A STUDY OF THE ACCIDENT/FAILURE EXPERIENCE OF CRYOGENIC AND STORABLE PROPELLENT SYSTEMS

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PREFACE

This study was completed at NASA's Lyndon B. Johnson Space Center (JSC). It is a result of a program of continuing management research which seeks to study specific areas of interest to the JSC and to advance the general state-of-the-art in management.

The author wished to express his appreciation to his adviser at Oklahoma State University, Dr. Ralph F. Catalanello, and to his adviser at the University of Houston, Dr. Winford E. Holland, for their guidance and assistance. Appreciation is also express to Ms. Cheryll Calio, who served as Research Assistant, and Ms. Anne Cunningham, who served as Research Analyst.

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GLOSSARY OF

ABBREVIATIONS, ACRONYMS AND TERMS

A-50 - Aerozine 50 - a storable fuel blend of 50 % hydrazine (N_2H_4) and 50 % unsymmetrical dimethylhydrazine (UDMH) by weight.

active failure - Instances in which the propulsion system exploded, disintegrated or in other violent ways failed to carry-out its function.

Agena - Space vehicle upper stage developed for the U. S. Air Force by Lockheed aircraft. Propellants: nitric acid and unsymmetrical dimethylhydrazine (UDMH).

Apollo program - NASA's third manned program; preceded by the Mercury and Gemini programs.

Centaur - The first U. S. space vehicle upper stage to employ the cryogenic propellants liquid oxygen and liquid hydrogen.

cryogenics - Liquefied gas propellants with very low boiling points (-230 F to -430 F) at ambient pressure and a low critical temperature (10 F to -400 F).

Gatv - A vehicle in the Gemini program which was used to demonstrate the rendervous and docking abilities of the space program, a major step to lunar landing.

hypergolic propellants - Rocket propellants that ignite spontaneously when mixed with each other.

LH2 - Liquid hydrogen - a cryogenic liquid fuel used in the Centaur vehicle.

LM APS - Lunar module ascent propulsion system - the engine and system which is used to take off from the moon's surface and rejoin the command and service module.

LM DPS - Lunar module descent propulsion system - the engine and system which is used to take the lunar module out of orbit and down to the surface of the moon.

LM RCS - Lunar module reaction control system - it controls the lunar module role and pitch.

LOX - Liquid oxygen - a cryogenic liquid oxidizer used in the Centaur vehicle.

N2H4 - Hydazine - a storable liquid fuel.

N2O4 - Nitrogen tetraoxide - a storable liquid oxidizer used in the Apollo spacecraft.

NASA - National Aeronautics and Space Administration - The U. S. agency responsible for all civilian aeronautical and space activities.

passive failure - Instances in which the propulsion system underperformed or otherwise failed to provide the necessary support.

RFNA - Red-fuming nitric acid - an oxidizer used in the Agena vehicle.

RP-1 - A highly refined kerosene fuel.

RSO - Range Safety Officer - An official monitor of the course of a rocket. If the vehicle goes seriously off course, he must give the command destruct signal, which blows it up, to insure that it does not come down on land or in busy shipping lanes.

SM RCS - Service module reaction control system - It controls spacecraft rates, rotation, and minor translations in all axes.

SPS - Service propulsion system - The main propulsion engine, providing thrust for all major velocity changes throughout a mission.

Saturn V - The 281-ft. (363 ft. with spacecraft), three stage launch vehicle for Apollo.

Space Shuttle System - A post-Apollo project known as the space transportation system. The program objective is to develop a re-usable vehicle - half rocket, half aircraft - to reduce the cost of space flight.

storables - Liquid propellants which are stable over a reasonable range of temperature and pressure, and are sufficiently nonreactive with construction materials to permit storage in closed containers for periods of a year or more.

Tug/third stage - Third stage option of the Shuttle System; used if it is necessary for higher orbit insertion of payloads.

UDMH - Unsymmetrical dimethylhydrazine - a storable fuel used in the Agena vehicle.

A STUDY OF THE ACCIDENT/FAILURE EXPERIENCE OF CRYOGENIC AND STORABLE PROPELLANT SYSTEMS

INTRODUCTION

The Background

With the return of the final Skylab crew, the space program will undertake a brief Russian - American joint venture before turning attention to the Space Shuttle System. Although several years from realization, the shuttle system is well into engineering development.

The shuttle program will utilize two pieces of hardware--an orbiter and a booster. On the launch pad, the orbiter will be mounted piggyback on the large booster tank. The booster will launch the orbiter to an altitude of about 22 nautical miles. The orbiter, with its payload and crew, will detach from the booster and fire into an orbit path. This orbiter has the capability of carrying into orbit a Tug/third stage, to deliver payloads to even higher orbits. After a 7 to 30 day mission, the orbiter will fire out of orbit and land on earth, much like a conventional plane.

Of the Shuttle System's estimated 500 flights, 200 will require the Tug/third stage.

The Problem

There are two propellent systems under consideration for the Tug/third stage -- cryogenic and storable. Since each system has some advantages over the other, the decision of which system to use will probably be influenced by safety considerations.

This study is undertaken in order to provide an input in determining which system would be safer, from a historical viewpoint, for use in the shuttle program.

The intent of this study is (1) to develop a methodology and conceptual framework for the analysis of accident/failure experience and (2) to use this methodology to gather, analyze, and report the accident/failure experience of the two propellent systems.

A complex selection problem arises because of the dispersion of data and the consequential reliance upon intuitive measures by program officials. This lack of information, coupled with the prospect of up to 200 shuttle missions requiring the Tug/third stage, has prompted officials to make a complete examination of operations.

The Issues

The principal hazards of concern in the use of a cryogenic Tug/third stage as a payload in the orbiter cargo bay are the following:

(1) high-pressure-developing liquids;

(2) high energy propellants in large quantities;

(3) cold liquids and surfaces;

(4) oxygen-enriched atmospheres.

The principal hazards of concern in the use of a storable Tug/third stage as a payload in the orbiter cargo bay are the following:

(1) propellants of high energy in large quantities;

(2) propellants caustic to skin and to respiratory tract;

(3) propellants that ignite hypergolically;

(4) propellants that react spontaneously with certain materials.

These eight hazards are the central issues in assessing the risk of either system. Of particular interest to program officials is the experience record of the Agena and Centaur vehicles, since uprated versions of these stages are two prime Tug/third stage candidates. The Agena utilizes a storable propellant system employing as an oxidizer red fuming nitric acid (RFNA) and as a fuel unsymmetrical dimethylhydrazine (UDMH). The Centaur utilizes a cryogenic system employing as an oxidizer liquid oxygen (LOX) and as a fuel liquid hydrogen (LH2). (An examination of the Agena and Centaur propellant hazards is presented in Appendix A).

A Preview

This study will attempt to resolve the issue of propellant hazards by investigating two operating areas, flight and ground support operations which are fundamentally different from the Shuttle application, and in which fuel type becomes a factor in safe operations.

Propulsion failures associated flight, flight failures, are instances which, because of the inability of a system to perform its required function, jeopardize the safety of the craft, crew, or mission. The classification "flight failures" stresses the importance of a propellant as a part of a system and side-steps the issue of determining which failures were due solely to the nature of the propellant and which were not.

Propellant accidents associated with the non-flight use of propellants, ground support accidents, involve the hazards inherent in storing, transporting, loading and testing. These hazards are related not to the propellants as a part of a system, but to the inherent danger and nature of the propellant.

This study will examine the flight experience of major NASA launch vehicles and of the Apollo program systems. The ground support experience will come from the mishaps encountered in the Apollo program.

Flight failures and ground support accidents will be considered in the total safety experience of the propellants.

LITERATURE REVIEW

This literature review describes (1) the analytical tools of personnel and organizations concerned with accidents and failures and (2) previous studies of propellant hazards and mishaps.

Study Methods

The disciplines of safety and reliability employ both quantitative and qualitative evaluations in their analysis of accident and failure experience in an effort to provide a reasonable safe produce and/or production process.

Quantitative Methods

Risk measurement is needed because of contemporary problesm in the safety field. The quantitative measurement of hazard risks improves safety management decisions. In the past, risk evaluation has been mainly a management decision process involving expert judgment. The complexity of systems, plus the interaction of system characteristics, necessitates an objective quantitative method for risk measurement. The risk problem resolution must ultimately depend on management decisions; however, an analytical measurement of risk is highly desirable to reduce human judgment errors and to optimize program costs.

The risk (R) associated with a given hazard is taken as the product of the damage from a particular accident (D_i) and the probability of occurrence of that accident (P_i) summed over all accidents:[1]

$$R = \sum_{i=1}^{n} D_i P_i \qquad (1)$$

The damage term (D_i) can be expressed in a variety of ways, such as dollars, injuries, or overexposures, but must be in the same units throughout the analysis. The probability term (P_i), can be developed by a reliability analysis. The above expression (equation 1) accounts for both the severity and frequency of accidents and provides a single value for use in weighing hazards against potential benefits.

Another approach to system safety evaluation is to weigh the importance attached by the system to completion of stated objectives.[2] The hazard (H) associated with a given system is the produce of that system's failure rate (λ), its operation time (T), and its criticality value (B):

$$H = \lambda \cdot T \cdot B \qquad (2)$$

This expression (equation 2) accounts for the possiblity of failure, but does not quantitatively account for damage. Instead, a subjective index (criticality index) is developed to measure the importance of the system and the consequences involved in a loss of that system. Hypothetical criticality values might be expressed in the following manner:

1.0 = catastrophic

0.5 = critical

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[1]see S. Canale. Hazard Risk Measurement and Optimization. Goddard Space Flight Center: Government-Industry System Safety Conference (May 1-3, 1968), pp. 205-208.

[2]see R. M. Wolf. The Application and Implementation of a System Safety Engineering Analysis, presented at Apl. 9th Liquid Propulsion Symposium, (Sept. 1967), pp. 327-244.

0.3 = major

0.0 = none.

Since the system's safeness (S) is equal to 1 minus its hazardness (unsafety), safeness can be expressed:

$$S = 1 - (\lambda \cdot T \cdot B). \qquad (3)$$

The values of these two expressions (equations 2 and 3) are not absolute (as in the first summation), but are indices to compare one component or system against another.

Qualitative Methods

A qualitative approach to the measurement of risk views the problem as a need to understand the kinds of mishaps that happen and the ways in which they occur. A number of methods have been developed by reliability and safety engineers to determine, on an *a priori* basis, problems that could arise from malfunctions of hardware.[3] Variously called Failure Modes and Effects Analysis (FMEA), Criticality Analysis (CA), Failure Modes, Effects, and Criticality Analysis (FMECA) or Fault Hazard Analysis (FHA), these approaches are very similiar, usually differing only in the names given by the organization developing them. The analytical methods would anticipate such problems as the following:

- seperation failure;
- pressure burst;
- propellant leakage;
- inadvertant ignition.

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[3]see Willie Hammer. Handbook of System and Product Safety. Englewood Cliffs, N.J.: Prentice-Hall Inc., 1972. pp. 148-159.

These events are some general classes of mishaps that can occur during a mission and are viewed by reliability and safety engineers as a starting point for their safety analysis. Knowledge of concerns such as these are helpful in a posteriori sense to determine what pertinent information to look for in historical records. The reader is referred to the FMEA study[4] on the Space Tug.

Previous Studies

There are a number of previous studies of propellent hazards/accidents/mishaps/failures which provide useful information and guidelines for the problem at hand. Figure 1, which follows, presents a synopsis of these studies and their source.

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[4]Boyde et. al. Space Tug Propulsion System Failure Modes and Effects Analysis, Teledyne Brown Engineering Research Park, Nuntsville, Ala., May 11, 1972.

Figure 1: Previous Mishap Studies

Source	Description
Shuttle/Agena Study Lockheed Missiles and Space Company Sunnyvale, California February 25, 1972	This study of the feasibility of employing the Agena as a Tug/third stage in the shuttle program includes a discussion (Agena Safety History 7.2.2) of several accident associated with the storage, transfer, handling, and use of the propellants
Liquid Propellant Rocket Engines: Their Status and Future S. F. Iacobellis Proceedings from "Reusable Launch and Reentry Vehicles for Space Flight" short course, University of Tennessee August, 1969	A review of large rocket engine systems (principally those engines used to power the booster and upper stages of launch vehicles) including a section on performance reliability, with success/failure assessment and accompanied reliability index.
Space Flight Hardware Accident Experience Report Bell, Moody, and Farish Boeing Company Huntsville, Alabama 1970	This report has been compiled from data contained in the investigation reports for specific accidents that have occurred during the test or operation of NASA hardware and that have involved major damage to the system.
Analysis of Apollo Launch Operations Experience Hart NASA - KSC a paper presented to the AIAA/NASA Conference, Phoenix, Arizona March 16, 1971	An analysis of the failure that occurred with the command and service modules and launch vehicles during the processing of Apollo 7 through Apollo 13, and a list of the criticality 01 and 02 failure for Apollo 7 - Apollo 13

Figure 1 (continued)

Source	Description
Manned Program Accident/Incident Summaries (1963-1969) General Electric Company Daytona Beach, Florida March, 1970 And Manned Program Accident/Incident Summaries (1970-1971) Cranston Research, Inc. Alexandria, Virginia April, 1972	In addition to the compilation and summary of mishaps in NASA operations, statistical information graphically shows information considered to be of value to management. (i.e. distribution or mishaps by systems, causes, program activity, accidents vs. incidents, injuries, fatalities, damage and human error).
Mishaps with Oxygen in NASA Operations Paul Ordin Lewis Research Center Cleveland, Ohio November, 1971	A presentation of data from a substantial number of oxygen mishaps obtained from NASA and contractor records and descriptions of mishaps and their causes, for both liquid and gaseous oxygen accidents in ground test facilities and in space vehicle systems. Detailed descriptions of several accidents and incidents is given in order to define the combinations of conditions causing the mishap. Included (in addition to propellant system mishaps) are accident/incidents which occurred in space and ground system structures, in electrical systems, in ground support facilities, in ordnance, and in related operations.
Liquefied Hydrogen Safety - A Review F. J. Edeskuty and Roy Reider Los Alamos Scientific Lab Los Alamos, New Mexico November 26, 1968	The accident experience and accident potential in the use of liquefied hydrogen is examined with respect to cold damage to tissue, asphyxiation, hydrogen-air (O_2) mixtures, material properties, arid moisture condensation, and pressure buildup

Figure 1 (continued)

Source	Description
Cryogenic Vs. Storable Propellants for the Space Tug T. York, R. Heser, and L. Trevino Boeing Company Houston, Texas October 26, 1973	A study presenting a safety assessment of cryogenic and storable propellants to determine which would be safer for use on the Tug. Propellants currently being considered for the Tug are listed with associated hazards. Also included is a tabulation of U. S. and international launch vehicles and an account of propellant related flight and ground accidents/incidents that have occurred in the U. S. manned and unmanned space flight programs. A significant result of this study is that human error was found to be the major contributor to accidents/incidents irrespective of the propellant involved
Review of Recent Launch Failures Report of the Subcommittee on NASA Oversight of the Committee on Science and Astronautics U. S. Government Printing Office Washington, D. C. 1971	Public hearings exploring the causes of the launch failures of the OAO-B and Mariner 8 spacecrafts, and reviewing NASA's policies and practices regarding back spacecraft and recovery programs for unmanned missions. (The reliability of the Centaur vehicle is of particular importance to the committee; at stake is a major portion of the NASA program of the 1970's).

Summary

This literature review sought to identify some analytical tools and how they were utilized in previous studies. The chosen studies vary from short discussions of accidents to complete analysis of systems. These studies were taken from NASA as well as non-NASA sources (but all are concerned with liquid rockets and propellants) and date no earlier than 1968.

METHODOLOGY

A "total" approach to safety assessment must include both the system risks and the operational (or ground support) risks of the two propellent systems under investigation. Ideally, the work would provide a statistical basis of comparison. Actually, inaccessible, unquantified, and incomplete data forces a qualitative comparison.

Design of Inquiry

In developing an investigative format, consideration must be given to decision needs, available methods, and anticipated problems.

Decision Needs

The needs of the organization are described in the NASA Safety Manual:

> Knowledge of hazards is basic to the NASA Safety Program. Safety research is needed to provide additional information for use both in understanding the basic nature of hazards and in understanding effective means of eliminating or controlling hazards. Finally, data sources are needed both (a) to understand the history of exposure to and the effectiveness of control of hazards, and (b) to interpret known data or define gaps in data on hazards for design, operations or research purposes.[5]

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[5] "Basic Safety Requirement" NASA Safety Manual National Aeronautics and Space Administration (July, 1969), paragraph 1800.

This description of the input requirements does not specify the format but the content should be as reliable and usable as data in similar decision problems. As an indication of the information necessary for their decisions, the reader is again referred to the FMEA study by Boyd et. al.

The Inquiry

The ideal inquiry, involving a calculation of risk measures similar to those described in the last section, places great importance on the substance and availability of the data. The ideal inquiry would be awkward to implement because of the following difficulties:

(1) Duration of Use - Accidents, or near accidents, are infrequent and it may take years to collect enough instances to form a reasonable classification of the kinds of troubles that occur.

(2) Exposure of Item - It is difficult to estimate exposure to the risk of accidents because it is virtually impossible to get any meaningful comparisons of the absolute or relative frequencies of occurrences of various kinds of accidents.

(3) Definition of Accident/Failure - In an operational system, each item is subject to different levels of stress and judged by different criteria standards.

(4) Accuracy of Evidence - It is difficult or impossible to reconstruct and to derive the cost of some accidents because of the hardware and program elements involved.

The workable inquiry must allow for the imperfect arrangement of data. Proceeding from input, to process, to output would be conceptually

Similar to the process illustrated by Figure 2. This inquiry employs an intervening step: the determination of the relative exposure to accidents and to failures. This inquiry also classifies accidents (rather than quantifying them) and defines system performance (in terms of either success or failure).

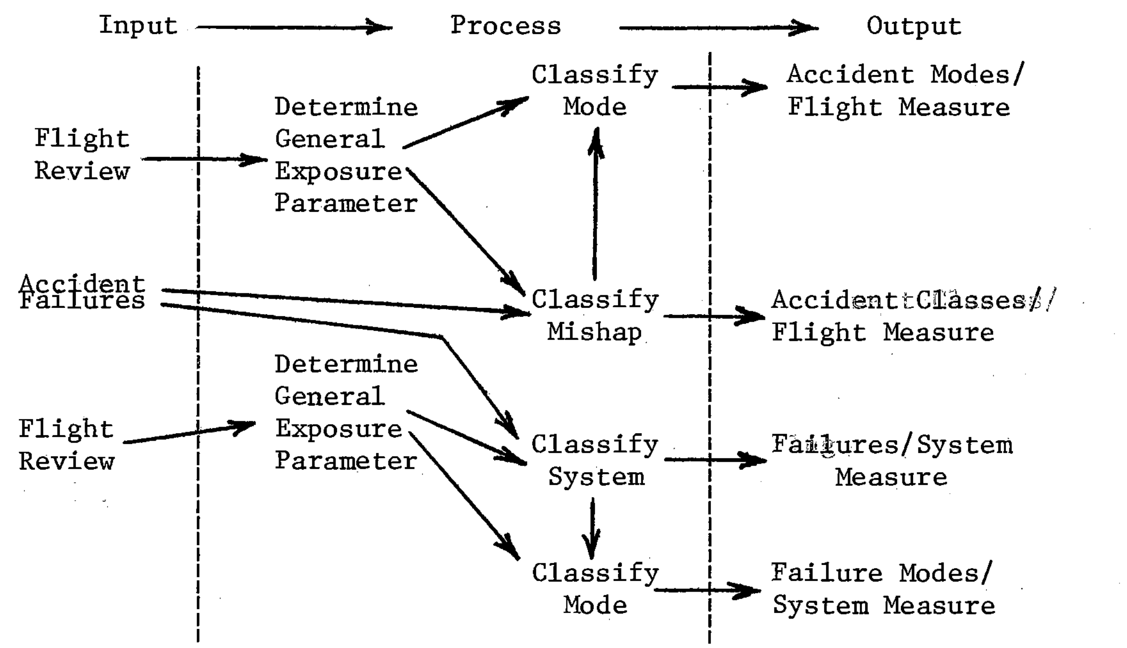

Figure 2: WORKABLE INQUIRY

Data Sources

Flight

The principal sources of mishap documentation relative to space flight are the Mission Reports by NASA and its annual chronology Astronautics and Aeronautics. The mission reports for the manned programs are prepared by a mission evaluation team at NASA's Johnson Space Center and evaluate, among other things, the spacecraft, launch vehicle, and crew performance. These evaluations are published in the first few months following the completion of a mission.

Astronautics and Aeronautics compiles and verifies scattered information to provide an annual historical reference to launches of all rocket vehicles (larger than sounding rockets) launched either by NASA or under "NASA direction" (e.g. ComSatCorp's Intelsat Satellites). Since the publication is about two years in preparation , timely information for launchings in 1972 and 1973 comes from NASA Activities, a monthly review of NASA's work. However, this newsletter does not provide the detail or depth of the yearly reports.

Ground Support

The principal source of information relative to mishaps in the space program supportive functions is a compilation of mishaps covering several years of space flight activity by NASA, Accidents/Incidents (1963-1971).

This reference report briefly describes the mishaps, possible causes, and recommended corrective actions of over 700 accidents/incidents (reported in approximately 15,000 documents) which reflected significant lessons, involved equipment and facilities providing direct support to the space program, or resulted in personal fatalities and/or injuries. The majority of accidents/incidents selected occurred during various phases of the Apollo or other manned space programs.

Problems/Reservations

There are three residual problems basically associated with the use of secondary data (data which the analyst must accept in its form or no form and use to his advantage):

(1) Valuation of Injury, Mission and Hardware - In reports of accident/failures there is no definitive yardstick to measure the degree of damage and to allow reconstruction by later investigators. Valuation is typically reported by such interpretive titles as "minor damage," "considerable injury," "damage to wiring," or "damage to test facility."

(2) Missing Data - In many descriptions of mishaps the propellant and/or system involved in the incident is not specified, due mainly to the destruction of evidence by the act itself.

(3) Reporting Format - There is no established format for classifying the circumstances surrounding the incident. Since mishap data is collected and reported by the agency involved in the incident, the breakdown by firms involved with booster development will be different from the breakdown by firms developing and testing reaction control thrusters.

Summary

This methodology development sought to anticipate problems and to identify data sources. By considering the data format and availability, an inquiry was designed which allowed for the imperfectly arranged data to be used. There were some residual problems such as valuation, missing data, and reporting format which were identified and discussed.

DATA

The data will be presented in three parts - (1) launch vehicle experience, (2) spacecraft system experience, and (3) ground support experience. The first two sections will be concerned with the failure record of propulsion systems, the last section, the accident record.

Flight

Launch Vehicle

Of the 260 major NASA launchings from 1 October 1958 to 31 December 1973 there were 42 vehicles which failed to perform satisfactorily. These 42 failures are tabulated in Figure 3 by (1) launch vehicle and by (2) mode of failure. The active failures (explosions, disintegrations, or RSO destructions) totaled 4% of the launch attempts. All failures, (both active and passive) totaled 16% of launch attempts.

A breakdown of the failures by genetic stages is given in Appendix B. Of particular interest is the Agena and Centaur performance. The Centaur vehicle did not experience an -ctive failure during 15 years and 33 exposures. The Agena vehicle had 1 active failure in 43 attempts. On 25 October 1965 the Agena stage target vehicle (Gatv) for the Gemini 6 rendezvous disintegrated at time of ignition of the main Agena engine. This failure caused postponement of the luanch of Gemini 6, which later rescheduled to rendezvous with Gemini 7.

NASA SPACE LAUNCH RELIABILITY, 1 OCTOBER 1958 - 31 DECEMBER 1973					
Vehicle	Exposures	Failures/Mode		Observed Reliability	
		Active	Passive	All	Active
Atlas/agena	26	1	5	0.77	0.96
Atlas/centaur	35	2	4	0.83	0.94
Thor/agena	13	1		0.92	0.92
Thor/delta	99	2	7	0.91	0.98
Saturn V	13		1	0.92	1.00
Saturn 1, 1B, C-1	18			1.00	1.00
Tital 11	12			1.00	1.00
Juno 11	10	1	5	0.40	0.90
Atlas	13	2		0.85	0.85
Jupiter C	11		1	0.00	1.00
Thor/able	5		2	0.60	1.00
Vanguard	4		3	0.25	1.00
Atlas/able	3	1	2	0.00	0.67
Thor	2			1.00	1.00
Atlas/Gatv	6	1	1	0.67	0.83
total	260	11	31	0.84	0.96

Figure 3: NASA LAUNCH VEHICLE RELIABILITY

SYSTEM RELIABILITY, 1 OCTOBER 1958 - 31 DECEMBER 1973					
System Design Oxidizer - Fuel	Exposures	Failures Active	Failures Passive	Observed Reliability All	Observed Reliability Active
cryogenics	77	-	7	0.91	1.00
LOX - storable	253	9	10	0.92	0.96
Storables	176	2	18	0.89	0.99

Figure 4: SYSTEM RELIABILITY

Additional breakdown of the failures by stage design is tabulated in Figure 4. The launch experience of the cryogenic design historically has fewer failures than the launch experience of the storable design, but any evaluation must take into account that the cryogenics were employed in 56% fewer launches than were the storables. The hydrid systems - cryogenic oxidizer and storable fuel - show little superiority in total performance; however, their active failures experience is the poorest of all three systems.

Spacecraft

The Apollo spacecraft has been virtually free of mission-threatening failures, with the exception of the much publicized Apollo 13 failure.

In the Apollo 13 mishap the blow-out plug in cryogenic oxygen tank 2 of the service module ruptured when electrical shorts in the tank's fan circuits caused pressure and temperature increases. This failure resulted in the loss of power in two of the three service module's fuel cells, forcing the astronauts to abandon the command-service module and use the lunar module as a "lifeboat" in an aborted lunar mission.

Although minor anomolies were noted, all propulsion systems were otherwise judged satisfactory in post-mission reports. This record speaks well for storable systems in that they are the only propellants employed in the spacecraft's propulsion systems. The Apollo 13 mishap, although not a propulsion failure, serves to illustrate the experience of a cryogenic material in spaceflight. Figure 5 is a review of the Apollo systems.

A post-flight accident with Apollo 16 occurred during detanking of the CM RCS. A scrubber tank containing transferred N204 propellant and decontaminated agents exploded, causing physical injuries to two personnel and inhalation of fumes by 44 others.

The Apollo launch vehicles, Saturn I and Saturn V, performed satisfactorily, with the exception of the Apollo 6 vehicle. Although Apollo 6 was launched into earth orbit, two of the five second-stage engines stopped permaturely, and the third-stage engine failed to restart. However, the command module achieved intended apogee, reentered, and was recovered. These launches are included in Figure 2.

Ground Support

There were 121 accidents/incidents which were determined to be propellant related: Propellants directly involved (as in the case of a fire) or propellants indirectly contributed to the hazard of a mishap (as in the case of a spill). In 11 cases the nature of the propellant involved (cryogenic or storable) could not be deduced from the narrative.

The distribution of mishaps is presented in Charts 6-8. The classifications "major accident," "minor accident," and "incident" are somewhat

APOLLO SYSTEMS, Apollo 4 - Apollo 17			
System	Agents Oxidizer - Fuel	Approximate Load (lbs) Oxidizer - Fuel	Mission Use
Spacecraft			
SPS	N204 - A-50	25,200 - 15,760	13
SM RCS	N204 - A-50	900 - 450	13
CM RCS	N204 - A-50	180 - 90	13
LM DPS	N204 - A-50	11,300 - 7,000	10
LM APS	N204 - A-50	3,200 - 2,000	9
LM RCS	N204 - A-50	408 - 200	10
Power			
Fuel Cells	LOX - LH2	652 - 58	13
Launch Vehicle			
S-1B	LOX - RP-1	638,000 - 272,000	2
S-1C	LOX - RP-1	3,312.000 - 1,411,000	12
S-11	LOX - LH2	836,400 - 158,700	12
S-1VB	LOX - LH2	195,800 - 43,700	14
S-1VB auxilliary	LOX - LH2	400 - 250	14

Figure 5: APOLLO SYSTEMS

arbitrary indices of the extent of damage. "Major accident" involved damage extensive to both the system and the facility. "Minor accident" involved damage confined to the system. "Incident" involved minimal damage that could have resulted in extensive loss, upon certain conditions.

In addition to the damage severity, additional knowledge of the nature of the mishap can be gained by examining the destructive consequences of the accident/incident. This mode classification is not as arbitrary as the damage classification and, as experience data, points to different accident/incident events.

The storables (N2O4, A-50, N2H4, and some unidentified hypergolics) accounted for 40% of the mishaps observed. The bulk of these mishaps

STORABLE ACCIDENTS					
	Fire/Explosion	Spill/Leak/Vapor Release	Pressure Rupture	Contamination	Inadvertant Firing
Major Accident	–	–	–	–	–
Minor Accident	15	3	1	–	–
Incident	3	25	–	2	–
Fatality	–	–	–	–	–
Injury	–	5	1	–	–
Exposure	1	9	–	–	–

Figure 6: STORABLE ACCIDENTS

were spills, leaks, and vapor releases classified as "incident." They resulted in 14 instances in which personnel were injured or were exposed to dangerous situations. This may be somewhat misleading, as investigators may be more inclined to report exposures to storables (because of knowledge of the greater toxicity involved) than exposures to cryogenics.

The cryogenics (LOX and LH2) accounted for 50% of the mishaps observed. The bulk of these mishaps - fires and explosions - were classified as "minor accidents," but they also included a fatality, all the "major accident," and the majority of pressure ruptures (10).

CRYOGENIC ACCIDENTS					
	Fire/Explosion	Spill/Leak/Vapor/Release	Pressure Rupture	Contamination	Inadvertant Firing
Major Accident	7	-	-	-	-
Minor Accident	27	-	4	-	-
Incident	2	8	6	6	1
Fatality	1	-	-	-	-
Injury	2	-	2	-	-
Exposure	-	1	1	-	-

Figure 7: CRYOGENIC ACCIDENTS

<u>Appendix C</u> presents information from a selected number of these propellant accidents, representative of the hazards inherent in handling of these materials and illustrative of the typical distribution in <u>Figures 6 and 7</u>.

Any conclusions as to the relative experience of ground-handling mishaps must be tempered by a knowledge of the use of the two materials in the Apollo program. A review of Figure 5 indicates an average of 5 cryogenic and 5 storable systems in a typical mission. However, there are about 80 times as many crytogenic as storable materials handled (by weight) in servicing these systems.

UNSPECIFIED ACCIDENTS					
	Fire/Explosion	Spill/Leak/Vapor Release	Pressure Rupture	Contamination	Inadvertant Firing
Major Accident	-	-	-	-	1
Minor Accident	3	-	2	-	-
Incident	1	1	-	-	3
Fatality	-	-	-	-	1
Injury	-	-	1	-	-
Exposure	-	1	-	-	-

Figure 8: UNSPECIFIED ACCIDENTS

Summary

This three-part data account sought to present both the failure and accident records of the two propellant systems. It was revealed that a one-to-one comparison was not always possible because of different exposure levels.

CONCLUSION

This study sought to resolve the issues of propellant hazards by investigation the safety records of present cryogenic and storable systems. This study was undertaken because of a dispersion of data and the consequential reliance upon intuitive measure by program officials. The conclusions are divided into two parts: (1) Findings of Present Study and (2) Recommendations for Future Studies. This arrangement facilitates the use of the present work while offering guidelines for later research.

Findings of Present Study

As systems, cryogenic and storable propellant vehicle stages show little differences in performance. The experience record of the Agena and Centaur upper stages both approximate the total vehicle performance of all stages and have shown a reliability of 98% and 100% respectively, against active failures.

The employment of storable propellants in the Apollo systems exhibits a clean record so far as mission-threatening anomolies are concerned. Even though these systems do not employ the same propellants as the Agena vehicle, these accomplishments must not be overlooked when judging the experience of the materials as potential Tug/third stage candidates. This observation is of special importance, because the lunar module's functions - rendezvous and docking, orbit altitude and plane changes, and starts in orbit - closely resembel those requirements of the Tug/third stage.

The ground-support experience of the propellants confirms the dissimilar nature of the materials and verfies hazards unique to both types of propellants. As to which of these materials experienced the better or poorer record, it remains a question as to which materials were exposed to a greater employment risk in the Apollo program. The storables were involved in fewer and less violent mishaps; however, they were handled in smaller quantities and consequently, there were limited as to the amount of fuel and oxidizer necessary for the major fires and explosions typical of cryogenic accidents.

The shuttle System's Tug/third stage will present problems unique to space flight. There is no present system which parallels this application from which to draw historical data. However, because of (1) their proven success in the Apollo program and (2) their comparable experience as an upper stage vehicle and (3) their handling record, the storables represent a historically reliable system design for application to the Shuttle System's Tug/third stage.

Recommendations for Future Studies

A study such as this arises because of an immediate problem and concludes when that problem is resolved. Each problem differs from the last, and each involves different program elements.

If similar safety studies are to be undertaken, it is recommended that original documents be secured as the basis for the investigation. As data is summarized and abstracted, detail and depth is sacrificed for conciseness. This brevity leaves no more than a skeleton of a description from which to reconstruct the event. A more rigorous study could be possible if detailed, first-hand accounts of the mishap were used. This approach would facilitate the classification or events according to prior definitions (e.g. NASA definitions -- Type A, Type B, and incident) and possibly provide insight into other distributions (e.g. program activity or calendar year).

A measure of the activity level (or exposure risk) is essential to a safety study. Without a risk measure, the comparison framework lacks a base upon which to bring out the characteristics of each element. In the Space program, the activity level not only fluctuates but the exposure/

risk level itself is inconsistent. Even if the exposure/risk level and activity levels are known, the degree that the interaction of these different measures determine different accident/failure events may be unknown.

Finally, this study could be expanded to included agencies outside NASA (such as the Air Force and Department of Defense) which conduct programs (largely defense-orientated) involving the use of rockets and the development of rocket systems. However, the records of these programs are felt to be sensitive to the National security and, consequently, involve materials available only to personnel with security clearances.

BIBLIOGRAPHY

Apollo Mission Reports, Houston, Texas: Johnson Space Center. Apollo 4, MSC-PA-R-68-1, January, 1968.

Apollo Mission Reports, Houston, Texas: Johnson Space Center. Apollo 5, MSC-PA-R-68-7, March, 1968.

Apollo Mission Reports, Houston, Texas: Johnson Space Center. Apollo 6, MSC-PA-R-68-9, June, 1968.

Apollo Mission Reports, Houston, Texas: Johnson Space Center. Apollo 7, MSC-PA-R-68-15, December, 1968.

Apollo Mission Reports, Houston, Texas: Johnson Space Center. Apollo 8, MSC-PA-R-69-1, February, 1969.

Apollo Mission Reports, Houston, Texas: Johnson Space Center. Apollo 9, MSC-PA-R-69-2, May, 1969.

Apollo Mission Reports, Houston, Texas: Johnson Space Center. Apollo 10, MSC-00126, August, 1969.

Apollo Mission Reports, Houston, Texas: Johnson Space Center. Apollo 11, MSC-00171, November, 1969.

Apollo Mission Reports, Houston, Texas: Johnson Space Center. Apollo 12, MSC-01855, March, 1970.

Apollo Mission Reports, Houston, Texas: Johnson Space Center. Apollo 13, MSC-02680, September, 1970.

Apollo Mission Reports, Houston, Texas: Johnson Space Center. Apollo 14, MSC-04112, April, 1971.

Apollo Mission Reports, Houston, Texas: Johnson Space Center. Apollo 15, MSC-05161, December, 1971.

Apollo Mission Reports, Houston, Texas: Johnson Space Center. Apollo 16, MSC-07230, August, 1972.

Apollo Mission Reports, Houston, Texas: Johnson Space Center. Apollo 17, JSC-07904, March, 1973.

Astronautical and Aeronautical Events of 1962. NASA, Washington, D. C.: U. S. Government Printing Office, 1963.

Astronautics and Aeronautics. NASA Historical Staff, Office of Policy and Planning. Washington, D. C.: U. S. Government Printing Office. 1963, SP-4004, published 1964.

Astronautics and Aeronautics. NASA Historical Staff, Office of Policy and Planning. Washington, D. C.: U. S. Government Printing Office. 1964, SP-4005, published 1965.

Astronautics and Aeronautics. NASA Historical Staff, Office of Policy and Planning. Washington, D. C.: U. S. Government Printing Office. 1965, SP-4006, published 1966.

Astronautics and Aeronautics. NASA Historical Staff, Office of Policy and Planning. Washington, D. C.: U. S. Government Printing Office. 1966, SP-4007, published 1967.

Astronautics and Aeronautics. NASA Historical Staff, Office of Policy and Planning. Washington, D. C.: U. S. Government Printing Office. 1967, SP-4008, published 1968.

Astronautics and Aeronautics. NASA Historical Staff, Office of Policy and Planning. Washington, D. C.: U. S. Government Printing Office. 1968, SP-4010, published 1969.

Astronautics and Aeronautics. NASA Historical Staff, Office of Policy and Planning. Washington, D. C.: U. S. Government Printing Office. 1969, SP-4014, published 1970.

Astronautics and Aeronautics. NASA Historical Staff, Office of Policy and Planning. Washington, D. C.: U. S. Government Printing Office. 1970, SP-4015, published 1971.

Astronautics and Aeronautics. NASA Historical Staff, Office of Policy and Planning. Washington, D. C.: U. S. Government Printing Office. 1971, SP-4016, published 1972.

"Basic Safety Requirement." NASA Safety Manual. National Acronautics and Space Administration, July, 1969.

Bazovsky, Igor. Reliability Theory and Practice. Englewood Cliffs, N. J.: Prentice-Hall Inc., 1961.

Boyd et. al. Space Tug Propulsion System Failure, Mode, Effects and Criticality Analysis. Huntsville, Alabama: Teledyne Brown Engineering Research Park, May 11, 1972.

Canale, S. Hazard Risk Measurement and Optimization. Goddard Space Flight Center: Government-Industry System Safety Conference, May 1-3, 1968.

Hammer, Willie. Handbook of System and Product Safety. Englewood Cliffs, N. J.: Prentice-Hall Inc., 1972.

The Handling and Storage of Liquid Propellants. Washington, D. C.: Office of the Director of Defense Research and Engineering, January, 1963.

Herd, G. Ronald. Reliability Analysis and Prediction. San Diego, California: Seventh Military-Industry Missile and Space Symposium, June 18-21, 1962.

Manned Spacecraft: Engineering Design and Operation. Edited by Paul E. Purser, Maxime A. Faget, and Norman F. Smith. New York: Fairchild Publications, Inc., 1964.

NASA Activities. NASA. Washington, D. C.: U. S. Government Printing Office, December, 1972.

NASA Activities. NASA. Washington, D. C.: U. S. Government Printing Office, December, 1973.

Ordway, Frederick I. and Ronald C. Wakeford. Interantional Missile and Spacecraft Guide. New York: McGraw-Hill Book Company, Inc., 1960.

Rodgers, William P. Introduction to System Safety Engineering. New York: John Wiley & Sons, Inc., 1971

Vesley, W. E. Evaluation of Failure and Failure Related Data. prepared for U. S. Atomic Energy Commission, August, 1971.

Wolf, R. M. The Application and Implementation of a System Safety Engineering Analysis. Air Force Systems Command, Los Angeles, California: Apl. 9th Liquid Propulsion Symposium, Vol. 11, September, 1967.

APPENDIX A

Discussion of the hazards inherent to

the following propellants:

Liquid hydrogen

Liquid Oxygen

Unsymmetrical Dimethylhydrazine

Red Fuming Nitric Acid

Liquid Hydrogen

Health Hazards

Hydrogen is not toxic in the usual sense. The liquid has a very low temperature, so serious "burns" can result when skin or other tissues come into contact with the liquid or with pipes and valves containint the liquid. The gas can exclude oxygen and cause asphyxiation. Cold hydrogen vapors can also "burn" the skin.

Fire

Since the gas is extremely flammable, a serious fire hazard always exists when hydrogen-gas vapors are in the area. When no impurities are present, hydrogen burns in air with an invisible flame. Hydrogen-air mixtures containing as little as 4 percent or as much as 74 percent hydrogen by volume are readily ignited. Hydrogen-oxygen mixtures are flammable over the range of 4 to 94 percent by volume.

Explosion

An explosive hazard exists when the hydrogen-air mixture is completely or partially confined. Such a mixture will propagate a detonation wave when initiated by an explosive. A deflagration will occur when this mixture is ignited from a spark source. Either type of ignition will cause serious damage. Explosive hazards also exist in the presence of oxygen-enriched solid air or strong oxidizers. Pressure rupture can occur, with severe consequences, when the liquid is held in a closed system with no refrigeration. Hydrogen cannot be maintained as a liquid if its temperature rises above $-400^{o}F$ regardless of the confining pressure. Liquid hydrogen trapped between valves can cause a violent rupture of the pipe, while the loss of refrigeration or vacuum insultation can cause a storage tank to rupture if the pressure is not relieved by suitable devices. Liquid hydrogen does not normally present an explosive hazard when it evaporates and mixes with air in an unconfined space.

Liquid Oxygen

Health Hazards

The health hazards of liquid oxygen are associated with its very low temperature.

Fire

Liquid oxygen does not burn but vigorously supports combustion. Normally it is not hypergolic with fuels. Liquid oxygen causes liquid fuels to cool and freeze if both liquids are brought together. Such a mixture of frozen fuel and liquefied oxygen is shock-sensitive and can react with the violence of a detonation. This hazard must be considered in fire control and prevention measures taken in connection with spills or liquid oxygen. Fire blankets must not be used.

Because gaseous oxygen can saturate normal clothing and make it extremely flammable, workers must not smoke or strike fires in oxygen storage or handling areas or while wearing clothing saturated with oxygen. Clothing will retain a high concentration of oxygen for as long as an hour.

Explosion

When mixed with liquid oxygen, all materials that will burn, especially rocket fuels, represent an explosion hazard. These mixtures can usually be exploded by static electricity, mechanical shock, electrical spark and other similar energy sources, especially when the mixtures are frozen. Under most conditions, the ordinary burning of rocket fuels or other combustible materials, when mixed with liquid oxygen, may progress to a detonation. Thus, every fire of liquid oxygen is an explosion hazard.

Whether leaking or spilling, liquid oxygen forms high concentration of oxygen gas. During transfer operations, large volumes of gas are formed from the liquid's "boiling off." In confined areas, gaseous oxygen can form mixtures with fuel vapors that can be exploded by static electricity, electrical spark or flame.

When liquid oxygen is trapped in a closed system and refrigeration is not maintained, pressure rupture may occur. Oxygen cannot be kept liquie if its temperature rises above $-181.8^{o}F$, regardless of the confining pressure. Liquid oxygen trapped between valves can make the pipe or tube rupture violently. Loss of refrigeration can cause the storage tank to rupture if the oxygen is not dumped or pressure-relieved by suitable devices. The loss of vacuum in vacuum-jacketed tanks can cause evaporation to increase and overload an inadequately designed venting system, which raises pressure.

Unsymmetrical Dimethylhdrazine

Health Hazards

UDMH is a clear, mobile liquid of high volatility. It is slightly alkaline and mildly caustic to tissue.

Fire

UDMH vapor is flammable in air over a very wide range of concentrations.. UDMH is hypergolic with some oxidants, such as fuming nitric acids, nitrogen tetroxide, hydrogen peroxide, chlorine triflouride and fluorine.

Materials with a large surface area, such as rags, cotton waste, wood scraps and excelsior, that have absorbed UDMH should not be stored under conditions that prevent the dissipation of heat that can evolve by the gradual process of air oxidation and may eventually cause spontaneous ignition. When UDMH comes into contact with such organic materials, it may cause fire.

Explosion

UDMH vapors greater than 2 percent in air can be exploded by an electric spark or an open flame. Liquid UDMH is not sensitive to shock or friction.

Red Fuming Nitric Acid

Health Hazards

Since all fuming nitric acids are very corrosive liquids, they are very hazardous on contact with the body. Type III acids (RFNA) contain oxides of nitrogen in solution which are readily released into the atmosphere. On contact with a variety of materials, such as organic compounds, many metals and wood, all types of nitric acids produce additional fumes of nitrogen oxides, of which the most dangerous is nitrogen dioxide.

Fire

Nitric acids by themselves will not burn. The fumes liberated by the acids support combustion.

Explosion

Although nitric acid is stable to mechanical shock and impact, upon contact with certain fuels (such as the hydrazines or furfuryl alcohol) it will react violently. Nitric acid will form explosive mixtures with nonhypergolic fuels (such as hydrocarbons) and with hypergolic fuels if either the fuels or the nitric acid contain excessive water. High temperature in confined spaces may cause containers or other equipment to rupture from pressure build-up.

Source: The Handling and Storage of Liquid Propellants. Washington, D. C.: Office of the Director of Defense Research and Engineering, January, 1963.

APPENDIX B

Summary of genetic stage performance in major NASA launchings

NASA SPACE LAUNCH RELIABILITY, 1 OCTOBER 1958 - 31 DECEMBER 1973

Genetic Stage	Oxidizer - Fuel	Exposure	Failures/Mode		Observed Reliability	
			Active	Passive	All	Active
Centaur	LOX - LH2	33		5	0.85	1.00
Agena	RFNA - UDMH	43	1	7	0.81	0.98
Atlas	LOX - RP-1	83	6	3	0.89	0.93
Thor	LOX - RP-1	119	2	2	0.97	0.98
Delta	IRFNA - UDMH	99	1	5	0.94	0.99
Saturn V						
S-IC	LOX - RP-1	13			1.00	1.00
S-11	LOX - LH2	13		1	0.92	1.00
S-IVB	LOX - LH2	13		1	0.92	1.00
Saturn 1, 1B, C-1						
S-1	LOX - RP-1	18			1.00	1.00
S-1VB	LOX - LH2	18			1.00	1.00
Titan II						
1	N2O4 - N2H4 + UDMH	12			1.00	1.00
2	N2O4 - N2H4 + UDMH	12			1.00	1.00

NASA SPACE LAUNCH RELIABILITY, 1 OCTOBER 1958 - 31 DECEMBER 1973

Genetic Stage	Oxidizer - Fuel	Exposure	Failures/Mode		Observed Reliability	
			Active	Passive	All	Active
Jupiter C	LOX - Hydyne	1		1	0.00	1.00
Juno 11	LOX - RP-1	10	1	2	0.70	0.90
Redstone	LOX-ethyl alcohol + water	5		1	0.80	1.00
Able	WFNA - UDMH	6		3	0.50	1.00
Vanguard						
1	LOX - RP-1	4		1	0.75	1.00
2	WFNA - UDMH	4		3	0.25	1.00

Source: Astronautics and Aeronautics.1958-1971, prepared by the NASA Historical Staff, Office of Policy Planning. and: NASA Activities. NASA. Washington, D. C.: U. S. Government Printing Office.

APPENDIX C

Selection of propellant accidents in the Apollo program

SELECTION OF PROPELLANT ACCIDENTS IN THE APOLLO PROGRAM

Accident/Incident Description	Causes	Hazard Illustration
During a demonstration test involving nine pressure and temperature count-downs to demonstrate certain capabilities of foam insulation, a LOX tank dome ruptured and scattered throughout the test area.	Failure to proof test the tank after rework. Contributing causes were poor workmanship in the welding and inadequate inspection of welds.	Pressure/rupture of cryogenics.
Following loading of propellant run tanks in preparation for a firing of a vehicle stage, the insulation jacket for the test stand LH2 storage tank burst, due to expanding cryogenic liquid and generation and storage of liquid air. Theburst disc on the jacket failed to relieve the overpressure condition.	Failure of the burst disc to relieve the overpressure was due to ice formation. Design should have taken into consideration the possibility of the insulation leaking "in" moist air and the formation of ice on the disc.	Pressure/rupture of cryogenics.
Main stage exploded during final countdown phase of static firing, destroying the stage and causing major damage to the facility.	Failure of the LOX vent valve to function; due to solid LOX particles. Contributing causes were failure to follow approved procedures and an unsatisfactory Helium shut off valve during cold conditions.	Explosive characteristics of hydrogen.
Major damage to a test facility occured when a LH2 Dewar exploded during conduct of laboratory tensil tests of metals at cryogenic temperature. Two explosions occurred, the initial one equivalent to ¼ pound of TNT and a secondary explosion, from mixing of released vapors, of a much higher order.	A design deficiency in the test installations. Two electric heaters being used to accelerate boil-off provided the ignition source when the surface temperature was allowed to rise too high. Air had entered the dewar through the dewar vent, and air probably leaked into the system	Explosive characteristics of hydrogen

Accident/Incident Description	Causes	Hazard Illustration
	through cryogenic pumping of air through the porous foam insulation in the top of the dewar.	
During de-fueling operations after a test, a fire occured at the vent when LOX was ignited by an electrical short during venting.	A design deficiency in the test installation in that the LOX vent was located in a manner in which vapors were emitted in the area of electrical wiring.	Combustion in oxygen-enriched atmosphere.
During planned LOX discharge from a storage tank into a drainage ditch, three automobiles in the area caught fire and were destroyed. One driver narrowly escaped severe injury.	Personnel error in that employees who were handling the road block operations, during the LOX discharge, drove autos into an area where LOX vapor clouds were present.	Combustion in oxygen-enriched atmosphere
During disconnection of a line to an oxidizer transfer tank, residual N204 vapor escaped, resulting in burns to both hands of the technician. Technician was wearing an acid suit, hood, and goggles but did not have gloves.	Verification was not made that residual pressure in the line had been relieved. The line did not have a relief valve for bleeding off residual vapors.	Toxicity of propellants.
During preparation for vacuum drying operations on a flight configuration ball valve package, following cleaning operations, a puff of N204 fuel was released when GN2 pressure and electrical power was applied to the valve. Personnel received minor nose and throat irritations.	A design deficiency in that the electrical harness used to operate the valve during cleaning operations allowed only one half of the valve to operate, resulting in incomplete cleaning and N204 entrapment.	Toxicity of propellants.

Accident/Incident Description	Cause	Hazard Illustration
Fuel and oxidizer were inadvertently mixed during a Development Test, causing extensive damage to the engine and test instrumentation.	Inadequate test procedure which permitted the operator to open a valve out of sequence.	Hypergolic ignition of propellants.
During routine calibration for a facility test cell, inadvertent actuation of fuel and oxidizer valves caused fuel and oxidizer to be spilled on test cell floor causing a fire. Three test cell personnel escaped injury; however, minor equipment damage occured.	Hand and signal communications resulted in the inadvertent actuation of two valves. Contributing causes were lack of proper protective equipment in the test cell and lack of written procedures for operating the control console.	Hypergolic ignition of propellants.
A propellant system exploded during a test when N204 was introduced to the system due to residual cleaning fluid in the system (Halogenated Carbon solvents).	Failure to properly purge the system after using cleaning solvents and failure to determine compatibility of solvents with N204.	Spontaneous ignition with certain materials.
An explosion occured during a test when N204 and ethylene/glycol water solution were inadvertently mixed when a leak occured in the ethylene/glycol system	A design deficiency in the test installation in that incompatible systems were located in a manner which permitted inadvertant mixing.	Spontaneous ignition with certain materials.

Source: Manned Program Accident/Incident Summaries (1963-1971), General Electric Company, Daytona Beach, Florida and Cranston Research, Inc., Alexandria, Virginia.

VITA

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Master of Business Administration

Thesis: A STUDY OF THE ACCIDENT/FAILURE EXPERIENCE OF CRYOGENIC AND STORABLE PROPELLANT SYSTEMS

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Institution: Oklahoma State University

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Title of Study: A STUDY OF THE ACCIDENT/FAILURE EXPERIENCE OF CRYOGENIC AND STORABLE PROPELLENT SYSTEMS

Pages in Study: Candidate for Degree of Master of Business Administration

Major Field: Business Administration

Purpose of Study: The purpose of the study was to (1) develop a methodology and conceptual framework for the analysis of accident/failure experience and (2) to use this methodology to gather, analyze, and report the accident/failure experience of two types of rocket propulsion systems. The two systems, cryogenics and storables are currently being considered for the Space Shuttle's Tug/third stage.

Findings and Conclusions: The conclusions are divided into two parts: (1) Findings of Present Study and (2) Recommendations for Future Studies. Although their use in the Shuttle program will not resemble their present applications, the study's findings is that the storables would be a safer system because of their historical record. Specific recommendations for future studies include securing original documents for investigation, developing an activity level (or exposure risk), and expanding the study to include agencies outside NASA.

ADVISER'S APPROVAL R. F. Catalanello