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**DEVELOPMENT OF A COMPREHENSIVE DIGITAL AVIONICS
CURRICULUM FOR THE AERONAUTICAL ENGINEER**

THESIS

Thomas W. Hofer, Lieutenant Colonel, USMC
AFIT/GAE/ENG/06-01

**DEPARTMENT OF THE AIR FORCE
AIR UNIVERSITY**

AIR FORCE INSTITUTE OF TECHNOLOGY

Wright-Patterson Air Force Base, Ohio

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AFIT/GAE/ENG/06-01

**DEVELOPMENT OF A COMPREHENSIVE DIGITAL AVIONICS
CURRICULUM FOR THE AERONAUTICAL ENGINEER**

THESIS

Presented to the Faculty

Department of Electrical and Computer Engineering

Graduate School of Engineering and Management

Air Force Institute of Technology

Air University

Air Education and Training Command

In Partial Fulfillment of the Requirements for the
Degree of Master of Science in Aeronautical Engineering

Thomas W. Hofer, MS

Lieutenant Colonel, USMC

March 2006

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**DEVELOPMENT OF A COMPREHENSIVE DIGITAL AVIONICS
CURRICULUM FOR THE AERONAUTICAL ENGINEER**

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Abstract

The purpose of this research was to develop a comprehensive digital avionics curriculum that will serve the needs of aeronautical engineering students at the Air Force Institute of Technology (AFIT). Due to the closing of the aeronautical engineering program at the Naval Postgraduate School, and the subsequent requirement to establish a digital avionics specialty course sequence at AFIT, a mature avionics curriculum does not yet exist that satisfies the needs of graduates who will serve as aeronautical engineers involved with the development, integration, testing, fielding, and supporting of military avionics systems as part of the overall aircraft system. Research was conducted through a comprehensive literature review and the use of a Delphi Technique survey process. 28 panel members representing the military, academe, and industry participated in a three round survey process that sought to identify the desired attributes of a newly-graduated engineer and the specific subject areas of study that should be included within the avionics curriculum.

The result of this research was the development of a proposed three course curriculum that will instill the desired attributes within the aeronautical engineers and provide them with the avionics knowledge required at the correct level of proficiency. Recommendations on how to implement the proposed curriculum in an effective and timely manner are presented.

AFIT/GAE/ENG/06-01

Dedicated to my wife and our sons

Acknowledgments

I would like to express my sincere appreciation to my faculty advisor, Dr. Guna Seetharaman, for his direction and for providing me the latitude to complete this thesis in the manner of my choosing. I would also like to express my gratitude to the 28 professionals who agreed to participate as part of my Subject Matter Expert panel. Their inputs were enlightening and invaluable.

Thomas W. Hofer

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DEVELOPMENT OF A COMPREHENSIVE DIGITAL AVIONICS CURRICULUM FOR THE AERONUTICAL ENGINEER

I. Introduction

1.1 General Discussion

Today's advanced commercial and military aircraft are highly dependent upon the sophisticated avionics they carry as part of the air vehicle, as well as the ground-based avionics with which they interact. Aircraft stability and control, engine fuel control, navigation, communications, sensors, weapons employment, data links, defensive systems, and landing aids are all utilized or assisted through the use of avionics. The requirement to integrate these separate systems and package them for transport within the air vehicle, with its limited amount of space, cooling, and electrical power available, poses a serious challenge to aircraft design teams. Requirements are even more difficult to deal with when new systems are integrated into an existing platform that was not originally designed with these systems as a requirement. Over the last 30 years the Department of Defense (DoD) has increasingly looked to the inclusion of new avionics systems onto existing legacy platforms to achieve a new warfighting capability without the additional cost and time involved with developing an entirely new platform. The classic example of avionics upgrades adding new capability to a legacy platform is the B-52 Stratofortress, originally deployed in 1955 as a long-range heavy bomber, which can now deliver precision weapons and air-launched cruise missiles in all-weather conditions [1]. Another example is the EA-6B Prowler aircraft flown by the United States Navy and

Marine Corps. Originally deployed in 1971 as a radar jammer, it now also carries the AGM-88 High-Speed Anti-Radiation Missile (HARM) for the Suppression of Enemy Air Defense (SEAD) mission and performs tactical communications jamming using the USQ-113 communications jamming system [2]. Each of these additional warfighting capabilities were brought about by changes to the avionics of the aircraft, not by building a new aircraft specifically designed for the new mission requirement.

Incorporation of an understanding of digital avionics principles is critical to an aeronautical engineer that will be operating in the role of an aircraft designer, systems integrator, program manager, or test aircrew/engineer. For modern high performance military aircraft, avionics were approximately 30% of the flyaway cost in the 1990s [3:44] and have undoubtedly become an even greater percentage of flyaway cost as avionics become more pervasive and sophisticated in newer aircraft. Additionally, engineers face a significant challenge in designing and building systems based on rapidly changing technology to be installed in an aircraft with a useful service life of 30-40 years [3:45]. Therefore, it is imperative that there exists a discipline within the aeronautical engineering profession that understands the development, integration, testing, fielding, and supporting of avionics systems as part of the overall aircraft system. As the DoD graduate institute responsible for aeronautical engineering education, the Air Force Institute of Technology (AFIT) must establish a curriculum that is sufficient in educating engineers and test aircrew from the Joint Services in this necessary discipline.

1.2 Background

The Naval Postgraduate School (NPS) at Monterey, California previously offered a separate avionics curriculum (curriculum code 611) within the Department of Aeronautics and Astronautics in order to train military and civilian engineers who would go on to serve in jobs such as Avionics Class Desk Officer, Avionics System Project Officer, or Deputy Program Manager at the Naval Air Systems Command (NAVAIR) [4:123]. Navy officers who graduated from the avionics curriculum received an Engineering & Technology (Avionics) subspecialty code which designated them for future assignment in areas requiring their avionics expertise. Officers in the subspecialty were expected “to have the background necessary to identify, formulate, and solve engineering and/or technical problems in the areas of avionics or electronics as applied to flight vehicles and weapon systems [5].” In addition to these specialized engineering officers, Pilots and Naval Flight Officers taking part in the joint NPS/ U. S. Naval Test Pilot School (USNTPS) cooperative program also enrolled in the avionics courses in preparation for their follow-on training in the Engineering Test Pilot and Engineering Test Flight Officer syllabi at USNTPS [6:1]. The curricula previously offered at NPS are contained in Appendix A [7].

In 2002, a decision was made by the Secretary of the Air Force (SECAF) and the Secretary of the Navy (SECNAV) to close the aeronautical engineering portion of the Department of Aeronautics and Astronautics at NPS and begin sending all naval officers (both Navy and Marine) that required graduate education in aeronautical engineering to AFIT. In order to ensure that the education requirements of all the Joint Services were

satisfied by the AFIT program, a Joint Oversight Board (JOB) was formed consisting of members from all the interested parties, with the exception of the United States Marine Corps. Composition of the JOB is shown in Table 1. Participation in the AFIT program by the first naval officers began in the Winter 2003 (January 2003) quarter [8].

Table 1: Joint Oversight Board Composition

Position Title	Service
Vice Commander, Naval Air Systems Command (Chairman)	USN
Program Executive Officer, Army Aviation	USA
Director of Engineering and Technical Management, Air Force Materiel Command	USAF
Director of Engineering, Air Armament Center	USAF
Assistant Deputy Commander for Research and Engineering, Naval Air Systems Command	USN

Prior to the consolidation of the aeronautical engineering programs, the study of avionics had not been offered as a specialty sequence of classes within the AFIT Department of Aeronautics and Astronautics. Consequently, a curriculum that focused on avionics and their incorporation into air vehicles did not exist prior to the merging of the aeronautical engineering programs of NPS and AFIT, and no existing member of the department faculty had expertise in the area [9]. Due to the similarity of the subject with some of the already existing classes within the AFIT Electrical and Computer Engineering Department, the task of developing a specialty sequence for digital avionics for aeronautical engineers was assigned to that department. The Digital Avionics Applications and Design specialty sequence course descriptions, as they are presently offered, are shown below [10]:

CSCE 581-Digital Avionics Systems I: This course will provide an introduction to embedded computer architecture and design with an emphasis on avionics applications. Topics include binary number systems, microprocessor architectures, field programmable logic arrays (FPGA), static and dynamic memory systems, and inter-computer communications. A brief introduction to avionics building blocks (buses, displays, etc.) provides a definition of clear, correct, and complete requirements for avionics systems and salient architectural aspects of F-22 and B-777 architectures.

CSCE 681-Digital Avionics Systems II: This course covers the architecture of the modern avionics system such as F-22 and B-777. The evolution of the system design, including design specifications, modular system integration, bus-oriented systems design, integration and evaluation. Operation of the avionics in the real world: Link 16, SPS guided weapons, Wide Area Augmentation Systems, and scientific visualization and monitoring of airspace, etc.

EENG 533-Navigation Using the Global Positioning System: This course provides a theoretical and practical foundation for understanding the Global Positioning System (GPS). Emphasis is on the use of GPS for determining navigational information such as user position and velocity relative to the local navigational frame of reference (latitude, longitude, altitude, and their time derivatives). Topics include basic properties, navigation solution theory, satellite orbits and positioning, signal structure, code

generation, code correlation, receiver design, ranging errors, geometrical errors, differential GPS, relative GPS, and carrier-phase GPS.

1.3 Problem Statement

Due to the relatively recent requirement to offer a digital avionics curriculum within the AFIT aeronautical engineering graduate program, a mature comprehensive digital avionics curriculum does not yet exist that serves the needs of military officers (all services) and civilian engineers that will operate as aeronautical engineers involved with the development, integration, testing, fielding, and supporting of avionics systems as part of the overall aircraft system.

1.4 Research Objectives/Questions

The objective of the research contained within this thesis was to formulate a comprehensive digital avionics sequence curriculum that fit within the time allowed, satisfied accreditation requirements, instilled desirable attributes, and provided the student with a solid background in the principles required. In order to accomplish the research objective, answers to the following questions were sought:

1. What subject areas are being taught within an avionics curriculum at other institutes of higher learning, both within the United States and Internationally?
2. What are the requirements for a curriculum to satisfy the Accreditation Board for Engineering and Technology (ABET) standards?
3. What attributes are desirable for a newly graduated aeronautical engineer to possess?

4. What areas of study should be included in an avionics curriculum within an aeronautical engineering Masters of Science degree program?

1.5 Research Focus

Research focused on three main areas: extensive review of literature pertaining to desired attributes of an engineer, curriculum development, and accreditation standards; a survey of avionics programs at other institutes of higher learning; and completion of a Delphi technique study using an advisory group of Subject Matter Experts (SME) in the field of avionics.

1.6 Assumptions/Limitations

The following assumptions and/or limitations were placed upon the research to provide a framework within which a solution to the Problem Statement could be addressed.

1. Curriculum will be a joint effort between the Department of Aeronautics and Astronautics and the Department of Electrical and Computer Engineering.
Instructors will be available from both departments to teach necessary classes or specific modules of classes.
2. Emphasis will be on top-level knowledge of systems that comprise an avionics suite in a modern military and/or civilian aircraft. Internal workings of individual boxes at the electrical engineering level are not required.
3. The majority of students (75-90%) will fulfill Test and Evaluation and/or Program Management positions of developing avionics systems upon

completion of the curriculum. Positions will be within the U.S. Department of Defense.

4. Course structure will consist of three (3) courses, each being a four (4) credit hour course spanning a ten week quarter. Each course will have an additional one (1) credit hour lab period available for use at the discretion of the instructor.

1.7 Preview

This thesis will investigate how to construct a comprehensive digital avionics sequence curriculum to be offered within the Aeronautical Engineering Masters of Science program at AFIT. Working forward from the starting assumptions/limitations, an extensive review of pertinent literature in the fields of the desired attributes of an engineer, curriculum development, and the accreditation process will be presented, followed by a review of avionics programs being offered at other institutions of higher learning. The Delphi technique and its application to the problem statement will be explained, along with the results of the group survey process. Finally, a recommended avionics curriculum containing specific areas of study based upon the research conducted will be presented.

II. Literature Review

2.1 Chapter Overview

The purpose of this chapter is to present a review of the literature researched during the course of this study. By reviewing previously published documents, a basis of understanding was developed as to how others have approached the same or similar subjects and what methods they used to propose a solution to their particular problem statements. The specific desired attributes of a newly-educated engineer, the concept of how curriculum development is accomplished in the academic world, and an explanation of the requirements that must be satisfied to achieve ABET accreditation will be presented. Finally, a review of avionics programs at other institutes of higher learning and continuing education in the field of avionics for working professionals will be discussed.

2.2 Attributes of Engineers

Prior to starting to form a curriculum, it is logical to first decide the nature of the product the curriculum should produce. Having an ultimate end goal gives direction to the formidable process of formulating a curriculum. In the case of engineering education, the end product should be a graduate that possesses certain attributes that are desired by the customers. Customers of graduate engineering educational institutions are industry, government, and follow-on education programs. The overriding question that should direct the formulation of a curriculum should be: What are the attributes that a newly-graduated engineer should possess? Answering this question has been the subject of many articles, seminars, and debates both within the United States and Internationally.

The Boeing Company, one of the largest aerospace industry companies in the world, has developed a list of attributes that it looks for in the engineers it hires. Their list is made up of basic attributes that have persisted over time and which can be mapped to specific skills they feel reflect the diversity of the overall engineering environment. By only specifying desired attributes of graduates, rather than specific areas of knowledge, they avoid specifying how a given university should go about meeting industry needs, leaving curriculum development as a university task to be done in cooperation with their customers. Boeing feels that industry, as one of the important customers of educational institutions, must be an active partner in this process [11]. The list of desired attributes of an engineer developed by The Boeing Company is shown in Figure 1.

- **A good understanding of engineering science fundamentals**
 - Mathematics (including statistics)
 - Physical and life sciences
 - Information technology (far more than "computer literacy")
- **A good understanding of design and manufacturing processes**
 - (i.e., understands engineering)
- **A multi-disciplinary, systems perspective**
- **A basic understanding of the context in which engineering is practiced**
 - Economics (including business practices)
 - History
 - The environment
 - Customer and societal needs
- **Good communication skills**
 - Written, oral, graphic and listening
- **High ethical standards**
- **An ability to think both critically and creatively - independently and cooperatively**
- **Flexibility. The ability and self-confidence to adapt to rapid or major change**
- **Curiosity and a desire to learn for life**
- **A profound understanding of the importance of teamwork.**

Figure 1: Boeing Company Desired Attributes of an Engineer [11]

Other industry employers feel that today's engineering education may be insufficient in instilling certain attributes in their graduates. Watson claims, "employers of recent engineering graduates complain that many new engineers are poorly prepared for the realities of the 21st century. "While graduates may be well trained in engineering analysis, employers say, they lack skills in interdisciplinary problem-solving, concurrent engineering, teamwork and communication [12: 31]." Kulacki and Krueger feel that "in the next few years engineers will enter into a professional environment that is dominated

by knowledge-based industries that will rely on the brainpower of engineers to solve problems using the fundamentals of science [13: 469],” rather than specific tool sets to solve well-defined problems. They further suggest that “engineers who have the attributes of adaptability, flexibility, and a profound ability to learn will be best suited to serve the long-term needs and viability of industry and developing economies [13: 469].” Berry et al. also agreed with this idea when they wrote, “A well-developed and well-delivered curriculum must provide learners with a strong ability to think, especially by applying well-understood principles. This ability is foundational in developing the attributes of adaptability and flexibility in the students [14: 473].” These writers all predict that the engineer of the future must be more than a human computer who can intake well-defined problems, apply proven numerical techniques, and output a solution. Rather, engineers will have to think on their feet and apply the learned engineering fundamental concepts to devise a method to fix the problem. They must also recognize when their own limits have been reached and others must be brought in to find a solution through teamwork.

Evolution of the desired attributes of an engineer is well-recognized in the engineering field, as well as academe. The National Academy of Engineering (NAE) chartered a study with the goal of defining what an engineer should be in the 21st century, with an initial target year of 2020. NAE believes [15: 53]:

Engineers in 2020, like engineers of yesterday and today, will possess strong analytical skills. At its core, engineering employs principles of science, mathematics, and domains of discovery and design to a particular challenge and for a practical purpose. This will not change as we move forward. The core knowledge base on which engineers develop products and services may shift as technologies involving the life sciences, nanoscience, optical science, materials

science, and complex systems become more prevalent. Also, information and communications technologies will be ubiquitous—embedded into virtually every structure and process and vital to the success and usefulness of all engineered products. Just as important will be the imperative to expand the engineering design space such that the impacts of social systems and their associated constraints are afforded as much attention as economic, legal, and political constraints (e.g., resource management, standards, and accountability requirements). Engineers will also concentrate on systemic outcomes in the same ways that focused outcomes are considered. Even though the scientific knowledge that defines operating principles is expected to be more fluid and more complex, the core analysis activities of engineering design—establishing structure, planning, evaluating performance, and aligning outcomes to a desired objective—will continue.

NAE summarized their requirements by developing a list of *Successful Attributes for the Engineer of 2020* shown below in Figure 2. A strong correlation can be seen between NAE's desired attributes and the desired attributes of the previous authors.

1. Possess strong analytical skills
2. Exhibit practical ingenuity; posses creativity
3. Good communication skills with multiple stakeholders
4. Business and management skills; Leadership abilities
5. High ethical standards and a strong sense of professionalism
6. Dynamic/agile/resilient/flexible
7. Lifelong learners
8. Ability to frame problems, putting them in a sociotechnical and operational context

Figure 2: NAE Successful Attributes for the Engineer of 2020 [15: 55]

International groups that recognize the need for a change in the direction of engineering education are also being formed. One such group, comprised of leading engineering schools in the United States, Europe, Canada, United Kingdom, Africa, Asia, and New Zealand, has undertaken the Conceive, Design, Implement, and Operate (CDIO)

Initiative. The CDIO Initiative, which includes the Massachusetts Institute of Technology and the U.S. Naval Academy, hopes to correct what it sees as a gap developing between engineering education and real-world demands on engineers. As a starting point for the CDIO Initiative, the group developed a list of desired attributes of an engineering graduate and the underlying needs that drive the attributes, shown in Table 2. By adopting CDIO as the engineering context of education, the group envisions a curriculum that “stresses the fundamentals, set in the context of Conceiving-Designing-Implementing-Operating systems and products [16].”

Table 2: CDIO Desired Attributes and Underlying Needs [16]

Desired Attributes	Underlying Needs
Understanding of fundamentals	
Understanding of design and manufacturing process	Understand how to conceive-design-implement-operate
Possess a multi-disciplinary system perspective	Complex value-added engineering systems
Good communication skills	In a modern team-based engineering environment
High ethical standards	

Another International group, the UNESCO International Centre for Engineering Education (UICEE) at Monash University in Melbourne, undertook a survey of 979 individuals from academe, industry, and engineering students with the objective of “eliciting their views on what the essential generic and specialist skills and attributes are for a modern engineer [17].” By statistically analyzing the views of the surveyed

individuals, the authors of the study hoped to use the findings of the study to revise and modernize engineering education in order to better prepare the engineers of the future. Revision of the present educational model will be outcome-based, meaning that all decisions of what will go into the curriculum will be based directly on achieving one of the desired skills or attributes. A summary of their findings is shown in Figure 3.

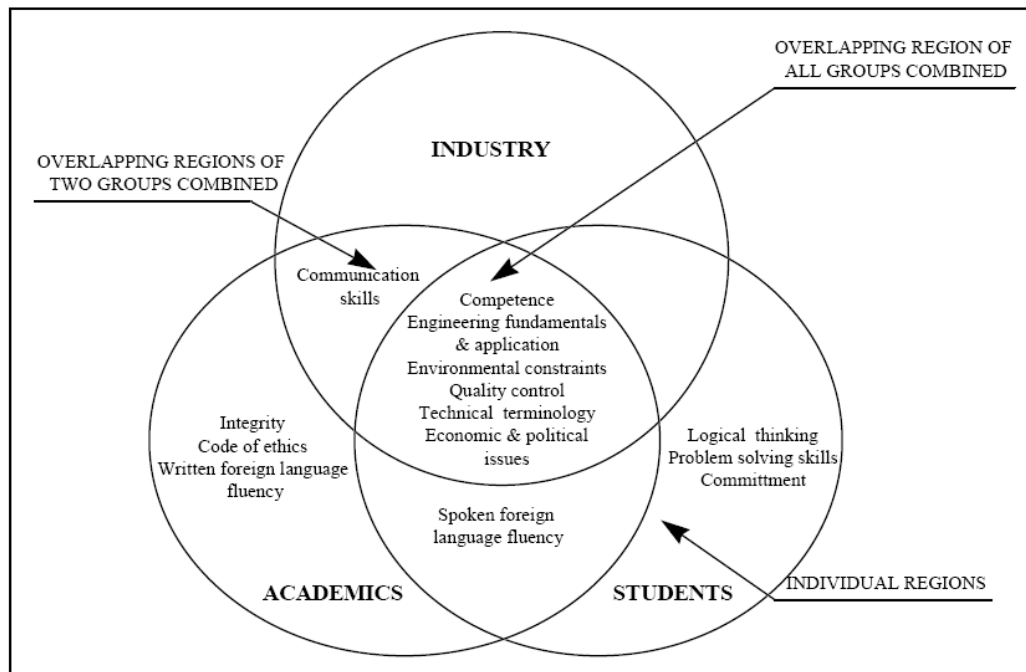


Figure 3: UICEE Desirable Skills and Attributes for an Ideal Engineer [17]

Clearly, the answer to the question of what attributes should be possessed by a newly-graduated engineer has been a topic of much discussion among leaders in both the academic world and industry within the United States and Internationally. While many different ideas come forward, there is a general consensus across the varied lists that certain attributes are highly desired. The attributes most commonly found are:

1. Knowledge of Engineering Fundamentals
2. Systems Perspective

3. Communication Skills
4. High Level of Ethical Behavior
5. Creative Thinking
6. Flexibility
7. Desire to Learn

2.3 Curriculum Development

Developing curriculum for an educational program that leads to the graduates of that program to be ready to enter their chosen professional field outfitted with all of the knowledge and attributes necessary for that field is a complicated task. Not only is the complexity and size of the task daunting, it often meets with opposition from the very people who most need to be involved with accomplishing the task. Duggan states, “In all countries of the world, strong traditional views can be detected, with a frequently encountered unwillingness to accept that past practices and traditions are no longer appropriate in satisfying current and future needs [18: 38].” Unwillingness to change, although understandable as a normal human trait, must be overcome if engineering education is to move forward to meet the needs of today’s students. The Joint Task Force for Computing Curricula 2004 had the following to say about curriculum development in the discipline of computing degree programs [19:48]:

When we look at high-quality programs, we see coherent programs that are driven and developed from within. Faculty and local administrators contribute because they have looked beyond the boundaries of conventional subject-matter areas, recognized that their students and their community need something new and different, and innovated to solve what they see as a legitimate and substantive problem. They value their students, see both student and community needs as legitimate, and strive to hold students to high standards.

When we look at low-quality programs, we see programs that are driven from without. One scenario involves a top-down process wherein someone in power

decrees that new programs will be created, perhaps to fit an arbitrary timeline. Faculty and administrators contribute because they are told to do so. They do not see intrinsic positive value in the initiative; they do not see it addressing legitimate needs of students or the community.

Although written about computing curriculum development, some institutes have realized the same holds true in the engineering fields, and despite opposition from within, many engineering colleges across the United States have instituted their own curriculum innovation programs [12: 31]. Watson's proposals for curriculum reform and how it will benefit the students is shown in Figure 4. The term qualities, used by Watson, are analogous to the term attributes used by the author of this thesis and several of the previously reviewed authors.

How curriculum reform will help students

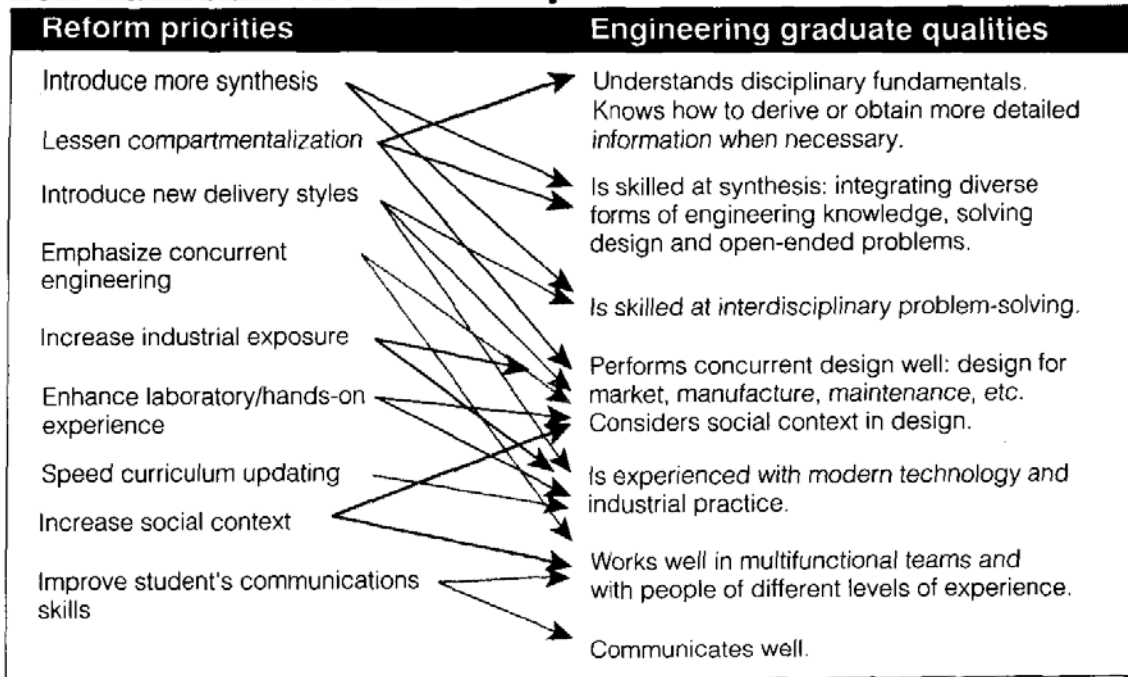


Figure 4: Curriculum Reform Benefits [12: 35]

Investigation of the manner and techniques that help students learn best should be undertaken prior to developing a curriculum. Today's students are a different generation than those that have gone before them. For example, the engineering students of today now consider the computer as an everyday tool, whereas the students of 20 years ago viewed it as something that required a whole separate curriculum to learn how to use. The explosion in the use of media devices at a younger and younger age makes the use of these devices in a classroom something that should be considered. Gollub and Spital proposed that the following seven points must be considered to maximize students' learning [20]:

1. Learning is facilitated when knowledge is structured around major concepts and principles.
2. A learner's prior knowledge is the starting point for effective learning.
3. Awareness and self-monitoring of learning ("meta-cognition") are important for acquiring proficiency.
4. Learners' beliefs about their ability to learn affect their success.
5. Recognizing and accommodating differences in the ways people learn are essential.
6. Learning is shaped by the context in which it occurs.
7. Learning can be strengthened through collaboration.

One area that comes up repeatedly in the literature about how students learn best is the use of the laboratory as a teaching tool. Smith states, "In the development of insight, judgment, and design ability, the role of the laboratory is of primary importance, and adequate time must be devoted to well-designed laboratory work with a strong design emphasis, including at least one opportunity to undertake a significant independent design task [21: 158]." Loughborough University of Technology agrees with this approach in their Avionics curriculum. They have created a systems laboratory, the purpose of which is "to provide students with a variety of tools to undertake systems

projects [22:9].” “The focus of the projects is on the underlying principles of systems and the development life cycle, rather than the individual technologies of which systems components are built [22: 9].” As part of an introductory course in avionics, students conduct laboratory work using a radar system, built virtually using the LABVIEW software product [22: 10].

Another method of learning that has been proposed by the CDIO Initiative is the concept of Problem-Based Learning (PBL). “PBL derives from the theory that learning is a process in which the learner actively constructs knowledge [23].” Unlike traditional teaching, involving students being lectured to by faculty, the learning results from the students’ actions. Faculty instruction “plays a role only to the extent that it enables and fosters constructive activities [23].” Three major theoretical principles support the practice of PBL [23]:

1. Learning is a constructive process
2. Knowing about knowing (metacognition) affects learning
3. Social and cultural factors affect learning.

Figure 5 graphically depicts the differences between the PBL approach to learning and the old-fashioned Subject-Based Learning approach that has been used for decades. By using the PBL approach, the hope is that students will remember the information they have learned and be able to apply it to real-world engineering problems.

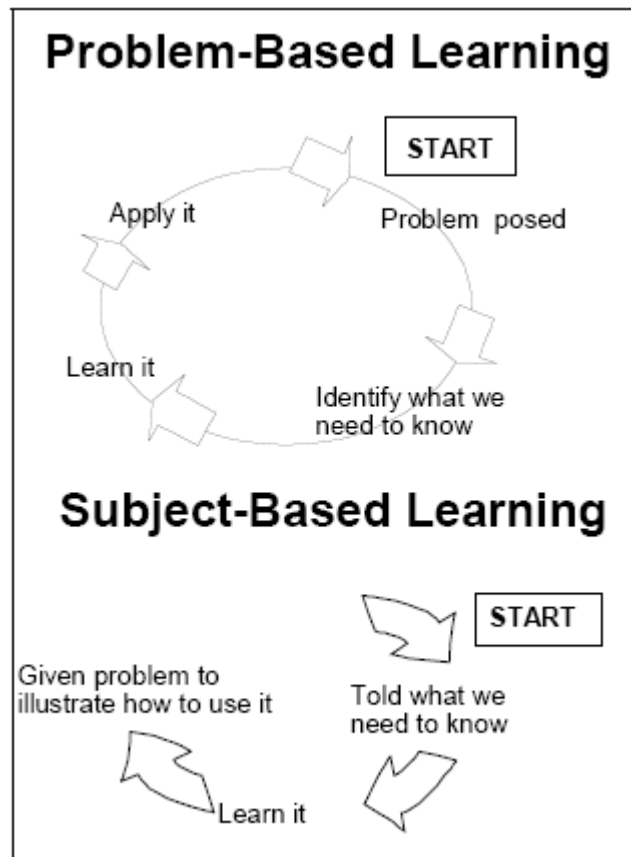


Figure 5: PBL Based Learning Cycle [24: 12]

PBL is presently being used at the Massachusetts Institute of Technology in the undergraduate curriculum in Aeronautics and Astronautics. Freshman students in their initial aeronautical engineering course design, build, and fly radio-controlled lighter-than-air vehicles, while sophomore students design, build, and fly radio-controlled electric propulsion aircraft as a means of solidifying the theories covered in class. Upper-level capstone courses are entirely problem-based [23]. “Rather than being assigned specific problems to address, students identify problems of interest to them and experiment to find solutions, as well as design complex systems that integrate engineering fundamentals in a multidisciplinary

approach [23].” By using this sort of problem-based teaching method, students can expand their knowledge, apply learned principles and theories, and even have a little fun.

Once the method of instruction that best allows the students to learn is decided upon, development of the curriculum can begin. While seemingly a daunting task at the outset, many experts in the field have published their methods and opinions on the subject. Oliver stated “Education and instruction programs must address what they are to do, how they will go about it, and measure the results [25: 4].” Finch and Crunkeilton wrote “Educational strategies and the outlining of engineering programs’ content should be based on a functional approach and an analysis of the goals of the graduates [26].” Smith proposed using the limited time available in the academic setting to develop “an engineering outlook-the mix of physical insight, modeling skill, engineering judgment, and design ingenuity which characterizes the capable engineer [21: 158].” Targeting the educational process to achieve the desired outcome is repeated by Waks and Frank who wrote, “It is recommended to identify skills and knowledge to be possessed by the graduates and to examine how well the curriculum matches the needs of the industry [27: 349].” In 2000, as part of developing the curriculum for the Oregon Master of Software Engineering Program, four distinct steps were identified by Faulk in the curriculum development process [28, 294-300].

1. Identify stakeholders and their curriculum needs
2. Establish and document curriculum requirements
3. Design and specify the curriculum
4. Validate the curriculum with stakeholders

Identifying the stakeholders and their needs falls in line with the previously mentioned concept of matching the curriculum to customer needs. The academic institution,

industry, and even the students all have different requirements, concerns, and expectations of the program. By identifying these issues early on, priorities can be developed and tradeoffs performed where necessary. Establishing and documenting the identified curriculum needs allows the conflicting mix of viewpoints, concerns, questions, and desires to be turned into requirements that the program must satisfy to be acceptable. Once these requirements are established and documented, a curriculum design (course structure and content) that demonstrably satisfies its requirements can be constructed, including designing the overall structure of the curriculum as well as specifying and documenting the content of each course. Finally, the curriculum must be presented back to the stakeholders for validation [28: 294-300]. This step is important and should be ongoing to ensure the product meets the needs of the stakeholders identified at the beginning. Faulk based his curriculum design process on the following five principles [28: 294-300].

1. Fundamentals over Fads
2. Career-long value
3. Learn by doing
4. Demonstrate relevance
5. Useful application

Using the approach of a results-based, or outcome-based, curriculum that employs teaching methods that make use of the best approaches to learning for today's students, Evans et al. constructed what they believe is the model curriculum for electrical and computer engineering programs in the year 2013 and beyond [29]. While their curriculum content differs from that of the subject addressed in this thesis, the model, curricular structure, pedagogy, and desired attributes of their graduates can be applied in

other engineering areas. The important differences between traditional curriculum and delivery in today's colleges and their proposed curriculum and delivery for the engineering program of 2013 are shown in Figure 6.

Old Curriculum	New Curriculum
Disciplinary Model of Content Historical Topics to cover, e.g, Physics, Chemistry, Mathematics, Engineering Sciences, followed by Engineering Design	Interdisciplinary Model for Content Problems to solve: Bio-XX, Nanotechnology, Systems, Environment, Energy, Entrepreneurialism, Information Technology, Arts Integrated into Design problems
Engineering Design as a Course	Design Integrated Throughout
Practice in the Profession Follows Graduation	Practice in the Profession is Part of the Course of Study
Curricular Structure <ul style="list-style-type: none"> • Constrained/linear course offerings in major • Students take general studies first, professional program later. • Menu of general studies courses 	Curricular Structure <ul style="list-style-type: none"> • Interdisciplinary • Integration of topics viewed with different disciplinary lenses • General studies integrated with professional studies
Pedagogy <ul style="list-style-type: none"> • Talking head • Teacher centered • Well-defined problems • Individual work • Low-level cognition (recall, recognition) 	Pedagogy <ul style="list-style-type: none"> • Talking students • Learner-centered • Authentic problems • Mixture of grouping options • Higher order thinking
Aesthetic of an Educated Citizen <ul style="list-style-type: none"> • Ability to spout trivia • Narrow discipline • Narrow set of skills • One job for rest of life 	Aesthetic of an Educated Citizen <ul style="list-style-type: none"> • Ability to think deeply, flexibly • Interdisciplinary • Upgradeable for life (Lifelong learning) • Many jobs, portability

Figure 6: Traditional Curriculum versus Curriculum in 2013 [29: 424]

As evidenced by the preceding paragraphs, curriculum development is an ongoing process that should continue to evolve in order to teach students using the best methods available while ultimately satisfying the needs of the customers that will employ the students upon graduation. Curricula at all educational institutions should be continually

analyzed for improvement and not allowed to stagnate merely because of the size and complexity of the task. An institution that continues to deliver education in the 21st century using the same methods of the 20th century will soon find it has lost its relevance and no longer serves the needs of its students.

2.4 ABET Accreditation

The current aeronautical engineering degree offered at AFIT is fully accredited at the undergraduate level by the Accreditation Board for Engineering Technology (ABET). ABET is a recognized accreditor for college and university programs in applied science, computing, engineering, and technology. As a federation of 28 professional and technical societies representing these fields, ABET currently accredits some 2,700 programs at over 550 colleges and universities nationwide and is recognized by the Council for Higher Education Accreditation [30]. In order to achieve accreditation from ABET for the aeronautical engineering degree, the program must provide a foundation in the theoretical and applied aspects of the fundamental areas of aeronautical engineering. The stated program educational objectives of the AFIT program are [31]:

1. *Produce graduates who are technically well prepared for their subsequent duties and responsibilities as aeronautical engineers in DoD organizations.* Such positions may range from requiring very detailed and advanced level work in a specific discipline to broad responsibilities requiring interaction among many disciplines and technical organizations.
2. *Ensure that students have been provided a core education in aeronautical engineering.* Core topics are determined by such organizations as AIAA and include the requirement for a solid background in the fundamental topical areas of aeronautical engineering to include aerodynamics, flight mechanics, stability and control, structures, materials, propulsion and design.
3. *Provide students a detailed understanding in one or two specialty areas.*

4. *Provide experience in conducting and documenting an independent investigation on a problem of DoD interest.*

In order to accomplish these objectives and maintain an ABET accredited program, the Department of Aeronautics and Astronautics at AFIT has developed the following degree requirements [31]:

1. *Core Aeronautical Engineering*-Aerodynamics, Flight Mechanics/Stability and Control, Aerospace Structures, Propulsion, Materials, Design, Aeronautical lab
2. *Mathematics*- Two (2) graduate level courses containing a major emphasis in mathematics
3. *Specialty Sequences*-Two (2) three-course sequences that form a coherent body of knowledge in a particular area and provide the student with a strong theoretical background for thesis work and post-graduation assignments.
4. *Independent Investigation*-Investigation of a problem of current DoD interest, conducted and documented by the student, with supervision of the faculty. The investigation is presented as a formal thesis and carries 12 credit hours.
5. *Electives*-Supporting courses and elective courses and seminars covering current technical developments and DoD projects
6. *48 graduate quarter hours, minimum*

The comprehensive curriculum for digital avionics investigated in this thesis only pertains to the specialty sequence portion of the degree requirements. Maintaining the quality standards required of a program for ABET accreditation is a must. ABET program criteria for aeronautical engineering requires the following for the basic (undergraduate) level [32]:

1. *Curriculum*-Programs must demonstrate that graduates have knowledge of aerodynamics, aerospace materials, structures, propulsion, flight mechanics, and stability and control. Programs must also demonstrate that graduates have design competence that includes integration of aeronautical topics.
2. *Faculty*- Program faculty must have responsibility and sufficient authority to define, revise, implement, and achieve program objectives.

In addition to the criteria for the basic level, ABET requires the following for advanced level (graduate) programs [32]:

1. *General*- Criteria for advanced level programs are completion of a program of study satisfying the general criteria for basic level engineering programs, one academic year of study beyond the basic level, and an engineering project or research activity resulting in a report that demonstrates both mastery of the subject matter and a high level of communication skills.
2. *Faculty*-Faculty teaching upper-division courses must have an understanding of current professional practice in the aerospace industry.

Accreditation by ABET “assures that a program has met quality standards set by the profession, and graduation from an accredited program signifies adequate preparation for entry into the profession [30].” Therefore, the stringent requirements set by ABET will be stringently observed during the course of this thesis.

2.5 Avionics Programs

Before setting out to construct a model avionics sequence curriculum for AFIT, it makes sense to first review what other institutes of higher learning, both within the United States and worldwide, are doing to provide education in the field of avionics. The program that had been taught previously at NPS will be reviewed first, since the AFIT sequence was designed directly to replace the NPS program, followed by a review of the programs at Ohio University, McGill University (Canada), the National Standard for all universities within the country of Pakistan, and the Queensland University of Technology (Australia). In addition, the Professional Education courses in the areas of military avionics offered by the Georgia Institute of Technology will be discussed.

In 1947, the U.S. Navy established the Department of Aeronautics at NPS in order to “better prepare naval aviation officers for the transition from piston engine powered aircraft to gas turbine powered jet aircraft [6: 1].” Similarly, as avionics began to represent a larger portion of the total acquisition and lifecycle cost of an aircraft, an avionics curriculum was added to the Department of Aeronautics. Designed to meet the needs of the Navy technical managers, each of the three programs offered within the department; Aeronautical Engineering, Aeronautical Engineering (Avionics), and Test Pilot School Cooperative Program, included a broad aeronautical engineering education. Principal areas of aeronautics included were: aerodynamics, flight mechanics, propulsion, flight structures, avionics, systems integration, aircraft/missile design, and aero-computer science. Differences between the separate programs came during the advanced graduate phase, when each student received in-depth graduate coverage through advanced electives in one of the following areas: flight dynamics, gas dynamics, propulsion, structures, avionics, and aircraft or missile design [33]. The aeronautical engineering curricula at NPS were fully ABET accredited and approved by the curriculum sponsor, NAVAIR.

In May of 2002, the last biennial review of the NPS aeronautical engineering curricula was held, chaired by the Vice Commander of NAVAIR. During the review, the proposed curricula for all three programs (curriculum codes 610, 611, and 612) offered within the department were reviewed and approved [7]. An important part of the review was the definition of the skills requirements for individuals graduating from the programs. Using this outcome-based approach, the curriculum was developed to meet those skill

requirements required by the end-users, the Joint Services and International community. The curricula approval letter, educational skill requirements, course matrices, and course descriptions for the three NPS curricula are contained in Appendix A [7]. Completion of the 611 curriculum led to the Aeronautical Engineering (Avionics) Masters degree, but it should also be noted that the 610 and 612 curricula both contained the same instruction in avionics, with the exception of the capstone design course. In contrast to the six quarter program at AFIT, the course of instruction lasted eight academic quarters and included 90 credit hours of lecture, 41 credit hours of laboratory, and completion of a thesis.

Since this thesis only deals with the avionics sequence of classes within the aeronautical engineering curriculum, only the NPS avionics courses were reviewed. A total of six classes that dealt with avionics can be found within the curricula, although not all six classes dealt exclusively with avionics. Classes were divided up into two preparatory, three graduate, and one advanced-graduate course. The two preparatory classes were AA2440 Intro to Digital Computation, which covered computer programming in high-level programming languages (C, MATLAB, and FORTRAN) for application to the solution of selected engineering problems, and SW3460 Software Methodology, which was designed to teach students the basic concepts of software engineering, methods for requirements definition, and design and testing of software [7]. Although the two preparatory classes did not deal exclusively with avionics, they did establish a basic understanding of programming requirements, structures, and tools used in computer programming. The three graduate courses made up the bulk of the digital avionics curriculum. General function and systems architecture of a typical avionics system,

typical navigation systems (INS, GPS, TACAN), and the technique of Kalman Filtering were all included in the AA3276 Intro to Aircraft Navigation course [7]. AA3641 Digital Avionics I offered an introduction to digital technology with an emphasis on avionics applications [7]. Avionics architectures, communication methods, bus structures, data representation, and digital circuit design were covered during the course. It should be noted that while the focus of the course was on digital technology, the applications of the digital technology were focused on avionics. Building upon the initial course, AA4641 Digital Avionics II covered microprocessor technology and embedded computer system design as applied to modern military avionics systems, to include laboratory projects that provided the students with experience in hardware and software system integration [7]. Completion of these three courses led to the capstone design class, of which the students had a choice from the two offered. Completion of either of the two courses satisfied the ABET requirement that states, “Programs must also demonstrate that graduates have design competence that includes integration of aeronautical topics [32].” AA4642 Digital Avionics Design focused on utilizing microprocessor technology with an emphasis on aeronautical engineering applications. The project-oriented course allowed the students to carry through from problem definition to problem solution, considering engineering tradeoffs along the way [7]. AA4276 Avionics System Design was also a project-oriented course that took students through each stage involved in the design, modeling, and testing of a core avionics system made up of guidance, navigation, and control subsystems. Computer modeling through the use of the SIMULINK software application

provided the students with a means to evaluate their project and make improvements along the way [7].

The NPS program was unusual in that it sought to provide a broad-based aeronautical engineering education to all of the students, rather than make the graduate students experts in one or two particular areas. Inclusion of avionics classes into each of the three offered curriculums shows that NAVAIR considered avionics a critical part of any aeronautical engineering program. Confirmation of this emphasis is apparent in the curricula approval letter contained in Appendix A which states, “All three programs meet the sponsor’s requirements [7].” Closure of the NPS aeronautical engineering program and the transfer to AFIT of the requirement to provide aeronautical engineering graduate training to all of the Joint Services at the beginning of 2003 precluded the implementation of the curriculum reviewed in May 2002.

Ohio University, founded in 1804 and located in Athens, Ohio, is a leader in avionics engineering, with a specific emphasis on electronic navigation, communication, and surveillance systems. The Avionics Engineering Center at Ohio University specializes in the research, development, and evaluation of electronic navigation, communication, and surveillance systems [34]. However, Ohio University differs from NPS in that it treats avionics as a subspecialty within the Electrical Engineering Department and not part of their Aviation Department, offering a Master of Science degree in Electrical Engineering with a concentration in Electronic Navigation. Targeted primarily to serve engineers working in federal research laboratories or employed by industry, the degree offers a highly specialized concentration [34]. Completion of 45 quarter hours of graduate

courses, 14 quarter hours of research in electrical engineering, and presentation of a research project is required within the program, but a thesis is not required. The 45 quarter hours are comprised of the following 15 courses, of which a complete course description is contained in Appendix B [35]:

- EE 541 Antennas
- EE 570 Communication Engineering
- EE 571 Statistical Analysis
- EE 585 Electronic Navigation Systems I
- EE 586 Electronic Navigation Systems II
- EE 587 Electronic Navigations Systems III
- EE 601 Electromagnetic Wave Propagation in Electronic Navigation Systems
- EE 602 Radar Systems
- EE 603 Inertial Navigation Systems I
- EE 604 Inertial Navigation Systems II
- EE 605 Advanced Satellite Navigation Systems
- EE 606 Integrated Navigation Systems
- EE 607 Navigation Receiver Design
- EE 608 Aviation Standards, Software Design and Certification
- EE 610 Aerospace Controls

Analysis of the course descriptions illustrates that the Ohio University avionics program is more in-depth and specialized than the NPS program. By focusing specifically on communication, navigation, and surveillance, it leaves out large portions of a standard avionics suite found within a military aircraft and is more inclusive of the ground-based avionics with which aircraft interact. While the program is different than that required at AFIT, it is complementary and should be considered as a source of topics for inclusion in an avionics sequence within an aeronautical engineering degree.

McGill University, founded in 1821, is a public university located in Montreal, Canada. McGill is considered to be one of the best universities in Canada, with a 2004 ranking as 21st in the world and 12th in North America by the Times Higher Education

Supplement [36]. In particular, the Times study recognized McGill as having the most international faculty and students of the top 50 universities in North America [36].

Similar to NPS and AFIT, McGill offers an Avionics and Control specialization within the Aerospace Engineering Masters degree program. Requirements of the program are a minimum of 45 credit hours, which must include [37]:

1. A minimum of 12 credits in core or preparatory classes
2. MECH 687 Aerospace Case Studies (3 credits)
3. Either an Industrial Stage or Aerospace Engineering Project Courses (6 credits)
4. Two advanced courses taken at other Universities (6 credits)
5. Advanced courses (18 credits)

Core classes required for a student with a non-electrical engineering background are:

ECSE 502 Control Engineering or MECH 513 Control Systems
MECH 532 Aircraft Performance, Stability, and Control
ECSE 411 Communications Systems 1
ECSE 412 Discrete Time Signal Processing
ECSE 451 EM Transmission and Radiation

A full course description of all of the courses available in the Avionics and Control specialization program are contained in Appendix C [38]. The MECH 687 Aerospace Case Studies class covers topical case studies drawn from aerospace industry engineers currently in practice. An integral portion of the curriculum is the Industrial Stage that is completed under the supervision of an experienced engineer at the facilities of a participating company. The student serves a sort of internship on a topic of choice and receives an evaluation of their performance upon completion of the work period. If a degree candidate and the University are unable to arrange for a suitable Industrial Stage, they can substitute Aerospace Engineering Project Courses to earn the required credits.

Substitution is not encouraged, due to the school's emphasis on practical learning. An unusual aspect of the McGill program is the requirement to take advanced courses at other Universities. Five other institutions are available within the Montreal area to satisfy this requirement.

Advance Courses taken at McGill make up the remaining 18 required credits. Students must choose six courses, based upon their own interests, from the 18 courses listed below. A full description of each course can be found in Appendix C.

- ECSE 505 Nonlinear Control Systems
- ECSE 506 Stochastic Control and Decision Theory
- ECSE 507 Optimization and Optimal Control
- ECSE 510 Random Processes and Systems
- ECSE 512 Digital Signal Processing 1
- ECSE 513 Robust Control Systems
- ECSE 521 Digital Communications 1
- ECSE 527 Optical Engineering
- ECSE 528 Telecommunication Network Architecture
- ECSE 529 Image Processing and Communication
- ECSE 531 Real Time Systems
- ECSE 532 Computer Graphics
- ECSE 545 Microelectronics Technology
- ECSE 565 Introduction to Power Electronics
- ECSE 573 Microwave Electronics
- ECSE 596 Optical Waveguides
- COMP 538 Person-Machine Communication
- COMP 557 Fundamentals of Computer Graphics

It is clear that the McGill program puts a premium on gaining experience in the field and keeping abreast of what is currently happening in the field. Completion of the Industrial Stage and the Aerospace Case Studies class can be seen as a substitute for a thesis, required by most other graduate programs. Similar to Ohio University, analysis of the course descriptions for the Advance Courses shows that the McGill program requires

in-depth electrical engineering courses within the degree program. This level of instruction is in line with the target student population for the program being working engineers desiring to specialize in the Avionics and Control area [37]. Although the target student population of the McGill program is different than that of an AFIT student enrolled in the digital avionics sequence, it can be a source of ideas for areas of study within the AFIT program.

Pakistan has taken a different approach than most countries towards curriculum development at their institutes of higher education. While institutions in most countries are left to develop their own curriculum for their degree programs, in compliance with accrediting agency requirements, curriculum development in Pakistan is standardized across all institutions. In 1976, Federal Law appointed the Higher Education Commission as the competent authority “to look after the curriculum revision work beyond Bachelor level and onwards to all Degrees, Certificates, and Diplomas awarded by Degree Colleges, Universities, and other Institutions of higher education [39: 4].” In accordance with this mandate, the National Curriculum Revision Committee on Aeronautical Engineering held a meeting in May 2004 to finalize and publish the revised national curriculum for aeronautical engineering degrees, to include a Masters of Science in Avionics Engineering. As a starting point, the Commission formulated the following Vision Statement for Aerospace/Avionics education in Pakistan [39: 9]:

The Aerospace/Avionics education in Pakistan will focus on imparting to students the knowledge and training which should enable them to harmonize theory with practice, concept with application, and problem with solution. It will prepare them to ably apply engineering principles, processes and practices to aerospace and avionics systems, and their maintenance. The program will also, in addition to students’ professional growth, attend to development of their personal and

interpersonal skills. It will help students to enhance their ability in oral and written communication, and their adaptability to group-work environments. The program will inculcate among students a strong sense of civic, professional and ethical responsibility. The program will strive to develop in the professionals a capacity for innovation and a passion for life-long learning.

Guided by this lofty Vision Statement, the Committee identified major knowledge areas that must be included within the Aerospace/Avionics Engineering program. Ten areas were identified specifically for the avionics engineering curriculum [39: 9-10]:

1. Electronics
2. Energy Conversion/Electro-Mechanical Systems/Power Electronics
3. Electromagnetism
4. Communications
5. Computer Systems
6. Controls
7. Guidance, Navigation and Control
8. Microwaves/Radar/Antenna
9. Supporting Areas (Mathematics, Basic sciences, Aerodynamics,
10. Thermodynamics, Propulsion, and Engineering Management)
11. General Education

In addition to identifying the major knowledge areas, the Committee identified objectives for the M.S. Avionics program [39: 13-14]:

“Therefore, the objectives of the M.S. Aerospace/Avionics Engineering programs should be to produce graduates who [39: 13-14]:”

1. Are well-educated, highly valued and successful professionals, technically well-prepared for their subsequent assignments, duties and responsibilities as Aerospace/Avionics engineers in public as well as private sector organizations.
2. Have been provided core education in Aerospace or Avionics Engineering.
3. Possess detailed understanding in one or two specialty areas.
4. Apply foundational scientific concepts and sound engineering principles to efficiently and effectively advance technological capabilities in the country.
5. Have experience in conducting and documenting an independent investigation of a problem pertaining to Aerospace or Avionics Engineering.
6. Professionally communicate technical solutions and results.

7. Continue to pursue lifelong multidisciplinary learning as professional engineers.

Not surprisingly, since the Committee was guided by the ABET Engineering Criteria 2000 [39: 8], these objectives are remarkably similar to the stated program educational objectives of the ABET-accredited AFIT program reviewed previously. Engineering education principles do not seem to vary greatly around the world.

The scheme of studies for a Pakistani student working towards a Masters of Science degree in avionics engineering requires 30 credit hours at a minimum. Within the avionics engineering program, students can choose either from the Microwave Engineering major or the Controls major. A breakdown of the 21 major credit hours for each respective major is shown in Table 3:

Table 3: Breakdown of Credit Hours by Major [39: 57]

Subjects	Credit Hours
Microwave Engineering Major:	
Mathematics	3
Microwave Engineering related subjects	12
Thesis	6
Controls Major:	
Mathematics	3
Controls related subjects	12
Thesis	6
Respective Major Total	21

In addition to these major credit hours, students take nine additional credit hours of classes in wireless communication, digital signal processing, and power electronics. A full course description of the required courses listed below can be found in Appendix D [39: 58-63].

MATHEMATICS (3 Total Credits)

MA-5xx Advanced Engineering Mathematics 3-0

MICROWAVE ENGINEERING MAJOR (12 Total Credits)

EE-5xx Electromagnetics 3-0

EE-5xx Transmission Lines and Waveguides 3-0

EE-5xx Microwave Engineering 3-0

EE-5xx RF and Microwave Circuit Design 3-0

CONTROLS MAJOR (12 Total Credits)

EE-5xx Modern Control Systems 3-0

EE-5xx Linear Systems Theory 3-0

EE-5xx Intelligent Adaptive Control Systems 6-0

M.S. THESIS (6 Total Credits)

EE-6xx MS Thesis Research 6-0

BOTH (9 Total Credits)

EE-5xx Wireless Communication 3-0

EE-5xx Digital Signal Processing 3-0

EE-5xx Power Electronics 3-0

Scrutiny of the course descriptions shows that the Controls major within the Avionics Engineering degree includes material very similar to the material covered within the AFIT Aircraft Stability and Control sequence of courses. One addition to the material covered at AFIT is the inclusion of intelligent-adaptive control systems that employ a variety of intelligent control techniques, to include fuzzy logic. The course descriptions for the Microwave Engineering major show a program that is focused upon in-depth electromagnetic theory, propagation, and design of microwave circuits. A higher-level look at how these concepts are used within avionics systems installed within air vehicles is missing. Graduates of the Pakistani program should be well-prepared for designing avionics systems at the box-level, but will be reliant upon more traditional aeronautical

engineers to integrate those boxes into a coherent avionic system that falls within the constraints of being employed on an aircraft.

While the programs being taught at McGill University in Canada and the National Standard of Pakistan offer excellent insight into what International institutes of higher learning are teaching within their avionics programs, it should be noted that the strategic military concerns of those two particular countries differ from that of the United States. This difference in strategic military concerns will cascade down into their avionics programs, resulting in a different focus based upon different customer needs. The U.S. military, and specifically the aerospace portion of the military, focuses on worldwide power projection capable of traveling long distances from either shore or sea-based airfields in order to deliver conventional or nuclear weapons on heavily defended land or sea-based targets. Canadian military forces are much smaller and guided by their 2004 National Security Policy which states, “There can be no greater role, no more important obligation for a government, than the protection and safety of its citizens [40].” In line with this overarching Policy, the Air Forces, both regular and reserve, “will place much greater emphasis on protecting Canada [40].” The primary mission of the single tactical military aircraft flown by the Canadian Air Force, the CF-18, will be “the defense of Canada and North America [40].” In contrast, the Pakistan Air Force (PAF) is focused both on defending its airspace and providing close air support to the Army in a war against their archrival India [41]. The close proximity of India to Pakistan and the need for extensive close air support for the Army drives unique aircraft and avionics mission requirements. Both Canada and Pakistan have military goals which differ from the

United States, and neither of them have large civil aircraft suppliers on the order of Boeing or Airbus. As a result, the focus of the avionics programs taught within their universities will differ than those taught within the United States, as different customer needs will drive different educational objectives.

One country that is geographically similar to the United States and interested in playing a major role in world affairs is Australia. The Vision of the Royal Australian Air Force is, “To be a balanced expeditionary Air Force capable of achieving the Government’s objectives through swift and decisive application of air and space power in joint operations or as a part of a larger coalition force [42].” This Vision is in concert with the policy of U.S. air forces, particularly the emphasis on joint and combined air operations in an expeditionary fashion. Due to this similar mission and the history of a close alliance between the U.S. and Australia, a look at an avionics program being offered within Australia was performed.

The Queensland University of Technology (QUT) in Brisbane, Australia offers a Bachelor of Engineering in Aerospace Avionics. Graduates of this program are employed by the Royal Australian Air Force and Navy, and by government bodies such as the Defense Research Center and the Civil Aviation Authority [43]. Students within the avionics curriculum study the normal basic engineering disciplines and aeronautical engineering subjects in addition to avionics specific subjects. In later years of the degree, specialist study is undertaken in the design of aircraft and satellite systems, aircraft technology, satellite technology, and their applications [43]. The QUT four-year course structure is shown below [43]:

Year 1 - Semester 1

EEB112 Electrical and Computer Engineering 1

EEB130 Introduction to Avionics

PCB136 Engineering Physics 1C

MAB131 Engineering Mathematics 1A

or

MAB180 Engineering Mathematics 1

Year 1 - Semester 2

BNB007 Professional Studies 1

CEB109 Engineering Mechanics 1

EEB212 Electrical and Computer Engineering 2

MAB132 Engineering Mathematics 1B

Year 2 - Semester 1

EEB312 Analog and Digital Electronics

EEB340 Introduction to Telecommunications

MAB134 Electrical Engineering Mathematics 3

MMB251 Aerodynamic Principles

Year 2 - Semester 2

EEB412 Advanced Electronics and Embedded Systems

EEB431 Aircraft Systems and Flight Control

EEB440 Classical Signal Processing

MAB135 Electrical Engineering Mathematics 4

Year 3 - Semester 1

EEB512 Industrial Electronics and Digital Design

EEB535 Modern Flight Control Systems

EEB560 Digital Communications

EEB585 Systems Engineering Design

Year 3 - Semester 2

EEB612 Software Systems Design

EEB640 Digital Signal Processing

EEB641 Fields Transmission and Propagation

EEB685 Advanced Systems Design

Year 4 - Semester 1

EEB732 Space Technology
EEB781 Professional Studies 2
EEB782-1 Systems Project
Elective Unit 1

Year 4 - Semester 2

EEB782-2 Systems Project
EEB833 Spacecraft Guidance and Navigation
EEB835 Navigation Systems for Aircraft
Elective Unit 2

Electives (Minimum of 2)

EEB760 Aerospace Radio and Radar Systems
EEB831 Military Combat Electronics
EEB904 Advanced Topics in Electrical Engineering A
EEB905 Advanced Topics in Electrical Engineering B
EEB941 Modern Signal Processing
EEB960 Wireless Communications
EEB961 RF and Applied Electromagnetics
EEB976 Advanced Industrial Electronics
EEB992 VLSI Circuits and Systems
PCB469 Astrophysics 1

A full course description, including the specific content of each course, is contained in Appendix E for those classes which are specifically focused towards avionics. Analysis of the course descriptions shows that a graduate of this program should have comprehensive knowledge of analog and digital signal processing, communications, navigation, electromagnetic theory, radar, and military weapons systems at the individual box level and at the system integration level. While this education is more than that required of the AFIT program, it demonstrates the importance our Australian allies place on the value of avionics within the overall aircraft system. Due to their similar strategic

military aircraft needs, incorporation of several of the included subjects at a less in-depth level of instruction should be considered for an AFIT program.

Industry is one of the important customers that educational institutions and programs must strive to serve at the undergraduate, graduate, and continuing professional education levels. Partnerships are often developed between industry leaders and universities as a means of fostering a close relationship and ensuring the educational needs of the industry partner are being met while the financial requirements of the university are being met. In 1999 a partnership was announced between Lockheed Martin and the Georgia Institute of Technology to establish an endowed Professorship in Avionics Integration. Dr. Robert Loewy, chair of Georgia Tech's School of Aerospace Engineering, said "It is becoming more important for the integration of avionics systems to be taken into account at the earliest stages of aerospace vehicle design to obtain optimum aircraft performance [44]." Lockheed Martin agreed with this assessment when their Chief Operating Officer said, "The avionics integration program will address key challenges to the future of our industry [44]." As a result of this partnership, an extensive set of avionics courses have been developed by Georgia Tech that specifically target professionals working in the aerospace industry. These courses are offered through Georgia Tech's Professional Education program, which teaches intensive one-week, 40-hour courses in specific areas of interest. The avionics topics covered in these courses are valuable sources of what today's industrial component believes are important avionics topics, as evidenced by the money and man-hours it cost a company to send their employees to one of these courses. A comprehensive list of the Professional Education courses offered by Georgia Tech and

their corresponding course descriptions are contained in Appendix F [45]. While the list is made up of 49 separate courses offered, the courses can be categorized into the following 10 subject areas:

1. Radar
2. Electronic Warfare
3. Antenna Engineering
4. Test and Evaluation
5. Radar Cross Section
6. Electro-Optical/Infrared
7. Modeling and Simulation
8. Signal Processing (Analog and Digital)
9. Guidance, Navigation, and Control
10. Digital and Wireless Communication

Although the digital avionics sequence taught at AFIT could never cover these subjects at the same depth within the time allowed, the above subject areas are clearly at the forefront of what the industry feels is critical to their business success.

2.6 Summary

This chapter has presented a review of literature written about what attributes an engineer should possess upon graduation, how the curriculum development process is accomplished, and what is required for an engineering program to achieve the important ABET accreditation. The first two areas have been the subject of many writings over the years as engineering programs around the world seek to update their curriculum to produce graduates that have the attributes and knowledge sought out by today's employers. By starting with the desired end-product, an outcome-based curriculum development approach can stay focused throughout the process.

Review of the now defunct NPS avionics program, which the AFIT digital avionics sequence was supposed to replace, was presented, along with a review of avionics

programs at other institutions. Although each of these programs had a different focus and desired end-product, they do present a good background of the material being covered elsewhere in the country and the world.

The preceding review of previously published documents formed a basis from which the research conducted in this thesis could progress.

III. Methodology

3.1 Overview

This chapter will describe the methodology used to acquire and analyze the data collected during the research portion of this thesis. Unlike most experimental studies in the aeronautical engineering discipline, the technique used during this research was less rooted in engineering, physics, and math, but more rooted in human behavior, thought process, and opinion based upon personal experience. Although different, the methodology has proven itself over time and is well accepted in academe and within the DoD. Background of the particular survey technique used, reasons for choosing the technique, procedures of the technique, and drawbacks of using the technique will be reviewed. Finally, a description of how the research was designed and implemented within this study will be presented.

3.2 Delphi Method

Like many other technologies and methods developed during the 20th century, the Delphi method is a by-products of research conducted to support the DOD that has found usefulness in other areas. In 1944, when General Hap Arnold, USAAF, asked noted aeronautical engineer Theodor von Karman to prepare a forecast of future technological capabilities that might be of interest to the military, the new science of technology forecasting studies began which eventually led to the development of the Delphi method [46]. Building upon the initial idea, in 1946 General Arnold convinced the Douglas Aircraft Company to establish a Project RAND (an acronym for Research and Development) to study the "broad subject of inter-continental warfare other than surface

[47].” In 1948, Project RAND separated from the Douglas Aircraft Company and became an independent, nonprofit corporation dedicated “to furthering and promoting scientific, educational, and charitable purposes for the public welfare and security of the United States [48].” Project Delphi was the name given to an Air Force-sponsored RAND Corporation study, starting in the early 1950s, concerning the use of expert opinion. The first study used a group of experts “to predict the selection of an optimal U.S. industrial target by Soviet strategic planners and provide an estimation of the number of atomic bombs required to reduce the munitions output by a certain percent [49: 1].” Since that time, the Delphi technique has become a fundamental tool for people in the area of technological forecasting and has spread to other areas seeking to include subjective opinion into the decision-making process [50]. Linstone and Turoff claim, “Even in the areas of classical management science and operations research there is a growing recognition of the need for incorporating subjective information directly into evaluation models [51: 11].” Streveler et al. wrote, “Proponents of the Delphi method recognize human judgment as a legitimate and useful input in generating forecasts and therefore believe that the use of experts, carefully selected, can lead to reliable and valid results [52].”

Over time, the Delphi method has become the name of a set of procedures for eliciting and refining the opinions of a group of people [53: 1]. Used to provide a structure to a group communication process, it can be effective in allowing a group of individuals, as a whole, to deal with a complex problem [51: 3]. While maximizing the input from a diverse group of individuals should present a comprehensive solution to the problem at

hand, dealing with a relatively large group of people can also be difficult and several drawbacks may be encountered [53: 2-3]. One major drawback to group communication is the influence of the dominant individual. Studies have shown that the group's opinion is likely to be highly influenced, if not determined, by the views of the group member of who does the most talking [53: 3]. A second drawback is the noise, irrelevant or redundant material, introduced in discussions between group members that blocks out the directly relevant material offered by participants. A third drawback is group pressure that puts a premium on compromise, resulting in a groupthink mentality in which dissenting opinions are suppressed. Addressing these drawbacks is critical when using the Delphi method and procedures must be constructed that minimize or eliminate the potential problems that may arise from these drawbacks.

Dalkey wrote, "In spite of the potential drawbacks of employing the Delphi method, it is one of the most efficient ways of uncovering the implicit models that lie behind the opinions in the soft areas [53: 9]." In order to utilize the advantages of the process without encountering the drawbacks, procedures have been designed to reduce the negative effects of group interaction while garnering the desired inputs. Three distinctive characteristics that are an integral part of every Delphi are [53: 3, 54: 73]:

1. Anonymity (reduces effect of dominant individual)
2. Controlled feedback (reduces noise)
3. Statistical group response (reduce pressure toward conformity)

When used as a tool to study a complex problem, the systematic processing of expert opinion, as is done with the Delphi method, "can produce significant improvements both in accuracy and reliability [53: 8]." Although several other different methods are also

available to solicit opinion from a group of experts, usually one or more of the following properties of the application leads to the need for employing the Delphi method [51: 3]:

1. The problem does not lend itself to precise analytical techniques but can benefit from subjective judgments on a collective basis.
2. The individuals needed to contribute to the examination of a broad or complex problem have no history of adequate communications and may represent diverse backgrounds with respect to experience or expertise.
3. More individuals are needed that can effectively interact in a face-to-face exchange.
4. Time and cost make frequent group meetings infeasible
5. The efficiency of face-to-face meetings can be increased by a supplemental group communication process.
6. The heterogeneity of the participants must be preserved to assure validity of the results, i.e., avoidance of domination by quantity or by strength of personality.

Clayton claimed, “If the objective of the study is the identification of content based on expert consensus, then the Delphi technique is an appropriate choice as it may enhance the significant contributions of the panel [55: 377].”

The Delphi process exists in two distinct forms, conventional and real-time. A conventional Delphi is the most common and the simplest since it uses a paper-and-pencil (possibly word-processing and email) survey. Although slow and more workload-intensive for the monitors of the study, the conventional Delphi offers a low cost solution for collecting the opinions of a group. The second form, real-time Delphi, uses a computer which has been programmed to carry out the compilation of group results. Although capable of providing real-time feedback to participants and minimizing the time required to accomplish the Delphi, the cost and resources required by a real-time Delphi may exceed the capabilities of the monitor team, leading to the choice of the less resource-intensive conventional Delphi.

A conventional Delphi consists of a monitor team that develops a questionnaire designed to answer the specific questions being researched. Once developed, the questionnaire is sent to a larger respondent group made up of individuals whose inputs have been deemed of some value by the monitor team. After the questionnaire is returned, the monitor team summarizes the results and, based upon the results, develops a new questionnaire for the respondent group. The respondent group is usually given at least one opportunity to reevaluate its original answers based upon examination of the group response. An iterative process continues until a consensus is reached or the group results stabilize [51: 5]. The following ten steps have been developed by Fowles for undertaking a conventional Delphi [56]:

1. Formation of a team to undertake and monitor a Delphi on a given subject
2. Selection of one or more panels to participate in the exercise. Customarily, the panelists are experts in the area to be investigated.
3. Development of the first round Delphi questionnaire.
4. Testing the questionnaire for proper wording (e.g., ambiguities, vagueness)
5. Transmission of the first questionnaires to the panelists
6. Analysis of the first round responses
7. Preparation of the second round questionnaires (and possible testing)
8. Transmission of the second round questionnaires to the panelists
9. Analysis of the second round responses (Steps 7 to 9 are reiterated as long as desired or necessary to achieve stability in the results.)
10. Preparation of a report by the analysis team to present the conclusions of the exercise

Turoff and Hiltz wrote “Perhaps the most important and least understood property of the Delphi method is the ability of the group members to participate in an asynchronous manner [50].” They felt the property of asynchronous interaction had two valuable characteristics: “1) a person may choose to participate in the group communication process when they feel they want to, and 2) a person may choose to contribute to that

aspect of the problem to which they feel best able to contribute [50].” It does not matter when the Delphi participants think of good ideas to include in their response since they can fill out the Delphi survey at whatever point in time the individual feels he or she has thought of significant things to include in their response. Participants can revise and add to their responses over time, before sending them to the group monitor for dissemination to the others [50]. A distinct advantage of the asynchronous property over face-to-face group meetings is that participants have adequate time to fully consider the problem before inputs are required, which is not usually the case in a scheduled meeting environment.

Even with all the benefits the Delphi method can offer, the monitor team must be careful to avoid traps and pitfalls that can cause failure of the process. Linstone and Turoff cautioned against the following common reasons for failure of a Delphi study [51: 6]:

1. Imposing monitor views and preconceptions of a problem upon the respondent group by over specifying the structure of the Delphi and not allowing for the contribution of other perspectives related to the problem.
2. Assuming that Delphi can be a surrogate for all other human communications in a given situation.
3. Poor techniques of summarizing and presenting the group response and ensuring common interpretations of the evaluation scales utilized in the exercise.
4. Ignoring and not exploring disagreements, so that discouraged dissenters drop out and an artificial consensus is reached.
5. Underestimating the demanding nature of a Delphi and the fact that respondents should be recognized as consultants and properly compensated for their time if the Delphi is not an integral part of their job function.

It is the task of the Delphi designers to avoid these pitfalls throughout the survey process by balancing the various communication goals of the particular Delphi study and the nature of the individual participants [51: 7].

3.3 Research Design and Implementation

3.3.1 Overview

The research undertaken during this thesis used the ten steps developed by Fowles [56] in order to avoid the pitfalls described by Linstone and Turoff [51]. The monitor team consisted of Lieutenant Colonel Thomas Hofer as the Principal Investigator and Dr. Guna Seetharaman as the Faculty Advisor. Design and implementation of the research by the monitor team, using the ten-step process, will be fully explained in the following paragraphs. Chapter 4 of this thesis will describe the results of the research.

3.3.2 Human Subjects Testing

All research completed at AFIT, including surveys, which involve the collection or use of information about Human Subjects is subject to the regulations of Air Force Instruction 40-402 [57], Protection of Human Subjects in Biomedical and Behavioral Research. The term Human Subject means a living individual “about whom an investigator conducting research obtains data, whether the data is collected directly through interaction with the individual or obtained from a secondary source that includes private, identifiable information about the individual [57].” AFI 40-402 provides guidance and procedures for research investigations involving human subjects conducted and/or funded by the Air Force. The Delphi method used to conduct the research for this thesis was determined to be subject to AFI 40-402 and the procedures described within

the instruction were followed. However, it was determined by the Air Force Research Laboratory/Wright Site Institutional Review Board (IRB) that the research to be conducted was eligible for an exemption since the confidentiality of the personally identifiable information was maintained throughout the research and thereafter. A copy of the exemption request letter, the Informed Consent Document supplied to all research participants, and the approval of the exemption request are contained in Appendix G.

3.3.3 Panel Member Selection

The selection of the Subject Matter Expert (SME) panel members was a critical step in implementing the Delphi process. A cross-section of military, academe, and industry experts with adequate experience in either military or commercial avionics with areas of experience including aeronautical engineering, electrical engineering, computer science, systems engineering, program management, and test and evaluation was desired. No single military service or single industry company was overrepresented and a mix of educators was included, along with professionals currently practicing in the field. The preferred education level was a Masters Degree or above, but exceptions were made in cases where experience in the field of avionics, either by years or position, was substantial. The final SME panel prospective members identified by the monitor team consisted of 40 individuals whose credentials fit within the desired composition.

Once the desired SME panel members were identified, an email letter was sent to each of them individually inviting their participation in the Delphi process. The emails were sent on an individual basis rather than a group basis to preserve the anonymity of the participants from the other participants, an important Delphi concept utilized to avoid the

groupthink phenomenon. A copy of the invitation email letter is contained in Appendix H. The letter specifically gave the addressee the option to not participate in the survey process if their own job requirements did not allow them the time or if they did not feel they could offer an expert opinion on the areas under study. Of the 40 potential members solicited, 28 agreed to participate in the survey process. Statistical composition of the SME panel is shown in Table 4. A complete list of the SME panel membership is contained in Appendix I, with the names of the experts removed to preserve their anonymity.

Table 4: SME Panel Composition

Statistic	Number
Total on Panel	28
Military (active duty, reserve, or retired)*	18
Civilian DoD (current or retired)*	7
Civilian Industry*	9
Academe*	3
Test Pilot School Faculty* (USN or USAF)	3
Test Pilot School Graduate* (USN or USAF)	14
PhD	7
MS	14
Average Years Experience	18.4
*Individuals may fall into more than one category	

3.3.4 Delphi Round 1

Development of the first round survey was the next step in the process. Although critical for the ultimate success of the process, there is no specific method delineated with which to develop questions in the Delphi process. Rather, it is left to the monitor team to shape the questionnaire in a manner that will result in stimulating thought about a complex problem. However, care must be taken to not over specify the questions to the

point where the monitor team pushes the experts into providing specific answers. Open-mindedness is a key virtue the monitor team must respect while implementing a Delphi survey. Development of the first round Delphi questionnaire was based upon the research questions sought to be answered and within the assumptions/limitations stated previously in Chapter 1. Questions 1-4 dealt with the attributes that should be possessed by an engineer graduating from a graduate-level engineering curriculum. The term attribute was defined as “a quality, characteristic, or trait displayed by a person.” A particular emphasis was placed upon attributes of test engineers, test aircrew, and engineering program managers based upon the beginning assumption that the majority of students (75-90%) will fulfill Test and Evaluation and/or Program Management positions upon completion of the curriculum. Question 5 dealt with what areas of study should be included in an avionics curriculum within an aeronautical engineering Masters of Science degree program. The diverse mix of electrical engineers, aeronautical engineers, test and evaluation aircrew, and program managers were expected to have somewhat different ideas of which areas of study should be included. Each of the questions was purposely left open-ended in order to facilitate a brainstorming type process that would develop a wide range of ideas coming from each SME’s own experience. The developed questionnaire, shown in Appendix J, was checked for ambiguities and readability, and then distributed via individual emails to the SME panel. A seven-day turnaround was requested by the monitor team to avoid stagnation of the process. 25 out of the 28 SME panel members completed and returned the Round 1 survey. Results and analysis of the Round 1 survey are presented in Chapter 4.

3.3.5 Delphi Round 2

In keeping with the Fowles ten-step process, analysis of the responses from the Round 1 survey formed the basis for the construction of the second round survey. The purpose of the Round 2 survey was to begin to put some numerical values to the SME panel inputs in order to allow some statistical analysis on the relative importance of different attributes of an engineer and at what level of proficiency each area of study should be covered within the curriculum. A total of 21 different attributes of an engineering graduate were identified by the SME Round 1 survey respondents, with 12 of those attributes being identified by three or more of the survey respondents. The Round 2 survey, shown in Appendix K, asked the respondents to assign a numerical value of 1-5 to each of these 21 different attributes using the following scale:

- 1 Not required
- 2 Somewhat desirable
- 3 Desirable
- 4 Highly desirable
- 5 Essential

A total of 32 separate areas of study for inclusion within the avionics curriculum were identified by the Round 1 survey respondents, with 21 of the areas being identified by three or more of the respondents. The Round 2 survey asked the respondents to assign a numerical value of 1-5 to the level of proficiency each area of study should be taught using the following scale, which is a modified version of the numerical scale developed by the CDIO Initiative for use in their survey about the construction of a model undergraduate aeronautics and astronautics curriculum [58]:

- 1 Not required for an Aeronautical Engineer
- 2 To have been experienced or exposed to

- 3 To be able to understand and explain
- 4 To be skilled in the practice or implementation of
- 5 To be able to lead or innovate in

Transmission of the Round 2 survey to the 28 SME panel members was accomplished via email with a requested seven-day turnaround time. 27 out of the 28 SME panel members completed and returned the Round 2 survey. Results and analysis of the Round 2 survey are presented in Chapter 4.

3.3.6 Delphi Round 3

Construction of the Round 3 survey was accomplished in the same manner as the Round 2 survey. Fowles' 10-step process for a Delphi study called for an iterative procedure that allowed the SME panel members to first look at the results of the Round 2 survey, and then give them a chance to either change their inputs or keep them the same. Consequently, the Round 3 survey, shown in Appendix L, gave the respondents another opportunity to apply numerical values to the relative importance of different attributes of an engineer and to the level of proficiency each area of study should be covered within the curriculum. Values were assigned to the same 21 attributes and 32 areas of study using the same numerical scales as Round 2. Additionally, respondents were asked to assign numerical values of 1-4 to the relative importance of different areas of study within an avionics program using the following scale:

- 1 Not required
- 2 Minimally important
- 3 Highly important
- 4 Critically important

Assignment of relative importance to each area of study was added to the survey as a means to help prioritize which areas would eventually be included in the curriculum

within the limited time available. Transmission of the Round 3 survey to the 28 SME panel members was accomplished via email with a requested seven-day turnaround time. 26 out of the 28 SME panel members completed and returned the Round 3 survey. Results and analysis of the Round 3 survey are presented in Chapter 4.

The survey process concluded at the end of Round 3 due to the time constraints of the academic environment.

3.4 Summary

This chapter described the Delphi methodology used to acquire the data collected during the research portion of this thesis. Background of the Delphi survey technique, reasons for choosing this particular technique, procedures of the technique, and drawbacks of using the technique were reviewed. Design and implementation of the research using the 10-step Delphi process developed by Fowles was presented. Results and analysis of the Delphi process will be presented in Chapter 4.

IV. Results and Analysis

4.1 Chapter Overview

This Chapter will summarize the results of the data collected during the research portion of this thesis. A summary of the desired attributes of an engineer and areas of study included within the previously reviewed avionics programs will be covered. Results and analysis of each Delphi survey round will be presented in the context of answering the investigative questions posed at the beginning of this thesis. Finally, definitive answers to the investigative questions will be offered.

4.2 Results and Analysis of Literature Review

Desired attributes of a newly graduated engineer were the first area addressed in Chapter 2. Numerous writings on this subject from both academe and industry were reviewed, with many different lists presented. While many different ideas came forward during the review, there was a general consensus across the varied lists that certain attributes were highly desired. The attributes most commonly found across many of the separate lists were:

- Knowledge of Engineering Fundamentals
- Systems Perspective
- Communication Skills
- High Level of Ethical Behavior
- Creative Thinking
- Flexibility
- Desire to Learn

An interesting perspective into what is desired of today's engineer is offered by the above list. Evidently, a solid understanding of traditional engineering fundamentals is still required, but a big-picture Systems Engineering perspective seems to also be highly desired. When coupled with flexibility, creative thinking, and a desire to learn, it can be seen that industry wants engineers that have the ability to tackle a problem they have never seen before, develop an engineering approach to solving the problem, work as part of a group to solve the problem, and then pass on the solution to non-engineering managers. Excellent communication skills, both written and verbal, will be necessary to develop the solution in a group setting and relate the solution to others outside of the engineering profession. Educational programs being developed or updated today need to strive to provide an atmosphere and learning opportunities that will result in the students developing these attributes prior to graduation.

Each of the five university avionics programs and the professional continuing education program reviewed in Chapter 2 had different subject areas that were covered during each course of instruction. Although many differences in included subjects occurred, each of the programs offered insight as to the specific areas of study within the avionics field that each program felt was significant. Differences in subject areas often arose due to the differences in customer needs that the programs were constructed to meet. Table 5 offers a summation of which subject areas were offered within the different programs.

Table 5: Summation of Subject Areas Offered by Program

Subject	Naval Postgrad School	Ohio University	McGill University	Pakistan National Standard	Queensland Tech	Georgia Tech
Systems Engineering/Integ	X					
Software Engineering	X	X	X		X	
Digital Electronics	X	X	X	X	X	X
Control Theory	X	X	X	X	X	X
Digital Signal Processing	X	X	X	X	X	X
Digital Communication	X	X	X	X	X	X
Radar		X		X	X	X
Electro-Optical			X		X	X
Navigational Theory	X	X			X	X
Bus Architecture	X				X	
Controls and Displays			X		X	X
Electronic Warfare					X	X
Test and Evaluation	X	X				X
Modeling and Simulation	X	X				X
Electromagnetic Theory	X	X	X	X	X	X
Military and Civilian Stds		X			X	X
National Airspace Rqmnts		X			X	
Embedded Computing	X				X	
Low Observable Rqmnts						X
Stores Management					X	X
Antennas/Apertures		X		X	X	X
Statistics		X	X			
Optimization Theory			X			
Reliability	X					

Analysis of Table 5 highlights the subject areas considered important by the different programs. All six of the reviewed programs contained elements of the following subjects:

- Digital Electronics
- Control Theory
- Digital Signal Processing
- Digital Communication
- Electromagnetic Theory

Four of the reviewed programs contained elements of the following subjects:

- Software Engineering
- Radar
- Navigational Theory
- Antennas/Apertures

Three of the reviewed programs contained elements of the following subjects:

- Electro-Optics
- Controls and Displays
- Test and Evaluation
- Modeling and Simulation
- Military and Civilian Standards

Two of the reviewed programs contained elements of the following subjects:

- Bus Architecture
- Electronic Warfare
- National Airspace Requirements (ATC)
- Embedded Computing
- Stores Management
- Statistics

One of the reviewed programs contained elements of the following subjects:

- Systems Engineering/Integration
- Low Observable Requirements
- Optimization Theory

- Reliability

Breaking out the subject areas by the number of programs that include the subject shows that some areas are so important that they are included in all the curriculums, while other subject areas are more targeted towards achieving the specific objectives that the program was designed to meet. Programs designed to provide engineers to the military and the military industrial complex will have different components than a program designed to serve civilian aviation needs. Clear definition of the needs of the customer for which an educational program is designed to meet is a critical first step that must be accomplished prior to developing an educational curriculum.

4.3 Results and Analysis of Delphi Round 1 Survey

The Delphi Methodology detailed in Chapter 3 was put into action as a means of collecting separate inputs from a geographically separated group of experts in the field of avionics in order to ultimately arrive at a group consensus. Specifically, the information desired from the group was what attributes are desired of a newly graduated engineer and what areas of study should be included within an avionics sequence that is part of an aeronautical engineering Masters of Science program. Initial thought was that the findings of the Delphi study would reflect the findings of the Literature Review section. A series of three survey rounds were undertaken to see if this initial thought would prove to be true or false.

A summary of the Round 1 survey statistics are shown in Table 6:

Table 6: Round 1 Survey Statistics

Statistic	Data
Dates survey conducted	27 October 05-18 November 05
Number of surveys sent out	28
Number of surveys returned	25
Average days to return survey	8.8

A total of 21 separate desired attributes of an engineer were identified by the respondents. Figure 7 shows the distribution of the 21 attributes. Respondents could identify as many or as few attributes as they desired. Although some of the attributes might appear to be closely related, all attributes identified by the survey respondents were retained and presented in the data. The number in parentheses next to the attribute title is the number of respondents that identified that particular attribute.

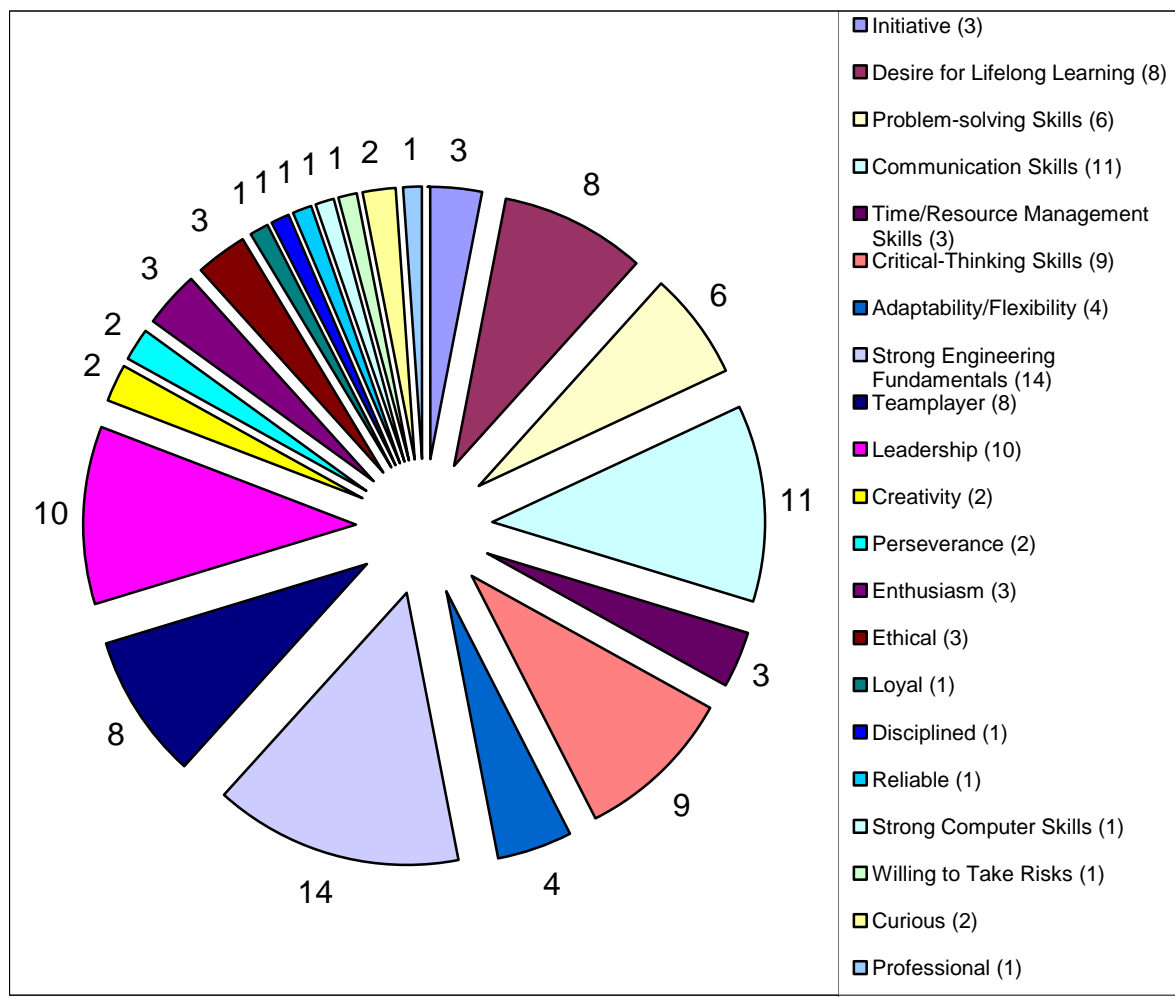


Figure 7: Desired Attributes Identified in Round 1

A total of 12 attributes were identified by three or more of the respondents, representing that at least 10% of the respondents felt those attributes were desired.

Figure 8 shows the distribution of the attributes identified by three or more of the respondents.

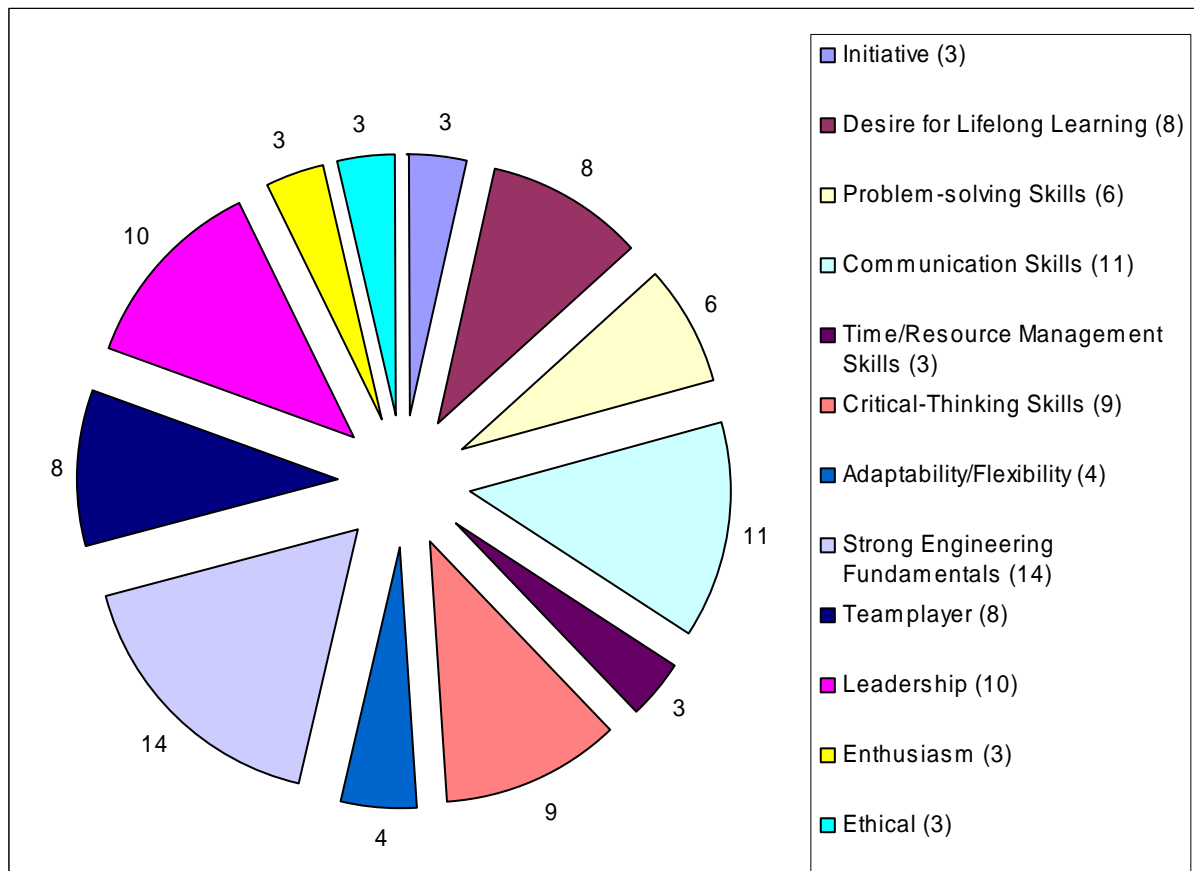


Figure 8: Desired Attributes Identified by 3 or More Respondents in Round 1

Analysis of Figures 7 and 8 shows that there are varied ideas on what attributes should be possessed by a newly-graduated engineer. This inconsistency was not unexpected due to the varied backgrounds from which the panel members based their inputs. However, a closer look at those attributes identified by three or more panel members shows that the inconsistency decreases dramatically, from 21 down to 12. When further compared to the list of seven common desired attributes found during the Literature Review, the list of 12 attributes shown in Figure 8 contains six of the seven. The seventh attribute was systems perspective, which could be argued to encompass the attributes of problem-solving skills, time/resource management skills, leadership skills, and being a team

player. Since the Delphi methodology employed during this research sought to encourage a brainstorm type process throughout the iterative procedure, all 21 of the attributes supplied by the survey respondents were carried through to the second survey round. Further clarification of the importance of each identified attribute was explored during succeeding survey rounds.

The second area addressed by the Round 1 survey was the identification of the areas of study which should be included in an avionics curriculum within an aeronautical engineering Masters Degree program. Once again, a large and varied number of topics were provided by the diverse cross section of panel members representing the military, academe, and industry. A total of 32 separate areas of study were identified by the respondents. Figure 9 shows the number of respondents who identified each separate area of study. Respondents could identify as many or as few areas of study as they desired.

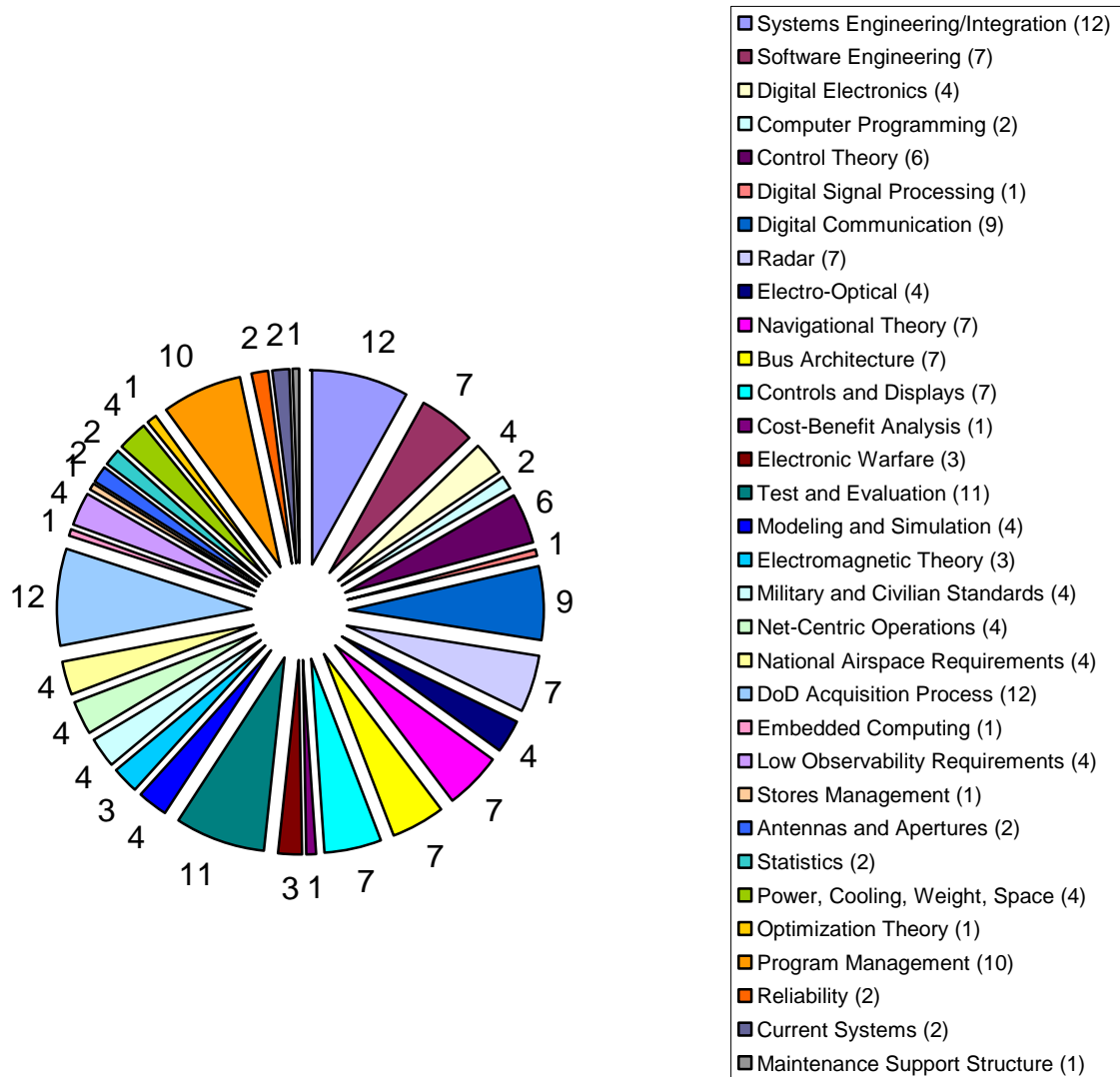


Figure 9: Areas of Study Identified in Round 1

A total of 21 areas of study were identified by three or more of the respondents, meaning the areas were included by at least 10% of the respondents. Figure 10 shows the distribution of the areas of study identified by three or more of the respondents.

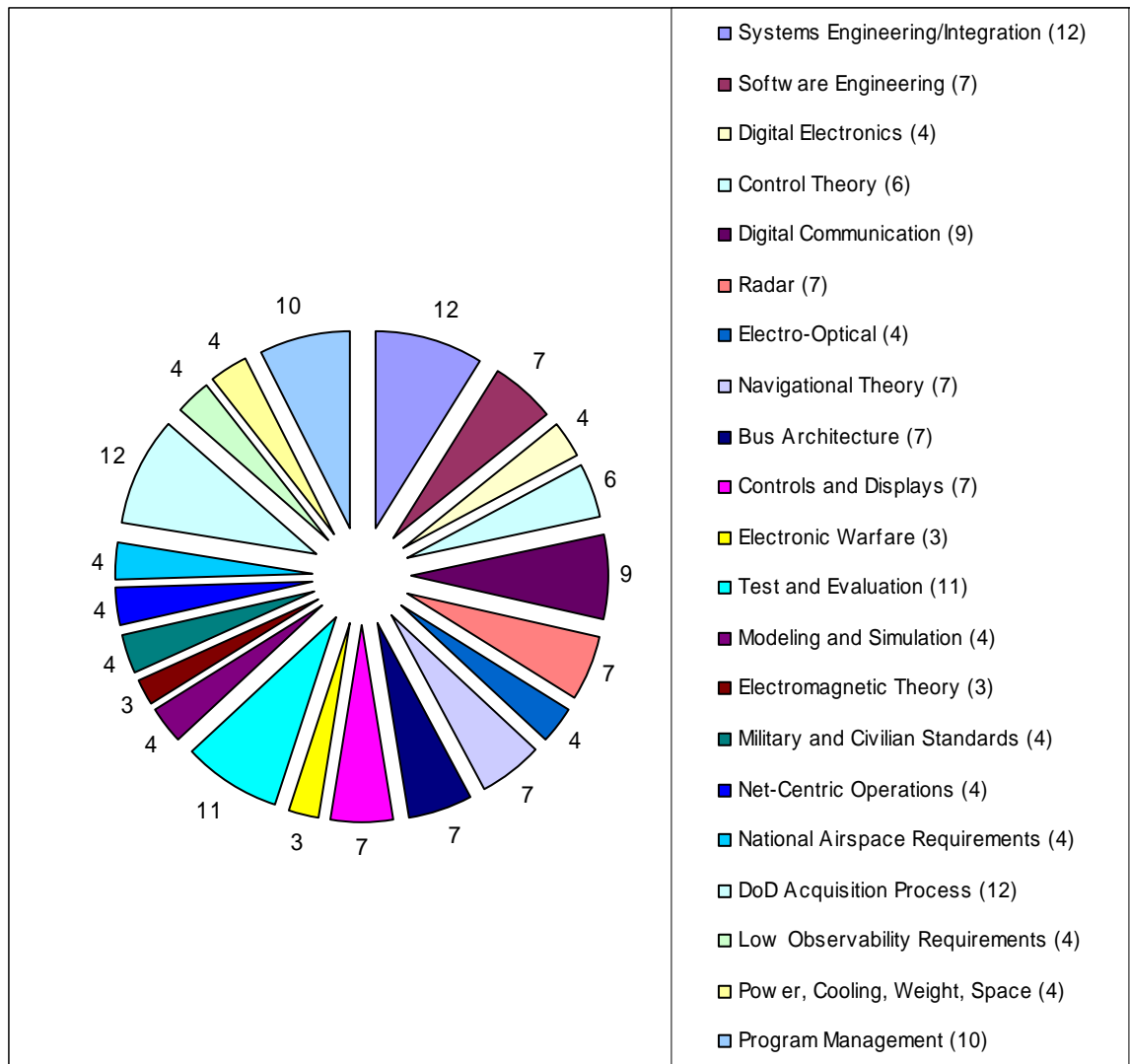


Figure 10: Areas of Study Identified by 3 or More Respondents in Round 1

Analysis of Figures 9 and 10 uncovers a close correlation between the areas of study being covered currently by the avionics programs previously reviewed and the areas of

study recommended by the survey respondents. All 24 of the subjects shown in Table 5 also appear in Figure 9. However, when the number of subjects is reduced down to those recommended by only three or more survey respondents, several discrepancies can be noticed. The following seven subjects identified in Table 5 do not appear in Figure 10:

- Digital Signal Processing
- Embedded Computing
- Stores Management
- Antennas and Apertures
- Statistics
- Optimization Theory
- Reliability

Conversely, the following four subjects were identified in Figure 10, but were not part of the reviewed avionics programs shown in Table 5:

- Net-Centric Operations
- DoD Acquisition Process
- Power, Cooling, Weight, Space Requirements
- Program Management

While an explanation for these discrepancies was unclear at this early stage, these particular areas of study merited special attention as the survey process continued into the succeeding rounds.

4.4 Results and Analysis of Delphi Round 2 Survey

The purpose of the Round 2 survey was to begin to put some numerical values to the Round 1 inputs in order to allow some statistical analysis on the relative importance of different attributes of an engineer and at what level of proficiency each area of study should be covered within the curriculum. Statistical analysis would be used as a tool to assist in the final formulation of the digital avionics curriculum proposed for AFIT.

A summary of the Round 2 survey statistics are shown in Table 7:

Table 7: Round 2 Survey Statistics

Statistic	Data
Dates survey conducted	28 November 05-14 December 05
Number of surveys sent out	28
Number of surveys returned	27
Average days to return survey	5.4

Survey participants were asked to assign a number between 1 and 5 to each of the 21 attributes identified in Round 1 using the following numerical scale:

- 1 Not required
- 2 Somewhat desirable
- 3 Desirable
- 4 Highly desirable
- 5 Essential

The numerical values assigned by the survey respondents to each attribute were analyzed for a mean value, a variance, a standard deviation, the coefficient of variation, and for the number of times each discrete numerical value was assigned. Variance for the sample was determined using equation 1 [59].

$$s^2 = \frac{\sum(X - M)^2}{N-1} \quad (1)$$

where

S^2 = sample variance

X = sample value

M = sample mean

N = # of observations

Sample standard deviation was determined by taking the square root of the sample variance. The coefficient of variation was determined using equation 2.

$$CV = S/M \quad (2)$$

where

CV = Coefficient of Variation

S = sample standard deviation

M = sample mean

The coefficient of variation measures the spread of a set of data as a proportion of its mean and is often expressed as a percentage [59]. The higher the CV, the higher the variability and the lower the CV, the higher is the consistency of the data [60]. Once analyzed, the attributes were sorted in descending order by mean value and are presented in Table 8. The numerical value most often assigned to each attribute, the mode, is highlighted in yellow.

Table 8: Round 2 Numerical Values of Attributes

Attribute	Mean	Variance	Coefficient of Variation	# of 1s	# of 2s	# of 3s	# of 4s	# of 5s
Problem-solving Skills	4.692	0.293	0.115	0	0	1	6	20
Communication Skills	4.538	0.259	0.112	0	0	0	13	14
Critical-Thinking Skills	4.538	0.336	0.128	0	0	1	11	15
Strong Engineering Fundamentals	4.538	0.410	0.141	0	0	2	8	17
Ethical	4.346	1.011	0.231	1	1	1	8	16
Initiative	4.307	0.846	0.213	1	0	2	10	14
Professional	4.307	0.846	0.213	1	0	2	10	14
Disciplined	4.192	0.487	0.166	0	1	1	16	9
Reliable	4.192	0.487	0.166	0	0	4	13	10
Time/Resource Mngt Skills	4.038	0.575	0.188	0	1	4	15	7
Adaptability/Flexibility	4.038	0.687	0.205	0	0	8	9	10
Perseverance	3.884	0.718	0.218	0	1	8	11	7
Creativity	3.846	0.516	0.187	0	0	9	13	5
Teamplayer	3.730	0.564	0.201	0	1	8	14	4
Curious	3.615	0.781	0.244	0	2	11	9	5
Loyal	3.615	0.923	0.266	1	1	9	11	5
Leadership	3.538	0.872	0.264	2	0	8	15	2
Strong Computer Skills	3.461	0.564	0.217	0	2	13	10	2
Enthusiasm	3.461	0.567	0.217	1	0	12	13	1
Desire for Lifelong Learning	3.461	0.644	0.232	1	0	13	11	2
Willing to Take Risks	3.346	0.934	0.289	1	3	11	9	3

Mean values for all of the attributes were greater than 3, implying that all 21 attributes were seen as at least desirable by the survey respondents. A low coefficient of variation ($CV < 0.25$), denotes that the distribution is grouped tightly about the mean numerical value with limited outlying values, implying that the group is generally in consensus. A CV value of 0.25 was chosen as the arbitrary defining line between a group consensus and not a group consensus, based upon the determination that if the sample standard deviation exceeded 25% of the mean value, the data was too greatly dispersed to represent a consensus. Other defining values of CV could be chosen by a different investigator. It can be seen from Table 8 that 18 of the 21 attributes have a coefficient of variation of less than 0.25, identifying that a true group consensus had yet to be reached

on three of the attributes. Another measure of the true group consensus about the importance of each attribute is the identification of the mode, shown highlighted in Table 8. In a straight voting scheme where each member of the group possessed an equal vote, the mode would become the final group value. In the case of the iterative Delphi process used during the research portion of this thesis, the tendencies of the values to change and solidify towards a single value was expected during the successive rounds. Analysis of the succeeding round results would determine if presentation of the Round 2 survey results to the respondents prior to filling out the Round 3 survey resulted in movement toward a group consensus with less variance.

In the second part of the Round 2 survey, respondents were asked to assign a numerical value to the level of proficiency each of the 32 separate areas of study identified in Round 1 should be taught. The following numerical scale was used:

- 1 Not required for an Aeronautical Engineer
- 2 To have been experienced or exposed to
- 3 To be able to understand and explain
- 4 To be skilled in the practice or implementation of
- 5 To be able to lead or innovate in

The numerical values assigned by the survey respondents to each area of study were analyzed for a mean value, a variance, a standard deviation, the coefficient of variation, and for the number of times each discrete numerical value was assigned. Computation of the statistical values was accomplished in the manner described previously. Once analyzed, the attributes were sorted in descending order by mean value and are presented in Table 9. The numerical value most often assigned to each area of study, the mode, is highlighted in yellow.

Table 9: Round 2 Numerical Values for Proficiency of Areas of Study

Area of Study	Mean	Variance	Coefficient of Variation	# of 1s	# of 2s	# of 3s	# of 4s	# of 5s
Systems Engineering/Integration	3.885	0.977	0.254	0	2	9	7	9
Test and Evaluation	3.615	0.627	0.219	0	8	10	8	1
Modeling and Simulation	3.308	0.692	0.252	0	5	14	8	0
Statistics	3.308	0.769	0.265	1	10	12	4	0
DoD Acquisition Process	3.308	1.217	0.333	0	7	7	12	1
Navigational Theory	3.269	0.601	0.237	0	7	14	6	0
Control Theory (guidance)	3.231	0.815	0.279	0	4	13	10	0
Controls and Displays	3.192	0.464	0.213	0	7	11	9	0
Digital Communication	3.192	0.487	0.219	0	7	12	8	0
Net-Centric Operations	3.192	0.772	0.275	0	5	9	13	0
Program Management	3.154	1.410	0.377	1	7	13	6	0
Digital Electronics	3.115	0.487	0.224	0	3	17	6	1
Power, Cooling, Weight, Space Rqmnts	3.077	0.487	0.227	1	8	10	6	2
Software Engineering	3.077	0.764	0.284	1	5	15	6	0
Radar	3.038	0.610	0.257	0	2	9	13	3
Military and Civilian Standards	3.038	0.917	0.315	0	4	12	9	2
Electro-Optical	3.000	0.575	0.253	0	8	13	5	1
Cost-Benefit Analysis	3.000	1.000	0.333	1	6	12	6	2
Current Systems	2.962	0.652	0.273	1	4	12	9	1
Digital Signal Processing	2.923	0.499	0.242	2	9	12	4	0
Electronic Warfare	2.923	0.575	0.260	1	6	8	8	4
Electromagnetic Theory	2.923	0.652	0.276	2	9	14	2	0
Bus Architecture	2.846	0.641	0.281	2	8	15	2	0
Antennas and Apertures	2.808	0.593	0.274	2	13	9	3	0
Optimization Theory	2.731	0.410	0.235	0	10	11	6	0
Reliability	2.692	0.524	0.269	1	2	13	9	2
Computer Programming	2.692	0.601	0.288	0	5	14	8	0
Low Observable Requirements	2.615	0.550	0.284	0	9	15	3	0
National Airspace Rqmnts	2.615	0.692	0.318	2	5	10	5	5
Maintenance Support Structure	2.615	0.781	0.338	1	9	14	3	0
Embedded Computing	2.577	0.558	0.290	0	9	10	8	0
Stores Management	2.462	0.644	0.326	2	11	9	5	0

Initial analysis of the values in Table 9 shows that the panel members felt that most of the areas of study that might be included in an avionics course sequence should be taught at the level where the student can understand the concepts involved and explain them to

some level of expertise short of actually implementing the concept in practice. A higher level of proficiency requiring skill in the implementation of the concepts was recommended for the DoD acquisition process, net-centric operations, radar, and electronic warfare areas of study. Expectations for a higher level of understanding in these areas was not unexpected since one of the initial starting assumptions was that the majority of students (75-90%) will fulfill Test and Evaluation and/or Program Management positions within DoD upon completion of the curriculum. The area of systems engineering/integration was split evenly between the values of 3 and 5. A close examination of the succeeding Round 3 responses pertaining to this area of study was required to further define the consensus of the group. Two other exceptions were the antennas/apertures and stores management areas of study where the majority of the panel members felt that a simple exposure to those areas was adequate. Coefficient of variation values exceeding 0.25 for 24 of the 32 areas of study showed that a true group consensus was not yet reached in Round 2 for the level of proficiency required to be taught in each subject area.

Execution of the Round 3 Delphi study was undertaken to further clarify the results found in Round 2.

4.5 Results and Analysis of Delphi Round 3 Survey

The purpose of the third round of the survey process was to see if the SME panel had come to a group consensus on the desired attributes of an engineer and on the level of proficiency at which each area of study should be taught in an avionics curriculum. In keeping with the Delphi methodology, each of the participants had the opportunity to

view the overall group results of the Round 2 survey prior to filling out the Round 3 survey. Individual results were not supplied to the group. Expectations were that the viewing of the Round 2 survey results would cause the group to move more towards a consensus during Round 3.

A summary of the Round 3 survey statistics are shown in Table 10:

Table 10: Round 3 Survey Statistics

Statistic	Data
Dates survey conducted	03 January 06-17 January 06
Number of surveys sent out	28
Number of surveys returned	26
Average days to return survey	4.0

In the first part of the Round 3 survey, all attributes were assigned a numerical value by the respondents in the same manner as in the Round 2 survey. Statistical analysis of the returned surveys was performed as described earlier. Once analyzed, the attributes were sorted in descending order by mean value and are presented in Table 11. The discrete numerical value most often assigned to each attribute, the mode, is highlighted in yellow.

Table 11: Round 3 Numerical Values of Attributes

Area of Study	Mean	Variance	Coefficient of Variation	# of 1s	# of 2s	# of 3s	# of 4s	# of 5s
Problem-solving Skills	4.769	0.185	0.090	0	0	0	6	20
Strong Engineering Fundamentals	4.538	0.258	0.112	0	0	0	12	14
Critical-Thinking Skills	4.423	0.494	0.159	0	0	3	9	14
Communication Skills	4.346	0.475	0.159	0	0	3	11	12
Ethical	4.269	0.685	0.194	0	1	3	10	12
Reliable	4.038	0.438	0.164	0	0	5	15	6
Initiative	4.000	0.560	0.187	0	1	4	15	6
Professional	4.000	0.560	0.187	0	0	7	12	7
Perseverance	3.769	0.425	0.173	0	0	9	14	3
Time/Resource Management Skills	3.731	0.445	0.179	0	1	7	16	2
Adaptability/Flexibility	3.731	0.525	0.194	0	0	11	11	4
Disciplined	3.654	0.475	0.189	0	1	9	14	2
Teampayer	3.577	0.574	0.212	0	1	12	10	3
Creativity	3.423	0.414	0.188	0	1	14	10	1
Leadership	3.385	0.806	0.265	1	2	11	10	2
Loyal	3.231	0.585	0.237	0	4	13	8	1
Strong Computer Skills	3.154	0.615	0.249	0	5	13	7	1
Curious	3.154	0.695	0.264	1	3	14	7	1
Enthusiasm	3.077	0.394	0.204	0	4	16	6	0
Desire for Lifelong Learning	3.077	0.554	0.242	0	6	12	8	0
Willing to Take Risks	2.885	0.426	0.226	0	7	15	4	0

Several interesting observations were made about the data in Table 11. All but one of the 21 attributes had a mean value of greater than 3, meaning once again that they were seen as at least desirable by the panel. The attribute of willing to take risks had a mean value of slightly less than 3, although 3 was the discrete value assigned most often. Only two of the 21 attributes had a coefficient of variation in excess of 0.25, meaning that the displayed mean numerical values were very close to a group consensus. Another indicator of the group consensus was the correlation between the numerical value most often assigned and the mean value. Table 11 shows that the highlighted discrete mode values are closely correlated to the mean values, meaning that the spread of assigned

values was small among the group members. Changes from the Round 2 survey were minimal, as only one of the 21 attributes changed ranking by more than three positions. The attribute of discipline slid from a rank of 8 in Round 2 to a rank of 12 in Round 3, with a corresponding mean value decrease from 4.192 to 3.654. While additional rounds of the survey process may have solidified the values and rankings shown in Table 11, the small changes between Round 2 and Round 3 indicated that a group consensus had been reached for the desired attributes of an engineer.

In the second part of the Round 3 survey, all areas of study were assigned a numerical value by the respondents in the same manner as the Round 2 survey. Statistical analysis of the returned surveys was performed as previously described. Once analyzed, the areas of study were sorted in descending order by mean value and are presented in Table 12. The numerical value most often assigned to each area of study, the mode, is highlighted in yellow. In the case of a tie between two values, the number closest to the mean value is highlighted.

Table 12: Round 3 Numerical Values for Proficiency of Areas of Study

Area of Study	Mean	Variance	Coefficient of Variation	# of 1s	# of 2s	# of 3s	# of 4s	# of 5s
Systems Engineering/Integration	4.000	0.880	0.234	0	2	5	10	9
Test and Evaluation	3.769	0.905	0.252	0	3	6	11	6
Modeling and Simulation	3.500	0.660	0.232	0	3	9	12	2
Program Management	3.308	1.102	0.317	1	5	8	9	3
Digital Electronics	3.269	0.445	0.204	0	3	13	10	0
Navigational Theory	3.269	0.605	0.238	0	4	12	9	1
Control Theory (guidance)	3.192	0.721	0.266	0	5	13	6	2
Digital Communication	3.154	0.375	0.194	0	3	16	7	0
Statistics	3.154	0.615	0.249	0	5	13	7	1
Software Engineering	3.115	0.586	0.246	0	6	11	9	0
DoD Acquisition Process	3.077	1.034	0.330	1	6	12	4	3
Digital Signal Processing	3.038	0.518	0.237	0	6	13	7	0
Controls and Displays	3.038	0.598	0.255	0	7	11	8	0
Net-Centric Operations	3.038	0.838	0.301	1	6	11	7	1
Power, Cooling, Weight, Space Rqmnts	3.000	0.560	0.249	0	7	12	7	0
Radar	2.923	0.553	0.255	0	8	12	6	0
Military and Civilian Standards	2.923	1.034	0.348	2	7	9	7	1
Reliability	2.846	0.455	0.237	0	8	14	4	0
Electro-Optical	2.807	0.562	0.267	1	7	14	4	0
Optimization Theory	2.769	0.425	0.235	0	9	14	3	0
Electronic Warfare	2.769	0.505	0.257	1	7	15	3	0
Electromagnetic Theory	2.731	0.525	0.265	0	11	11	4	0
Current Systems	2.731	0.685	0.303	1	10	10	5	0
Cost-Benefit Analysis	2.731	0.765	0.320	2	8	11	5	0
Computer Programming	2.692	0.622	0.293	1	10	11	4	0
Bus Architecture	2.692	0.782	0.328	2	8	13	2	1
Low Observable Requirements	2.654	0.635	0.300	1	10	13	1	1
Maintenance Support Structure	2.615	0.566	0.288	1	11	11	3	0
Antennas and Apertures	2.538	0.578	0.299	1	13	9	3	0
National Airspace Requirements	2.461	0.978	0.402	5	8	9	4	0
Embedded Computing	2.385	0.486	0.292	1	16	7	2	0
Stores Management	2.269	1.005	0.442	6	11	5	4	0

Evidence of a group consensus on the level of proficiency each area of study should be taught was less evident than was seen in the desired attributes. Coefficient of variation values greater than 0.25 were present in 20 of the 32 areas of study, compared to Round

2, which had 24 areas of study with a coefficient of variation greater than 0.25. While the decrease represented a movement towards a group consensus, it showed a group consensus had not yet been reached. Additionally, 13 of the 32 areas of study had changed rankings by more than 3 positions, signifying that the panel members' inputs fluctuated between the successive rounds. In order to accomplish a true group consensus, or to see if the Round 3 inputs were the panel members' final inputs with no further changes, additional survey rounds would need to be completed. However, the academic timeline required of this thesis precluded the continuation of the survey process. Further examination was performed using a statistical mode analysis, in which the discrete values most often assigned by the SME panel, the mode, served as the input for the entire panel.

Based upon the highlighted data shown in Table 12, the majority of the panel members felt that the correct level of proficiency for 25 of the 32 areas of study was a 3, meaning the student should be able to understand and explain the concepts of the subject, but extensive in-depth knowledge of the area is not required. This finding is not surprising since the majority of the students enrolled in the avionics sequence curriculum at AFIT will be aeronautical engineering students who will move on to test and evaluation and program management positions upon graduation. Four of the areas had a majority assigned value of 4, meaning that the student should have a level of proficiency that would allow him/her to be skilled in the practice or implementation of the concepts in that subject area. The four areas: Systems Engineering/Integration, Test and Evaluation, Modeling and Simulation, and Program Management, fit closely into the areas in which the graduates will move on to, and therefore these areas should be covered

in more depth inside of the curriculum. The remaining three areas of study had a majority assigned value of 2, meaning the students should experience or be exposed to the concepts in the subject area, without an expectation to understand or explain the engineering behind the subject.

In an effort to narrow down the large number of areas of study that should be included in an avionics curriculum, the Round 3 survey added a third section which asked panel members to assign a numerical value as to the importance of including each area of study. The addition of the third part only to the Round 3 survey did not allow for an iterative process resulting in a group consensus. Therefore, the statistical mode assigned by the panel members was treated as the group's input. Numerical values were assigned using the following scale:

- 1 Not required
- 2 Minimally important
- 3 Highly important
- 4 Critically important

The numerical values assigned by the survey respondents to each area of study were analyzed for a mean value, a variance, a standard deviation, the coefficient of variation, and for the number of times each discrete numerical value was assigned. Computation of the statistical values was accomplished in the same manner as described previously. Once analyzed, the attributes were sorted in descending order by mean value and are presented in Table 13. The numerical value most often assigned to each area of study, the mode, is highlighted in yellow. In the three cases of more than one mode value, the number closest to the mean value is highlighted.

Table 13: Round 3 Numerical Values for Importance of Areas of Study

Area of Study	Mean	Variance	Coefficient of Variation	# of 1s	# of 2s	# of 3s	# of 4s
Systems Engineering/Integration	3.692	0.382	0.167	0	2	4	20
Modeling and Simulation	3.192	0.322	0.178	0	2	17	7
Test and Evaluation	3.192	0.562	0.235	1	2	14	9
Navigational Theory	3.115	0.426	0.210	0	4	15	7
Statistics	3.038	0.518	0.237	0	6	13	7
Digital Electronics	3.000	0.400	0.211	0	5	16	5
Controls and Displays	3.000	0.400	0.211	0	5	16	5
Software Engineering	3.000	0.480	0.231	0	6	14	6
Control Theory (guidance)	3.000	0.480	0.231	0	6	14	6
Program Management	2.846	0.935	0.340	2	8	8	8
Digital Communication	2.808	0.322	0.202	0	7	17	2
Electro-Optical	2.808	0.402	0.226	1	5	18	2
Power, Cooling, Weight, Space Rqmnts	2.808	0.562	0.267	0	10	11	5
Radar	2.769	0.505	0.257	1	7	15	3
DoD Acquisition Process	2.769	0.905	0.343	2	9	8	7
Digital Signal Processing	2.731	0.365	0.221	0	9	15	2
Antennas and Apertures	2.692	0.702	0.311	1	11	9	5
Bus Architecture	2.654	0.555	0.281	1	10	12	3
Net-Centric Operations	2.654	0.875	0.353	3	8	10	5
Reliability	2.615	0.486	0.266	1	10	13	2
Low Observable Requirements	2.615	0.566	0.288	2	8	14	2
Electronic Warfare	2.577	0.414	0.250	1	10	14	1
Electromagnetic Theory	2.538	0.418	0.255	0	14	10	2
Military and Civilian Standards	2.538	0.658	0.320	2	11	10	3
Cost-Benefit Analysis	2.538	0.738	0.339	3	9	11	3
Computer Programming	2.462	0.498	0.287	1	14	9	2
Current Systems	2.462	0.818	0.368	4	9	10	3
Optimization Theory	2.423	0.334	0.238	0	16	9	1
Embedded Computing	2.231	0.265	0.231	1	18	7	0
National Airspace Requirements	2.192	1.04	0.466	8	8	7	3
Stores Management	2.154	0.775	0.409	7	9	9	1
Maintenance Support Structure	2.077	0.634	0.383	7	10	9	0

While the iterative process was not performed as to the importance of each area of study, the data shows that 15 of the 32 areas had a coefficient of variation equal to or less than 0.25, meaning the group was more in consensus about the importance of each area after one survey round than they were about level of proficiency after two survey rounds. Table 13 shows that the overwhelming majority of areas of study, 22 out of 32, were seen

as highly important by the panel members while only one area, Systems Engineering/Integration, was seen as critically important. The high importance placed on Systems Engineering/Integration agrees with the higher level of proficiency for the same area seen previously in Table 12, with the desired attributes found in the Literature Review, and the high ranking in Table 11. The remaining nine areas were judged to only be minimally important by the panel members. Of these nine areas, only the subjects of Electromagnetic Theory and Embedded Computing were included in the curriculum previously taught at the Naval Postgraduate School. The remaining seven areas were eliminated from consideration to be included within the proposed avionics sequence curriculum.

4.6 Investigative Questions Answered

The results and analysis of the data collected during the Delphi process, in conjunction with the Literature Review, formed the basis for the answers to the following investigative questions posed in Chapter 1:

1. What subject areas are being taught within an avionics curriculum at other institutes of higher learning, both within the United States and Internationally?

Avionics degree programs at the Naval Postgraduate School (now defunct), Ohio University, McGill University, and Queensland University of Technology, along with the Pakistani National Standard and the Professional Education courses offered by the Georgia Institute of Technology were researched to determine what subject areas were included within their programs. The following subject areas were present within one or more of the reviewed avionics programs.

- Systems Engineering/Integration
- Software Engineering
- Digital Electronics
- Control Theory
- Digital Signal Processing
- Digital Communication
- Radar
- Electro-Optical
- Navigational Theory
- Bus Architecture
- Controls and Displays
- Electronic Warfare
- Test and Evaluation
- Modeling and Simulation
- Electromagnetic Theory
- Military and Civilian Standards
- National Airspace Requirements
- Embedded Computing
- Low Observable Requirements
- Stores Management
- Antennas/Apertures
- Statistics

- Optimization Theory
 - Reliability
2. What are the requirements for a curriculum to satisfy the Accreditation Board for Engineering and Technology (ABET) standards?

The basic requirements to satisfy ABET standards were shown previously in section 2.4. Since this thesis deals specifically with a sequence of specialty classes within a graduate level program, the following graduate criteria will need to be met by any proposed curriculum [32]:

- *General*- Criteria for advanced level programs are completion of a program of study satisfying the general criteria for basic level engineering programs, one academic year of study beyond the basic level, and an engineering project or research activity resulting in a report that demonstrates both mastery of the subject matter and a high level of communication skills.
 - *Faculty*-Faculty teaching upper-division courses must have an understanding of current professional practice in the aerospace industry.
3. What attributes are desirable for a newly graduated aeronautical engineer to possess?

Based upon the results and analysis of the pertinent literature and the conducted Delphi research survey process, the following 14 attributes were found to be considered desirable of newly graduated engineers. Using an outcome-based

curriculum development approach, promotion of these attributes should take place throughout all engineering educational programs. In the case of the avionics curriculum that will be proposed in Chapter 5 of this thesis, the development of these attributes will serve to direct the formulation of the educational objectives and the identification of the proposed teaching, learning, and evaluation methods used during the execution of the proposed curriculum.

- Creative and Critical Problem-Solving Skills
- Strong Engineering Fundamentals
- Communication Skills (written, oral, graphic, and listening)
- Ethical
- Reliable
- Initiative
- Professional
- Perseverance
- Time/Resource Management Skills
- Adaptable/Flexible
- Disciplined
- Team-player (Leader and Follower)
- Loyal
- Possess Desire for Lifelong Learning

4. What areas of study should be included in an avionics curriculum within an aeronautical engineering Masters of Science degree program?

Based upon the results and analysis of the pertinent literature and the conducted Delphi research survey process, 25 subject areas of study were found to be of significant importance that they should be included within the proposed curriculum. Seven of the original 32 areas of study identified by the SME panel members were eliminated from further consideration due to low rankings in the survey process. Further exclusion of subject areas from the proposed avionics curriculum may be recommended in Chapter 5 in order to provide for a curriculum that can fit within the time constraints imposed. The 25 identified subject areas that should be included in an avionics curriculum are:

- Systems Engineering/Integration
- Modeling and Simulation
- Test and Evaluation
- Navigational Theory
- Statistics
- Digital Electronics
- Controls and Displays
- Software Engineering
- Control Theory (guidance)
- Program Management
- Digital Communication

- Electro-Optical Theory
- Power, Cooling, Weight, Space Requirements
- Radar Theory
- DoD Acquisition Process
- Digital Signal Processing
- Antennas and Apertures
- Bus Architecture
- Net-Centric Operations
- Reliability
- Low Observable Requirements
- Electronic Warfare
- Electromagnetic Theory
- Current Systems
- Embedded Computing

4.7 Summary

This Chapter presented the results of the data collected during the Literature Review portion and the Delphi methodology survey portion of this thesis. In addition to the results, analysis was presented leading to conclusions about the desired attributes of an engineer and areas of study that should be included within the proposed avionics curriculum. Definitive answers to the investigative questions posed in Chapter 1 were offered. Chapter 5 will use the answers to the investigative questions to form conclusions

about the structure of a comprehensive digital avionics curriculum within the aeronautical engineering program at AFIT.

V. Conclusions and Recommendations

5.1 Chapter Overview

This chapter will present the conclusions of the author based upon the research and analysis presented in the preceding chapter. Development of an avionics curriculum will follow a systematic six-step process and culminate in a recommend course structure for the digital avionics sequence that fits within the time allowed, satisfies accreditation requirements, and provides the student with a solid background in the principles required. In addition, recommendations for action and future follow-on research will be made.

5.2 Conclusions of Research

5.2.1 Overview

Based upon the answers to the investigative questions posed at the beginning of this thesis and answered at the end of Chapter 4, a six-step process was developed and followed to build a course structure that will satisfy the needs of AFIT students enrolled in the Digital Avionics Applications and Design specialty course sequence, within the constraints/limitations imposed in Chapter 1. The six steps of the developed process were:

1. Define Vision Statement
2. Identify Target Student Populations
3. Identify Desired Attributes
4. Formulate Educational Objectives
5. Identify Teaching Methods
6. Outline Course Structure

5.2.2 Define Vision Statement

Definition of a Vision Statement served as the starting point for the development of the course structure because it established a desired endpoint from the start of the process and presented a benchmark against which all decisions that needed to be made during the process could be measured. The Vision Statement defined for the curriculum proposed within this thesis was:

The Digital Avionics Applications and Design specialty course sequence will provide the aeronautical engineer with the broad-based technical knowledge, principles, theories, and skills necessary to understand, lead, and manage the development, integration, testing, fielding, and supporting of modern avionics systems as an integral part of the overall aircraft system. The sequence will provide opportunities to develop the attributes most sought after by the military and industry, as well as produce a well-rounded professional capable of applying a strong engineering background to the solution of real-world problems and communicating the solution to others through written, oral, and graphic means.

5.2.3 Identify Target Student Populations

Identification of the target student populations early in the curriculum development process allowed for the course structure to be focused on satisfying the educational needs of the student at a level commensurate with past education and experience and in line with future job expectations. The defined mission of AFIT is different than that of civilian graduate institutions in that AFIT “is committed to providing defense-focused

graduate and professional continuing education and research to sustain the technological supremacy of America's air and space forces [61].” Unlike students attending other graduate institutions, graduates of AFIT do not have to wonder what their immediate future holds, as their individual services have sent them to AFIT to gain an education that will be put to use immediately. Identification of specific target populations for a course structure to be built around was made possible by the well-defined AFIT educational mission.

All courses taught within the AFIT Aeronautics and Astronautics Department assume that admitted students have an undergraduate educational background in either an engineering or science discipline [9], making them eligible to undertake any of the offered specialty course sequences. If this is not the case, the student is sent to one of the Dayton Area Graduate Studies Institute (DAGSI) schools to take preparatory courses prior to starting a graduate-level syllabus at AFIT. Therefore, all prospective student populations within the Aeronautics and Astronautics Department are eligible to enroll in the Digital Avionics Applications and Design specialty course sequence.

Based upon past history of enrollment in the avionics sequence, current enrollment in the avionics sequence, and recognition of who will benefit directly in follow-on job assignments, the following student populations within the Aeronautics and Astronautics Department were identified as the target audience for the avionics course sequence:

- U.S. Naval Test Pilot School Students
 - Pilots
 - Naval Flight Officers

- U.S. Air Force Test Pilot School Students
 - Pilots
 - Navigators
 - Civilian Flight Test Engineers
- Navy Quota Students
 - Aviation Engineering Duty Officers
 - Follow-on assignment to NAVAIR
- USMC Quota Students
 - Follow-on assignment to NAVAIR
- USAF Quota Students
 - Follow-on assignment to Test and Evaluation
 - Follow-on assignment to Aeronautical Systems Center (ASC)
 - Follow-on assignment to Electronic Systems Center (ESC)
- All others interested in digital avionics as part of the overall aircraft system

While each of these student populations has slightly different educational needs, they all deal with one or more stages of the development, integration, testing, fielding, and supporting of modern avionics systems as an integral part of the overall aircraft system. By focusing on meeting the educational needs of these populations, the course structure can be narrowed to fit within the restrictive timeline posed by the academic environment.

5.2.4 Identify Desired Attributes

Using the outcome-based curriculum development philosophy, where the complexion of the desired end product is identified prior to starting the process of formulating a curriculum, gave clear direction to the choices made during the process. In the case of engineering education, the end product should be a graduate that possesses certain attributes that are looked for by the customers. The primary customer of AFIT graduates are the Joint Services, meaning that the attributes desired by the military should be weighted heavily in the final decision of what attributes the curriculum proposed in this thesis should seek to develop.

Based upon the Delphi survey process, in which 23 of the 28 SME panel members were current or retired military and/or civilian DoD employees, the development of the following attributes was incorporated in the proposed educational objectives, teaching methods, evaluation methods, and course structure:

- Creative and Critical Problem-Solving Skills
- Strong Engineering Fundamentals
- Communication Skills (written, oral, graphic, and listening)
- Ethical
- Reliable
- Initiative
- Professional
- Perseverance

- Time/Resource Management Skills
- Adaptable/Flexible
- Disciplined
- Team-player (Leader and Follower)
- Loyal
- Possess Desire for Lifelong Learning

5.2.5 Formulate Educational Objectives

Guided by the first three steps of the process and the core skill requirements required for the Navy avionics subspecialty code [5], educational objectives for the Digital Avionics Applications and Design specialty course sequence were developed that supplement the educational objectives for the overall aeronautical engineering degree program. By establishing specific objectives, all proposed teaching methods, evaluation methods, and the proposed course structure could be traced back to satisfying a specific objective, providing for a focused and streamlined program built to fulfill the needs of the students and the institution. Specific objectives developed were:

1. Produce students that have a broad-based education in the area of military avionics that will allow participation in the research, development, and test and evaluation of aircraft avionics systems.
2. Gain a thorough understanding of the capabilities, requirements, and limitations brought about by the incorporation of avionics systems within a flight vehicle.
3. Provide the background knowledge and skills necessary to identify, formulate, and solve engineering problems in the areas of avionics as applied to flight vehicles.

4. Provide the opportunity to develop creative and critical solutions to real-world avionics problems in a group atmosphere and communicate those solutions in a professional manner to external agents.
5. Ensure that students have the opportunity to have hands-on experience with current and future avionics systems.
6. Expose students to practicing experts in the field of avionics.

5.2.6 Identify Teaching Methods

The teaching methods identified for use during the execution of the proposed curriculum should enforce the development of the desired attributes within the students and directly result in satisfying the proposed educational objectives. By first identifying the desired attributes that should be instilled within the students, an outcome-based approach was used to identifying the best teaching methods, listed below:

- Lectures
- Visiting Lecturers
- Field Trips (AFRL, ASC, Flight Line)
- Homework
- Term Papers
- Presentations
- Design Project

Lectures are a time-tested and still important learning method, as they give the instructor the opportunity to supplement assigned readings, explain background theories, answer student questions, and engage in thought-provoking exchanges with the students. To truly be effective, lectures should incorporate real-world examples as much as

possible and stress the application of theory to practice. Lectures by visiting experts should be presented regularly as a means to present the students with the latest technologies being used in the field of avionics and expose them to the challenges presented by the aircraft environment. Visiting lecturers can be drawn from within AFIT, the Air Force Research Lab (AFRL), the Aeronautical Systems Center (ASC), Wright State University, University of Dayton, or from the many defense contractors present in the Dayton area. If fiscally possible, visiting lecturers can also be drawn from other universities, industry, and non-local military commands.

As highlighted by the recent Base Realignment and Closure (BRAC) Commission hearings, AFIT is unique in that it has the good fortune to be co-located with AFRL, which employs some of the world's finest experts in the field of avionics and performs cutting-edge research for future avionics systems. At the same time, many AFIT students perform research for AFRL and receive follow-on assignments to AFRL upon graduation. Utilization of this symbiotic relationship should be increased in the form of visiting lecturers from AFRL and field trip visits to the directorates of AFRL. Exposure to current research will provide the students with real-world applications of the theories being taught in the classroom environment and widen their horizons on what is possible with avionics systems. The advantage of the AFRL/AFIT relationship is unique and something that is unavailable to other avionics programs throughout the world.

Field trips should also be made to System Program Offices (SPOs) at the ASC and to the Wright-Patterson Air Force Base flight line. Officers and civilians working within the SPOs deal with the program management issues that arise during the development,

acquisition, fielding, and supporting of avionics systems in today's Air Force. By hearing their issues, students would be exposed to the many considerations that must go into the lifecycle of avionics systems. Additionally, field trips to the flight line will give students hands-on contact with the avionics systems employed in aircraft as diverse as the C-5 Galaxy and the C-21, or any other USAF aircraft that could be scheduled to visit. Once again, open panel access to current USAF aircraft is something that is unique to AFIT and should be capitalized on.

Homework in the proposed curriculum will be somewhat different than the traditional exercise of applying rigid engineering tools in a systematic process to solve a clearly defined problem. Instead, the assigned homework will pose practical problems within the subject areas that require the student to apply the learned theories in a manner they think may solve the problem. The homework itself should be a learning tool, rather than an evaluation tool, which allows the students to apply unconventional thinking and methods based upon fundamental engineering knowledge.

Term papers, presentations, and the final design project are additional teaching methods that will allow the students to tackle a large loosely-defined problem, work together as a group to solve the problem, and then present their solution in a written, graphic, and oral fashion. Active involvement and teamwork will be required to accomplish the task and learning will be enforced through the need to perform research, formulate conclusions, and present them in a clear and concise fashion.

By employing these identified teaching methods throughout the execution of the proposed curriculum, the students will have the opportunities to develop the desired attributes while satisfying the educational objectives.

5.2.7 Outline Course Structure

Built upon the literature review and the Delphi survey research presented to this point, the proposed course structure is the final step in the six-step process. Due to the academic timeline imposed by the need to graduate students within an 18 month period, specialty course sequences at AFIT are limited in the number of courses that can be required within the sequence and the number of hours available to each course. As a result, the following limitation was established at the beginning of this thesis and will be followed in the outline of the course structure:

Course structure will consist of three (3) courses, each being a four (4) credit hour course spanning a ten week quarter. Each course will have an additional one (1) credit hour lab period available for use at the discretion of the instructor.

The proposed courses will be entitled Digital Avionics Systems I, Digital Avionics Systems II, and Digital Avionics Systems III, with each preceding course being a prerequisite for the succeeding course. Course descriptions, course content, and course specific evaluation methods for all three proposed courses within the sequence are detailed in the following paragraphs. Course content is presented in a table fashion showing the specific subject areas of study in sequential order, the number of class days the subject area will be addressed, and the level of proficiency at which the student

should be capable of achieving once instruction has been completed. Recommended levels of proficiency were drawn directly from the results of the Delphi survey process, as shown in Table 12. The level of proficiency ranking is repeated here for clarification:

- 1 Not required for an Aeronautical Engineer
- 2 To have been experienced or exposed to
- 3 To be able to understand and explain
- 4 To be skilled in the practice or implementation of
- 5 To be able to lead or innovate in

While some subject areas may require a higher level of proficiency than others, they may require less days of instruction due to the volume of subject matter within the area of study. Therefore, not all areas with the same level of proficiency will have the same number of days of instruction devoted to them.

CSCE 581 Digital Avionics Systems I

Course Description: This course is the first in a sequence of three courses that will provide an introduction to digital avionics systems and their integration into flight vehicles. Background knowledge in required building block technologies will be covered in order to provide the student with a broad-based perspective of the theories that modern avionics systems are built upon. Topics include digital signal processing, digital electronics, software engineering, embedded computing, electromagnetic theory, antennas and apertures, bus architecture, and navigational theory. Students will select one of these topics to investigate and present to the class. Modern avionics examples of the use of these theoretical building blocks will be presented.

Course Content:

Table 14: Course Content for CSCE 581

Subject	Days of Instruction	Level of Proficiency
Class Introduction	1	N/A
Digital Signal Processing	8	3
Digital Electronics	4	3
Software Engineering	5	3
Embedded Computing	3	2
Electromagnetic Theory	6	3
Antennas and Apertures	2	2
Bus Architecture	3	3
Navigational Theory	8	3

Course Evaluation Methods:

- Homework
- Individual presentation on a specific application within one of the subject areas.
(10-15 minutes in length)
- Individual term paper (5-8 pages in length) supporting presentation
- Final written exam

CSCE 681-Digital Avionics Systems II

Course Description: This course is a continuation to CSCE 581 that will continue to build upon the theories covered previously. Focus will shift to applications of previously covered theories in specific weapon subsystems that make up the avionics suite of a modern military aircraft. Topics include control theory, controls and displays, digital communication, net-centric operations, and electro-optics. Students will be required to

perform an in-depth study of a current or future system in one of these subject areas and present their findings to the class.

Course Content:

Table 15: Course Content for CSCE 681

Subject	Days of Instruction	Level of Proficiency
Class Introduction	1	N/A
Control Theory (guidance)	8	3
Controls and Displays	8	3
Digital Communication	5	3
Net-Centric Operations	4	3
Electro-Optics	8	3
Group Presentations	6	N/A

Course Evaluation Methods:

- Homework
- Group presentation on a specific application of one of the subject areas.
(50 minutes in length)
- Group term paper supporting presentation
- Final written exam

CSCE 682-Digital Avionics Systems III

Course Description: This course is the final course in the sequence. Applications of theory in specific weapon subsystems will continue to be covered in the first portion of the class. The second portion of the class will address specific challenges faced when integrating all of the weapons subsystems into an aircraft and the stringent requirements for reliability in avionics systems. The third portion of the class will introduce modeling

and simulation techniques, ground test techniques, and airborne test techniques used in the development and test and evaluation of avionics systems. The final portion of the class will step through in-depth analyses of complete avionics suites of current military or civilian aircraft (e.g. F-35, UCAV, Boeing 777, AH-64D). Topics include radar theory and application, low observable requirements, electronic warfare, integration issues, reliability, modeling and simulation, and test and evaluation. Students will be required to design a complete avionics suite for a military aircraft in response to a request for proposal and present their design to the class.

Course Content:

Table 16: Course Content for CSCE 682

Subject	Days of Instruction	Level of Proficiency
Radar	8	3
Low Observable Requirements	3	3
Electronic Warfare	5	3
Power, Cooling, Weight, Space Rqmnts	3	3
Reliability	3	3
Modeling and Simulation	5	3
Test and Evaluation	4	3
Current Systems	4	3
Design Project Presentations	5	3

The level of proficiency values for the Test and Evaluation and Modeling and Simulation subject areas differ than those recommended by the SME panel. Specifically, both subject areas have a value of 3 in Table 16 and a value of 4 in Table 12, due to the limited amount of days of instruction available for these subject areas not providing for the higher level of proficiency. Students continuing on to either of the Test Pilot School programs will receive extensive additional training in these subject areas.

Course Evaluation Methods:

- Mid-term written exam
- Group presentation on design project.
(50 minutes in length)
- Group term paper supporting design project.

Four prominent subject areas of study that were recommended by the SME panel for inclusion within the digital avionics sequence curriculum are noticeably absent from the proposed course structure. Systems Engineering/Integration, Program Management, and the DoD Acquisition Process were all highly ranked by the SME panel members for inclusion. Currently, these subject areas are covered in detail in the SENG 520 Systems Engineering Design course offered at AFIT. In order to fully cover these subjects to the level of proficiency required, they remained as part of the stand-alone SENG 520 class that is recommended to be taken by all engineers at AFIT. Both the reviewed literature and the Delphi survey process highlighted the importance that today's industry places on every engineer, regardless of their discipline, having training in the area of systems engineering. Additionally, all officers and civilians working for the DoD in program management positions need to be familiar with the acquisition process utilized by all of the services.

The fourth prominent subject area missing from the proposed course structure is the science of statistics. Rather than including the lengthy and unrelated topic of statistics as part of the classes focusing on avionics, students without undergraduate training in statistics should be highly encouraged by their academic advisors to enroll in the STAT

525 Applied Statistics for Managers I course as one of their two required math courses. Familiarity with descriptive statistics, probability theory, and statistical inference, which are the subject areas covered in the STAT 525 course, is important for test and evaluation personnel and program managers. In addition, the non-traditional statistical subjects of time series analysis and wide-sense stationary processes should either be added to STAT 525 or covered in CSCE 581 as a portion of the Digital Signal Processing subject area.

5.2.8 Course Content Subject Area Summary

The subject areas included within the proposed three-course avionics sequence were chosen based upon the findings of the review of six other avionics programs and the Delphi survey process. Table 17 provides a summary of the subject areas included within the proposed curriculum, what proposed course the subject area is contained within, the frequency with which the subject areas were included in the six reviewed avionics programs, and the corresponding ranking of importance from the Table 13 Round 3 survey results.

Table 17: Course Content Subject Area Summary

Subject Area	Proposed Course	# of Reviewed Programs	Survey Ranking
Digital Signal Processing	CSCE 581	6	16
Digital Electronics	CSCE 581	6	6
Software Engineering	CSCE 581	4	8
Embedded Computing	CSCE 581	2	29
Electromagnetic Theory	CSCE 581	6	23
Antennas and Apertures	CSCE 581	4	17
Bus Architecture	CSCE 581	2	18
Navigational Theory	CSCE 581	4	4
Control Theory (guidance)	CSCE 681	6	9
Controls and Displays	CSCE 681	3	7
Digital Communication	CSCE 681	6	11
Net-Centric Operations	CSCE 681	0	19
Electro-Optics	CSCE 681	3	12
Radar	CSCE 682	4	14
Low Observable Requirements	CSCE 682	1	21
Electronic Warfare	CSCE 682	2	22
Power, Cooling, Weight, Space Rqts	CSCE 682	0	13
Reliability	CSCE 682	1	20
Modeling and Simulation	CSCE 682	3	2
Test and Evaluation	CSCE 682	3	3
Current Systems	CSCE 682	0	27
Systems Engineering/Integration	SENG 520	1	1
Program Management	SENG 520	0	10
DoD Acquisition Process	SENG 520	0	15
Statistics	STAT 525	2	5

5.3 Recommendations for Action

Based upon the research conducted during the course of this thesis and the formulation of the conclusions presented in this chapter, the following three recommendations for action are proposed:

1. Further develop the proposed curriculum.
2. Hire a dedicated avionics instructor within the Aeronautics and Astronautics Department who has a military avionics background.

3. Build a dedicated avionics lab.

Further development of the proposed curriculum should be completed prior to implementation. While this thesis has presented a detailed outline of the course structure and content, further development should include the assignment of learning objectives within each subject area and the identification of reading materials which support the subject matter covered within class lectures. Once these tasks have been accomplished, lecture notes and presentations should be developed for distribution to the students and use in classroom lectures.

Hiring of a dedicated avionics instructor within the Aeronautics and Aerospace Department will allow the avionics curriculum to get the full-time attention of the instructor and be responsive to the needs of the aeronautical engineering students enrolled in the classes. Presently, the instructor tasked with teaching the avionics curriculum is also tasked with teaching non-related subjects within the Electrical and Computer Engineering Department, not allowing for the instructor to devote his full professional time to advancing his own knowledge of avionics. In addition, by having the instructor come from an outside department, the avionics courses cannot receive the attention required to ensure that the needs of the aeronautical engineering students are being met. In order to provide instruction with an aeronautical engineering viewpoint to the material, rather than an electrical engineering viewpoint, any dedicated avionics instructor that is hired should have a background in one or more of the following areas; development, testing, acquisition, or use of installed military avionics systems. A background of this

nature will provide credibility with students who themselves often have extensive operational or acquisition backgrounds.

Finally, after the first two recommendations are instituted and the proposed course structure has had the opportunity to be adjusted and improved, a dedicated avionics lab should be built at AFIT to support the theories learned in class. Like many other courses taught at AFIT, the avionics sequence would benefit greatly by presenting hands-on opportunities for students to learn. Avionics labs at other universities, coordination with the former avionics lab director at NPS, and a survey of similar labs within the electrical engineering department could provide a basis for the outfitting of a dedicated avionics lab at AFIT. If the building of a dedicated avionics lab at AFIT proves unfeasible due to fiscal or space restraints, close coordination could be developed with the existing avionics labs present at AFRL.

5.4 Recommendations for Future Research

Performance of one additional Delphi round is recommended as a means to garner the SME panel members' opinions on the proposed course structure. In contrast to the previous rounds in which the monitor team merely collected, analyzed, and distributed the inputs of the group without offering opinions or judgments, this additional round would start with the panel members reviewing the proposed curriculum and then providing feedback. Conducting the survey in this manner would allow the panel members to see the reasoning behind the construction of the curriculum and present a venue to point out any detected deficiencies. It would then be up to the individual

responsible for the curriculum to incorporate or ignore the recommendations of the panel members.

Completion of the recommendation to further develop the proposed curriculum prior to implementation will require further research be performed on each subject area so that learning objectives, lecture notes, and supportive reading assignments can be identified. It is recommended that a U.S. Naval Test Pilot School student completing their AFIT program be given this task as an independent research project to accomplish under the direction of the avionics instructor. Undertaking a project of this magnitude would serve as an excellent learning opportunity for the student, would provide the student with required credits for graduation, and serve the needs of AFIT. Many of the Naval Flight Officer students have time in their six-quarter schedule to accommodate a project of this magnitude.

While there are several textbooks on the market that cover different portions of the subject area, and extensive professional journal articles exist for all of the subject areas, there is not a current textbook that covers all of the recommended areas at the levels of proficiency desired. Therefore, it is recommended that a new textbook be developed under the editorial direction of the AFIT avionics instructor, which will address the cross-discipline subject areas in a coherent manner that follows the proposed course structure. Development of this textbook would solidify the reputation of AFIT as a leader in the field of avionics and lead the professional community in the direction desired by the DoD, the primary customer of military avionics in the U.S. marketplace.

5.5 Summary

This chapter presented the conclusions of the author based upon the literature review and analysis of the research conducted using a Delphi survey process as a means to gather recommendations from a geographically separated group of experts in the field of avionics. Development of a proposed avionics curriculum through a six-step process developed by the author was presented, culminating in a recommended course structure for the digital avionics sequence that fits within the time allowed, satisfies accreditation requirements, and provides the student with a solid background in the principles required. Finally, recommendations for action based upon the conclusions were made and recommendations for future follow-on research were made.

In conclusion, the organized study detailed in this thesis, coupled with the experience gained over the first three years of implementing the avionics sequence, presents an opportunity for a close review of the Digital Avionics Applications and Design specialty course sequence. In a quest for continued improvement to the AFIT program, careful consideration should be given to the incorporation of some or all of the conclusions and recommendations presented in this thesis. The importance of avionics to the future of America's air and space forces necessitates that the institute tasked with providing graduate level education in aeronautical engineering to the Joint Services lead the way and not allow education in the important field of avionics to fall behind.

Appendix A: Naval Postgraduate School Curriculum

A-1 Curricula Approval Letter

A-2 Educational Skill Requirements

A-3 Curricula 610/611 and 612 Syllabi

A-4 Avionics Course Descriptions

A-1 Curricula Approval Letter

1550
Ser 31/

From: Superintendent, Naval Postgraduate School
To: Chief of Naval Operations (N7)
Via: Commander, Naval Air Systems Command

Subj: BIENNIAL REVIEW OF THE NAVAL POSTGRADUATE SCHOOL
AERONAUTICAL ENGINEERING (#610, 611, 612) CURRICULA

Ref: (a) OPNAVINST 1520.23 (SERIES)

Encl: (1) List of Participants
(2) Revised Education Skill Requirements
(3) Revised curricula matrices for 610/611 and 612 curricula
(4) List of action items

1. Per reference (a), detailed reviews of the Naval Postgraduate School's Aeronautical Engineering curricula (#610, 611, 612) were conducted on 23-24 May 2002 by RADM Charles H. Johnston Jr., Vice Commander, Naval Air Systems Command. The personnel listed in enclosure (1) attended the review. Education skill requirements shown in enclosure (2) were approved. Curricula matrices for curricula 610, 611 and 612 are shown in enclosure (3). All three programs meet the sponsor's requirements. RADM Johnston expressed satisfaction with the length, thesis requirement and overall education provided by each program. A list of action items is contained in enclosure (4).

2. The strong support and interest demonstrated by RADM Johnston and the Naval Air Systems Command are greatly appreciated. The Naval Postgraduate School remains committed to providing the highest quality education for the students who study in these curricula.

DAVID R. ELLISON

Copy to:
N1

A-2 Educational Skill Requirements

EDUCATIONAL SKILL REQUIREMENTS AERONAUTICAL ENGINEERING CURRICULUM 610/611 Subspecialty Codes XX71P and XX72P

Officers completing the educational skill requirements for this curriculum are qualified to receive an XX71P or XX72P subspecialty code. They consist of a core of prescribed aeronautical engineering skills in nine disciplines, which all graduates must acquire; plus a choice of several specialization options of advanced topics in aircraft structures, aerodynamics, propulsion, flight mechanics, aircraft systems design, electrical engineering and avionics systems design, which the student may pursue as electives. The choice of the specialization options pursued by the student will determine which subspecialty code or if both subspecialty codes can be awarded.

CORE REQUIREMENTS

1. **STRUCTURES AND MATERIALS:** Possess a knowledge of basic structural concepts of stress, strain, and deflections and their interrelationships and be able to analyze beams in simple bending, shafts transmitting torque, thin-walled vessels subjected to internal pressure and buckling of long columns. Possess analytical skills built upon a fundamental understanding of aircraft materials and familiarity with nondestructive means of experimental evaluation, which includes detection of hidden damage and repair of military flight vehicles that might be done up to the depot level.
2. **FLIGHT MECHANICS:** Be able to calculate all performance parameters for both propeller driven and jet powered military aircraft, and to determine their longitudinal and lateral-directional, static and dynamic stability characteristics. Be able to analyze and design aircraft and missile guidance and control systems, including feedback stabilization schemes and stochastic processes, using classical and modern control techniques.
3. **AIRCRAFT AND MISSILE PROPULSION:** Understand the principles and operating characteristics of aircraft and missile propulsion engines and be able to analyze the performance of gas turbines through a knowledge of the behavior and design characteristics of the individual components.
4. **AERODYNAMICS:** Be able to use classical analytic, experimental and modern computational techniques of subsonic and supersonic aerodynamics, including laminar and turbulent boundary-layer viscous effects, with or without heat addition, to calculate internal flow properties through inlets, nozzles and engines and external air flow pressure distributions over wings, canards, tails, and other lifting surfaces to determine the resulting lift, drag and pitching moment.
5. **SYSTEMS DESIGN:** Be able to integrate all of the disciplines of aeronautics into a design of a fixed-wing aircraft, rotary-wing aircraft, engine or an aircraft avionics system in response to a realistic set of military requirements, specifications, constraints and cost limitations. The design must include considerations for safety, reliability, maintainability and survivability.
6. **INFORMATION PROCESSING:** Be able to use current computer methods to solve aeronautical engineering problems and possess knowledge of the application of dedicated avionic and systems computers on board Naval aircraft. Understand the general functional and system architecture of typical military avionics systems, including avionics interfaces.
7. **ENGINEERING MATHEMATICS:** Demonstrate analytic ability to apply differential and integral calculus, ordinary and partial differential equations, complex variables, vector calculus, matrix algebra, probability and statistics and numerical analysis in the development of engineering theory and its application to military engineering problems.

8. STRATEGY AND POLICY: Officers develop a graduate-level ability to think strategically, critically analyze past military campaigns, and apply historical lessons to future joint and combined operations, in order to discern the relationship between a nation's policies and goals and the ways military power may be used to achieve them. Fulfilled by completing the first of the Naval War College course series leading to Service Intermediate-level Professional Military Education (PME) and Phase I Joint PME credit.

9. RESEARCH, DEVELOPMENT, TEST AND EVALUATION: Apply principles of project scoping, planning, design and execution to investigate a current research, development, test or evaluation problem of interest to the Department of Defense that culminates in the publication of a thesis of academic quality.

A-3 Curricula 610/611 and 612 Syllabi

(610/611) Aeronautical Engineering Matrix FALL/SPRING Entry (Eng Science Begins Jul/Jan) Updated: 10 APR 02				
Engineering Science Refresher Quarter - 460				
0 Su/W	AA2042 (3-2) Fund of Thermo & Fluid Dynamics	MA1042 (2-0) Matrix Algebra	MA1118 (5-2) Multi-variable Calculus	ME2601 (4-1) Mechanics of Solids

Core Curriculum

1F/Sp	AA2021 (4-1) Intro to Flight Structures	AA2440 (3-2) Intro to Digital Computation	MA2121 (4-0) Differential Equations	SW3460 (3-1) Software Methodology
2 W/Su	AA2035 (3-2) Aircraft and Helo Aerodynamics	AA2043 (3-2) Fundamentals of Gas Dynamics	MA3243 (4-1) Partial Differential Equations	MA3046 (4-1) Matrix Analysis
3 Sp/F	AA3339 (3-2) Flight Mech I	AA3276 (3-2) Intro to Acft Navigation	AA3641 (3-2) Digital Avionics I	AA3101 (3-2) Flight Vehicle Structural Analysis
4 Su/W	AA3451 (3-2) Acft/Missile Propulsion	AA3802 (3-2) Aero Measurement Techniques	AA3501 (3-2) Aero Analysis	AA3440 (3-2) Acft & Missile Design Tools
5 F/Sp	AA4302 (3-2) Aeromechanics or AA4318 (4-0) Aeroelasticity	AA4340 (3-2) Flight Mech II	AA4342 (3-2) Flight Controls	AA4641 (3-2) Digital Avionics II
6 W/Su	AA4273 or 4306 or AA4451 or 4276 or 4642 Capstone Design (3-2) (Acft, Helo, Engine, Avionics, Digital Avionics) (see note 4)	AA4251 (4-1) Aircraft Combat Survivability, Reliability and Systems Safety Engineering	AA0810 Thesis Research	JPME or Elective
7 Sp/F	AA3202 (3-2) Acft Structural Fatigue	AA0810 Thesis Research	AA0810 Thesis Research	JPME or Elective
8 Su/W	AA4XXX (4-0) Elective	AA0810 Thesis Research	JPME or Elective	JPME or Elective

Notes:

- (1) AA4000 - Required for all quarters but final quarter
- (2) Fall/Winter design sequence: Helo Aeromechanics and Helo Design
- (3) Spr/Summer design sequence: Aeroelasticity and Aircraft Design
- (4) One design course depending on student interest and faculty availability

(612) Test Pilot School Co-op Matrix				
SUMMER/WINTER Entry (Eng Science Begins Apr/Sep) Updated: 9 APR 02				
Engineering Science Refresher Quarter - 460				
0 Sp/F	AA2021 (4-1) Intro to Flight Structures	AA2440 (3-2) Intro to Digital Computation	MA2121 (4-0) Differential Equations	SW3460 (3-1) Software Methodology

Core Curriculum

1 Su/W	AA2035 (3-2) Aircraft and Helo Aerodynamics	AA2043 (3-2) Fundamentals of Gas Dynamics	MA3243 (4-1) Partial Differential Equations	MA3046 (4-1) Matrix Analysis
2 F/Sp	AA3339 (3-2) Flight Mech I	AA3276 (3-2) Intro to Acft Navigation	AA3641 (3-2) Digital Avionics I	AA3101 (3-2) Flight Vehicle Structural Analysis
3 W/Su	AA3451 (3-2) Acft/Missile Propulsion	AA3802 (3-2) Aero Measurement Techniques	AA3501 (3-2) Aero Analysis	AA3440 (3-2) Acft & Missile Design Tools
4 Sp/F	AA4302 (3-2) Aeromechanics or AA4318 (4-0) Aeroelasticity	AA4340 (3-2) Flight Mech II	AA4342 (3-2) Flight Controls	AA4641 (3-2) Digital Avionics II
5 Su/W	AA4273 or 4306 or AA4451 or 4276 or 4642 Capstone Design (3-2) (Acft, Helo, Engine, Avionics, Digital Avionics) (see note 4)	AA4251 (4-1) Aircraft Combat Survivability, Reliability and Systems Safety Engineering	AA3/4XXX (4-0) Aero Elective	ME4300 (3-2) Weaponneering

NFO Program additional quarter

6 F/Sp	AA3202 (3-2) Acft Structural Fatigue	AA3/4XXX (4-0) Aero Elective	MN3331 (5-1) Sys Acq and Prog Mgmt	Elective
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Notes:

- (1) AA4000 - Required for all quarters but final quarter
- (2) Fall/Winter design sequence: Helo Aeromechanics and Helo Design
- (3) Spr/Summer design sequence: Aeroelasticity and Aircraft Design
- (4) One design course depending on student interest and faculty availability

A-4 Avionics Course Descriptions

AA2440 INTRODUCTION TO DIGITAL COMPUTATION (3 - 2)

Introduction to system operations and program development on the department UNIX workstations and the NPS computer facilities. High-level programming languages, including C, MATLAB, and FORTRAN. Development of computer programs, subroutine organization, input and output. Applications of programming techniques to the solution of selected problems in engineering.

SW3460 SOFTWARE METHODOLOGY (3-1)

This course is designed to teach students the basic concepts of software engineering and methods for requirements definition, design and testing of software. Specific topics include introduction to the software life cycle, basic concepts and principles of software engineering, object-oriented methods for requirements analysis, software design and development.

AA3276 INTRODUCTION TO AIRCRAFT NAVIGATION (3 - 2)

This course will introduce the students to the general functional and system architecture of a typical avionics system as well as that of a typical navigation system. It then proceeds to discuss examples of several inertial sensors. This is followed by the introduction of typical coordinate systems used for aircraft navigation and derivation of inertial, north-slaved and wander azimuth mechanizations. The course covers navigation using navigation aids such as LORAN, TACAN, and GPS. Finally, students are introduced to Extended Kalman filtering as a way to integrate inertial and NAVAID sensors.

AA3641 DIGITAL AVIONICS I (3 - 2)

An introduction to digital technology with emphasis on avionics applications. Topics include avionics architectures, binary number systems and data representation, an introduction to digital circuit design, I/O systems, and communication methods used in avionics systems including MIL-STD-1553.

AA4641 DIGITAL AVIONICS II (3 - 2)

This course covers microprocessor technology and embedded computer system design as applied to modern military avionics systems. Laboratory projects are used to provide experience with both software and hardware aspects of system integration. Current topics in digital avionics systems will be covered.

AA4276 AVIONICS SYSTEM DESIGN (3 - 2)

This course will take students through each stage involved in the design, modeling and testing of a core avionics system, i.e., guidance, navigation and control (GNC) systems. Students will be asked to choose an airplane, model its dynamics on a nonlinear simulation package such as SIMULINK and then design a GNC system for this airplane. The complete design is to be tested on SIMULINK. Course notes and labs will cover all the relevant material.

AA4642 DIGITAL AVIONICS DESIGN (3 - 2)

A design-project oriented course, utilizing microprocessor technology with emphasis on aeronautical engineering applications. Both software and hardware aspects of system integration will be considered for engineering tradeoffs during problem definition and solution.

Appendix B: Ohio University Course Descriptions

EE 541 ANTENNAS

Fundamental concepts and definitions, radiation integrals and potentials functions, linear wire antennas, loops, arrays, matching techniques, antenna measurements, laboratory demonstrations.

EE 570 COMMUNICATION ENGINEERING

Unified approach to communications stressing principles common to all transmission systems. Review of Fourier series. Fourier integral and complex frequency techniques with emphasis on communication networks, time response and convolution, measurement of information, amplitude modulation (double and single sideband techniques), frequency modulation, sampling theory, pulse modulation systems, with emphasis on modern digital signaling techniques including PCM, DPCM, PAM, PDM, PPM, and DELTA modulation; fundamentals of random signal theory and its application to communication systems; noise figure, noise suppression techniques, and other related topics.

EE 571 STOCHASTIC PROCESSES IN ELECTRICAL ENGINEERING

Brief review of probability concepts, including densities, moments, etc. Random process fundamentals (ensembles and realizations), stationarity concepts, 2nd-order statistics, Gaussian processes, random signal through linear systems, Markov chains.

EE 585 ELECTRONIC NAVIGATION SYSTEMS I

Principles and theory of operation of electronic navigation systems with emphasis on avionics; aircraft instrumentation, VOR DME, Inertial, Omega, LORAN, ILS, MLS, TRANSIT, GPS, air traffic control, and radar.

EE 586 ELECTRONIC NAVIGATION SYSTEMS II

Continuation of 585 focused on current and future avionics systems and aircraft electronics. Design and signal processing in navigation receivers.

EE 587 ELECTRONIC NAVIGATION SYSTEMS III

Continuation of 585 and 586 with emphasis on mathematical modeling of navigation and landing systems, fault tolerant avionics system design and architecture, night testing, and current developments.

EE 601 ELECTROMAGNETIC WAVE PROPAGATION IN ELECTRONIC NAVIGATION SYSTEMS

Electromagnetic principles and propagation of radio waves over the earth surface and through the atmosphere. Topics include groundwaves, skywaves, tropospheric and ionospheric effects, Total Electron Content, group and phase velocity, incident fields, reflection coefficients, Brewster angle, diffraction, scattering, Fresnel Zone.

EE 602 RADAR SYSTEMS

Theory of operation of radar systems. Topics include the radar equation, radar cross-sections, radar altimeter, Air Traffic Control radar, Doppler radar, weather radar, synthetic aperture radar, Mode A/C/S.

EE 603 INERTIAL NAVIGATION SYSTEMS I

Principles of operation of inertial navigation systems. Topics include rigid body kinematics, observation equations, attitude update, earth rate and transport rate, position and velocity updates, initialization, orientation, sensor technology.

EE 604 INERTIAL NAVIGATION SYSTEMS II

Continuation of Inertial Navigation Systems I. Emphasis on error sources and propagation/simulation of errors, including gravity, Schuler period, vertical damping, scale factors, biases, drift, temperature, noise, alignment, initialization, cross-coupling, g-sensitive errors, magnetic field-sensitive errors

EE 605 SATELLITE-BASED NAVIGATION SYSTEMS

Theoretical development of spread spectrum ranging and positioning with space-based transmitters; ephemerides, broadcast signal structure; ranging observables; absolute and relative positioning methodologies; error source characterization and mitigation.

EE 606 INTEGRATED NAVIGATION SYSTEMS

Theoretical development of positioning and navigation with multiple sensors; optimal navigation solutions; the Kalman Filter as an integration tool; fault detection and isolation.

EE 607 NAVIGATION RECEIVER DESIGN

Theoretical development of receiver design with emphasis on spread spectrum ranging; low-noise amplifiers; radio frequency processing; down conversion and intermediate frequency processing; In-phase and quadrature components; analog-to-digital conversion; signal acquisition and tracking.

EE 608 AVIATION STANDARDS, SOFTWARE DESIGN AND CERTIFICATION

Overview of aviation standards including Federal Aviation Regulations, Technical Standard Orders, Advisory Circulars, RTCA documents and ARINC standards. Software design using military and civilian standards, IEEE software standards, software life cycle processes, program design language, documentation, testing, independent test verification, case studies.

EE 610 AEROSPACE CONTROLS

Theory of controls for aerospace applications. Topics include: state-space models, coordinate systems and transformations, Euler angles, quaternions, continuous and discrete feedback systems, Bode plots, aircraft control, aerodynamics, flight path reconstruction, update rate, latency, stability.

Appendix C: McGill University Course Descriptions

MECH 513 CONTROL SYSTEMS- Stability: Lyapunov, Routh-Hurwitz and Nyquist criteria. Root-locus design of feedback control systems. Controller design based on polynomial methods and internal model principle. Frequency-response controller design. State feedback control. Controllability, observability, LQR, full- and reduced-order observer design. Robust control design. Optimization problems in control.

MECH 532 AIRCRAFT PERFORMANCE, STABILITY, AND CONTROL- Aircraft performance criteria such as range, endurance, rate of climb, maximum ceiling for steady and accelerated flight. Landing and take-off distances. Static and dynamic stability in the longitudinal (stick-fixed and stick-free) and coupled lateral and directional modes. Control response for all three modes.

ECSE 411 COMMUNICATIONS SYSTEMS 1- Communication system models; AM and FM modulation, performance of AM and FM systems in noise; sampling, PCM and DPCM techniques; FDM and TDM multiplexing systems; baseband digital transmission over band limited channels, digital modulation and detection techniques; illustrative examples of subscriber loop telephone systems, cable TV systems and broadcasting systems.

ECSE 412 DISCRETE TIME SIGNAL PROCESSING- Discrete-time signals and systems; Fourier and Z-transform analysis techniques, the discrete Fourier transform; elements of FIR and IIR filter design, filter structures; FFT techniques for high speed convolution; quantization effects.

ECSE 451 EM TRANSMISSION AND RADIATION- Microwave transmission through waveguides: impedance matching, microwave devices, filters and resonators; microwave transmission through free space; near and far field behavior of electromagnetic radiators, simple antennas, antenna arrays, practical antenna parameters; the physics of the radio communication channel: reflection, diffraction and scattering and their macroscopic impact (multi-path, fading).

ECSE 502 CONTROL ENGINEERING- No course description available.

ECSE 505 NONLINEAR CONTROL SYSTEMS- Basic ODE formulation of non-linear systems; structural properties; Lyapunov and LaSalle stability theory and nonlinear and multivariable controller design; input-output stability; small gain theorem, conservation, passivity; system linearization, zero and inverse dynamics and regulator design; discontinuous and sliding mode control; applications to deterministic adaptive control.

ECSE 506 STOCHASTIC CONTROL AND DECISION THEORY- Gaussian processes and tail bounds; Bandit problems and optimal policies; Markov decision processes; Dynamic programming and optimal control in discrete time; learning models control from data; the ODE method and stochastic approximation; Q-learning;

Approximate dynamic programming, linear stochastic systems; linear Gaussian systems; linear-quadratic control; system identification and stochastic adaptive control.

ECSE 507 OPTIMIZATION AND OPTIMAL CONTROL-General Introduction to optimization methods including steepest descent, conjugate gradient, Newton algorithms. Generalized matrix inverses and the least squared error problem. Introduction to constrained optimality; convexity and duality; interior point methods. Introduction to dynamic optimization; existence theory, relaxed controls, the Pontryagin Maximum Principle. Sufficiency of the Maximum Principle.

ECSE 510 STOCHASTIC PROCESSES AND SYSTEMS-Basic notions. Linear state space (SS) systems. Least squares estimation and prediction: conditional expectations; Orthogonal Projection Theorem. Kalman filtering; innovations; Riccati equation. ARMA and SS systems. Stationary processes; Wold decomposition; spectral factorization; Weiner filtering. The Weiner process; linear stochastic differential equations; continuous time filtering. Chapman-Kolmogorov, Fokker-Plank equations. Applications.

ECSE 512 DIGITAL SIGNAL PROCESSING I-Review of discrete-time transforms, sampling and quantization, frequency analysis. Structures for IIR and FIR filters, coefficient quantization, roundoff noise. The DFT, its properties, frequency analysis and filtering using DFT methods, the FFT and its implementation. Multirate processing, subsampling and interpolation, oversampling techniques.

ECSE 513 ROBUST CONTROL SYSTEMS-Feedback interconnections of LTI systems; Nominal stability and performance of feedback control systems; Norms of signals and systems; H₂-optimal control; H-infinity-optimal control; Uncertainty modeling for robust control; Robust closed-loop stability and performance; Robust H-infinity control; Robustness check using mu-analysis; Robust controller design via mu-synthesis.

ECSE 521 DIGITAL COMMUNICATIONS I-Modulation: orthogonal and biorthogonal signalling, MPSK, QAM, modulation with memory. Detection: coherent, noncoherent and differentially coherent detection, performance issues and channel capacity, synchronization. Coding: block and convolutional codes, fast Hadamard Transform decoding, Viterbi algorithm, turbo-codes. Bandlimited channels: intersymbol interference, spectral shaping, correlative coding, data estimation and channel equalization.

ECSE 527 OPTICAL ENGINEERING-A structure introduction to modern optical engineering. Topics covered include the propagation of light through space, refraction, diffraction, polarization, lens systems, ray-tracing, aberrations, computer-aided design and optimization techniques, Gaussian beam analysis, micro-optics and computer generated diffractive optical elements. Systems and applications will be stressed throughout.

ECSE 528 TELECOMMUNICATION NETWORK ARCHITECTURE-

Organization of large, highspeed, multiservice telecommunication networks. Connection hierarchies, protocol stacks, transmission formats. Local-area networking: Token Ring and Ethernet. Multiplexing for wide-area transport: performance modelling and analysis, traffic scheduling and shaping. Routing and flow control. Switch architecture: performance criteria, buffer management, routers versus switches and hybrids.

ECSE 529 IMAGE PROCESSING AND COMMUNICATION-Introduction to vision in man and machine; computer vision systems; biological vision systems; biological signal processing; edge detection; spatial- and frequency-domain processing; color. Low-level visual processing in computer vision, psychophysics, and neurobiology, and their similarities and differences.

ECSE 531 REAL TIME SYSTEMS-Real-time engineering applications of computers to on-line control, communication systems and data acquisition. Aspects of hardware, software, interfacing, operating systems, and their integration into a complete system are addressed.

ECSE 532 COMPUTER GRAPHICS-Introduction to computer graphics systems and display devices: raster scan, scan conversion, graphical input and interactive techniques - window environments; display files: graphics languages and data structures: 2D transformations; 3D computer graphics, hidden line removal and shading; graphics system design; applications. Laboratory project involving the preparation and running of graphics programs.

ECSE 545 MICROELECTRONICS TECHNOLOGY-Basic techniques in the fabrication of microelectronic circuits. Four-point probe, alloyed contacts, diffusion processes, ion implantation epitaxy, silicon dioxide, photolithography, selected diffusion and metallization, transistor fabrication, dry etching, monolithic integrated circuits, isolation, mask making, thin and thick film components, MOS gate voltage and integrated circuits.

ECSE 565 INTRODUCTION TO POWER ELECTRONICS-Semiconductor power switches - thyristors, GTO's, bipolar transistors, MOSFET's. Switch mode power amplifiers. Buck and boost principles. Modulation methods -PWM, delta, hysteresis current control. Rectifiers, inverters, choppers.

ECSE 573 MICROWAVE ELECTRONICS-Physical basis of modern microwave devices and circuits. Microwave transistors and tunnel diodes, transferred electron devices, transit time devices and infra red devices. Microwave generation and amplification, microwave FET circuits. Noise and power amplification.

ECSE 596 OPTICAL WAVEGUIDES-An in-depth analysis to guided-wave propagation. Dielectric waveguides (slab, 2D, nonlinear, spatial solitons), optical fibers (modes, dispersion relations, propagation in dispersive, nonlinear fibers, temporal solitons), beam propagation method, coupled mode theory, waveguide devices (couplers,

gratings, etc.). Selection of current research topics of interest (e.g. photonic crystals, optical signal processing, etc.)

COMP 538 PERSON-MACHINE COMMUNICATION-Theory and practice of the design, implementation, and evaluation of human-computer interfaces.

COMP 557 FUNDAMENTALS OF COMPUTER GRAPHICS-No course description available.

Appendix D: Course Descriptions for Avionics Engineering in Pakistan

MATHEMATICS (3 TOTAL CREDITS)

MA-5xx ADVANCED ENGINEERING MATHEMATICS 3-0

System of linear equations: Gauss elimination method, decomposition methods, Jacobi and Gauss Siedal Method. Linearly dependent and independent vectors. Orthogonal vectors. Determination of eigenvalues and eigenvectors. Numerical solutions of non-linear system of equations. Numerical solutions of ordinary differential equations including finite difference methods for linear and non-linear problems Numerical solutions of partial differential equations including elliptic, parabolic and hyperbolic equations.

MICROWAVE ENGINEERING MAJOR (12 TOTAL CREDITS)

EE-5xx ELECTROMAGNETICS 3-0

This is the first course in Electromagnetics (EM) and forms part of a sequence of two courses, which together are intended to develop the ability to analyze and apply the fundamentals of EM fields. The prime objective of this course is to provide an insight into the electromagnetic phenomena, as well as prepare for more advanced subjects in EM theory.

EE-5xx TRANSMISSION LINES AND WAVEGUIDES 3-0

This is the second course in Electromagnetics (EM) and forms part of a sequence of two courses, which together are intended to develop the ability to analyze and apply the fundamentals of EM fields. The prime objective of this course is to provide an insight into wave propagation, reflection and reflection. Transmission Lines & waveguides as well as radiation are covered in sufficient details in this course.

EE-5xx MICROWAVE ENGINEERING 3-0

To introduce students to Wave propagation in unbounded media, Transmission Line and matching techniques, Microwave waveguides and model analysis and Microwave Network analysis and component.

EE-5xx RF AND MICROWAVE CIRCUIT DESIGN 3-0

This course is intended to develop the ability to apply the concepts and phenomenon of EM fields with a focus on Maxwell's equations, wave propagation, transmission lines & wave-guides, and network theory to modern microwave engineering. The primary objective of this course is to provide an insight into basic design ideas and motivations and to develop an understanding of the process of applying the fundamental principals to realize a useful, practical, and creative design.

CONTROLS MAJOR (12 TOTAL CREDITS)

EE-5xx MODERN CONTROL SYSTEMS 3-0

This is the course in modern feedback control systems taught to graduate students.

The course is aimed at building a comprehensive foundation in the analysis and design of control systems using classical and modern techniques. The mathematical models of common components that appear in control systems are developed. The course covers in detail the analysis and design of linear control systems which includes the study of control system characteristics along with important concepts of system stability, sensitivity and steady-state accuracy. Later part of the course covers the analysis and design of control systems by root locus procedures and through various other frequency response methods. An introduction to modern control techniques using the state-space approach rounds off this course.

EE-5xx LINEAR SYSTEMS THEORY 3-0

It is a linear control systems course taught to MS Control System class to Avionics Engineering students. This course is aimed at building a comprehensive foundation for the analysis and design of linear control systems using linear modern control techniques i.e. linear state equations. The course covers system modeling, system responses, control system characteristics, stability analysis. The core material is the theory of time-varying linear systems, in both continuous-and discrete-time.

EE-5xx INTELLIGENT ADAPTIVE CONTROL SYSTEMS 6-0

The aim of this course is to give students an overview of the intelligent adaptive control systems techniques. Specifically, a student will be able to learn the functional operation of a variety of intelligent control techniques. Also, this course will emphasize the understanding of control-theoretic foundations of intelligent control systems. Also, the computer will be utilized for simulation and evaluation of intelligent control systems. Overall, this course is intended to give the students a "hands-on" working knowledge of several of the main techniques of intelligent control.

M.S. THESIS (6 TOTAL CREDITS)

EE-6xx MS THESIS RESEARCH 6-0

Students are required to work on a research topic for their M.S thesis.

MICROWAVE ENGINEERING AND CONTROLS MAJOR (9 TOTAL CREDITS)

EE-5xx WIRELESS COMMUNICATION 3-0

The objective of this course is to introduce mobile radio communication to graduate students. It begins with an introduction to the cellular concepts. The course then covers the large-scale path loss and small-scale fading and multi-path effects in mobile radio propagation. The topics of equalization, diversity, channel coding and speech coding are then covered. In addition, various multiple access techniques for wireless communication and wireless networking are covered. Some of the wireless systems and standards are then taught. In the end, network design and optimization is covered.

EE-5xx DIGITAL SIGNAL PROCESSING 3-0

The students are familiarized with phase issues and optical FIR filter design. The concept of time dependent Fourier transmission is discussed which is followed with cepstral

analysis. Then the students are introduced to two dimensional DSP. The parametric signal modeling is then discussed. They are then introduced with concepts of image enhancement, restoration and coding techniques.

EE-5xx POWER ELECTRONICS 3-0

This is a graduate level course thought to MS Avionics Engineering students. The core material is the theory and analysis of power conversion using power Electronics devices. The course introduces form and functions of modern power electronic converters resonant converters and ac/ac converters. The students are exposed to the problems of modeling and controlling modeling and controlling power electronic systems. Steady state and transient thermal behavior of power electronic systems/devices and their application are considered.

Appendix E: Queensland University of Technology Course Descriptions

EEB130 INTRODUCTION TO AVIONICS-The unit introduces students to Avionics in a non-technical way. It focuses primarily on aviation navigation and provides a basic understanding of avionics. A complete flight system is studied at an introductory level. The unit also gives an overview of the electronics inside an aircraft, the aircraft environment, and flight simulation.

Content

- Air/Spacecraft as a system
- Aircraft Environment (air flow, aircraft behaviour, degrees of freedom)
- Spacecraft Environment (space environment, spacecraft behaviour, degrees of freedom)
- Aircraft Regulations - safety aspects
- Aircraft Instruments (e.g. airspeed, altimeters)
- Aircraft Instrument Landing Systems
- Aircraft/Spacecraft Navigation Equipment
- Area Navigation
- Weather Radar
- Transponder
- Traffic Alert and Collision Avoidance
- Global Positioning Systems
- Flight Control Systems
- Complete Aircraft Electronics System
- Introduction to a computer based flight simulator (depending on availability)

EEB312 ANALOG AND DIGITAL ELECTRONICS-Analogue and digital electronics devices, circuits and systems are the foundation for all electronic systems. This foundation serves all electronics engineering disciplines and also provides a good hardware basis for computer engineering students. The aim of this unit is to provide awareness of the characteristics and operation of discrete semiconductor components, to introduce analogue circuit design and to provide a good grounding in the basic principles of digital design.

Content

Module 1: Analogue Electronics

- Semiconductors - intrinsic semiconductors, doping, drift and diffusion.
- PN junctions- drift and diffusion effects, depletion region, potential barrier.
- Diodes - minority and majority carrier concentrations and currents under forward and reverse voltages, diode equation and small signal model.
- Diode applications - rectification, peak detection.

- Bipolar Transistors - fundamental semiconductor principles of operation.
- Transistor biasing and small signal models.
- Transistor amplifiers - characteristics & signal equivalent circuits of various configurations.
- Junction FET's - principle of operation, characteristics, biasing and amplifiers.
- MOSFET's - principles of operation and characteristics.
- Multistage transistor amplifiers.

Module 2: Digital Electronics

- Binary numbers and arithmetic.
- Logic gates.
- Boolean algebra and logic minimization methods.
- Combinational logic.
- Logic families.
- Mid-semester review and problem solving.
- Sequential logic - asynchronous and synchronous
- Programmable logic devices.
- Interfacing methods.
- Tri-state logic, signal buses and memory.

EEB340 INTRODUCTION TO TELECOMMUNICATIONS-Telecommunications systems and the principles underlying their operations are introduced starting from mathematical preliminaries such as the Fourier series and the Fourier transform. Basic radio receivers and antennas, analogue modulation techniques (AM, SSB, VSB and FM), systems and circuits for generation and demodulation and basic properties of noise and its effects on modulation systems are studied using time and frequency domain analyses.

Content

- Revision of complex numbers and variables
- Classification of signals
- Fourier series expansion of signals
- Complex Fourier series
- Introduction to Fourier transforms and properties\
- Time and frequency domain representations
- Dirac delta function
- Concepts of convolution and correlation
- LTI systems, impulse response and transfer function
- Filters, frequency response and bandwidth
- Introduction to communication systems
- Introduction to basic terminology - source, receiver, channel, message, etc.
- Block diagram of an a communication system
- Amplitude modulation and demodulation- AM-FC, DSB-SC, SSB, VSB
- Frequency and phase modulation and demodulation - narrow band and wide band

- White noise, thermal noise, band limited noise
- Sources of noise in a communication system
- Generation and use of noise
- Noise analysis of AM, FM and PM systems
- The radio spectrum and frequency allocation
- Basic circuitry of transmitters and receivers

EEB412 ADVANCED ELECTRONICS AND EMBEDDED SYSTEMS-The two modules of this unit, Electronics and Embedded Systems, provide a basis for electronic circuit design in general but also in connection with microprocessor systems. Operational amplifiers and comparators for use in signal conditioning and instrumentation amplifiers are presented as well as integrated circuits as building blocks for system design. Students are given a good grounding in the basic principles and practical use of embedded microprocessor/microcontroller systems.

Content

Module 1: Advanced Electronics

- High-frequency equivalent circuits of transistors.
- Transistor amplifier response
- Differential amplifiers
- High frequency equivalent circuits of differential amplifiers
- Operational Amplifiers: Basic theory and characteristics.
- Operational Amplifiers: Basic configurations and applications.
- Comparators and Schmitt Triggers: characteristics and applications.
- Basic Feedback Theory: Configurations, Loop-Gain, Effect on Gain and impedance levels.
- ADC's and DAC's.

Module 2: Embedded Systems

- Fundamentals of embedded microprocessor systems, architectures, buses, and memories
- Parallel data transfer, address decoding, and Centronics interface.
- Synchronous and asynchronous serial data communications
- Software: Instructions, Addressing Modes, and Assembly Language Programming.
- Parallel IO Ports and interfacing.
- Timers and Interrupts.
- Matrix Keypads and Multiplexed Displays.
- Analog interfaces and ADC's.
- Asynchronous and Synchronous Serial Communications Interfaces.
- Interrupt Driven Real Time Systems.

EEB440 CLASSIC SIGNAL PROCESSING-The unit covers the area of Signals in Linear Systems for which a detailed study of Fourier theory applied to analog signals and

to the analysis of linear systems is given. System analysis is presented in time as well as in frequency and various characteristics and relationships in the two domains are discussed. Students are introduced to the classical design of filters such as the Butterworth and Chebyshev type along with a brief exposure to their realization as analog circuits. The sampling theorem and Nyquist criteria are discussed in detail and an introduction to discrete-time signal processing using the z-transform is provided.

Content

- An introduction to signals and systems: continuous-time and discrete-time signals, periodic and aperiodic signals, real and complex signals, energy and power signals, system models.
- System analysis in the time domain: convolution integral, properties of the convolution integral, linear shift-invariant systems, causality and stability of linear systems. Examples of Telecommunication channels, other applications.
- Fourier series & Fourier transform: Fourier series for periodic signals, properties of Fourier coefficients.
- Fourier series & Fourier transform: representation of Fourier coefficients in the frequency domain, the Fourier transform: definitions and properties.
- Fourier series & Fourier transform: Fourier transforms of special functions, applications.
- System analysis in the frequency domain: transfer function, steady-state system response to sinusoidal inputs, ideal filters; Laplace transform, examples of amplitude and frequency modulation.
- Circuits and filters: Butterworth, Chebyshev and Cauer filters.
- Circuits and filters: characteristics and transfer functions; Bode-Plots, and implementation using passive networks.
- Digital processing of analog signals: A/D conversion, sampling, quantising and encoding.
- Digital processing of analog signals: difference equations and digital systems, Z-transform, properties.
- Z-Transform: System analysis using Z-transform.
- Z-Transform: Frequency response, pole-zero plots, stability.
- Review of Unit: summary of fundamental concepts, solving problems from engineering world, relation of content to more advanced units in signal processing.

EEB560 DIGITAL COMMUNICATIONS-Revolutionary developments in the field of Digital Communication Technology have enabled improvement in the characteristics of communication systems in order to meet the performance requirements for transmission of information for private, business and industrial applications. This unit which covers Elements of a Digital Communication System aims at providing the students with an in-depth understanding of the theory and applications of digital communication systems and technology.

Content

- A thorough treatment of the elements of a digital communication system:
- Introduction to Digital Signal Processing
- Information Theory
- Coding Theory
- Base Band Transmission
- Digital Modulation Theory
- Error Control Coding
- Spread Spectrum Communication
- Introduction to Data Communication Networks, Standards and Protocols

EEB640 DIGITAL SIGNAL PROCESSING-The unit comprises the area of Digital Signal Processing and provides students with the fundamentals of discrete-time signal processing, discrete Fourier transform, discrete convolution, digital filters and digital spectral estimation. Examples and applications arising from various disciplines are presented to prepare the student to solve practical problems.

Content

- Introduction to DSP, properties of discrete-time signals and systems, Fourier transform of discrete-time signals (DTFT) and its properties, the Z transform
- Properties of the Z transform, Inverse Z transform, Relationship between Z and DTFT
- Transfer functions, pole-zero plots and their relationship to system properties
- Periodic sequences and convolution, Discrete Fourier series (DFS), The discrete Fourier transform (DFT) definition, Properties of the DFT
- Linear and circular convolution, Relationship between Z transform, DTFT and DFT
- The fast Fourier transform (FFT), FFT algorithms, decimation in time and decimation in frequency
- Fundamentals of filter design - continuous time filters, transformations, FIR filter design by the windowing method
- FIR filter design - frequency sampling, implementation of FIR filters
- IIR filter design - impulse invariant, bilinear transform
- IIR filter design, Digital filter implementations
- Digital Spectral analysis using the FFT

EEB835 NAVIGATION SYSTEMS FOR AIRCRAFT-This unit presents the principles and practices of modern navigation sensors and systems. To be a competent Avionics Engineer, a detailed knowledge of the principles of navigation is mandatory. Navigation is a fundamental building block for all aspects of aerospace projects.

Content

- A thorough treatment of the elements of navigation systems, ground, air and space based.
- Importance of navigation in guidance and control of aircraft including categories of navigation.
- Navigation equations
- Multisensor navigation systems
- Terrestrial radio navigation systems
- Satellite navigation systems
- Inertial navigation
- Doppler and altimeter radar
- Celestial navigation
- Landing systems
- Air traffic management
- Avionics interfaces _ displays, protocols
- Site visits to inspect navigation systems (ground and air based)

EEB941 MODERN SIGNAL PROCESSING-This unit gives a comprehensive introduction to the representation and processing of signals distorted or corrupted by noise, and the systems needed to process them. Techniques for estimating signal parameters for the detection of signals in the presence of noise will be discussed. The methods presented will be tested on real data drawn from different engineering applications, such as wireless communications, biomedical EEG signals and brain models, speech and music synthesis, and radars.

Content

- Introduction to the representation of signals in noise; overview of their practical applications; focus on wireless communications; radar, biomedical signal processing; and speech and audio technology.
- Noise and random signals; stationary and time-varying signals; correlation processing; applications to radar and multi-user signal separation in wireless communications and telephone echo cancellation.
- Power spectral density - relationship with Autocorrelation; cross-power spectral density; application to voice envelope representation; harmonic representation of music signals; solar activity.
- Random signals and linear systems - input-output relationships; time-invariant and time-varying systems, Gaussian random processes; representation of band-pass signals; application to QAM communication system; voice synthesis systems; EEG and brain modelling.
- Optimum filtering and speech enhancement matched filters for radar and sonar; filtering in the presence of white noise, correlation processing, Wiener filters; applications to wireless communications, and preprocessing of EEG signals for ECG and EOG artefacts removal.

- Introduction to parameter estimation and detection of signals in noise.
Applications to communications, radar, signal processing.

EEB760 AEROSPACE RADIO AND RADAR SYSTEMS-Radio and radar systems provide the backbone and arteries of all aerospace and avionics systems. A knowledge of the effects of electromagnetic compatibility and interference and the standards which apply as well as a detailed knowledge of the theory and techniques of ground, air and space based radio and radar systems is essential for all avionics engineers. Radio and radar systems are an integral part of the safe and efficient operation of aircraft movements and must be considered as part of the system as a whole.

Content

Radio

- Transmitters and receivers; all forms of technology in commonplace usage in the AA ndustry.
- Modulation and demodulation common to the AA industry
- Antennae: all the types in common usage. High gain, low gain, steerable, direction finding, phased arrays
- Aircraft mounting systems and the effects of the airframe on multipath and propagation patterns
- Frequency allocation and usage of radio for different purposes, voice, data, navigation. (NOTE that navigation will be covered in depth in another unit - so only the basics are presented here).

Radar

- Transmitters, receivers, signal processing and displays
- Radar antennae, steering and tracking
- Types of radar:
 - air traffic control
 - velocity measurement
 - weather radar
 - synthetic aperture radar
 - satellite earth observation
 - guidance
 - navigation
 - terrain following
 - Pavetack

EEB831 MILITARY COMBAT ELECTRONICS-This unit addresses the following: sound generation propagation and analysis in the military environment; principles and application of lasers to sighting and guidance systems; principles of detection of submarines using magnetometers; infra red propagation and its use in detection and

weapons guidance; ECM/ECCM; sonar processing; laser processing and guidance; radar guidance/sighting; gun sights; weapons control systems; IFF/transponders; command and control; magnetic anomaly detection; tactical navigation systems; infra red. Some ethical, social and moral aspects concerning military systems will be discussed.

Content

- Sound generation propagation and analysis in the maritime environment
- Principles and application of lasers to sighting and guidance systems
- Principles of detection of submarines using magnetometers
- Infra red propagation and its use in detection and weapons guidance
- ECM/ECCM
- SONAR Processing
- LASER Processing and Guidance
- RADAR Guidance/Sighting
- Gun Sights
- Weapons Control Systems
- IFF/Transponders
- Command and Control
- Magnetic Anomaly Detection
- Tactical Navigation Systems
- Infra Red Systems

EEB961 RF AND APPLIED ELECTROMAGNETICS- This unit addresses the following: lumped and distributed microwave and RF circuits, including [y], [t] and [s] parameters; impedance matching techniques; passive and active microwave devices; RF circuit design techniques; microwave and RF measurement techniques; linear antennas and microwave antennas; analysis and synthesis of antenna arrays; specialised antennas and antenna measurements; EMC definition, standards and regulations; test plan; measurements; interference coupling; susceptibility; EMC design techniques, component selection, circuit layouts, grounding, shielding, filters, suppressors, isolation and safety; EMC management; propagation of electromagnetic fields in electrical materials; application of numerical methods.

Content

Electromagnetic Compatibility (EMC)

- EMC definition, standards and regulations
- EMC test plan; measurements of conducted and radiated emissions, susceptibility, and evaluation of results
- Conducted and radiated interference coupling mechanisms - source characteristics and coupling path
- Susceptibility - radiated field, transients, ESD, supply voltage fluctuations
- EMC design techniques for electrical, electronic and avionic applications - circuit

- design, component selection, circuit layouts, grounding, shielding, filters, suppressors, isolation and safety
- EMC management.

Numerical Methods for Electromagnetic Field Analysis

- Propagation of electromagnetic fields into the interior of conductor
- Magnetic materials of electrical equipment
- Numerical techniques for solving electromagnetic field problems
- Basic ideas on which the different numerical methods are based
- Techniques used to establish the model and analyses of the output data
- Application of a numerical analyses software package to a problem.

Appendix F: Georgia Tech Professional Education Course Descriptions

Adaptive Array Radar Processing (RAD-109)

This course provides an in-depth look at adaptive algorithms and architectures that can be applied to any type of sensor array, but the course will primarily emphasize applications to radar. To develop a fundamental basis, overviews of the basics of digital filtering, data-independent beamforming, and spectrum estimation are presented.

Advanced Electronic Warfare Principles (EW-103)

This three and one-half day course contains the most recent developments in electronic warfare (EW) technology. Emphasis is placed on advanced on-board RF countermeasures, including ECM techniques to counter emerging radar threats and the latest technological advances in radar systems.

Antenna Engineering (including cellular, mobile, and portable antennas) (EE-101)

This course presents the theory and practice of antenna engineering, covering the range of antenna properties and types from basic to state-of-the-art.

Basic Airborne Fire Control Systems (RAD-123)

Basic Airborne Fire Control Systems is a course designed to provide students with a practical understanding of the fundamental principles of aircraft fire control systems.

Basic Antenna Concepts (RAD-116)

Basic Antennas Concepts is a course designed to provide students with a practical understanding of the fundamental principles of antennas. It consists of a unique combination of lectures, interactive computer simulations, and laboratory demonstrations that allows the student to obtain a basic understanding of modern antennas.

Basic Engineering Science Principles (ENGR-102)

The objective of the course is to introduce the student to basic applied math, physics, and electromagnetic concepts. Special emphasis will be given to concepts that are assumed to be understood by students attending other courses in this catalog.

Basic RF EW Concepts (EW-101)

The objective of this course is to provide students with a working understanding of the underlying principles of operation of both radar-controlled weapon systems and EW systems designed to counter them, as well as the test and evaluation of these systems.

Basic Radar Concepts (RAD-112)

Basic Radar Concepts is an intensive, but comprehensible, three-day short course in the fundamental principles of modern radar technology. This course assumes no prior knowledge of radar technology and is intended to impart to the student a basic, high-level understanding of today's modern radar technology in simple, easy-to-understand terms.

Design of Experiments (TE-111)

This course presents techniques for planning studies where the inputs to a system/process can be varied and the outputs observed. The course includes a "mini design project" involving hands-on experience with a personal computer with a statistical software package (e.g., MINITAB) installed.

Digital Radio Frequency Memory (DRFM) Technology (DE-110)

This 3-day course provides an in depth study of DRFM technology including application of the DRFM to Electronic Attack (EA), also known as Electronic Countermeasures or Radar Jamming.

Directed Infrared Countermeasures: Technology, Modeling, and Testing (TE-103)

The 3-day course reviews the 25 year history of directed infrared countermeasures, provides in-depth review of the threat operation, provides an overview of the supporting technologies, and examines the current DIRCM systems. New material in this course includes the properties of high-power damage mechanisms and future trends in missile warning and laser resonator design.

EMC/EMI for Engineers and Engineering Managers (DE-109)

This 4-day short course (Monday afternoon start and Friday morning finish) presents the fundamental concepts of electromagnetic compatibility (EMC) and electromagnetic interference (EMI). The student will be introduced to the various electromagnetic environments (EME) and the requirements that commercial and military electronic systems must meet.

EO/IR Polarimetric Imaging Systems (IR-107)

The objectives of this course are twofold: a general overview of polarized radiation sensing techniques and; a presentation of the significant technical issues associated with polarimetric imaging. Course content ranges from the phenomenology of material-radiation interactions to an overview of modern polarimetric sensing systems.

Far-Field, Anechoic Chamber, Compact, and Near-Field Antenna Measurements (EE-107)

This course presents the state-of-the-art in antenna measurements, including far-field, anechoic chamber, compact, and near-field measurements. The course also includes Range Evaluation and Compensation Techniques and Microwave Holography

Fundamentals of Airborne Electronic Combat Test and Evaluation (TE-104)

This short course deals with the test and evaluation of airborne electronic combat (EC) systems. The course outline includes such topics as threats and EC defensive systems, the EC test process, test monitoring equipment and test facilities, the role of modeling and analysis, and the effects of signature technology.

Fundamentals of Modeling (MS-106)

Fundamentals of Modeling

Fundamentals of Radar Signal Processing (RAD-102)

This intensive short course focuses on signal processing areas of special interest to radar applications. The topics are organized into four basic sections, generally following the flow of signals through a typical radar signal processor

Fundamentals of Synthetic Aperture Radar Signal Processing (RAD-110)

Substantially updated for 2003, this 3.5 day course provides engineers and scientists with a comprehensive introduction to modern synthetic aperture radar signal processing techniques. After establishing an intuitive understanding of the SAR principle, the course covers a wide range of modern SAR processing topics, including advanced 2D and 3D image formation algorithms, GMTI and SAR, super-resolution, calibration, and processor sizing.

Guidance, Navigation, and Control (DE-101)

This course provides the background for understanding modern Guidance, Navigation, and Control (GNC) systems. The course will describe the principles of Inertial Navigation Systems (INS), how INS errors arise and grow with time, and how other navigation systems (e.g., GPS) are integrated with an INS.

Infrared Countermeasures (IR-102)

This course is intended to provide a technical perspective for engineers, scientists, technicians, managers, sales, and operations personnel who need to understand the more specialized and often classified working principles of countermeasure techniques, threat counter-countermeasure methods, and their effectiveness.

Infrared Technology and Applications (IR-101)

This course is an introductory tutorial on Infrared Systems Engineering. The overall objective is to describe the operating principles of infrared systems, with emphasis on military systems. In pursuit of this objective, the course addresses the performance limitations of present IR systems, issues pacing the development of new systems, and key component technologies.

Infrared/Visible Signature Suppression (IR-103)

This course is intended for anyone needing specialized knowledge of low observable techniques. This includes platform designers, systems analysts, developers, and procurement decision makers.

Introduction to Radar Cross Section (RAD-125)

Radar Cross Section is a topic that has had much publicity in the last several decades and has been under development for over forty years. RCS reduction and control is now a standard design discipline, however, it is a topic that is often shrouded in mystery and poorly understood. The objectives of this course are to present topics from the book Radar Cross Section with emphasis on physical principles rather than mathematical detail.

Military Laser Principles and Applications (IR-105)

This course presents a review of the basic operating and design principles underlying laser-based military devices. The major objectives of this course include a description of the operating principles of lasers with an emphasis on military systems and an overview of important technical issues associated with designing systems incorporating lasers.

Modeling and Simulation in Electro-Optical and Infrared (EO/IR) Systems (MS-105)

The course covers modeling and simulation of electromagnetic waves; basic M&S of EO/IR physics principles; modeling of EO/IR systems and components, and phenomenology (targets, clutter, and propagation); and scenario development.

Modeling and Simulation in Radar Systems (MS-103)

The course covers modeling and simulation of electromagnetic waves; basic M&S using the Radar Equation; modeling of radar system components, coherent and non-coherent systems, radar functions, and phenomenology (targets, clutter, and propagation); and scenario development.

Modeling and Simulation of RF Electronic Warfare (EW) Systems (MS-104)

The course covers modeling and simulation of RF systems; basic M&S using the Radar Equation; modeling of EW/EA/EP system components; coherent and non-coherent systems; EW functions; phenomenology (targets, clutter, and propagation); and scenario development.

Phased Array Antennas and Adaptive Techniques (RAD-122)

This five-day course presents an in-depth look at the hardware and software which comprise state-of-the-art adaptive phased array systems. The objective is to present the student with the diverse spectrum of technologies and algorithms available and to show how they fit together into a design.

Phased Array Antennas for Radar and Communications (RAD-113)

This course is designed for anyone interested in becoming familiar with phased array antenna theory, design practices, and state-of-the-art technologies.

Phased Array Radar Systems (RAD-105)

This course addresses modern phased-array radar systems at two levels. An overview of phased-array radar system requirements and operation, reinforced by application examples, is presented to provide the system engineering context. Then, the major subsystems and associated technologies are described by specialists in those areas.

Principles of Continuous Wave (CW) Radar (RAD-108)

Engineers, scientists, technicians and managers interested in CW radar theory, applications, and trade-offs relative to other wide bandwidth radar waveforms will benefit from this course. Familiarity with basic radar concepts is desirable. However, there will be an initial review of radar fundamentals. A notebook of the presentation slides will be provided.

Principles of Imaging and High Resolution Radar (RAD-115)

This course provides an in-depth look at the basic principles and techniques applied in achieving enhanced resolution in three dimensions range, angle/cross-range, and Doppler. The course seeks to answer the question "What is resolution?" and to discuss techniques for achieving it.

Principles of Modern Radar (RAD-101)

This comprehensive course covers radar principles, systems, techniques, technology, and phenomenology. The course content ranges from a basic introduction of radar technology to up-to-date examples of modern radar systems and applications. The course includes lectures and demonstrations illustrating the salient principles of modern radar.

Principles of Pulse-Doppler Radar (RAD-104)

After laying a foundation of basic principles, this course will emphasize medium PRF and other topics not discussed in the more widely-used radar textbooks. Attendees will be guided through the conceptual design rationale for establishing the radar characteristics, such as PRF, antenna scan rate, number of pulses processed, etc., that are necessary to meet an overall system probability of detection requirement.

Principles of Radar Electronic Protection (EP) (EW-102)

This 4-day course presents the fundamental concepts of radar EP, also referred to as electronic counter-countermeasures (ECCM). The course provides an overview of essential radar electronic warfare (EW) principles, a summary of current EA threats, and a description of over 60 EP techniques from both theoretical and practical perspectives.

Principles of Radar Target Identification (RAD-106)

Principles of Radar Target Identification is an intensive 4-day short course in the basic fundamental principles of radar detection, discrimination, and recognition of both moving and stationary targets in varied clutter backgrounds.

Principles of Software Radio (DE-112)

This 3-day short course is designed to provide students with an introduction to the fundamental concepts and principles of software radio. The course consists of a combination of lectures and demonstrations. The curriculum includes introductory material that defines basic terminology and concepts, examines the history of military and commercial drivers that have spurred development of software radio, and introduces software radio software and hardware architectures.

RF and Wireless Engineering (EE-180)

This intensive 4 1/2-day course is designed to give electrical engineers the specialized training that they need to achieve competence in RF and wireless engineering. The emphasis of the course is on "learning by doing," with numerous design examples presented throughout the course.

RF/Wireless Packaging: Fundamentals, Principles, and Current Challenges (EE-254)

This course reviews the fundamentals of RF/Wireless Packaging definitions and mechanisms, and discusses the use of S-parameters and the nature of parasitic coupling, radiation and loss factors in common packaging geometries.

RF/Wireless Principles and Practice (EE-193)

The course first reviews the principles of analog/digital communication systems and then examines the design of the principal blocks that make up typical communication systems. Techniques important in the design of radio receivers, frequency synthesizers, and power amplifiers are presented.

Radar Cross Section Reduction (RAD-107)

This course is an introduction for engineers and managers who may have only a casual knowledge of radar echo characteristics and how these characteristics may be controlled or modified. More emphasis is given to the principles of RCSR and basic concepts than to the details of specific applications.

Radar Performance: Principles and Limitations (RAD-103)

This intensive 4-day course presents an overview of the operation of coherent radar systems, with several diverse applications, and an understanding of the performance limitations relative to the ideal system.

Signal Processing Refresher (RAD-126)

Signal Processing Refresher

Space-Time Adaptive Processing: Application to Radar (RAD-124)

This course provides in-depth discussion on the application of space-time adaptive processing (STAP) to radar. The course commences with a review of radar and digital signal processing fundamentals, thereby providing the necessary background for the remainder of the course.

Synthetic Aperture Radar (SAR) Image Formation Processing (RAD-119)

The objective of the SAR Image Formation Processing course is to provide the student with an in depth study of SAR signal processing techniques and system-level design requirements.

Target Tracking Concepts (RAD-120)

This course is for engineers and managers who are currently engaged or expect to be engaged in the specification, procurement, design and development, testing, and operation of target tracking systems.

Target Tracking in Sensor Systems (RAD-117)

This three and one-half day course presents the fundamentals of target tracking and overviews the principles of the sensor systems for which target tracking algorithms are implemented. Emphasis is placed on the concepts associated with target tracking, basic mathematics used in target tracking, and the operations of the more common sensor systems.

Test and Evaluation Using Modeling and Simulation (TE-107)

This course is intended as an introduction to M&S applications to T&E for technical and management personnel. It provides an overview of the broad range M&S applications by examples from many T&E programs. Upon completion of this course, the student should understand the range of M&S applications to T&E, how to select and accredit M&S for T&E application, and where to find resources to aid in the process.

Test and Evaluation of Defense Electronic Systems (DE-111)

This intensive course presents an overview of the requirements for testing defense-related electronics systems (Radar, EW, EO/IR, and sonar) and provides detailed descriptions of laboratory and in-situ testing methods for components, sub-assemblies, and assemblies.

Appendix G: Human Subjects Testing Exemption Approvals

G-1 Request for Exemption Letter

G-2 Informed Consent Document

G-3 Exemption Approval Letter

G-1 Request for Exemption Letter

11 Oct 05

MEMORANDUM FOR AFIT/ENG
AFIT/ENY
AFIT/ENR
AFRL/HEH
IN TURN

FROM: Lieutenant Colonel Thomas W. Hofer, USMC, AFIT/ENY/GAE-06M

SUBJECT: Request for Exemption from Human Experimentation Requirements (AFI 40-402): Thesis Research, AFIT/ENG, Title "DEVELOPMENT OF A COMPREHENSIVE DIGITAL AVIONICS CURRICULUM FOR THE AERONAUTICAL ENGINEER."

1. Request exemption from Human Experimentation Requirements of AFI 40-402 for the proposed Delphi technique survey to be conducted in conjunction with thesis research at the Air Force Institute of Technology. Purpose of this study is to utilize a panel of Subject Matter Experts in the field of avionics to provide input for formulating a comprehensive avionics curriculum at AFIT. A Delphi technique utilizing iterative surveys will be used to establish a group consensus of what areas of avionics should be studied in a graduate level avionics course and what attributes are most important for an engineer in the avionics field. The results of this study will assist in the formulation of the recommended avionics curriculum for an aeronautical engineer.

2. This request is based on the Code of Federal Regulations, title 32, part 219, section 101, paragraph (b) (3); Research activities that involve the use of educational tests (cognitive, diagnostic, aptitude, achievement), survey procedures, interview procedures, or observation of public behavior that is not exempt under paragraph (2) of this section will be exempt if (i) the human subjects are elected or appointed public officials or candidates for public office, or (ii) Federal statute(s) require(s) without exception that the confidentiality of the personally identifiable information will be maintained throughout the research and thereafter.

Methodology used to collect information for the thesis research is based on Delphi Technique survey procedures. The following information is provided to show cause for such an exemption:

2.1. Equipment and facilities: No special equipment or facilities will be used.

2.2. Subjects: Subjects will be Subject Matter Experts in the field of avionics from academe, industry, and the military. All subjects will have significant

experience in the field of avionics in order to qualify them as experts. Subjects will not be aware of the identity of other subjects taking part in the survey.

2.3. Timeframe: Data will be collected between October 2005 and March 2006. Analysis of data and publication of findings will take place in March 2006.

2.4. Description of the survey: The survey will be based upon the proven Delphi Technique. The Delphi Technique uses an iterative set of surveys to solicit a group consensus from a group of experts who are geographically isolated from one another. Round one of the survey will ask open-ended questions in order to allow for maximum varied inputs. The inputs will be analyzed and collated to construct the survey for follow-on rounds. The results of the second survey round will be analyzed and group results will be sent back out to the subject group along with a third survey. The subjects will have the opportunity to either change their inputs during the third round or keep them the same as the first round. The iterative process will continue until a group consensus is reached or minimal change is seen in the inputs. The planned survey for the first round is attached for review. A sample survey for the second through final rounds is also attached for review. The actual surveys will differ slightly based upon the previous round's inputs.

2.5. Data collected: The identity of each respondent will be coded to a number and responses will be connected only to the coded numbers, not to the subject's full name. The connected responses and corresponding identity code will be recorded in order to administratively track submissions and changes in rankings. All identifying data, coded identity numbers, and subject responses will be available only to the primary and assistant investigator and will be safeguarded. Data will be stored on an external mass storage device under password protection. Data will not be stored on network computers. Only analyzed group data with no identifying data will be distributed back to the subject group as part of the Delphi Technique process. Upon completion of the survey process, the collected data will be published collectively, not individually, and deleted using electronic means.

2.6. Informed consent: All subjects are self-selected to volunteer to participate in the survey. No adverse action is taken against those who choose not to participate. Subjects are made aware of the nature and purpose of the research, sponsors of the research, and disposition of the survey results. A copy of the Privacy Act Statement of 1974 is presented for their review. A copy of the informed consent form that will accompany the survey is attached for review.

2.7. Risks to Subjects: Individual responses of the subjects will not be disclosed. This eliminates any risks to the subjects as noted in paragraph 2. There are no anticipated medical risks associated with this study.

3. If you have any questions about this request, please contact Dr. Guna Seetharaman (primary investigator) – Phone 785-3636 x. 4612; E-mail – Guna.Seetharaman@afit.edu or Lieutenant Colonel Thomas Hofer (associate investigator)- Phone (937) 232-0933; E-mail – Thomas. Hofer@afit.edu.

THOMAS W. HOFER, LtCol, USMC
Graduate Student, AFIT/ENY/GAE-06M

GUNA S. SEETHARAMAN, PhD.
Faculty Advisor, AFIT/ENC

Attachment:
Informed Consent Document

G-2 Informed Consent Document

INFORMATION PROTECTED BY THE PRIVACY ACT OF 1974

Informed Consent Document

For

DEVELOPMENT OF A COMPREHENSIVE DIGITAL AVIONICS CURRICULUM FOR THE AERONAUTICAL ENGINEER

Air Force Institute of Technology/ENG, Wright-Patterson AFB, OH

Principal Investigator: Dr. Guna S. Seetharaman, 785-3636 ext. 4612, AFIT/ENG
Guna.Seetharaman@afit.edu

Associate Investigator: LtCol Thomas W. Hofer, 937-232-0933, AFIT/ENY
Thomas.Hofer@afit.edu

1. **Nature and purpose:** You have been offered the opportunity and have volunteered to participate in the “Development of a Comprehensive Digital Avionics Curriculum for the Aeronautical Engineer” research study. Your participation will occur sometime between 15 October 2005 and 28 February 2006. Participation will occur via electronic mail.

The purpose of this research is to solicit Subject Matter Expert advice for the construction of a comprehensive digital avionics curriculum within the aeronautical engineering department at the Air Force Institute of Technology (AFIT).

The time requirement for each volunteer subject is anticipated to be a total of 4 surveys of approximately 15 minutes each. A total of approximately 25 subjects will be enrolled in this study.

2. **Experimental procedures:** If you decide to participate, you will be asked as part of a group of subjects to fill out and submit a survey via electronic mail. Group members will be geographically separated from one another and unknown to one another. Results of the individual surveys will be analyzed in order to construct the survey for the follow-on round. The group results, but not the individual results, will accompany the second round survey. Subjects will complete the second round survey and submit it via electronic mail. This iterative process will continue until little change in inputs is seen between successive rounds. Upon completion of the survey process, the collected data will be published collectively, not individually, and deleted using electronic means.
3. **Discomfort and risks:** No discomfort or risks are anticipated.

4. **Benefits:** You are not expected to benefit directly from participation in this research study. However, the field of avionics is expected to benefit due to AFIT graduates being better prepared for a profession in the field of avionics.
5. **Alternatives:** Choosing not to participate is an alternative to volunteering for this study.
6. **Entitlements and confidentiality:**
 - a. Records of your participation in this study may only be disclosed according to federal law, including the Federal Privacy Act, 5 U.S.C. 552a, and its implementing regulations. A copy of the Privacy Act is shown below for your inspection.
 - b. The decision to participate in this research is completely voluntary on your part. No one has coerced or intimidated you into participating in this program. You are participating because you want to. You understand that Lieutenant Colonel Thomas W. Hofer will be available to answer any questions concerning procedures throughout this study. You further understand that you may withdraw at any time and discontinue further participation in this study without prejudice to your entitlements. If you have any questions or concerns about your participation in this study or your rights as a research subject, please contact Lieutenant Colonel Thomas W. Hofer at (937) 232-0933 or Thomas.Hofer@afit.edu.

Privacy Act Statement

Authority: We are requesting disclosure of personal information, to include your Social Security Number. Researchers are authorized to collect personal information (including social security numbers) on research subjects under The Privacy Act-5 USC 552a, 10 USC 55, 10 USC 8013, 32 CFR 219, 45 CFR Part 46, and EO 9397, November 1943.

Purpose: It is possible that latent risks or injuries inherent in this experiment will not be discovered until some time in the future. The purpose of collecting this information is to aid researchers in locating you at a future date if further disclosures are appropriate.

Routine Uses: Information (including name and SSN) may be furnished to Federal, State and local agencies for any uses published by the Air Force in the Federal Register, 52 FR 16431, to include, furtherance of the research involved with this study and to provide medical care.

Disclosure: Disclosure of the requested information is voluntary. No adverse action whatsoever will be taken against you, and no privilege will be denied you based on the fact you do not disclose this information. However, your participation in this study may be impacted by a refusal to provide this information.

G-3: Exemption Approval Letter



DEPARTMENT OF THE AIR FORCE
AIR FORCE MATERIEL COMMAND
WRIGHT-PATTERSON AIR FORCE BASE OHIO


21 October 2005

MEMORANDUM FOR: Lt Col Thomas W. Hoffer
AFIT/ENV

FROM: AFRL/Wright Site Institutional Review Board

SUBJECT: Request for exemption from human experimentation requirements

1. Protocol title: Development of a Comprehensive Digital Avionics Curriculum for the Aeronautical Engineer
2. Protocol number: F-WR-2006-0003-E
3. The above protocol has been reviewed by the AFRL Wright Site IRB and determined to be **exempt** from IRB oversight and human subject research requirements per 32 CFR 219.101(b)(2) which exempts "research involving the use of educational tests (cognitive, diagnostic, aptitude, achievement), survey procedures, interview procedures or observation of public behavior."
4. The IRB must be notified if there is any change to the design or procedures of the research to be conducted. Otherwise, no further action is required.
5. For questions or concerns, please contact the IRB administrator, Helen Jennings at (937) 255-0311 x232 or helen.jennings@wpafb.af.mil. All inquiries and correspondence concerning this protocol should include the protocol number and name of the primary investigator.


JEFFREY BIDINGER, Maj, USAF, MC, FS
Chair, AFRL/Wright Site IRB

Appendix H: SME Panel Invitation Email Letter

TO: <Subject>

FROM: LtCol Thomas W. Hofer, USMC

SUBJ: Participation in Thesis Study

Dear <Subject>,

My name is Lieutenant Colonel Thomas W. Hofer, USMC. I am currently a student at the Air Force Institute of Technology (AFIT) at Wright-Patterson AFB working on a Masters Degree in Aeronautical Engineering. As part of my degree, I have chosen to focus on the field of digital avionics within the realm of aeronautical engineering. Specifically, my thesis is entitled "Development of a Comprehensive Digital Avionics Curriculum for the Aeronautical Engineer." One portion of my research uses the Delphi method to solicit inputs from Subject Matter Experts (SME) in the field of avionics. Due to your experience and reputation in the field of avionics, you have been recommended to sit as a member of the SME panel.

I hope you can find time in your busy schedule to assist me in this endeavor. While I cannot offer any monetary compensation for your time, your inputs will assist in developing aeronautical engineers more suited to tackle the challenges they will face upon completion of their degree. I can assure you that all information provided to me as the researcher will be kept confidential, known only to me and my thesis advisor, Dr. Guna Seetharaman. The procedures and protocol that will be followed throughout this study are clearly delineated in the attached Informed Consent Document (ICD). If after reading the ICD, you decline to participate in the study, please inform me of your decision via email. I fully realize that your busy schedule may not permit your involvement. If after reading the ICD, you decide to assist me in the study, please complete the attached initial round survey and return it to me via email within 7 calendar days. The short return timeline is necessary in order for me to complete the entire thesis project in time for graduation in March of 2006.

Thank you for your consideration. Please contact me at the below email address or phone numbers if you have any questions.

Sincerely,
LtCol Tom "Burglar" Hofer, USMC
Air Force Institute of Technology
Aeronautical Engineering Student
937-643-2623 Home
937-232-0933 Cell
Thomas.Hofer@afit.edu

Appendix I: Subject Matter Expert Panel Membership

1. Airborne Systems Instructor, U.S. Naval Test Pilot School
GS-14, Commander, USN (retired)
PhD, 35 years experience
2. Consultant and IEEE AESS Board of Governors Member
Colonel, USAF (retired)
MS, 30 years experience
3. President, AvioniCon Inc.
GS-14 (retired)
MS, 29 years experience
4. Engineering Research Psychologist, AF Research Lab Human Effectiveness Branch
DR-II
PhD, 8 years experience
5. Lead Systems Engineer, MITRE Corporation
Colonel, USAF (retired)
MAS, 30 years experience
6. Director, Avionics Engineering Center, Ohio University
PhD, 27 years experience
7. Engineering Manager, Rockwell Collins
PhD, 8 years experience
8. Systems Master Instructor, U.S. Air Force Test Pilot School
NH-III
BSME, 20 years experience
9. Aircraft Material and Engineering Manager, Naval Air Forces Atlantic
Commander, USN
MS, 13 years experience
10. Test Pilot, U.S. Air Force Test Pilot School
Major, USAF
BS, 12 years experience

11. Flight Test Engineer, 31st Test and Evaluation Squadron
Captain, USAF
PhD, 1 year experience
12. Assistant Program Manager, EA-6B Avionics, Naval Air Systems Command
Lieutenant Colonel, USMC
BS, 3 years experience
13. Director of Engineering, 31st Test and Evaluation Squadron
Lieutenant Colonel, USAF
PhD, 16 years experience
14. President, Strategic Aeronautics Inc.
Lieutenant Colonel, USMC (retired)
MS, 20 years experience
15. Senior Systems Engineer, American Systems Corporation
Lieutenant Colonel, USAF (retired)
MS, 30 years experience
16. Chairman, Airlines Electronic Engineering Committee, ARINC
ARINC Fellow
BS, 15 years experience
17. Professor of Aerospace Engineering, U.S. Naval Academy
Captain, USN
PhD, 20 years experience
18. Avionics Flight Test Engineer, 419th Flight Test Squadron
NH-III
BS, 23 years experience
19. EA-6B Test Project Coordinator, Naval Air Test and Evaluation Squadron 23
GS-13, Major, USMCR (retired)
MS, 12 years experience
20. Professor of Telecommunications, University of Rome Tor Vergata
MS, 22 years experience
21. Airborne Systems Instructor, U.S. Naval Test Pilot School
GS-13
MS, 19 years experience

22. President, Strategic Systems Solutions Inc.
MS, 45 years experience
23. Astronaut (Pilot), National Aeronautics and Space Administration (NASA)
Lieutenant Colonel, USMC
MS, 15 years experience
24. B-52 Operational Test Pilot, 31st Test and Evaluation Squadron
Major, USAF
BS, 6 years experience
25. Avionics Military Director, Naval Air Systems Command
Captain, USN
MS, 5 years experience
26. Test Pilot, The Boeing Company
Major, USMCR
MS, 8 years experience
27. Military Flight Operations Quality Assurance Lead, Naval Air Systems Command
Commander, USN
MS, 10 years experience
28. Astronaut (Pilot), National Aeronautics and Space Administration (NASA)
Lieutenant Colonel, USMC
BS, 15 years experience

Appendix J: Delphi Round 1 Survey

This survey is being conducted by as part of an academic thesis at the Air Force Institute of Technology (AFIT). Inputs will be used to develop a recommended curriculum for digital avionics within the Aeronautical Engineering Department at AFIT.

Subject Background Information

Submission of all background information is optional. Information will be used to establish Subject Matter Expert (SME) status of subject. Information will be coded for tracking, but not connected to individual responses. Please write “anonymous” on the name line if you are unwilling to provide background information.

Name:

Rank/Grade (if government employee):

Current professional position:

Highest level of education achieved (BS, MS, PhD):

Years of experience in avionics field:

Curriculum starting assumptions:

- a. Curriculum will be a joint effort between the Aeronautical Engineering Department and the Electrical and Computer Engineering Department. Instructors will be available from both Departments to teach necessary classes or specific modules of classes.
- b. Emphasis will be on top-level knowledge of systems that comprise an avionics suite in a modern military and/or civilian aircraft. Internal workings of individual boxes at the electrical engineering level are not required.
- c. Majority of students (75-90%) will fulfill Test and Evaluation and/or Program Management positions of developing avionics systems upon completion of the curriculum. Positions will be within the Department of Defense (DOD).

Questions may be left blank if you feel that you possess insignificant expertise in the area to render an informed opinion.

1. What attributes are the most important for a newly hired test engineer to possess?

2. What attributes are the most important for a newly assigned test Aircrew (Pilot/NFO/Navigator) to possess?

3. What attributes are the most important for a test engineer with 5 years of experience to possess?

4. What attributes are the most important for an engineer with program management responsibilities to possess?

5. What areas of study should be included in an avionics curriculum within an aeronautical engineering Masters of Science degree program?

Appendix K: Delphi Round 2 Survey

This survey is being conducted by as part of an academic thesis at the Air Force Institute of Technology (AFIT). Inputs will be used to develop a recommended curriculum for the digital avionics sequence within the Aeronautical Engineering Department at AFIT.

Curriculum starting assumptions:

- a. Curriculum will be a joint effort between the Aeronautical Engineering Department and the Electrical and Computer Engineering Department. Instructors will be available from both Departments to teach necessary classes or specific modules of classes.
- b. Emphasis will be on top-level knowledge of systems that comprise an avionics suite in a modern military and/or civilian aircraft. Internal workings of individual boxes at the electrical engineering level are not required. However, Input/Output requirements are included within top-level knowledge of systems.
- c. Majority of students (75-90%) will fulfill Test and Evaluation and/or Program Management positions of developing avionics systems upon completion of the curriculum. Positions will be within the Department of Defense (DOD).

Questions may be left blank if you feel that you possess insignificant expertise in the area to render an informed opinion.

A. Using the following scale, please assign a number 1-5 to each **ATTRIBUTE** that a graduate of an engineering graduate-level curriculum should possess. An **ATTRIBUTE** is defined as “a quality, characteristic, or trait displayed by a person.”

- 1 Not required
- 2 Somewhat desirable
- 3 Desirable
- 4 Highly desirable
- 5 Essential

_____ Initiative
_____ Desire for Lifelong Learning
_____ Problem-solving Skills
_____ Communication Skills (Written & Verbal)

_____ Time/Resource Management Skills
_____ Critical-Thinking Skills
_____ Adaptability/Flexibility

_____ Strong Engineering
Fundamentals

_____ Team Player

_____ Leadership

_____ Creativity

_____ Perseverance

_____ Enthusiastic

_____ Ethical

_____ Loyal

_____ Disciplined

_____ Reliable

_____ Strong Computer Skills

_____ Willing to Take Risks

_____ Curious

_____ Professional

CONTINUE TO NEXT PAGE

B. Using the following scale, please assign a number 1-5 to the level of proficiency at which each **AREA of STUDY** should be taught in an avionics curriculum **within an aeronautical engineering graduate program**.

- 1 Not required for an Aeronautical Engineer
- 2 To have been experienced or exposed to
- 3 To be able to understand and explain
- 4 To be skilled in the practice or implementation of
- 5 To be able to lead or innovate in

_____ Systems Engineering/Integration	_____ Electromagnetic Theory
_____ Software Engineering	_____ Military and Civilian Standards
_____ Digital Electronics	_____ Net-Centric Operations
_____ Computer Programming	_____ National Airspace Requirements (ATC)
_____ Control Theory (guidance)	_____ DoD Acquisition Process
_____ Digital Signal Processing	_____ Embedded Computing
_____ Digital Communication	_____ Low Observable (LO) Requirements
_____ Radar	_____ Stores Management
_____ Electro-Optical	_____ Antennas and Apertures
_____ Navigational Theory and Systems	_____ Statistics
_____ Bus Architecture	_____ Power, Cooling, Weight, Space Requirements
_____ Controls and Displays (Human Factors)	_____ Optimization Theory
_____ Cost/Benefit Analysis	_____ Program Management
_____ Electronic Warfare	_____ Reliability
_____ Test and Evaluation	_____ Current Systems (F/A-22, F-35)
_____ Modeling and Simulation	_____ Maintenance Support Structure

Appendix L: Delphi Round 3 Survey

This survey is being conducted by as part of an academic thesis at the Air Force Institute of Technology (AFIT). Inputs will be used to develop a recommended curriculum for the digital avionics sequence within the Aeronautical Engineering Department at AFIT.

Curriculum starting assumptions:

- a. Curriculum will be a joint effort between the Aeronautical Engineering Department and the Electrical and Computer Engineering Department. Instructors will be available from both Departments to teach necessary classes or specific modules of classes.
- b. Emphasis will be on top-level knowledge of systems that comprise an avionics suite in a modern military and/or civilian aircraft. Internal workings of individual boxes at the electrical engineering level are not required. However, Input/Output requirements are included within top-level knowledge of systems.
- c. Majority of students (75-90%) will fulfill Test and Evaluation and/or Program Management positions of developing avionics systems upon completion of the curriculum. Positions will be within the Department of Defense (DOD).

Questions may be left blank if you feel that you possess insignificant expertise in the area to render an informed opinion.

A. Using the following scale, please assign a number 1-5 to each **ATTRIBUTE** that a graduate of an engineering graduate-level curriculum should possess. An **ATTRIBUTE** is defined as “a quality, characteristic, or trait displayed by a person.”

- 1 Not required
- 2 Somewhat desirable
- 3 Desirable
- 4 Highly desirable
- 5 Essential

_____ Initiative

_____ Problem-solving Skills

_____ Desire for Lifelong Learning

_____ Communication Skills (Written
& Verbal)

- | | |
|---------------------------------------|------------------------------|
| _____ Time/Resource Management Skills | _____ Enthusiastic |
| _____ Critical-Thinking Skills | _____ Ethical |
| _____ Adaptability/Flexibility | _____ Loyal |
| _____ Strong Engineering Fundamentals | _____ Disciplined |
| _____ Team Player | _____ Reliable |
| _____ Leadership | _____ Strong Computer Skills |
| _____ Creativity | _____ Willing to Take Risks |
| _____ Perseverance | _____ Curious |
| | _____ Professional |

CONTINUE TO PART B

B. Using the following scale, please assign a number 1-5 to the level of proficiency at which each **AREA of STUDY** should be taught in an avionics curriculum **within an aeronautical engineering graduate program**.

- 1 Not required for an Aeronautical Engineer
- 2 To have been experienced or exposed to
- 3 To be able to understand and explain
- 4 To be skilled in the practice or implementation of
- 5 To be able to lead or innovate in

- | | |
|---------------------------------------|---|
| _____ Systems Engineering/Integration | _____ Radar |
| _____ Software Engineering | _____ Electro-Optical |
| _____ Digital Electronics | _____ Navigational Theory and Systems |
| _____ Computer Programming | _____ Bus Architecture |
| _____ Control Theory (guidance) | _____ Controls and Displays (Human Factors) |
| _____ Digital Signal Processing | |
| _____ Digital Communication | _____ Cost/Benefit Analysis |

- | | |
|---|--|
| _____ Electronic Warfare | _____ Low Observable (LO) Requirements |
| _____ Test and Evaluation | _____ Stores Management |
| _____ Modeling and Simulation | _____ Antennas and Apertures |
| _____ Electromagnetic Theory | _____ Statistics |
| _____ Military and Civilian Standards | _____ Power, Cooling, Weight, Space Requirements |
| _____ Net-Centric Operations | _____ Optimization Theory |
| _____ National Airspace Requirements (ATC) | _____ Program Management |
| _____ DoD Acquisition Process | _____ Reliability |
| _____ Embedded Computing | |
| _____ Current Systems (F/A-22, F-35, A380,UCAV) | |
| _____ Maintenance Support Structure | |

CONTINUE TO PART C

C. Using the following scale, please assign a number 1-4 to the importance of including each **AREA of STUDY** in an avionics curriculum **within an aeronautical engineering graduate program**.

1 Not required	
2 Minimally important	
3 Highly important	
4 Critically important	
___ Systems Engineering/Integration	___ Military and Civilian Standards
___ Software Engineering	___ Net-Centric Operations
___ Digital Electronics	___ National Airspace Requirements (ATC)
___ Computer Programming	___ DoD Acquisition Process
___ Control Theory (guidance)	___ Embedded Computing
___ Digital Signal Processing	___ Low Observable (LO) Requirements
___ Digital Communication	___ Stores Management
___ Radar	___ Antennas and Apertures
___ Electro-Optical	___ Statistics
___ Navigational Theory and Systems	___ Power, Cooling, Weight, Space Requirements
___ Bus Architecture	___ Optimization Theory
___ Controls and Displays (Human Factors)	___ Program Management
___ Cost/Benefit Analysis	___ Reliability
___ Electronic Warfare	___ Current Systems (F/A-22, F-35, A380, UCAV)
___ Test and Evaluation	___ Maintenance Support Structure
___ Modeling and Simulation	
___ Electromagnetic Theory	

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Vita

Thomas W. Hofer was born in Ames, Iowa and graduated from Ames High School in May of 1986. He entered the United States Naval Academy at Annapolis, Maryland in July of 1986. He received his Bachelor of Science degree in Mathematics upon graduation in May of 1990, and was commissioned a Second Lieutenant in the United States Marine Corps. After initial Marine Corps ground officer training, he began flight training as a Student Naval Flight Officer, receiving his wings in January of 1993. After completing initial EA-6B Electronic Countermeasures Officer training at Naval Air Station Whidbey Island, Washington, he served an operational tour at Marine Corps Air Station Cherry Point, North Carolina. In June of 1997, he reported to the U.S. Naval Test Pilot School at Patuxent River Naval Air Station, Maryland, and graduated with class 113 in June 1998. After graduation, he served as an EA-6B Prowler and F/A-18 Hornet developmental test project officer with VX-23 and completed his Masters of Science degree in Aviation Systems from the University of Tennessee in May of 2000. From January of 2001 to January of 2002, he served as a Congressional Fellow in the office of Congressman J.C. Watts, Jr. (R-OK). Upon completion of his Congressional assignment, he returned to Marine Corps Air Station Cherry Point, North Carolina for another operational tour. In June of 2004, he entered the Air Force Institute of Technology in pursuit of a Masters of Science degree in Aeronautical Engineering. Lieutenant Colonel Hofer has over 2,000 flight hours in 18 different types of military aircraft and sits on the American Institute of Aeronautics and Astronautics Digital Avionics Technical Committee. Upon graduation, he will report to the U.S. Naval Academy to serve as an instructor in the Aerospace Engineering Department.

REPORT DOCUMENTATION PAGE				Form Approved OMB No. 074-0188	
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1. REPORT DATE (DD-MM-YYYY)		2. REPORT TYPE		3. DATES COVERED (From – To)	
06-03-2006		Master's Thesis		June 2005 – March 2006	
4. TITLE AND SUBTITLE Development of a Comprehensive Digital Avionics Curriculum for the Aeronautical Engineer				5a. CONTRACT NUMBER	
				5b. GRANT NUMBER	
				5c. PROGRAM ELEMENT NUMBER	
6. AUTHOR(S) Hofer, Thomas, W., Lieutenant Colonel, USMC				5d. PROJECT NUMBER	
				5e. TASK NUMBER	
				5f. WORK UNIT NUMBER	
7. PERFORMING ORGANIZATION NAMES(S) AND ADDRESS(S) Air Force Institute of Technology Graduate School of Engineering and Management (AFIT/EN) 2950 Hobson Way, Building 640 WPAFB OH 45433-7765				8. PERFORMING ORGANIZATION REPORT NUMBER AFIT/GAE/ENG/06-01	
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES) Dr. Vernon Gordon, Airborne Systems Department Head U.S. Naval Test Pilot School 22783 Cedar Point Rd., Unit 21 Naval Air Warfare Center Aircraft Division Patuxent River, MD 20670-1160 DSN 757-5036				10. SPONSOR/MONITOR'S ACRONYM(S)	
				11. SPONSOR/MONITOR'S REPORT NUMBER(S)	
12. DISTRIBUTION/AVAILABILITY STATEMENT APPROVED FOR PUBLIC RELEASE; DISTRIBUTION UNLIMITED.					
13. SUPPLEMENTARY NOTES					
14. ABSTRACT The purpose of this research was to develop a comprehensive digital avionics curriculum for aeronautical engineering students at AFIT. Due to the closing of the aeronautical engineering program at the Naval Postgraduate School, and the subsequent requirement to establish a digital avionics specialty course sequence at AFIT, a mature avionics curriculum does not yet exist that satisfies the needs of graduates who will serve as aeronautical engineers involved with the development, integration, testing, fielding, and supporting of military avionics systems as part of the overall aircraft system. Research was conducted through a comprehensive literature review and the use of a Delphi Technique survey process. 28 panel members representing the military, academe, and industry participated in a three round survey process that sought to identify the desired attributes of a newly-graduated engineer and the specific subject areas of study that should be included within the avionics curriculum. The result of this research was the development of a proposed three course curriculum that will instill the desired attributes within the aeronautical engineers and provide them with the avionics knowledge required at the correct level of proficiency. Recommendations on how to implement the proposed curriculum in an effective and timely manner are presented.					
15. SUBJECT TERMS Avionics, Delphi Technique, Aeronautical Engineer, Test and Evaluation, Air Force Institute of Technology					
16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT	b. ABSTRACT	c. THIS PAGE			Dr. Guna S. Seetharaman
U	U	U	UU	181	19b. TELEPHONE NUMBER (Include area code) (937) 785-3636, ext 4612, (gseethar@afit.edu)

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