce if changes are not made. The development program for JTRS is scheduled to end around the year 2011. With numerous tests still to be performed (refer to Table 1), the design and scheduling of the test program is a key focus of program management. To get a feeling of where the test program is at with regards to HFE, our team agreed to perform a quick survey related to some of the quick HFE problems addressed in a team meeting (refer to Appendix A).

Table 1 - Test Events Defined for JTRS

Test Type	Purpose	When Used
Design Verification Test	Engineering test to determine feasibility of design implementation	Early in Program Design and Typically when product improvements are being developed
Contractor Development Test	Government Required Test to assess current performance of product	Performed on first baseline design to assess early design conformance to specifications
Reliability Growth Test	Test developed for final design implementation to characterize the reliability	Performed on final design baseline to estimate the product reliability, availability, and time to/between failures
Environmental Stress Test	Test developed out of Reliability Growth Test to screen out component or workmanship issues	Typically developed during the Qualification Test and implemented for reliability testing and on a sample basis for production units

Test Type	Purpose	When Used
	during fabrication	
Security Verification Test	Government imposed test to determine if security requirements in design have been properly implemented	Performed on final design to assure security of data and tamper proofing of classified products
Production Acceptance Test	Test generated during final design to be implemented on every unit that is built	Performed to screen out workmanship and reliability product problems, as well as to check to see if unit is performing to functional or performance requirements
Production Qualification Test	Test on the final design that verifies every requirement in the entire product structure	Performed once to prove if product satisfies all lower and upper tier requirements. Generally a criteria for approval for production
First Article Test	Test on the very first production unit that comes out of the manufacturing floor (instead of a development lab) to verify all requirements are satisfied at that the product is reproducible	Performed once to prove if product satisfies all lower and upper tier requirements and producibility is achieved when transferring from laboratory to shop floor.

In a survey of 12 engineers, 6 test technicians (operators), 5 quality engineers, and 6 inspectors, most of the individuals concurred that the test schedule was too long. The results seen in Figure 2, show that the 96% of individuals surveyed stated that they are sitting in one place at least 3 hours a day. Of those, roughly 45% of those individuals claim to be sitting in one place more than 5 hours a day. Since this is a lab environment, most of the areas are not ergonomically designed to reduce OD's or strain from the interactions in the work environment. In addition, 62% of the individuals surveyed agreed that the test events were too long in schedule. The translation is that the perceived progress is low, which often lowers the morale and sense of urgency to complete the testing for the team. In combination with the long work hours and workweeks, there is a management concern that a lot of the workforce may request to transfer out of the program. With most test engineers, test technicians and quality assurance personnel spending most of there time in the labs, the longevity of the testing and poor ergonomic design of the lab environment has been identified as an HFE problem that is to be addressed by the test improvement team. In summary, there has been no consideration for human factors in the development of the current tests, or concerns to discuss and prevent ODs.

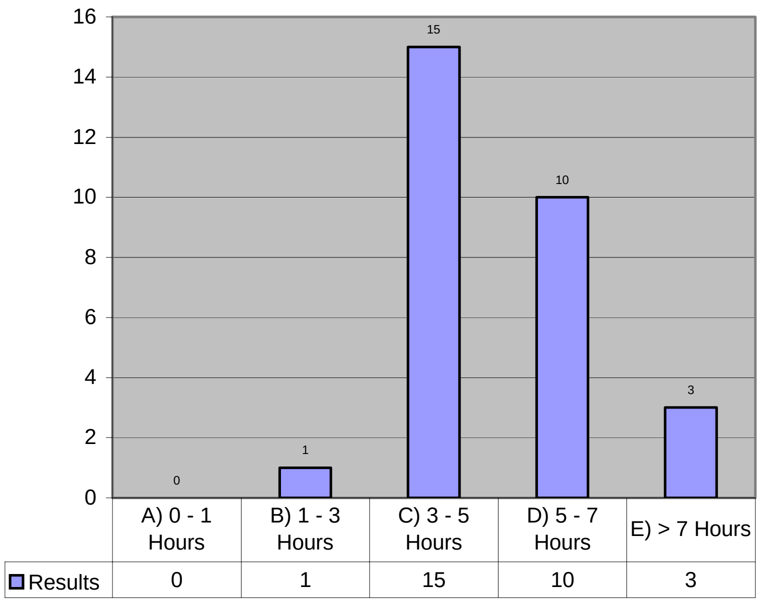

Figure 2 - Results of Question 4

Testing is very complex

In a recent review of the current mode of testing, our team identified that tests were designed to have very highly skilled engineers perform complex interactions with the product and test environment. Moreover, Operators, Quality Assurance Inspectors and/or Quality Engineers witnessing the test did not interact with the testing in most cases. This is both cost ineffective and requires a lot of controls in the test environment to assure repeatability and accuracy of test results. Our team was tasked to identify the root cause of how the testing ended up to be performed in this manner. The results were that the complexity in the software technology required to mimic twenty-three other existing radio system, required strong electrical and software engineering skill-sets, and that there was no consideration for who would end up performing the tests. In addition to the complexity in software, the hardware complexity produces additional challenges to the existing skill-set. The hardware design is intended to have specific buses (pathways) that will accommodate different modes of functionality, such that the hardware is designed to perform differently based on the software that is loaded on it. These functional modes are not easily understood by personnel who do not have advanced education in RF electronics and component design. Most of the testers are experienced test engineers, who write advanced software code using complex test software tools (custom CORBA tools, CASE, and C++) to verify these interfaces. Much of the testing is performed in the “un-compiled” codes, such that test software design parameters can be altered to option the appropriate test functionality. The current state of the test software design does not allow for usability by other functions.

Requirements for hiring a quality engineer include an engineering degree. Most of the quality engineers hired have been able to learn the product design requirements, such that they have been able to understand how testing and test software design can are implemented. Quality Engineers also participate in the development of the testing with engineers, to implement the process controls and trace testing to product requirements. The upfront involvement with Quality Engineers allows them better understand in how test are being performed. However, this is not the case with test technicians and quality inspectors, which are both union personnel. Union Operators and Inspectors are required to pass general examinations, such as general inspection, basic test equipment, and test process examinations, which authorize them to perform testing or accept product on behalf of The Boeing Company. The disconnect between the skill-sets is a problem because the level of education required by test technicians, quality inspectors, and engineers creates an instant knowledge gap with regards to understanding the product.

It was originally conceived the lack of engineering training from the union inspectors has created a lot of unplanned extra effort from the Quality Engineering group, to support product acceptable activities. However, it is clear that the design and development of the test and test software did not provide enough clear information to the specific personnel in how to determine product acceptance. This is validated by the knowledge gaps seen in how the product is built and tested. Figure 3 represents the HFE survey results from question 2, which was designed to ascertain the major issues with regards to testing. Around 45% of the individuals surveyed felt that the test controls for operation were too complex and not designed in a manner for lower skilled individuals to use. In addition, most of the engineers (7 out of 12) felt that test equipment design added to the test complexity and prolonged hours.

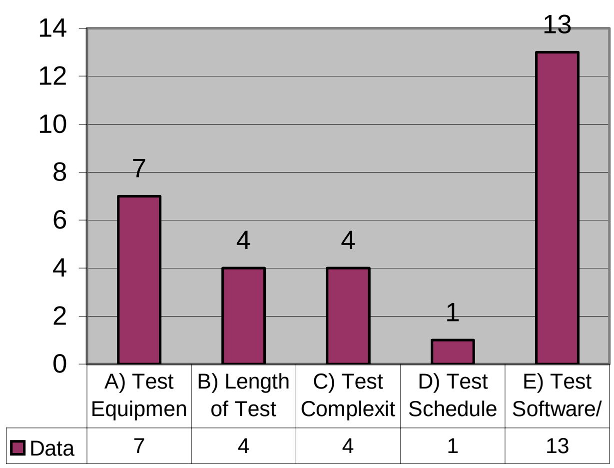

Figure 3 - Results of Question 2

In a test review performed by Quality Engineering, it was determine that most of the test software is executed through the coded state, with no detail indicators of status or performance. In addition, the data received from the test software still had to go through post processing to determine conformance to specification limits. There are no graphical user interfaces (GUIs) that walk the operator or inspector through the test sequencing, and there are no visual aids to support trouble shooting of issues. Figure 4 represents the results from Question 3 from HFE survey, with regards to how easy the test software was to use. The results show that most of the individuals surveyed felt that the software was complex, and not easy to use.

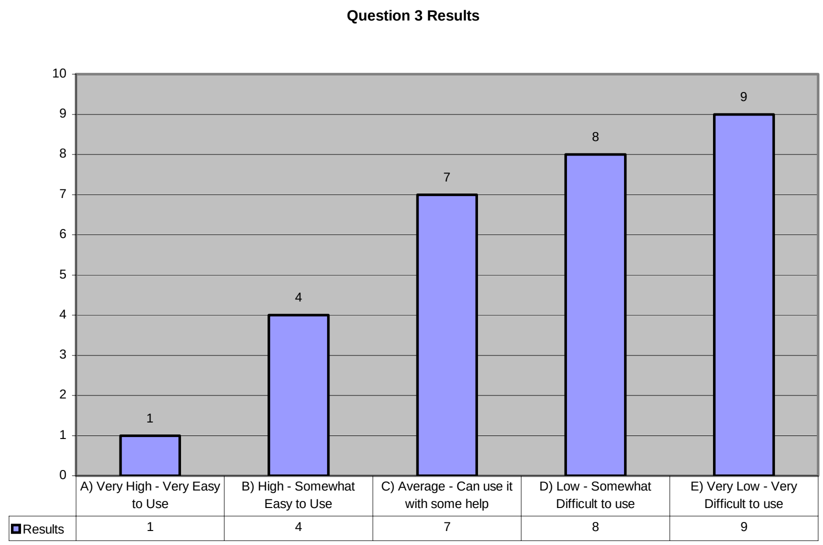

Figure 4 - Results from Question 3

Testing takes a lot of test environment changes

Another HFE problem with the test design is that it requires a lot of stopping of the test to change cabling or test software states. This is done for several reasons, the most critical being radio frequency (RF) safety. Most of the test cases were designed to test specific functionality of the legacy waveforms on specific configurations of the software-defined radio. In addition, the test equipment was not designed to aggregate all test cases, which causes a lot of switching of cabling and product restarts. To protect employees from RF radiation, the unit under test (UUT) has to be turned off when the cable switching is performed, such that radio is not capable of an accidentally transmitting when RF cables are being switched to different attenuators and measuring equipment. The HFE issue seen is that there is a lot of strain put on an individual's hand and wrists with regards to constantly removing cables that are designed to be difficult to remove.

Each RF cable is designed to handle the rugged environment seen in many military platforms. The connectors for each of the cables have pressure load spinners, which will lock the cable into its connector. It takes about 10 ft-lbs of force to break the connector free. Every time a radio is connected to a test station, there are thirty cables to be connected to the UUT and the test station. In a review of the survey results, 76% of the individuals surveyed expressed that they have felt pain or discomfort during execution of the testing. The combination of prolonged hours in a specific position, as well as the poor test equipment design, makes human interaction more difficult. Moreover, it introduces excessive strain on the muscles, back, and hands. Many of the female engineers have also complained about some of the tenderness and soreness in their hands from installing and removing these cables. The tight connector spacing of some test equipment has also introduced some minor injuries, mostly pinching of fingers.

Proposed HFE Solution

Three major areas of focus were discussed in our test process improvement team. Each one of these improvements will help address the HFE issues seen by the team, as well as help drive out costs in how test are being currently performed. The three areas of focus are:

- Test Automation
- Graphical User Interface (GUI) Test Software
- HFE Validation in Test Equipment Design/Selection

In addition, the team focused on the definition of test strategies for how tests will be conducted in the future, with the intent to optimize performance from the workers. After several brainstorming session and team meetings, we developed several HFE goals that every test developer must meet.

- Must use Graphical Indicators for Status of Test Progress
- Must have Graphical Indicator for pass or fail at completion of automated test
- Each Graphical Display Screen must have reference to test procedure
- Each Graphical Indicator have a reference to test procedure or help menu in test software
- Must have Indicators and instructions for when test environment changes have to occur
- Must have user validation of controls and usability prior to test certification
- Test must be automated in blocks that are not longer than 4 hours each

Test Automation

One of the current plans that our test-working group has been studying is automation in the test design. As part of the automation strategy, the test team has selected the Labview ® tool (a GUI based test software language) to be the primary interface for all testing. Some of the keys advantages of Labview® is that it can run “scripts or programs” inside itself, which can be used to control test equipment and perform data acquisition from many different types of test equipment. The existing programs already generated by the test engineers can be formatted into scripts, which are sub-programs called from a top-level interface. This is a cost effective implementation because the many tests has already been developed, and it will provide a GUI to allow for less complex test controls. In addition, the input variables can be controlled from the additional script file, which allows program execution scripts to be automated without user intervention. The scripts can be linked through Labview ® to create automation, with feedback loops into the GUI interface. The new test software design will allow for scalability of the test execution, and more robust automation of the test software through a modular design (object oriented), instead of linear design (case by case test).

To accomplish this, standard graphical user interfaces, (i.e. input and output controls) will be created using a standard set of graphical indicators. The graphical indicators will pull information from the software scripts, which will provide status to operator and instructions to execute specific steps in a test. The goal is that once the test is selected, and the hardware environment is properly set, the automated test will begin without intervention from the operator. The operator will be able to monitor progress of the test from the GUI, as well as obtain automatic printouts to review processed data real-time. This process will cut out a lot of over-the-shoulder inspections, and will reduce the number of personnel required to perform the tests.

Another key element to test automation is the design of the test equipment environment. Since we must comply with RF safety rules, the test team has selected an environment that will provide automatic switching of RF signals, which will be controlled from the Labview® test software. The improvement will allow only a single cable up sequence in the test process, and eliminate a lot of redundant power downs, power ups, and halting of test cases. This is expected to cut the test time by more than 50%. In addition, the repetitive motion from removing and switching cables manually will be reduced significantly, since the process will only be performed once per product. In conjunction with the standard GUI's and indicators, test technicians and quality assurance personnel will be able to multi-task when the automated portions of the testing has started, which will also reduce the amount of time spent in the engineering labs performing sitting in poorly designed environments. The goal is to have less personnel being forced to sit in ESD approved lab chairs (not ergonomically designed) to perform work, and have them be more active in the labs. This will help reduce the numbers of hours spent in a day testing, and well as shorten the test cycle time.

Graphical Indicators and Diagrams

The most important implication of Labview® use is the GUI design. One of the key HFE issues observed was the poor arrangement of input controls, displays, and output indicators. Creating an environment that is based on GUI helps an operator manage the test execution and increases usability. Some of the standard key Graphical Indicators that our team has agreed is the following:

- Test Start/Stop Indicator
- Total Test Time Status
- Script Test Time Status
- Test Paragraph Indicator

- Transmitting RF Indicator
- Receiving RF Indicator
- Ethernet Connected/Disconnect Status Indicator
- Test Error Indicator
- Test Sequence/Case Indicator

The standard design of the indicator will provide a common visual reference for test operator and inspector. The goal of the common feel to test software is to support the transition of having lower skill set personnel perform the execution of the test, such that critical engineering resources can be used to resolve system issues. This is a cost effective approach for the program; as well it will remove over-shoulder inspections, and help standardize work activities and schedules within job functions.

HFE Validation Steps in Test Equipment Design

To be able to support the transition of testing to lower skill set personnel, test engineering and quality engineering have defined a new process that will support the validation of the test equipment and station designs. An HFE checklist will be used to in the procurement of all new test equipment, to assess if the equipment has GUI capability and has support and instruction manuals that are not written with high degree complexity. Our Human Factors Engineer assigned to the program will be creating the checklist, based on a future assessment of our current test issues.

In addition to an HFE assessment of the test equipment, our team has agreed to perform a Human-Machine Interface (HMI) “dry-run” of the test equipment prior to formal test control by quality engineering (test certification). The goal of the HMI dry run is to determine if each test developed can be executed in less than 20 minutes from start-up, excluding the test time. The purpose of this assessment is to determine if operators, technicians, and quality personnel are having difficulties following the test instruction, as well as difficulties in the operation of the test software and environment. The results from the HMI dry run will be fed back into the test equipment design and documented for improvement. The process will be used to allow test operators to run independently, and allow program critical resources to be utilized more effectively.

Summary

Over the next six years, the JTRS program will be performing product verification and customer validation activities to assure that the product maturity and requirements will support the transformation of military communication systems for the future. The recent testing has had adverse effects on personnel lives, and has caused some concerns with wellness of employees. Most of the test issues that we have seen on the program can be mitigated with some HFE influence. The goal of the test program re-design is to reduce the cost of testing, and the amount of stress put on individuals who have been sacrificing their personal time to support this program. Eliminating a lot of test time and redundancy through automation through automation is a key focus. Our team is focused on making the test software more repeatable, structured, and less complex, such that highly skilled labor is not consumed with work that does not support critical program needs.

The three focus areas for improvement are test automation, standardization of graphical user interfaces, and validation from users prior to test implementation. When all three focus areas are put in place, we are anticipating a more standardized work and program test schedule, increase in morale and job responsibility, reduction of stress, and improvement in how operators interacts with the work environment. In addition, our goal is to educate experienced test designers be cognizant of HFE factors in the development of test software and test station design. This will help drive out cost upfront on future programs, as well as help less experienced or skilled individuals execute their job functions properly.

Appendix A – HFE Survey

Number	Question	Response	
1	Have you experienced any pain or discomfort in your lower back, neck, eyes, hands, wrists, or other part of the body while performing any portion of testing?	(Y)	(N)
2	Which do you feel are the biggest issues with the test design? A) Test Equipment Design B) Length of Test Events C) Test Complexity - Useability D) Test Schedule E) Test Software/Hardware Controls		
3	How would you rate the useability of the test software currently use to test the radio (scale 1 - 5)? A) Very High - Very Easy to Use B) High - Somewhat Easy to Use C) Average - Can use it with some help D) Low - Somewhat Difficult to use E) Very Low - Very Difficult to use		
4	How long do you sit down, on average, during the performance of the testing? A) 0 - 1 Hours B) 1 - 3 Hours C) 3 - 5 Hours D) 5 - 7 Hours E) > 7 Hours		
5	Do you feel that the long hours and daily testing time is excessive?	(Y)	(N)
6	Do you feel that the scheduled test events are too long?	(Y)	(N)
7	Have you felt any stress with regards to meeting a test schedule or milestone?	(Y)	(N)
8	Do you feel that the test design can be improved if you supported test engineers in development and validation of the test equipment and test software?	(Y)	(N)
9	Have you talked with a test designer with regards to recommending improvement?	(Y)	(N)