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# SPACECRAFT AND PROPULSION TECHNICIAN ERROR

by

Daniel Clyde Schultz

A Thesis Submitted to the College of Aviation Department of Applied Aviation Sciences  
in Partial Fulfillment of the Requirements for the Degree of  
Master of Science in Aeronautics

Embry-Riddle Aeronautical University  
Daytona Beach, Florida  
May 2012

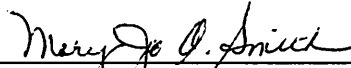
# SPACECRAFT AND PROPULSION TECHNICIAN ERROR

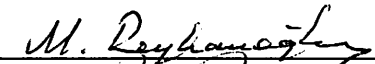
by


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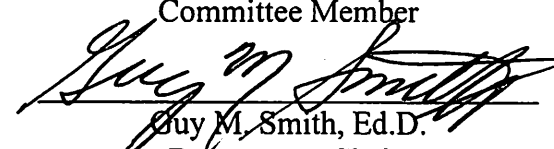
  
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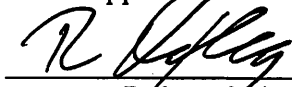
  
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I dedicate this thesis to my family; I would not have completed it without your love, support, and understanding. Angela, you have been instrumental in my success in all aspects of my life. You are my best friend, confidant, and partner. I may not always show it, but I sincerely appreciate all that you do, even though you do not have to. To my children, David, Steven, Presley, Kyler, Riley, and Dysten, you mean the world to me. Thank you for supporting me through these trying times. You keep me going. I would also like to thank my mom, Janice, and my dad, David, for instilling a strong sense of dedication and work ethics at an early age. Your love and support have encouraged me to continue to make myself a better person.

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## Abstract

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Title: Spacecraft and Propulsion Technician Error  
Institution: Embry-Riddle Aeronautical University  
Degree: Master of Science in Aeronautics  
Year: 2012

Commercial aviation and commercial space similarly launch, fly, and land passenger vehicles. Unlike aviation, the U.S. government has not established maintenance policies for commercial space. This study conducted a mixed methods review of 610 U.S. space launches from 1984 through 2011, which included 31 failures. An analysis of the failure causal factors showed that human error accounted for 76% of those failures, which included workmanship error accounting for 29% of the failures. With the imminent future of commercial space travel, the increased potential for the loss of human life demands that changes be made to the standardized procedures, training, and certification to reduce human error and failure rates. Several recommendations were made by this study to the FAA's Office of Commercial Space Transportation, space launch vehicle operators, and maintenance technician schools in an effort to increase the safety of the space transportation passengers.

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## **Chapter I**

### **Introduction**

“Next to wars, nuclear reactor accidents, major transportation accidents, and natural disasters, a space launch failure is one of the most expensive losses in the national resources for a nation in pursuit of technological advancement” (Chang, 1996, p. 198). Regardless of whether the launch failure was due to component failure or human error, the failure wasted vital national resources and negatively affected the country’s image within the scientific world. Often, these failures were a result of non-standard maintenance practices, which have been attributed to the lack of training and certification requirements for the maintenance technicians (Chang, 1996).

From 1957 through 2011, the world attempted 6,498 space launches, but only 5,880 of those attempts were successful, bringing the success rate to 90.4 percent. Of the 618 failures, U.S. launches accounted for 168 of the failures. Having a 90.4 percent average success rate is not terribly low except when the cost of failure is considered. For example, a small launch vehicle has a value of about \$15 million, while a larger more versatile launch vehicle has a value of over a billion dollars. In addition, a small satellite may be valued at a million dollars, but an advanced satellite is valued at more than a billion dollars. When the financial implications of a small launch vehicle carrying a small satellite, with a combined minimum value of \$16 million, are considered, a failure rate of even one percent is unacceptable. The \$16 million value only accounts for the loss of the vehicle and the satellite and does not account for the expenses associated with the recovery and cleanup after a launch failure (Chang, 2000).

April 28, 2001 marked the beginning of commercial space travel when Dennis Tito paid to travel into space aboard the Russian Soyuz TM-32 (Wall, 2011a). Several other individuals have paid to travel to space since 2001 (Wall, 2011b). Although all commercial space travel has only happened in foreign markets through 2011, the United States has been quickly advancing towards commercial space travel. Several non-government agencies, such as SpaceX and Boeing, have already conducted successful space launches. The advancement toward commercial space travel creates an increased risk for the potential loss of human life in space launch accidents (Federal Aviation Administration, 2008).

In U.S. commercial aviation, the Federal Aviation Administration (FAA) requires an FAA certificated inspector to inspect and signoff every maintenance action on an aircraft (Federal Aviation Administration Maintenance, Preventative Maintenance, Rebuilding, and Alteration, 1962). The strict regulations on aircraft maintenance are an effort to reduce maintenance errors and therefore, the potential for aircraft accidents, bodily harm, and/or loss of life. Many Aviation Maintenance Technician Schools around the country have developed specific courses of study to train and certify maintainers to meet the FAA regulation criteria (Federal Aviation Administration Aviation Maintenance Technician Schools, 1962).

### **Significance of the Study**

This study provided useful technical information about space-system technician training and procedures to the FAA's Office of Commercial Space Transportation, space launch vehicle operators, and space transportation passengers. The safety of human life, with regard to space travel, was the true goal of this study.

The Department of Transportation (DOT) governs the safety of commercial travel throughout the United States (Department of Transportation Purpose, 2010). The information contained in this study will aid the Office of Commercial Space Transportation to make decisions on the rules and regulations pertaining to the maintenance of space launch systems.

Space launch system operators can use the information contained in this study to enhance the maintenance procedures on their space launch systems; thereby, decreasing maintenance errors and resultant failures. Space launch system operators could save money that might have been lost due to a launch failure. The expenditures that could be saved include, but are not limited to, costs of the vehicle; repair/replacement of property damage; medical and insurance costs for bodily harm; and/or insurance costs for loss of life.

Ultimately, this study aimed to enhance the safety of the passengers traveling via commercial space-systems. People who intend on travelling into space rely on the knowledge, skills, training, and infallibility of the people who design, build, and maintain commercial transportation systems to keep the vehicles and passengers safe.

### **Statement of the Problem**

Although catastrophic, past launch failures have not resulted in the loss of civilian life. The one exception is Christa McAuliffe, who was among the crew of the Space Shuttle Challenger when it failed. The imminent future of commercial space travel creates an increased potential for the loss of civilian life, and passenger safety must be taken into account. Every effort must be made to reduce launch failures. The human

error rates in space-system maintenance must be reduced. It is essential that the industry recognize a need for specific space-system maintenance safety regulations.

The *Guide to Commercial Reusable Launch Vehicle (RLV) Operations and Maintenance* (Federal Aviation Administration, 2005) contains the requirements for space launch vehicle maintenance. Each of the guidelines for RLV maintenance utilizes the action word “should” as the requirement. The guide does not define standard maintenance action procedures, specific training levels, minimum experience requirement, or license requirements that should be mandatory for RLV maintenance personnel.

### **Purpose Statement**

The purpose of this study was to evaluate space transportation failures to determine whether a significant proportion of the failures were attributable to human error by maintenance technicians and, therefore, could be mitigated through standardized procedures, training, and certification. The secondary purpose of this study was to evaluate the minimum requirements for space-system technicians by space-system operators in order to develop a space-systems technician course curriculum.

### **Hypotheses**

Four hypotheses were tested in this study. The null hypotheses were:

- It was hypothesized that there was no significant relationship between space-system technician/engineer workmanship error and rocket launch outcome.
- It was hypothesized that there was no significant relationship between space-system design error and rocket launch outcome.

- It was hypothesized that there was no significant relationship between space-system process error and rocket launch outcome.
- It was hypothesized that there was no significant relationship between space-system component failure and rocket launch outcome.

Two research questions were also analyzed in this study. They were:

- Did space industry companies use standardized maintenance procedures?
- Was there a need for standardized FAA mandated maintenance procedures, training, and certification?

### **Delimitations**

The scope of this study covered only the U.S. space launches from 1984 to 2011, due to time constraints. The design of the study evaluated rules and regulations set by the Federal Aviation Administration, as they pertained to space-system operations conducted in the United States.

### **Limitations and Assumptions**

This study was limited to information that was available to the public. The U.S. military has conducted many secret space launches. Due to national security, the military's launch and result data were secret and were not available to this researcher.

This researcher conducted the study with the belief that there should be regulations that require standardized maintenance procedures, training, and certifications for space-system technicians. The researcher believed that safety was the main concern of public transportation and that regulating space technician procedures, training, and certification would aid in mitigating the possibility of a space launch failure due to technician error.



## Definition of Terms

A&P License	A three-part rating, General, Airframe, and/or Powerplant, for which a certificated mechanic may have one, two, or all three ratings. A certificated aircraft mechanic may obtain an Airframe and/or Powerplant (A&P) rating through the FAA. Therefore, the mechanic can inspect and signoff maintenance actions for which they are rated (Federal Aviation Administration Certification: Airmen Other Than Flight Crewmembers, 1962).
Airman Certificate	The certificate issued by the Federal Aviation Administration authorizing a person to perform certain aviation-related duties. Airman certificates are issued to pilots, mechanics, and parachute riggers (Crane, 2006).
lbf	The symbol lbf is used in science to distinguish the pound of force from the pound of mass (lbm) (Rowlett, 2004).
lbm	The symbol lbm is used in science to distinguish the pound of mass from the pound of force (lbf) (Rowlett, 2004).

## List of Acronyms

A&P	Airframe and Powerplant
AABI	Aviation Accreditation Board International
ACE	American Council on Education
AMS	Aviation Maintenance Science
AMT	Aviation Maintenance Technology

ASAT	Associate of Science in Aerospace Technology
AWIN	Aviation Week Intelligence Network
BCC	Brevard Community College
BSAT	Bachelor of Science in Aerospace Technology
CCC	Calhoun Community College
CHEA	Council for Higher Education Accreditation
CFR	Code of Federal Regulations
DOD	Department of Defense
DOT	Department of Transportation
ELV	Expendable Launch Vehicle
ERAU	Embry-Riddle Aeronautical University
FAA	Federal Aviation Administration
GPIB	General Purpose Interface Bus
IRB	Institutional Review Board
LEO	Low Earth Orbit
LRE	Liquid Rocket Engines
MEDA	Maintenance Error Decision Aid
MLV	Medium Launch Vehicle
NACA	National Advisory Committee for Aeronautics
NASA	National Aeronautics and Space Administration
NCACS	North Central Association of Colleges and Schools
OSHA	Occupational Safety and Health Administration
RLV	Reusable Launch Vehicle

S&P	Spacecraft and Propulsion
SACS	Southern Association of Colleges and Schools
SMT	Space-system Maintenance Technology
STAR	Space Transportation Analysis and Research
STS	Space Transportation System
WAD	World Access Database
WMU	Western Michigan University

## **Chapter II**

### **Review of the Relevant Literature**

The world of commercial space transportation is not much different from commercial aviation. Both commercial aviation and commercial space transportation require a passenger vehicle to leave the ground, fly, and land.

#### **Lifecycle of a Project**

Every project, including building an airplane or a space system, goes through a life cycle that consists of several phases from concept through termination (Cleland & King, 1975). Shtub, Bard, and Globerson (1994) described five phases in the project life cycle with a sixth possible phase. The six phases were Conceptual Design, Advanced Development, Detailed Design, Production, Termination, and Operation. If the operation phase was included in the life cycle, Shtub et al. (1994) indicated that it could come before, coincide with, or occur after the termination phase.

Shtub et al. (1994) stated that during the production phase “the focus is on actual performance and changes in the original plans” (p. 26). They further stated that when an operational phase was scheduled, preparations for personnel training and maintenance procedures required management’s attention during the production phase (Shtub et al., 1994).

In the lifecycle of a project, from the concept stage through the production phase, engineers normally performed all of the assembly, maintenance, and repair of the project. Once the project entered the operational phase, the responsibility for performing assembly, maintenance, and repair switched to maintenance technicians.

## **Aviation Maintenance History**

During the early years of aviation maintenance, “mechanics were often unlicensed test pilots” (Koontz, 2011, p. vii). The importance of Federal intervention concerning licensure was stressed as early as 1912 by a leading aviation journal called *Aeronautics*. The U.S. Government was slow to take responsibility for air commerce and establish regulations for civil aeronautics. In 1919, the National Advisory Committee for Aeronautics (NACA) began a campaign for Federal legislation of aeronautics, which included licensure of pilots and maintainers (Briddon, Champie, & Marraine, 1974).

On May 20, 1926, the Air Commerce Act of 1926 was signed into law, which established the Air Regulations Division under the Aeronautics Branch of the Department of Commerce. The first regulations written by the Air Regulations Division went into effect December 31, 1926. One of the regulations required all maintenance personnel of commercial aircraft to secure a license for engine maintenance, airplane maintenance, or both by March 1, 1927. The provision allowed maintenance personnel who had submitted their applications within the specified time to continue to operate until July 1, 1927 (Briddon et al., 1974). The Aeronautics Branch issued Mechanic License No. 1 (Airplane & Engine) on July 1, 1927, to Frank Gates Gardner (Koontz, 2011).

## **Aviation Maintenance Signoff Requirements**

Title 14, Aeronautics and Space, Part 43 of the Code of Federal Regulations (CFR) contains the rules and regulations pertaining to aircraft maintenance, preventative maintenance, rebuilding, and alteration (Federal Aviation Administration Maintenance, Preventative Maintenance, Rebuilding, and Alteration, 1962). Subpart 43.3 covers specifically who may or may not work on aircraft. Although certain specific instances

allow some degree of deviation, the regulation states that only those individuals with a certificate issued by the FAA or those under direct supervision of an FAA certificated individual may perform aircraft maintenance. Subpart 43.9a states that maintainers shall record every maintenance action. Maintenance records must include the name of the person performing the maintenance; a description of the work performed; the date; and the name, signature, certificate number, and type of certificate held by the person approving the work (Federal Aviation Administration Maintenance, Preventative Maintenance, Rebuilding, and Alteration, 1962).

The FAA did make a stipulation for experimental aircraft. Under the Application paragraph of Part 43, the regulation states that Part 43 does not apply to aircraft for which the FAA has issued an experimental certificate, unless the FAA has previously issued another type of certificate (Federal Aviation Administration Maintenance, Preventative Maintenance, Rebuilding, and Alteration, 1962).

**Training and certification.** Title 14, Aeronautics and Space, Part 65 of the CFR contains the certification requirements for aviation maintenance technicians desiring to obtain a General Mechanic Certificate (Federal Aviation Administration Certification: Airmen Other Than Flight Crewmembers, 1962). Subparts 65.75, 65.77, and 65.79 specify the knowledge, experience, and skills required before an individual is eligible to be certificated with additional ratings such as Airframe certificated, Powerplant certificated, or both Airframe and Powerplant (A&P) certificated. Subpart 65.80 grants authorization to aviation maintenance technician schools, which have been certificated under Part 147, to allow students who make satisfactory progress to take the A&P

certification exams (Federal Aviation Administration Certification: Airmen Other Than Flight Crewmembers, 1962).

*Aviation colleges.* Title 14, Aeronautics and Space, Part 147 of the CFR contains the rules and regulations for aviation maintenance schools to be certificated to train and test aviation maintenance technicians for General Mechanic Certificate, Airframe Certificate, and/or Powerplant Certificate (Federal Aviation Administration Aviation Maintenance Technician Schools, 1962). As of December 5, 2011, only 166 aviation maintenance technician schools were certificated under Part 147 (Federal Aviation Administration, 2011). Of those 166 schools, only Embry-Riddle Aeronautical University (ERAU) and Western Michigan University (WMU) were regionally accredited and had their aviation maintenance programs accredited by Aviation Accreditation Board International (AABI) (Aviation Accreditation Board International, 2012).

The Southern Association of Colleges and Schools (SACS) regionally accredits Embry-Riddle Aeronautical University. ERAU offers two aviation maintenance programs: Associate of Science in Aviation Maintenance Science (AMS) and Bachelor of Science in AMS. Both degree programs meet the FAA requirements (Embry-Riddle Aeronautical University, 2011). Both programs are Part 147 certificated by the FAA (Federal Aviation Administration, 2011) and both programs are AABI accredited (Aviation Accreditation Board International, 2012).

The North Central Association of Colleges and Schools (NCACS) regionally accredits Western Michigan University. WMU offers a Bachelor of Science in Aviation Maintenance Technology (AMT). The program meets the FAA requirements (Western

Michigan University, 2012). The WMU AMT program is Part 147 certificated by the FAA (Federal Aviation Administration, 2011) and is AABI accredited (Aviation Accreditation Board International, 2012).

### **Accreditation**

The definition of accredit is “to recognize (an educational institution) as maintaining standards that qualify the graduates for admission to higher or more specialized institutions or for professional practice” (Accreditation, n.d.). In the United States, the American Council on Education (ACE) formed in 1918. By 2012, ACE represented the interests of more than 1,600 presidents and chancellors of all types of U.S. accredited degree-granting institutions (American Council on Education, 2012). ACE supports the Council for Higher Education Accreditation (CHEA), which recognizes the agencies that accredit institutions and programs in the U.S. CHEA recognizes 61 programmatic accrediting organizations and 19 institutional accrediting organizations. CHEA recognizes NCACS and SACS as institutional accrediting organizations. CHEA recognizes AABI as a programmatic accrediting organization (Eaton, 2002; Eaton, 2011).

### **Space Launch Vehicle History**

Looking back at the wars of the world, dominance relied heavily on offensive capabilities. One of those dominant offensive capabilities was the use of rockets as weapons. The origins of rocketry trace back to the early 13<sup>th</sup> century when the Chinese used a mixture of gunpowder to launch solid rockets, called “fire arrows,” (Chang, 2000, p. 853) at invaders. Over hundreds of years, the fire arrows advanced into bomb-carrying, solid propellant rockets used during World War I. As World War I developed,



the first missiles were tested and used for offensive measures. By World War II, basic missiles had developed into ballistic missiles powered by liquid propellant. During the years of the cold war between the United States and the Soviet Union from 1945 to 1991, rocket technology advanced dramatically, but at great expense, due to the undying desire of both countries to be the first country in space (Chang, 2000).

As past advancements helped to create current military technologies, those advancements have also allowed aerospace engineers to develop space systems to launch satellites of all varieties and complexities into space for many different purposes (Chang, 2000). In the period between 1957 and 1998, multiple countries had sought to lead the world in space studies through their own advances; the United States and the Commonwealth of Independent States/Soviet Union have managed to stay at the forefront of the world's space launch abilities. The world's first satellite (Sputnik 1) was launched by the Soviet Union in 1957 and weighed only 184.3 lbm. The Commonwealth of Independent States/Soviet Union had produced the most reliable expendable launch vehicle (ELV) in the world, called the Soyuz and remained the world leader in satellite launches until its dissolution in 1991.

Advances in technology allowed the US to launch the Saturn V, which carried the 139,369 lbm Apollo 11 to the moon in 1969. By the 1980s, the US was routinely launching the Space Shuttle. The Space Shuttle was capable of launching cargo weighing more than 49,000 lbs into low earth orbit (LEO) and was considered the first reusable space transportation system (STS). It launched as a rocket, performed as a spacecraft while in orbit, then landed as a glider upon return. As of July 21, 2011, the era of the routinely launched U.S. Space Shuttle Orbiter ended (Wade, 2012).

## Space Launch Vehicle Reliability

In his article, *Investigation of Space Launch Vehicle Catastrophic Failures*, Chang (1996) reviewed worldwide space launch failures from January 1, 1984, through December 31, 1994. During that eleven-year period, 43 failures occurred worldwide. Of those 43 failures, 14 failures occurred in the United States. Table 1 shows the U.S. Department of Defense (DOD) and non-DOD space launch vehicle success-failure record from 1984 to 1994.

Table 1

*List of DOD and Non-DOD U.S. Space Launches from 1984 to 1994*

Year	U.S. DOD <sup>a</sup>		U.S. non-DOD		U.S. Total	
	Success	Failure	Success	Failure	Success	Failure
1984	12	0	9	1	21	1
1985	6	1	11	0	17	1
1986	4	1	2	2	6	3
1987	5	1	3	0	8	1
1988	6	1	5	0	11	1
1989	16	0	2	0	18	0
1990	14	0	12	1	26	1
1991	10	0	7	2	17	2
1992	12	0	15	1	27	1
1993	12	1	11	1	23	2
1994	8	0	18	1	26	1
Total	105	5	95	9	200	14
Success rate,	95.5		91.3		93.5	

*Note.* Adapted from “Investigation of Space Launch Vehicle Catastrophic Failures,” by I. -S. Chang, 1996, *Journal of Spacecraft and Propulsion*, p. 199. Copyright 1996 by American Institute of Aeronautics and Astronautics.

<sup>a</sup>Includes all DOD-involved government space launches.

In September/October 2010, Tomei and Chang presented success/failure data to the 61<sup>st</sup> International Astronautical Congress on the *U.S. Medium Launch Vehicle (MLV)*

*History.* “MLVs from 1958 to 2010 had an overall success rate of 90% with 929 successes and 103 failures” (p. 2). Tomei and Chang (2010) further broke down the failures into root failures and stated that “workmanship” (p. 3) was attributed to 22.3% of the MLV failures.

### **Space-systems Technician Training and Certification**

The FAA stated in the report *Support Services for Commercial Space Travel* (2008), “Training of technical personnel to support the space transportation industry has occurred primarily by the space transportation companies themselves” (p. 9).

Additionally the FAA (2008) stated, “No national certification similar to what the FAA offers for aircraft maintenance personnel existed until recently” (p. 9). The report then went on to identify SpaceTEC® as the organizing force in space maintenance technician certification (Federal Aviation Administration, 2008).

**Aerospace technician certification.** SpaceTEC® (2011a) at Kennedy Space Center in Florida states that they “provide the only national performance-based certifications for aerospace technicians in the United States today” (p. 1). The certification offered by SpaceTEC® is similar to the FAA’s A&P certification process. Technicians may obtain their certification in two categories:

1. A core certification for entry-level employees covering general knowledge in six areas: Introduction to Aerospace; Applied Mechanics; Basic Electricity; Test and Measurement; Materials and Process; and Aerospace Safety; or
2. A concentration certification for advanced standing in one of the following three areas: Aerospace Vehicle Processing, Aerospace Manufacturing, or Aerospace Composites. (SpaceTEC®, 2011b, p. 1)

Technicians must have met one of four prerequisites before they may sit for the core exam. The technicians must:

1. Have a two-year technical college program degree, or
2. Have completed at least a two-year technical military assignment, or
3. Have held a valid current FAA A&P certificate, or
4. Have had two or more years of on-the-job training and experience in the Aerospace industry. (SpaceTEC®, 2011b, p. 1)

Once any one of the prerequisites is satisfied, the technician obtains their Core Certification by successfully completing a three-part test consisting of: a written computer-based examination, an oral examination, and a practical performance-based skills examination. Core certificated technicians may obtain further certification in any of the three concentration areas by successfully completing the three-part test for each concentration certification desired.

Brevard Community College (BCC), in Brevard County, Florida, offers an Associate of Science in Aerospace Technology (ASAT) degree. “This program prepares students for employment as aerospace technicians” (Brevard Community College, 2011, p. 62). BCC also offers several courses, which resulted in certificates from SpaceTEC® (Brevard Community College, 2011).

Calhoun Community College (CCC), in Alabama, also offers an Associate of Science in Aerospace Technology (ASAT) degree (Calhoun Community College, 2011). “CCC is a member institution of SpaceTEC®, a national community college consortium funded by a National Science Foundation grant” (Calhoun Community College, 2011, p. 1).

## Human Error

Human error is strongly associated with technology. Human error refers to the reliability of humans in fields including manufacturing and transportation. Human error has long been the number one causal factor in most aviation accidents (Dhillon & Liu, 2006). Reliability is defined by Dhillon (2009) as “the probability that an item (or human) will perform its specified function adequately for the desired period when used according to the stated conditions” (p. 5). The association of human error and accidents has many forms from design errors to process errors to workmanship errors.

Workmanship is defined as “the art or skill of a workman, *also*: the quality imparted to a thing in the process of making” (Workmanship, n.d.).

In a study of utility companies around the U.S., Varma (1996) found that human error related failures were involved in 27 percent of all plant outages from 1990-1994. In one of the utilities studied, the number of human error-related failures was two and a half times greater than hardware related failures. After the utility companies instituted intensive training programs, the human error related failures dropped by more than 50% (Varma, 1996). In a study conducted by Boeing, 19.1% of in-flight engine shutdowns were caused by maintenance errors (Marx, 1998). Marx (1998) further stated that maintenance error was a causal factor in 15% of all air carrier accidents, which cost the U.S. aviation industry over 1 billion dollars annually.

Several aviation companies have developed programs in an effort to reduce the number of maintenance errors. Boeing has implemented a program called Maintenance Error Decision Aid (MEDA). MEDA was a structured process for investigating the causes of human errors made by aircraft maintenance personnel (Hibit & Marx, 1994).

Under these programs, one of the main areas of concentration was maintenance training. To reduce maintenance error, Dhillon (2009) recommended two guidelines: “to provide, on a periodic basis, training courses to all maintenance personnel with emphasis on company procedures” (p. 107) and “consider introducing crew resourcement for personnel involved with the maintenance activity” (p. 107).

### **Summary**

Every project, including designing an airplane or a space-system, goes through several stages in its lifecycle from concept to operation. During the experimental stage of developing a system, project managers must realize the importance of developing a system to carry the airplane into operation. In the operational stage, engineers/designers are no longer the ones assembling, maintaining, and/or repairing the aircraft, and maintenance technicians take over those responsibilities. The system should include the requirements to train and certify the technicians and the requirements for standardized maintenance procedures (Shtub et al., 1994).

The aviation industry has followed the life cycle of a project. During the experimental stage, in 1926, the Air Commerce Act was signed into law, which laid the framework for regulating aircraft maintainers (Briddon et al., 1974). The regulations evolved over the years to include requirements for how to document maintenance performed on the aircraft, who can work on the aircraft, who can sign-off the maintenance performed on the aircraft, and the requirements for training and certifying those individuals (Federal Aviation Administration Maintenance, Preventative Maintenance, Rebuilding, and Alteration, 1962). Individuals desiring to work on aircraft can, once they meet the prerequisites, take the tests and earn the Airman’s Certificate, as

well as obtain their A&P ratings (Federal Aviation Administration Certification: Airmen Other Than Flight Crewmembers, 1962).

Several colleges and universities around the country have developed training programs, which meet the FAA requirements for certifying maintenance professionals (Federal Aviation Administration, 2011). Embry-Riddle Aeronautical University and Western Michigan University have led the nation by having their maintenance programs individually accredited, in addition to their institutions' regional accreditation (Aviation Accreditation Board International, 2012).

With the advent of rocketry in 1957, space travel began its lifecycle (Chang, 2000). As of 2011, commercial space travel has only happened in Russia and has not made it into the United States (Wall, 2011b). The U.S. commercial space-systems of 2011 are still in the experimental stage (Wall, 2011b), which is the stage when managers should begin developing standardized maintenance procedures, training, and certification programs (Shtub et al., 1994).

BCC and CCC have developed space-system maintenance training programs, which allow their students to become core certified in space-system maintenance by the non-government agency SpaceTEC® (Brevard Community College, 2011; Calhoun Community College, 2011). The SpaceTEC® certification is similar to earning an A&P license for aircraft, except that the certification is for individuals to perform maintenance on space-systems (SpaceTEC®, 2011). As of 2011, the FAA has not mandated the certification developed by SpaceTEC® (Federal Aviation Administration, Office of Commercial Space Transportation, 2011).

Human error has long been known as a main causal factor for incidents in industry. Aviation and space travel are not exempt from that association (Dhillon & Liu, 2006). In an effort to reduce human error in aviation, several programs have been developed throughout the years, including MEDA by Boeing (Hibit & Marx, 1994). Two of the key contributing factors to human error in maintenance are the lack of training and the use of nonstandard procedures. The development of periodic training and standardized maintenance are highly recommended avenues for mitigating human error among maintenance professionals (Dhillon, 2009).



## **Chapter III**

### **Methodology**

The researcher used mixed-methods to perform this study. A mixed-methods review of rocket failures was performed and mixed-method survey research was performed.

#### **Research Approach**

The researcher performed a correlation study of space launches to determine if there was a relationship between engineer/non-engineer technician workmanship error and the failure of space launches. The researcher also performed a descriptive study of companies in the space industry to determine if there was a need for standardized training and/or procedures for the maintenance of space-systems.

**Design and procedures.** The researcher read publicly available failure reports and published articles for 1980 through 2011 space launch failures. This literature review allowed the researcher to develop a matrix of launch vehicle failures and the causal factors that led to the failures (see Appendix B1).

The researcher designed a mixed-method ten-question survey (see Appendix B2). The survey was sent electronically to a sample of 90 space industry companies. The survey was hosted on Surveymonkey.com.

#### **Population/Sample**

The population for the rocket failure analysis was all rocket launches in the United States from 1957 to 2011. The sample was a cluster sample of the 610 United States launches from 1984 to 2011, which included 31 launch failures (The Tauri Group, 2012).

The population for the training, certification, and standardized procedures analysis was all United States space industry companies, which included space component manufacturers, space-system developers, and space-system operators. The sample was a convenience sample of 90 space industry companies listed in the World Access Database (WAD), maintained by Aviation Week Intelligence Network (AWIN). The respondents were from space component manufacturers, space-system developers, and space-system operators.

### **Sources of the Data**

The data for launch failures was obtained through publicly available reports, journal articles, and books read and categorized by the researcher. The list of total launches and failures was obtained from the STAR database provided by The Tauri Group (The Tauri Group, 2012).

The data for the descriptive study were obtained through primary research conducted by the researcher utilizing a survey. The researcher was granted permission by the ERAU Institutional Review Board (IRB) to conduct the survey and solicit responses via email (see Appendix A).

### **Data Collection Device**

The launch outcomes were ranked from 0-2. A rank of “0” was assigned for a successful launch, a rank of “1” was assigned for a partial success, and a rank of “2” was assigned for a launch failure. The failure launches were categorized into six categories by the subsystem that failed. The subsystem categories were propulsion, structures, avionics, separation/staging, electrical, and other. The failures were further broken down into four causal factor classifications. The causal factor classifications were process

error, workmanship error, component failure, and design error. The causal factor classifications were ranked from 0-2. A rank of “0” was assigned if the causal factor classification was not included as a reason for the launch failure. A rank of “1” was assigned if the causal factor classification was a contributing factor for the launch failure. A rank of “2” was assigned if the causal factor classification was the main or primary cause for the launch failure.

The survey was a mixed-methods design. The questions in the survey were designed for the following purposes:

- Question 1 of the survey was designed to ensure that the subject had read and fully understood the Informed Consent Form and to ensure that the subject had received a copy of the Informed Consent Form. By selecting yes, the subject agreed to the statement and agreed to participate.
- Questions 2, 3, and 4 were for categorical purposes. These questions allowed the researcher to group the responses by field and/or component, as well as their stage in development.
- Questions 5 and 8 were designed to determine the structure of the company with regard to the engineers and/or technicians that assembled, maintained, and/or repaired the component or system. These questions were used in conjunction with Question 4 to explore the relationship between the stages in lifecycle and the structure of the company.
- Questions 6 and 7 were designed to determine the level and type of training required by space-system manufacturers/operators with regard to engineers and/or technicians. The responses to these questions allowed

the researcher to determine the type and level of training that an organization should include to meet the needs of the space industry. The responses aided in designing a course curriculum for space-system maintainers.

- Questions 9 and 10 were designed to determine to what degree space-system manufacturers and/or operators utilized and/or agreed with standardized maintenance and sign-off procedures. These questions aided the researcher in determining the level of safety to which the companies were committed

**Instrument reliability.** The research design for categorizing rocket failures utilized only data obtained from published journal articles, reports from the source, and published books. Reliability of the data collected relied on the integrity of the authors of the published literature that was reviewed; multiple sources were used for reliability and validity purposes.

Reliability of the survey was verified through a check of internal consistency. Questions 5 and 8 were reviewed and compared to ensure the respondents remained consistent with respect to their responses to the phase of lifecycle that their products were in throughout the survey. Any surveys that demonstrated inconsistent responses were discarded.

**Instrument validity.** A triangulation method was used to categorize the rocket failures and classify the causal factors. Two reports for each failure were reviewed to determine the causal factors and code them. If a discrepancy was noted between the two

reports, a third report was reviewed and the classification was made with the two complementary reports.

The survey was pre-tested via a group of the researcher's peers. A panel of ERAU faculty members reviewed and made changes to the survey. The revised survey was sent to the ERAU IRB, which approved the survey for use (see Appendix A).

### **Treatment of the Data**

The researcher utilized the ranks of the causal factors classifications (independent variable) to conduct an analysis of the launch outcomes (dependent variable) and determine if a statistically significant relationship existed. The data were analyzed using Spearman's *rho* and were held to a .05 significance level.

**Descriptive statistics.** The researcher used figures to depict all nominal data obtained in both sections of the study. Rocket failures resulted in several areas having categorical data. Frequencies and percentages of rocket launch successes and failures were depicted in tables.

**Hypothesis testing.** Because the data were ordinal, the null hypotheses were tested utilizing a Spearman's Correlation Coefficient for Ranked Data to calculate the correlation between each individual causal factor classifications and the launch outcome. The desired level of significance was  $\alpha = 0.05$ .

**Qualitative data.** The literature review provided qualitative descriptions of the launches from 1984 through 2011. The researcher read the journal articles, books, and reports that described the failures, which allowed the researcher to interpret the results and classify the causes of the failures in the matrix of launch vehicle failures (see Appendix B1).

Each question on the survey included a qualitative block in which the respondents could incorporate any additional information that they felt necessary to support their selected response. Due to the limited number of respondents willing to participate in the survey, a statistical analysis of the responses could not be performed, however some practical answers started to become evident.

## Chapter IV

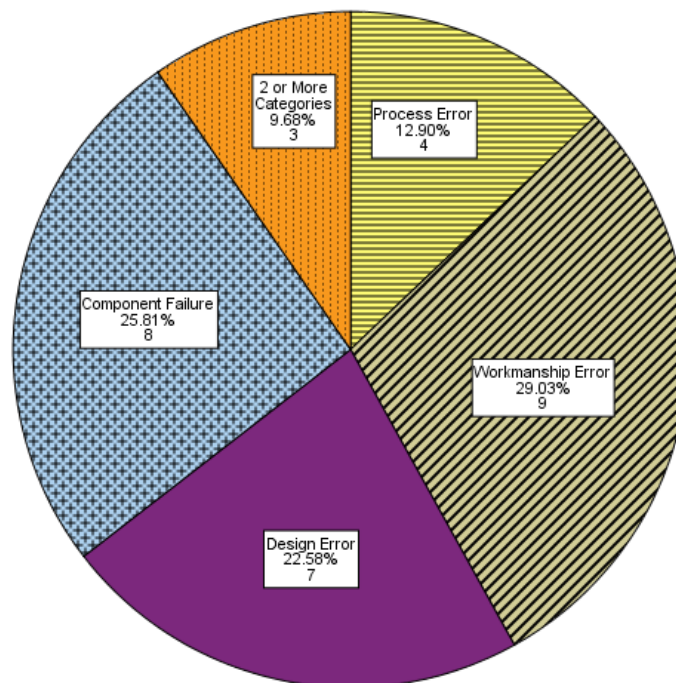
### Results

The total number of non-secret United States space launches from 1984 through 2011 was 610. Of those 610 launches, 31 launches were classified as failures, and four launches were classified as partial successes.

The response rate for the survey was too low to perform any statistical analysis. Of the 90 surveys sent out, the researcher received six responses. Two respondents agreed to participate, and four respondents did not agree to participate.

### Descriptive Statistics

A frequencies check of the data through SPSS resulted in a 94.3% success rate, a 0.6% partial success rate, and a 5.1% failure rate. The failures were further broken down by causal factor. Figure 1 describes the results.



*Figure 1.* Launch failures broken down by causal factor.

The launch failures were also broken down by the subsystem that failed. The results are depicted in Table 2.

Table 2

*Launch Failures Broken Down by Subsystem that Failed*

Outcome	Subsystem	Frequency	Percent
Failure	Propulsion	12	38.7
	Separation	10	32.3
	Avionics	4	12.9
	Electrical	2	6.4
	Other	3	9.7
	Total	31	100.0

The subsystem failure frequencies were then categorized by causal factor. The results are depicted in Figure 2.

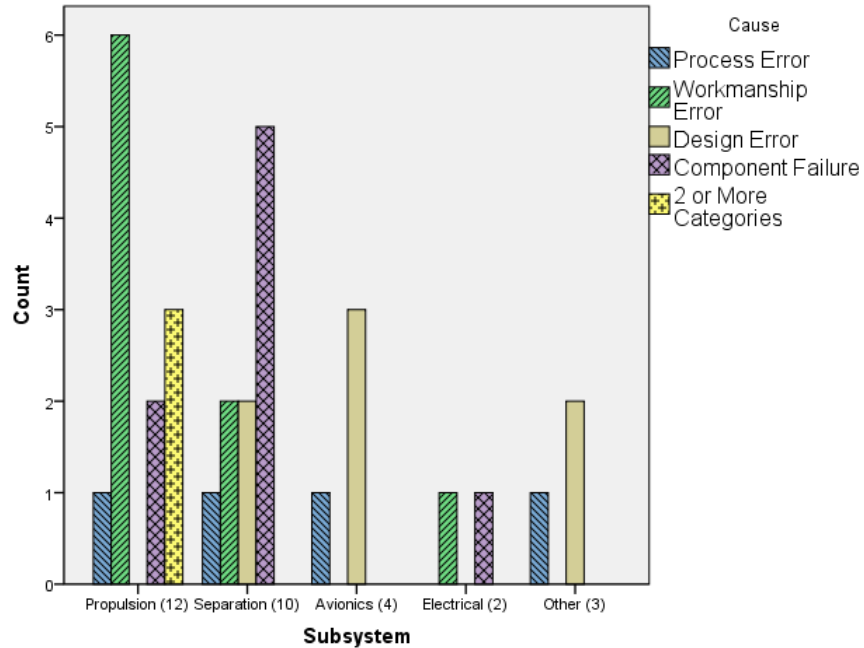


Figure 2. Subsystem failures categorized by causal factor.



The subsystem failures were categorized into three time spans of 1984 through 1993, 1994 through 2002, and 2003 through 2011. The results are depicted in Figure 3.

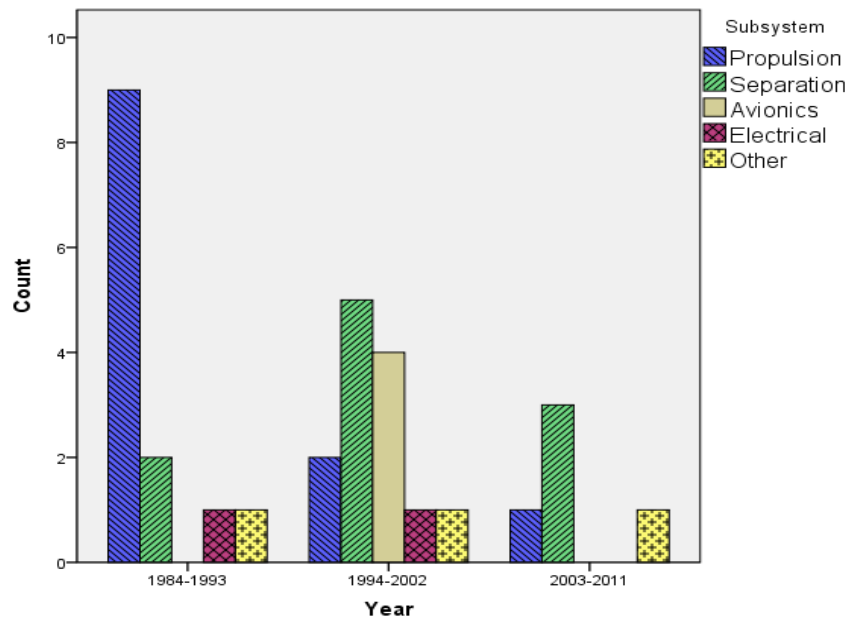


Figure 3. Subsystem failures categorized into three periods.

The last set of descriptive statistics was done to break down the failures by launch organization. Tables 3 through 5 depict the results.

Table 3

*Frequency Table for Success/Failure by Launch Organization*

Launch Organization	Outcome	Frequency	Percent
National Aeronautics and Space Administration (NASA)	Success	141	97.9
	Failure	3	2.1
U.S. Air Force	Success	109	93.2
	Failure	8	6.8
Non-DOD	Success	325	93.1
	Partial	4	1.1
	Failure	20	5.7

Table 4

*Launch Failures Broken Down by Launch Organization/Causal Factor*

Launch Organization	Causal Factor	Frequency	Percent
NASA	Process Error	1	33.3
	Component Failure	1	33.3
	2 or More Categories	1	33.3
U.S. Air Force	Process Error	3	37.5
	Workmanship Error	3	37.5
	2 or More Categories	2	25.0
Non-DOD	Workmanship Error	6	30.0
	Design Error	7	35.0
	Component Failure	7	35.0

Table 5

*Launch Failures Broken Down by Launch Organization/Weight Class*

Launch Organization	Rocket Weight Class	Process Error	Workmanship Error	Design Error	Component Failure	2 or More Categories
NASA	Small				1	
	Medium					1
	Intermediate					
	Heavy	1				
U.S. Air Force	Small					
	Medium	1				
	Intermediate					
	Heavy	2	3			2
Non-DOD	Small		1	6	6	
	Medium		1			
	Intermediate		3	1	1	
	Heavy		1			

**Hypothesis Testing**

The first hypothesis tested was that there was no significant relationship between space-system workmanship error and rocket launch outcome. Because the data were ordinal, a Spearman's *rho* correlation test was conducted. The test results showed

statistical significance,  $r_s(610) = .499$ ,  $R^2 = .249$ ,  $p < .001$ . The null hypothesis was rejected. There was a significant relationship between workmanship error and the launch outcome.

The second hypothesis tested was that there was no significant relationship between space-system design error and rocket launch outcome. Because the data were ordinal, a Spearman's  $\rho$  correlation test was conducted. The test results showed statistical significance,  $r_s(610) = .527$ ,  $R^2 = .278$ ,  $p < .001$ . The null hypothesis was rejected. There was a significant relationship between design error and the launch outcome.

The third hypothesis tested was that there was no significant relationship between space-system process error and rocket launch outcome. Because the data were ordinal, a Spearman's  $\rho$  correlation test was conducted. The test results showed statistical significance,  $r_s(610) = .440$ ,  $R^2 = .193$ ,  $p < .001$ . The null hypothesis was rejected. There was a significant relationship between process error and the launch outcome.

The fourth hypothesis tested was that there was no significant relationship between space-system component failure and rocket launch outcome. Because the data were ordinal, a Spearman's  $\rho$  correlation test was conducted. The test results showed statistical significance,  $r_s(610) = .527$ ,  $R^2 = .278$ ,  $p < .001$ . The null hypothesis was rejected. There was a significant relationship between component failure and the launch outcome.

### **Qualitative Data**

Due to the limited number of survey participants, no qualitative data was analyzed. The responses from the two participant companies indicated that both

companies utilized standardized maintenance procedures. Neither participant company required their engineers or maintainers to have either an A&P or a SpaceTEC® certification. Both companies also indicated that they believed that it was not necessary for the FAA to establish any oversight in the production and/or maintenance of their product. Both companies further believed that oversight should not occur even after their product entered the operational stage of development.

The responses from the four non-participants indicated that their companies had policies against participating in surveys or studies. The responses suggested two reasons for those company policies: (a) security and (b) due to the intense competition in the race to create a viable commercial space-system, proprietary information could not be provided.

## Chapter V

### Discussion, Conclusions, and Recommendations

Approximately 22 rocket launches occur in the United States every year. A 94.3% success rate sounds good, but a 5% failure rate equates to approximately one failure per year. Almost all launch failures are catastrophic. Although costly, space-system operators can eventually recover from an unmanned launch failure, but when there is a loss of life, a launch failure can never truly be recoverable.

#### Discussion

The overall launch success rate determined by this study was 94.3%. The success rate had only improved slightly from the 93.5% success rate noted in Chang's (1996) study of launches from 1984 through 1994. Although an improvement was noted, the improvement was very slight. Therefore, the space-system designers, manufacturers, and organizations have yet to correct or resolve the problem areas. Several of the rocket failures studied were carbon copies of previous failures indicating that the industry was not using previous launch outcomes as input into future launches. The problem areas evolved and changed over the time period covered in this report.

**Causal factors.** In Figure 1, the launch failures were categorized by causal factor. Two notable features became apparent from the depiction. The first notable feature was that component failures accounted for only 26% of the U.S. launch failures. The remaining 74% of the U.S. launch failures were due to human error. Of the three human error related causal factor classifications, workmanship error had the greatest frequency of primary occurrences in U.S. rocket failures (29%), followed by design errors (22.6%) then process errors (13%). The human errors that have occurred during

the lifecycle of the rockets must be reduced. Identifying workmanship error as the most frequent human error-related causal factor highlights the necessity for industry-wide consensus standards.

**Subsystem failures.** Table 2 categorized the U.S. launch failures by the subsystem that was the root cause of the failure. Table 2 confirmed what Chang (1996) presented in his study; the propulsion subsystem was the weakest link in achieving a successful launch with 12 failures and followed closely by separation with 10 failures.

***Subsystem failures by causal factor.*** When the subsystem failures were categorized by causal factor in Figure 2, two items of note stood out. First, in the propulsion subsystem, which had the highest frequency of failures, workmanship error was the primary causal factor of the failures. The second notable item was that the separation subsystem had component failures as its primary causal factor. Workmanship errors in the propulsion subsystem and component failure in the separation subsystem were the two main causal factors for launch failures; therefore, the industry needed to focus their program improvement efforts on providing the necessary consensus standards for all stages of the production lifecycle from design and manufacturing through operation.

***Subsystem failures by period.*** Figure 3 depicted the subsystem failures broken down into three time periods. The first period covered the span of Chang's (1996) study and supported his findings that the propulsion subsystem was the weakest subsystem. The data indicated that beginning in 1994, the problems with the propulsion subsystem were being resolved and the propulsion subsystem was becoming more reliable. Figure 3

also indicated that beginning in 1994, the separation subsystem had become the leading causal factor in rocket launch failures.

**Launches by organization.** Tables 3 through 5 depicted the U.S. launches categorized by organization. NASA had the highest success rate among the launch organization categories of NASA, U.S. Air Force, and all other non-DOD launch organizations. NASA's success may be attributable to their experience in launching rockets. NASA has been launching rockets since 1950 and the agency has learned many lessons throughout that time. One of NASA's lessons learned was found in the rigorous standards imposed on all contractors/subcontractors throughout the rocket's lifecycle from design through operation. Most of the non-DOD organizations had just begun launching rockets and were still in the early stages of production, which could account for their higher failure rate. In addition, the non-DOD organizations had not imposed or implemented the rigorous standards that NASA and the DOD had established.

Another notable item shown in Tables 3 through 5 was that NASA had zero failures due to workmanship error. Several reasons could be suggested to account for their success. The success may be due to funding, which allows the NASA contractors/subcontractors to employ more people and to have more time to complete maintenance cycles. NASA also held very strict maintenance procedures, which could account for their success.

**Statistical significance.** The results of the hypotheses testing showed that each of the four independent variables (workmanship error, design error, process error, and component failure) had a statistically significant relationship with U.S. rocket launches' outcome. The results made sense in that as the occurrences of the independent variables

increased, the number of rocket failures also increased. When the percent of variance accounted for by the relationship of the causal factors with the launch outcome were added together, 100% of the variance was accounted for. Therefore, design errors accounted for 27.8% of the variance with the launch outcome, component failures accounted for 27.8% of the variance with the launch outcome, workmanship errors accounted for 24.9% of the variance with the launch outcome, and process errors accounted for 19.3% of the variance with the launch outcome.

## **Conclusions**

The development of aircraft from the first airplane into a commercial airliner necessitated that the aircraft designers, manufacturers, and operators learn from their successes and failures. The lessons learned were always costly and sometimes included the loss of life. The U.S. DOT cannot afford to make those same mistakes with commercial space transportation, especially when the historical data indicates a 5.7% launch failure rate. As the industry moves into the commercial space age with passengers, these failures could include the loss of many lives. Advances in technology and lessons learned from previous space launch failures have only slightly increased the success rates over the last 20 years. Unfortunately, the same mistakes reoccur; therefore, the industry must make changes to minimize or prevent launch failures from happening.

**Causal factors.** Only 26% of the total number of failures were attributed to component failures. The remaining 74% of the total number of failures were attributed to human error in the forms of workmanship error, process error, and/or design error. Of the three forms of human error, workmanship error had the highest frequency of



occurrence (29%), while design errors accounted for the highest variance with the launch outcome (27.8%).

**Human error.** Design error accounted for 27.8% of the variance with the launch outcome, workmanship error accounted for 24.9% of the variance with the launch outcome and process error accounted for 19.3% of the variance with the launch outcome. The human error element of failure can be mitigated. Varma (1996) showed that the rate at which human error occurred in technical tasks was greatly reduced through the use of standardized maintenance practices, standardized technician training (both initial and follow-on), and certification of individuals to inspect the maintenance performed.

**Subsystems.** The results of this study found that the propulsion subsystem had the highest frequency of failures recorded during the 28 years covered. Although the propulsion subsystem had the most failures, the failure rate of the propulsion subsystem had improved in recent years. The manufacturers and launch operators appeared to have used the historical data to improve the reliability of the propulsion subsystem dramatically. Currently, the opportunity must be taken to further increase space system reliability by reducing the propulsion error rate to less than 1%.

Since 1994, the separation subsystem had become the subsystem with the highest frequency of failure. The data indicated that component failure had the highest frequency of occurrence within the separation subsystem. Most of the component failures were due to the extreme conditions present in a space environment. Therefore, the design of the individual components must account more fully for the extreme conditions in order to reduce the launch failures.

**Launch organizations.** The results found that NASA had developed the appropriate combination of standards for procedures, processes, technician training, and certifications that were necessary to minimize failure rates. Specifically, the results showed that NASA did not have any failures of rocket launches that were due to workmanship error.

### **Recommendations**

The following recommendations stem from the concept that commercial aviation and commercial space travel are very similar and that many parallels can be drawn between the two. The lessons learned in the world of commercial aviation were learned the hard way, and many corrective actions have been established. The commercial space industry can learn from commercial aviation and make the necessary changes without having to relearn those same lessons.

The differences between commercial aviation and commercial space travel are that a space vehicle must withstand much greater forces, withstand greater variances in environmental conditions, and utilize different materials for construction and operation. Throughout the life cycle, the same management principals are applicable in both cases.

Arguably, a commercial space vehicle is completely different from a commercial airplane, but very strong similarities can be made. A commercial space vehicle transports passengers in a mechanical structure that launches, flies, and lands. Beyond the capabilities of an aircraft, a commercial space vehicle has the capability to reach higher altitudes, leave the confines of earth's atmosphere, and travel in space. The requirements for maintaining such a precise system should have, at a minimum, the same requirements

that are required for commercial aviation. These recommendations are not an all-inclusive list but a starting point for the industry as a whole.

**Commercial space industry.** Everyone involved in the space industry must embrace a safety culture. The ultimate goal is to safely launch and recover space vehicles. Initially, establishing new safety procedures is costly; but, when the new costs are measured against the costs resulting from a failure, it is much more cost effective to make the investment in a positive safety culture and prevent the failure altogether.

In an article presented at the 36<sup>th</sup> AIAA/ASME/SAE/ASEE Joint Propulsion Conference and Exhibit, Owens (2000) discussed whether oversight or insight was more important in reducing rocket launch failures. Owens identified several of the same issues found by this study and recommended that the space industry adopt a “school house” (p. 11) approach to improve safety and reduce failures.

Owens’ (2000) idea of the schoolhouse approach requires everyone involved to embrace the concept that the space launch industry needs both insight and oversight to ensure safe operations. Insight builds on the premise that the developers, contractors, maintainers, operators, and all who are involved in commercial space industry know what they are doing and will do everything possible to produce a top quality product. Oversight builds on the premise that quality control is ensured through continuous test evaluations, observations, and inspections.

**Organizations.** When organizations build, operate, and/or maintain space-systems, they equate safety to additional costs. Safety costs can stem from additional time required to perform and sign-off maintenance tasks; additional salaries and benefits for people to perform the functions of inspection, oversight, recording, and filing; and

additional costs involved with the training and certification of employees, hiring employees with higher education and/or certification levels, and performing follow-on training. Those additional costs are minimal when compared to the cost of the space vehicle, the cost of cleanup, and the cost of lives associated with a launch failure.

Because safety is a cornerstone to launch success, space-system organizations must work together to develop an industry-wide safety culture. The schoolhouse insight approach should be adapted, including a cooperative agreement to share lessons learned among all organizations involved. Although the industry needs to maintain some level of secrecy due of the proprietary nature of equipment, the type and quantity of information shared can be varied, which will allow the lesson to be shared without divulging secrets. Therefore, once the rocket becomes operational on a commercial level, it is imperative that all space industry organizations share every safety related lesson learned with the rest of the industry.

NASA has set a very high standard that is worth following. NASA's success rates and lack of workmanship error establish NASA as a safety leader from which all other space industry organizations can benefit. Organizational management should mirror NASA strategies, policies, and procedures in an effort to limit failures.

Space-system organizations should require formal initial training and certification of the technicians who will be performing maintenance on commercially operational space-systems. Space-system organizations should also utilize follow-on training on a cyclical basis to maintain the currency of the technicians with industry changes.

Space-system organizations should develop and utilize standard maintenance procedures for each maintenance task to be performed. The procedures should include

steps that require a sign-off by the technician performing the work. Additionally, there should be a requirement for all maintenance tasks to be inspected and signed-off by a certified inspector. Maintenance tasks should be evaluated and assigned a risk level. The most experienced inspectors should inspect items that have a higher possibility of causing catastrophic failure.

**FAA.** Currently the FAA only recommends that space-system organizations should utilize standardized maintenance procedures, require standardized training, and require SpaceTEC® certification of maintenance technicians (Federal Aviation Administration, 2005). The following recommendations are provided to enhance oversight of U.S. space-systems.

The Office of Commercial Space Transportation should establish space-system maintenance requirements similar to the regulations for commercial aviation. The regulations should specify the minimum sign-off and inspection requirements for maintenance tasks on commercial space-systems. The requirements should target systems that have entered the operational stage of development and should make allowances for experimental space vehicles.

The Office of Commercial Space Transportation should either (a) develop and require their own testing and certification of space-system maintainers, such as a Spacecraft and Propulsion (S&P) certification, or (b) fully require SpaceTEC® certification of space-system maintainers. The Office of Commercial Space Transportation should standardize the prerequisite minimum qualifications for technicians to apply for and receive certification to maintain space-systems that transport

commercial passengers. In addition, the Office of Commercial Space Transportation should standardize the specific requirements for certification of inspectors.

The current recommendation by the FAA is to utilize SpaceTEC® as a certifying agency. The author believes that the SpaceTEC® program meets the needs of the industry; however, the author believes that the prerequisites are vague, and they should be better defined. If the intent of the Office of Commercial Space Transportation is to require certification of maintainers and inspectors through SpaceTEC®, then oversight of the certification program should occur. The oversight should include a review of the prerequisites; a review of program policies, procedures, and certification; and the approval of the program with requirements for follow-on inspections. SpaceTEC® should be required to report all certifications of maintainers and inspectors to the Office of Commercial Space Transportation for recordkeeping and management. The Office of Commercial Space Transportation should retain the final authority to approve, disapprove, or revoke all space-system maintenance certificates.

The Office of Commercial Space Transportation should establish the requirements for standardized initial training at technical schools. Those requirements should be, at a minimum, equivalent to the requirements for institutions certifying aviation technicians taking the A&P examinations under 14 CFR Part 147 (Federal Aviation Administration Aviation Maintenance Technician Schools, 1962).

**Colleges and institutions.** The space-system maintenance technician manufactures, assembles, service tests, troubleshoots, operates, and repairs systems. The space-system maintenance technician can be associated with space launch vehicles, platforms, payloads, related laboratories, and ground support equipment.

Colleges and institutions should create space-systems maintenance programs that meet FAA requirements, meet the Office of Commercial Space Transportation requirements, and align with the current developments in the space industry. According to the current recommendations of the FAA, those courses of instruction should lead to a SpaceTEC® Certification.

***Course of instruction.*** The following courses of instruction have been developed as a guideline for colleges and institutions, as they develop their programs. The author recommends that the spirit of these course curricula be captured in the development of each institution's programs.

The Associate of Science in Aerospace Technology (ASAT) is composed of 60 credits hours (see Appendix C1). The Bachelor of Science in Aerospace Technology (BSAT) is composed of 121 credit hours (see Appendix C2). Both programs are intended to prepare students for entry-level positions in the space-systems maintenance industry and to provide the prerequisite knowledge and skills necessary to attain certification through SpaceTEC®. The course descriptions for the space-system maintenance specific courses are described in Appendix C3.

***Future studies.*** An in-depth study of NASA, U.S. Air Force, and non-DOD organizations should be funded to examine where the similarities and differences are in their requirements for space-system maintenance safety procedures, Space-system technician training and space-system technician certification. The best requirements should be identified and brought forward for consensus of industry members.

A study to analyze the system failures in more detail, including the type of propulsion (solid fuel or liquid fuel) that was used in each rocket failure, should be initiated. The details of the system failures should be shared with the industry.

Lastly, a trend analysis of the component failures, in as much detail as possible, should be initiated. The trend analysis should identify which components have the highest failure rates and propose solutions to correct the deficiencies.



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## **Appendix A**

### **Permission to Conduct Research**

**Embry-Riddle Aeronautical University****Application for IRB Approval****Determination Form****12-122**

Principle Investigator: Student Daniel Schultz under advisement of Dr. MaryJo Smith

Project Title: *Analyzing Space-systems Engineer/Technician Structure and Training Requirements*

Submission Date: March 1, 2012

Determination Date: March 9, 2012

**Review Board Use Only**

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Initial Reviewer: Teri Vigneau/Bert Boquet

Exempt: ☒ Yes ☐ No

Approved: ☒ Yes ☐ No

**Comments:** The purpose of this survey is to analyze the current and future structure of Space-system manufacturers and operators in regards to utilization of engineers and /or technicians to perform assembly maintenance, and / or repair of space components, systems, and /or vehicles. This will be done through the use of survey monkey. As this is a survey it poses no risks to participants and may be considered **exempt**. [Teri Vigneau 3-5-12]

This protocol is **exempt**. [Bert Boquet 3-14-12]

## **Appendix B**

### **Data Collection Device**

B1 U.S. Launch Failures

B2 Questionnaire

# Appendix B1

## U.S. Launch Failures 1984-2011

Launch Date	Organization	Flight	Model	Size	Type	Subsystem	Process	Workmanship	CF	Design	Short Description	Reference 1	Reference 2	Reference 3
19840609	NASA	AC-62	Atlas	Medium	ELV	Propulsion	1	0	0	1	Fuel line leaking in Centaur reaction control system	1	2	
19850828	USAF	D-7	Titan 34D	Heavy	ELV	Propulsion	1	0	0	1	Stage I engine propellant leakage and premature shutdown	1	2	
19860128	NASA	51-L	STS-Challenger	Heavy	RLV	Propulsion	2	0	1	0	Hot gas leaked through O-ring in the SRM joint	1	2	
19860418	USAF	D-9	Titan 34D	Heavy	ELV	Propulsion	0	2	0	0	Motor case burn through	1	2	
19860503	NASA	178	Delta	Small	ELV	Electrical	0	0	2	0	Stage I relay box electrical short	1	2	
19870326	USAF	AC-67	Atlas-Centaur	Medium	ELV	Other	2	0	0	0	Thunderstorm	1	2	
19880902	USAF	D-3	Titan 34D	Heavy	ELV	Propulsion	0	2	0	0	Transtage fuel-tank leak	1	13	
19900314	Other	CT-2	Titan III	Heavy	ELV	Separation	0	2	0	0	Second stage failed to separate because of incorrect interface wiring	1	9	
19910418	Other	AC-70	Atlas-Centaur	Intermediate	ELV	Propulsion	0	2	0	0	Centaur engine failed to achieve full thrust	1	3	
19910717	Other	F-2	Pegasus	Small	ELV	Separation	0	0	0	2	Stage and payload separation anomalies	1	2	
19920822	Other	AC-71	Atlas-Centaur	Intermediate	ELV	Propulsion	0	2	0	0	Centaur engine failed to achieve full thrust	1	3	
19930325	Other	AC-74	Atlas-Centaur	Intermediate	ELV	Propulsion	0	2	0	0	Power loss and premature shutdown of first stage engine	1	3	
19930802	USAF	K-11	Titan 403A	Heavy	ELV	Propulsion	1	0	0	1	Motor case burn through	1	2	
19940627	Other	STEP-1	Pegasus XL	Small	ELV	Avionics	0	0	0	2	Autopilot software used erroneous aerodynamic load coefficient	1	2	
19950622	Other	F9	Pegasus XL	Small	ELV	Separation	0	2	0	0	Incorrect assembly of the interstage ring	2	7	



## U.S. Launch Failures 1984-2011

Launch Date	Organization	Flight	Model	Size	Type	Subsystem	Process	Workmanship	CF	Design	Short Description	Reference 1	Reference 2	Reference 3
19950815	Other	DLV	Athena	Small	ELV	Other	0	0	1	1	Vented hydraulic fluid damaged a nozzle feedback cable resulting in loss of directional control	2	8	
19951023	Other	F1	Conestoga	Small	ELV	Avionics	0	0	0	2	Faulty attitude data inputs caused an excess number of directional changes resulting in the depletion of hydraulic fluid and loss of directional control	2	11	
19961104	Other	F14	Pegasus XL	Small	ELV	Separation	0	0	2	0	A failed battery prevented the pyrotechnic system from firing at seperation	2	9	
19970117	Other	D241	Delta II	Medium	ELV	Propulsion	0	2	0	0	Solid booster ruptured in-flight due to damage during ground handling	2	7	
19980812	USAF	A20	Titan 401A	Heavy	ELV	Electrical	0	2	0	0	A wiring harness damaged prior to launch caused an intermittent power signal to the guidance system	2	14	
19980827	Other	D259	Delta III	Intermediate	ELV	Avionics	0	0	0	2	Overcompensation to oscilations caused the loss of hydraulic fluid for steering	2	9	
19990409	USAF	B27	Titan 402B	Heavy	ELV	Separation	2	0	0	0	1st and 2nd stage failed to separate completely due to aa electrical connector plug being wrapped and taped	2	9	
19990427	Other	LM005	Athena-2	Small	ELV	Separation	0	0	2	0	Fairing failed to separate due to operational ordnance failure	2	15	
19990430	USAF	B32	Titan 401B	Heavy	ELV	Avionics	2	0	0	0	An incorrect value entered into the	2	9	

## U.S. Launch Failures 1984-2011

Launch Date	Organization	Flight	Model	Size	Type	Subsystem	Process	Workmanship	CF	Design	Short Description	Reference 1	Reference 2	Reference 3
19990505	Other	D269	Delta III	Intermediate	ELV	Propulsion	0	0	2	0	flight software caused the rocket to perform incorrectly Combustion chamber rupture caused by a change in manufacturing procedures which resulted in pockets of air in the metal	2	12	
20010921	Other	T6	Taurus	Medium	ELV	Separation	0	0	2	0	One of the nozzle gimbal actuator drive shaft seized for about 5 seconds which cause the loss of directional control	2	8	
20060324	Other	F1-1	Falcon 1	Small	ELV	Propulsion	0	0	2	0	Failure of an aluminum B-nut on the fuel pump cause a fuel leak and subsequent fire	4	5	
20070321	Other	F1-2	Falcon 1	Small	ELV	Other	0	0	0	2	LOX sloshing was caused when contact was made between the 2nd stages and the interstage at separation	5	7	
20080803	Other	F1-3	Falcon 1	Small	ELV	Separation	0	0	0	2	The timing of the separation allowed the first stage to recontact the second stage which caused a loss of directional control	5	6	
20090224	Other	T8	Taurus XL	Small	ELV	Separation	0	0	2	0	A faulty pressure initiator caused the fairing not to separate	2	7	
20110304	Other	T9	Taurus XL	Small	ELV	Separation	0	0	2	0	Fairing failed to separate	2	9	

### U.S. Launch Failures 1984-2011 References

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- 2 The Tauri Group. (2012) *STAR Database*.
- 3 Eleazer, W. (2009). *Launch failures: An Atlas groundhog day*. Retrieved from <http://www.thespacereview.com/article/1321/1>
- 4 Berger, B. (2006, July 19). *Falcon I failure traced to a busted nut*. Retrieved from <http://www.space.com/2643-falcon-1-failure-traced-busted-nut>.
- 5 Space Launch Report. (2009). *SpaceX Falcon data sheet*. Retrieved from <http://www.spacelaunchreport.com/falcon.html>
- 6 Cowling, K. (2008, August 6). *SpaceX determines cause of Falcon 1 launch failur*. Retrieved from <http://www.spaceref.com/news/viewnews.html?id=1302>
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Appendix B2  
**Questionnaire**

**Embry-Riddle Aeronautical University**

Dear Participant,

Please complete the following questionnaire. The accuracy of your answers is very important to the study results. Please check or fill in the appropriate answer. If a question does not pertain to you, please leave the question blank. Thank you for participating in this research.

**1. I acknowledge that I have read and fully understand the consent form. I sign it freely and voluntarily. By selecting Yes, I consent to participating in the research project entitled: Analyzing Space-systems Engineer/Technician Structure and Training Requirements.**

- ☐ Yes  
☐ No

**2. What field/s is/are your company in?**

- ☐ Space-system Component Manufacturer  
☐ Space-system Developer  
☐ Space-system Operator  
☐ Spacecraft Operator

Please provide the name of your company in the space below

**3. Please identify the top 5 space products that your company assembles, maintains, operates, and/or repairs. Please label them 1 through 5.**



**4. What stage of production is your product/system in?**

**Stage of Development**

**Product 1**



**Product 2**



**Product 3**



**Product 4**



**Product 5**



**Other (please specify)**



Dropdown menu reads:

Conceptual (Just on paper)

Advanced Development (Research)

Detailed Design (Engineering)

Production (Execution, Assembly, and Experimental)

Termination (Final product)

Operational (Ready for commercial sale/use)

N/A

**5. What is the current approximate percentage of the employees (Engineers/Non-Engineer Technicians) that assemble, repair, and/or maintain your product/system? (e.g., 30 / 70 means 30% engineers and 70% non-engineer technicians)**

**Engineers / Non-engineer Technicians (Respectively)**

**Product 1**

**Product 2**

**Product 3**

**Product 4**

**Product 5**

**Other (please specify)**

Dropdown menu reads:

0 / 100

10 / 90

20 / 80

30 / 70

40 / 60

50 / 50

60 / 40

70 / 30

80 / 20

90 / 10

100 / 0

N/A

## 6. What are your current hiring requirements?

	Degree	FAA Airframe & Powerplant License	SpaceTEC® Certification
Engineer	<input type="text"/>	<input type="text"/>	<input type="text"/>
Non-Engineer Technician	<input type="text"/>	<input type="text"/>	<input type="text"/>

Please list the minimum EXPERIENCE required by your company for engineers AND non-engineers to be hired. You may also use this block for any additional requirements.

*Degree* dropdown menu reads:  
None  
Associates  
Bachelors  
Masters  
Doctorate

*FAA and SpaceTEC®* dropdown menus read:  
Required  
Not Required

## 7. How often does your company require follow-on training?

	Proficiency	Certification	Safety
Engineer	<input type="text"/>	<input type="text"/>	<input type="text"/>
Non-Engineer Technician	<input type="text"/>	<input type="text"/>	<input type="text"/>

Other (please specify)

Dropdown menus read:  
None  
Weekly  
Monthly  
Quarterly  
Semi-annually  
Annually  
Bi-annually

**8. How will the structure of the employees (Engineers / Non-Engineer Technicians) that assemble, repair, and/or maintain your product change WHEN/IF your product begins to OPERATE COMMERCIALY?**

**Engineers / Non-engineer Technicians (Respectively)**

**Product 1**

**Product 2**

**Product 3**

**Product 4**

**Product 5**

Other (please specify)

Dropdown menu reads:

0 / 100  
10 / 90  
20 / 80  
30 / 70  
40 / 60  
50 / 50  
60 / 40  
70 / 30  
80 / 20  
90 / 10  
100 / 0  
N/A



**9. To what degree does your company utilize STANDARDIZED maintenance procedures?**

	No Standard Procedures	Standard Procedures (Recommended Use)	Standard Procedures (Required to Use)
a. To <b>PERFORM</b> maintenance	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
b. To <b>DOCUMENT</b> the maintenance performed	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
c. To require the <b>ENGINEER/TECHNICIAN</b> to <b>SIGN-OFF</b> each maintenance action performed	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
d. To require an <b>INSPECTOR</b> to <b>SIGN-OFF ROUTINE</b> maintenance actions	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
e. To require an <b>INSPECTOR</b> to <b>SIGN-OFF SAFETY OF FLIGHT</b> maintenance actions	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

Other (please specify)

**10. To what degree do you believe there is a need for the FAA to mandate the below requirements?**

	Not Necessary	Engineers Only	Non-Engineers Only	Both Engineers & Non-engineer Technicians
a. STANDARD MAINTENANCE PROCEDURES: Production Stage of Lifecycle	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
b. STANDARD MAINTENANCE PROCEDURES: Operational Stage of Lifecycle	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
c. STANDARD TRAINING REQUIREMENTS: Production Stage of Lifecycle	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
d. STANDARD TRAINING REQUIREMENTS: Operational Stage of Lifecycle	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
e. MAINTAINER CERTIFICATION: Production Stage of Lifecycle	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
f. MAINTAINER CERTIFICATION: Operational Stage of Lifecycle	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

Other (please specify)

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## **Appendix C**

### **Recommended Space-system Maintenance Degree Programs**

- C1 ASAT Degree Requirements
- C2 BSAT Degree Requirements
- C3 Space-system Maintenance Technology (SMT) Description of Courses

## Appendix C1

**ASAT Degree Requirements**

Communication Theory & Skills (6 CR)	
• 100 Level English Composition & Literature	3 CR
• 200 Level Speech	3 CR
OR	
• 200 Level Technical Report Writing	3CR
Humanities (3 CR)	
• 100 Level Humanities	3 CR
Social Sciences (3 CR)	
• 100 Level Introduction to Psychology	3 CR
Computer Science (3 CR)	
• 100 Level Microcomputer Applications in Aviation	3 CR
Mathematics (3 CR)	
• 100 Level College Mathematics for Aviation I	3 CR
Space-systems Maintenance Technical Courses (42 CR)	
• 100 Level Aerospace Fundamentals	3 CR
• 100 Level Basic Electricity	3 CR
• 100 Level Industrial and Aerospace Safety	3 CR
• 100 Level Spacecraft Materials and Processes	3 CR
• 200 Level Aerospace Electrical/Electronic Systems	3 CR
• 200 Level Aerospace Structural Fabrication I	3 CR
• 200 Level Aerospace Structural Fabrication II	3 CR
• 200 Level Applied Aerospace Mechanics I	3 CR
• 200 Level Applied Aerospace Mechanics II	3 CR
• 200 Level Precision Measurements and Tests	3 CR
• 300 Level Maintenance of Aerospace Life Support Systems	3 CR
• 300 Level Maintenance of Aerospace Propulsion Systems	3 CR
• 300 Level Maintenance of Aerospace-Systems	3 CR
• 300 Level Maneuvering Propellants	<u>3 CR</u>
Total credits	60 CR

## Appendix C2

**BSAT Degree Requirements**

Communication Theory & Skills (9 CR)	
• 100 Level English Composition & Literature	3 CR
• 200 Level Speech	3 CR
• 200 Level Technical Report Writing	3 CR
Social Science Lower Level (3 CR)	
• 100 Level Introduction to Psychology	3 CR
Humanities Lower Level (3 CR)	
• 100 Level Humanities	3 CR
Social Sciences – Upper Level (3 CR)	
• 300 Level Human Factors I: Principles and Fundamentals	3 CR
Computer Science (3 CR)	
• 100 Level Microcomputer Applications in Aviation	3 CR
Mathematics (6 CR)	
• 100 Level College Mathematics for Aviation I	3 CR
• 100 Level College Mathematics for Aviation II	3 CR
Physical & Life Science (7 CR)	
• 100 Level Technical Physics I	3 CR
• 100 Level Technical Physics II	3 CR
• 100 Level Technical Physics Lab	1 CR
Common Core Curriculum (3 CR)	
• 200 Level Principles of Management	3 CR
Space-system Maintenance Technical Courses (42 CR)	
• 100 Level Aerospace Fundamentals	3 CR
• 100 Level Basic Electricity	3 CR
• 100 Level Industrial and Aerospace Safety	3 CR
• 100 Level Spacecraft Materials and Processes	3 CR
• 200 Level Aerospace Electrical/Electronic Systems	3 CR
• 200 Level Aerospace Structural Fabrication I	3 CR
• 200 Level Aerospace Structural Fabrication II	3 CR
• 200 Level Applied Aerospace Mechanics I	3 CR
• 200 Level Applied Aerospace Mechanics II	3 CR
• 200 Level Precision Measurements and Tests	3 CR
• 300 Level Maintenance of Aerospace Life Support Systems	3 CR

- 300 Level Maintenance of Aerospace Propulsion Systems 3 CR
- 300 Level Maintenance of Aerospace-Systems 3 CR
- 300 Level Maneuvering Propellants 3 CR

Space transportation Area of Concentration (42 CR)

- 100 Level Introduction to Computing for Engineers 3 CR
- 200 Level Applied Climatology 3 CR
- 200 Level Planetary and Space Exploration 3 CR
- 200 Level Space Transportation System 3 CR
- 200 Level Survey of Meteorology 3 CR
- 200 Level Weather Information Systems 3 CR
- 300 Level Ergonomics and Bioengineering 3 CR
- 300 Level Human Factors in Space 3 CR
- 300 Level Planetary Atmospheres 3 CR
- 300 Level Satellite and Spacecraft Systems 3 CR
- 300 Level Thermodynamics of the Atmosphere 3 CR
- 400 Level Aerospace Physiology 3 CR
- 400 Level Human Factors Engineering 3 CR
- 400 Level Introduction to Space Navigation 3 CR

Total credits 121 CR

## Appendix C3

**Space-system Maintenance Technology**  
**Description of Courses****100 Level Aerospace Fundamentals 3 CR**

This course covers aerospace industry terminology and acronyms as well as hands-on activities related to tools, procedures, and standard practices on space launch platforms and vehicles. It provides an emphasis on inspection procedures, workplace rules and regulations, safety procedures, good housekeeping practices and lessons learned.

**100 Level Basic Electricity 3 CR**

A comprehensive introduction using a broad based approach covering principles upon which modern electronic/electrical systems operate. Introduction to basics of electronics, measuring devices, basic units, resistance, conductors, measurement, sources, series/parallel circuits, common DC/AC circuits, and safety will be covered.

**100 Level Industrial and Aerospace Safety 3 CR**

This course focuses on the theories and principles of occupational safety and health in a practical and useful real world job-related setting. The major topics include Occupational Safety and Health Administration (OSHA) compliance, safety standards, code enforcement, ergonomic hazards, mechanical hazards, falling, lifting, electrical hazards, fire hazards, industrial hygiene, radiation, noise, emergencies, and environmental safety. This course also covers identification of hazards; personal protective equipment; safe practices; and protection of personnel, property, and equipment in the aerospace environment. Safety procedures, including OSHA regulations and hazardous materials handling, are also covered. Basic principles of quality assurance engineering relating to work processes will be discussed.

**100 Level Spacecraft Materials and Processes 3 CR**

This course covers the physical properties and characteristics of common materials and commodities used in the aerospace industry. Materials compatibility, basic metallurgy, and treatment processes are also covered. Additionally, this course provides information on aerospace applications of non-metallic materials. The use and inspection of adhesives, coatings, sealants, and issues with delaminations, and faulty bonds are covered. The effects of spacecraft fuels and oxidizers, including cryogenics and hypergolics, are also included.

**200 Level Aerospace Electrical/Electronic Systems 3 CR**

A review of the operation of standard laboratory test equipment, the measurement of electrical parameters, and an introduction to computer controlled instrumentation systems. Major topics are: general instrumentation, transducers and signal conditioning, electromechanical devices, servo controls, General Purpose Interface Bus (GPIB) overview, and GPIB software and hardware. This course applies a hands-on learning approach to the soldering, wire wrapping, potting, crimping and cable lacing of electronic components. Printed circuit construction and repair are covered, as well as cable installation and troubleshooting. This course also covers the basics of fiber optics and the

fabrication of fiber optic cable assemblies, using a variety of connectors and splicing techniques.

**200 Level Aerospace Structural Fabrication I 3 CR**

This course provides an introduction to basic machining and fabrication skills, including mathematical computations and measurements as they apply to metal structures, fabrication, and repair.

**200 Level Aerospace Structural Fabrication II 3 CR**

This course introduces the student to advanced core materials that are used in composites manufacturing. It focuses on the inspection and repair theory, including damage detection and repair instructions. It provides the knowledge and techniques, for the student to refine and enhance his or her skills on projects using composite materials.

**200 Level Applied Aerospace Mechanics I 3 CR**

This course applies a hands-on approach to the identification, uses, and care of tools and equipment used in aerospace-systems. Blueprint reading, geometric dimensioning, and tolerancing for English and metric measuring systems are included.

**200 Level Applied Aerospace Mechanics II 3 CR**

This course provides an introduction to orbital mechanics or astrodynamics, as applicable to ballistics and celestial mechanics, and the practical problems concerning the motion of rockets and other spacecraft. This course also focuses on spacecraft trajectories, including orbital maneuvers, orbit plane changes, and interplanetary transfers, and how mission planners use aerospace mechanics to predict the results of propulsive maneuvers.

**200 Level Precision Measurements and Tests 3 CR**

This course covers electrical and mechanical testing procedures (primarily non-destructive testing), equipment, measurements, and instrumentation involved in aerospace-systems. Verification of tool and equipment calibration is also covered. This course provides information in aerospace applications of non-metallic materials.

**300 Level Maintenance of Aerospace Life Support Systems 3 CR**

This course provides an introduction to expendable and reusable spacecraft systems including Environmental Control and Life Support Systems. The interaction of systems with computerized data acquisition systems is also covered.

**300 Level Maintenance of Aerospace Propulsion Systems 3 CR**

This course introduces the student to the classification of propulsion systems, such as chemical, electric, and nuclear propulsion, with a focus on the analysis and performance of each system. Key features, performance characteristics, and maintenance techniques of existing and planned (near future) propulsion systems for use on spacecraft are summarized.



### 300 Level Maintenance of Aerospace-Systems 3 CR

This course provides an introduction to expendable and reusable spacecraft systems including hydraulic, pneumatic, electrical, propulsion, mechanical, and HVAC. It focuses on techniques used in repair and troubleshooting of these systems.

### 300 Level Maneuvering Propellants 3 CR

This course includes a familiarization of fluid system components, their characteristics, and applications. Storable propellants, such as cryogenic and hypergolic materials and high-pressure systems, are also covered.