AEROSPACE REPORT NO.
ATR-71(7233)-1, VOL I

Safety Analysis of Parallel Versus Series Propellant Loading of the Space Shuttle

Final Report, Volume I: Management Summary Report

Prepared by SYSTEMS PLANNING DIVISION

71 JUN 30

Prepared for OFFICE OF MANNED SPACE FLIGHT
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
Washington, D. C.

Contract No. NASW 2129

Systems Engineering Operations
THE AEROSPACE CORPORATION

Report No.
ATR-71(7233)-1
Vol. I

SAFETY ANALYSIS OF PARALLEL VERSUS SERIES PROPELLANT LOADING OF THE SPACE SHUTTLE

FINAL REPORT, VOLUME I: MANAGEMENT SUMMARY REPORT

Prepared by

Systems Planning Division

71 JUN 3Ø

Systems Engineering Operations
THE AEROSPACE CORPORATION
El Segundo, California

Prepared for

Office of Manned Space Flight
National Aeronautics and Space Administration
Washington, D. C.

Contract No. NASW 2129

Report No.
ATR-71(7233)-1
Vol. I

SAFETY ANALYSIS OF PARALLEL VERSUS
SERIES PROPELLANT LOADING OF THE SPACE SHUTTLE

FINAL REPORT, VOLUME I:
MANAGEMENT SUMMARY REPORT

Submitted by:

R.R. Wolfe

R.R. Wolfe, Director
Operations Office
Advanced Vehicle Systems Directorate

Approved by:

Samuel M. Tennant

S.M. Tennant
Assistant General Manager
Systems Planning Division

PREFACE

This study was initiated as Subtask 2, Dual Propellant Loading of the Space Shuttle to NASA Study C-II, Advanced Missions Safety Studies. Other studies in this series are: Subtask 1, TNT Equivalency Study, Aerospace Report No. ATR-71(7233)-4; and, Subtask 3, Orbiting Propellant Depot Safety Study, Aerospace Report No. ATR-71(7233)-3.

The study was supported by NASA Headquarters and managed by the Advanced Missions Office of the Office of Manned Space Flight. Mr. Herbert Schaefer, as the study monitor, provided guidance and counsel that significantly aided this effort.

The results of the study are presented in two volumes: Management Summary Report (Volume I) and Technical Discussion (Volume II). The Management Summary Report (Volume I) presents a brief, concise review of the study content, and summarizes the principal conclusions and recommendations. The Technical Discussion (Volume II) is the principal volume. It provides a discussion of the relative magnitude of hazards of a series versus parallel propellant loading system for the Space Shuttle. Suggested design and procedural criteria that would tend to minimize hazards are provided where appropriate. Also included is a consideration of equalizing the hazard levels associated with the two loading system concepts. A composite system, capable of either series or parallel operation, is suggested as desirable.

CONTENTS

TABLES

FIGURES

1. INTRODUCTION

Current mission timelines for the Space Shuttle indicate a requirement for a two-hour launch capability from vehicle ready on launch pad to launch. Contractor reports indicate that they are considering allocating 75 minutes of the two-hour period to propellant loading.

In an unpublished study conducted in 1969, The Aerospace Corporation evaluated the operational and economic feasibility of satisfying a two-hour reaction time with an allocation of 60 minutes to propellant loading. That study indicated that this was feasible. It further indicated a potential cost reduction of $12 million if a parallel system were used. However, since a propellant transfer system capable of simultaneous loading of fuel and oxidizer at such high flow rates had not previously been employed, a study of the relative safety of such a system to a more conventional series loading system was recommended.

A top level safety study has been performed to identify and compare the types of hazards associated with each of the two loading systems. Design and procedural criteria have been recommended to minimize the hazards that were identified.

2. STUDY OBJECTIVE

The primary objective of this study was to analyze the potential hazards associated with a parallel propellant system (oxidizer and fuel loaded simultaneously) versus a conventional sequential (series) loading system for the Space Shuttle within the same time constraints.

3. RELATION TO OTHER NASA EFFORTS

The results of this study provide safety-related criteria which will be useful in selecting the type of propellant loading system to be used for the Space Shuttle. Further, the criteria will assist in establishing safety requirements for design of the system selected and will provide a baseline against which design progress can be weighed with respect to safety.

4. METHOD OF APPROACH

The general plan followed in this study was to:

a. Develop conceptual parallel and series propellant loading systems to serve as baseline for analysis

b. Assess comparative level of safety for the systems

c. Establish recommended safety requirements and criteria for normal and emergency operations

5. RESULTS

5.1 GENERAL

Table 1 indicates the quantities of propellants required by a typical booster, orbiter, and a propellant resupply tank as the payload. For comparison, the quantities required by the Saturn V vehicle have been indicated.

5.2 LOADING TIMELINES

The propellant loading system timeline, based on a 75-minute loading time, for series and parallel loading are illustrated in Figs. 1 and 2, respectively. These figures also identify two major differences between series and parallel loading:

a. The flow rates for LH_2 and LO_2 are higher in series loading.

b. Simultaneous rapid loading of LH_2 and LO_2 occurs during parallel loading whereas in series, rapid loading is performed sequentially.

5.3 HAZARD ANALYSIS

The analysis was confined to assessing the relative difference in hazards between the two loading systems. Conditions producing the same level of hazard regardless of the system configuration were excluded from the analysis.

The hazards identified were evaluated with respect to three independent criticalities of the expected effect:

a. Probability of failure

b. Time criticality relative to reaction time available

c. Consequence of the failure if uncompensated for

Table 1. Total Vehicle Propellant Loads

Space Shuttle

	LH_2				LO_2			
Stage	m^3	t†	gals	lb ($\times 10^6$)	m^3	t†	gals	lb ($\times 10^6$)
Booster	2330	165	615,300	0.363	767	875	202,760	1.930
Orbiter	533	37.7	140,860	0.083	189	211	48,900	0.464
B/O Total	2863	202.7	756,160	0.446	956	1086	251,660	2.394
Tanker	257	18.2	67,700	0.040	18	20	4,670	0.044
B/O/T Total	3120	220.9	823,860	0.486	974	1106	256,330	2.438

Saturn V Vehicle (Comparison)

	LH_2				LO_2			
Stage	m^3	t†	gals	lb ($\times 10^6$)	m^3	t†	gals	lb ($\times 10^6$)
SIC	----	-----	------	-----	1310	1490	345,000	3.280
S II	1040	73.5	275,000	0.162	326	371	80,000	0.816
S IV B	277	19.5	73,000	0.043	76	86.3	20,000	0.190
Total	1317	93.0	348,000	0.205	1712	1947.3	451,000	4.286

†t = metric tons

††Tanker will contain either LH_2 or LO_2, not both.

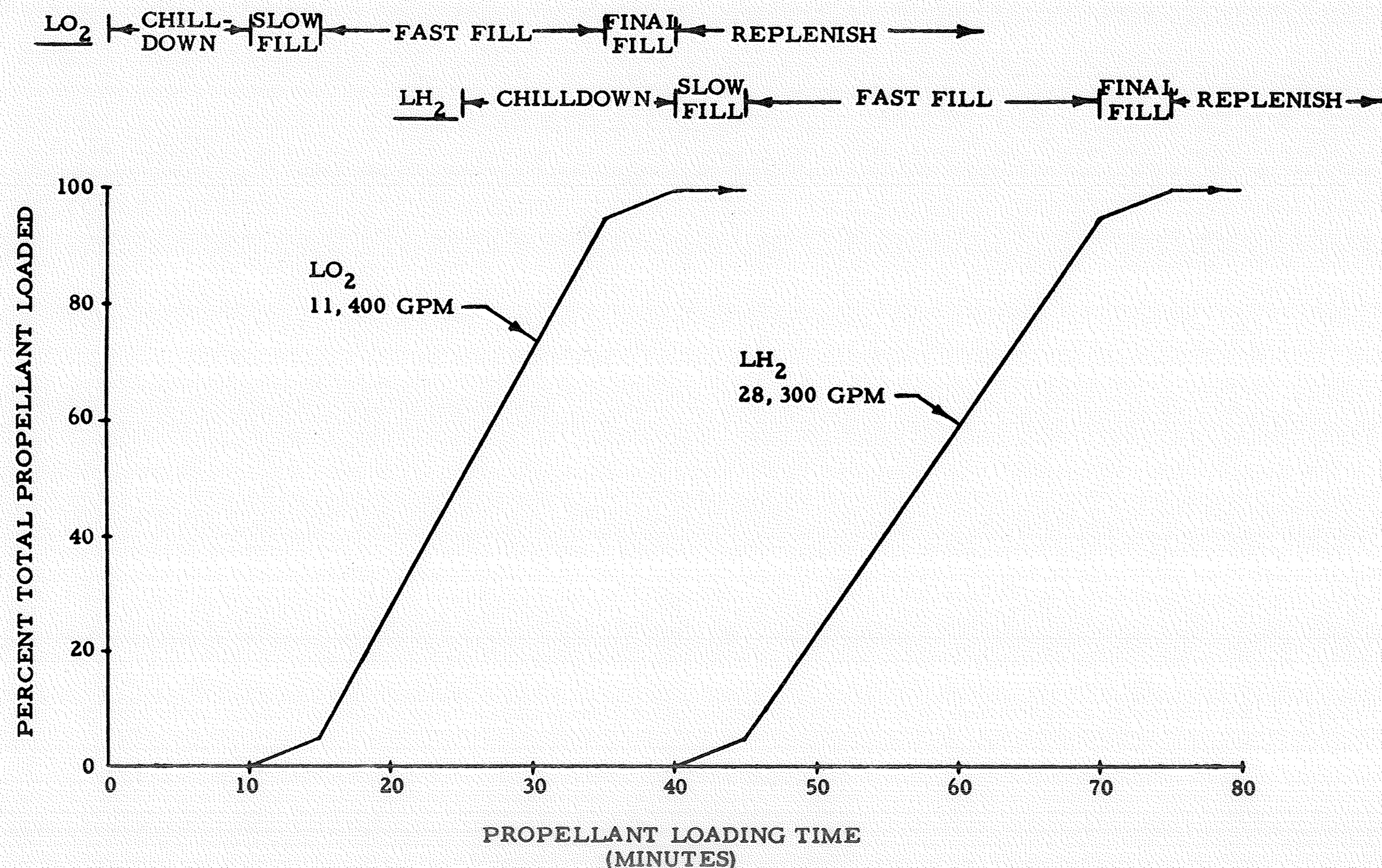


Fig. 1. Series Propellant Loading

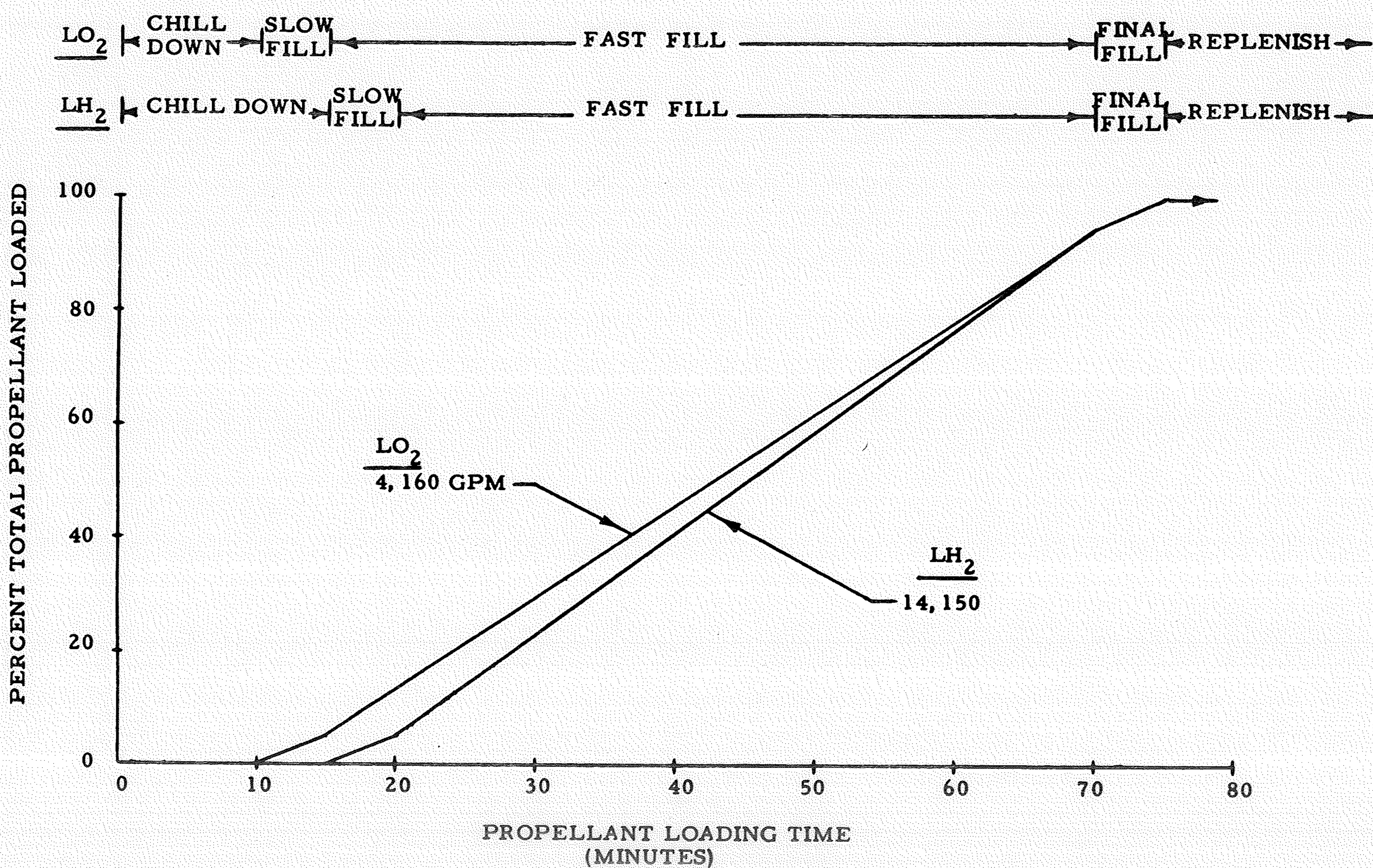


Fig. 2. Parallel Propellant Loading

Each hazard was evaluated against these criteria and an assessment made to determine whether the hazard was of greater consequence in the series or parallel method of propellant loading. The following paragraphs contain a discussion of the more critical hazards occurring in each of the systems.

5.3.1 Series Loading

In the series method of loading the flow rate in both the LO_2 and LH_2 transfer is approximately twice that of the respective transfer line in the parallel method. If a failure in any one of the lines in a series loading system should occur, the potential for larger amounts of spillage would exist, creating a greater hazard with respect to fire and thermal shock of surrounding structures. Additionally, the faster filling of the vehicle tanks also creates a potentially greater hazard relative to structural damage of components. An assessment of the relative fire hazards of the two loading methods indicates that a higher fire hazard exists for the series loading method (Fig. 3). The fire hazard was evaluated as a function of potential heat release. The heat released in the event of a vehicle fire is directly relatable to the LO_2 available to support combustion of the vehicle structural materials. A comparison of the loading methods, Figs. 1 and 2, will show that the series method provides larger quantities of LO_2 that would support combustion earlier in the loading cycle than does the parallel method.

5.3.2 Parallel Loading

The parallel loading method allows lower flows in both the LH_2 and LO_2 systems than the series method. However, if a failure in one of the systems (LO_2 or LH_2) should create a failure in the other system, the potential for mixing of the two fluids at rapid flow rates exists. A failure of this type in the parallel system would create a greater explosion hazard than the series method of loading where only one of these fluids is flowing at rapid rates at any one time. With respect to the fluids in the vehicle tanks, it can be shown that a greater explosive potential exists for the parallel

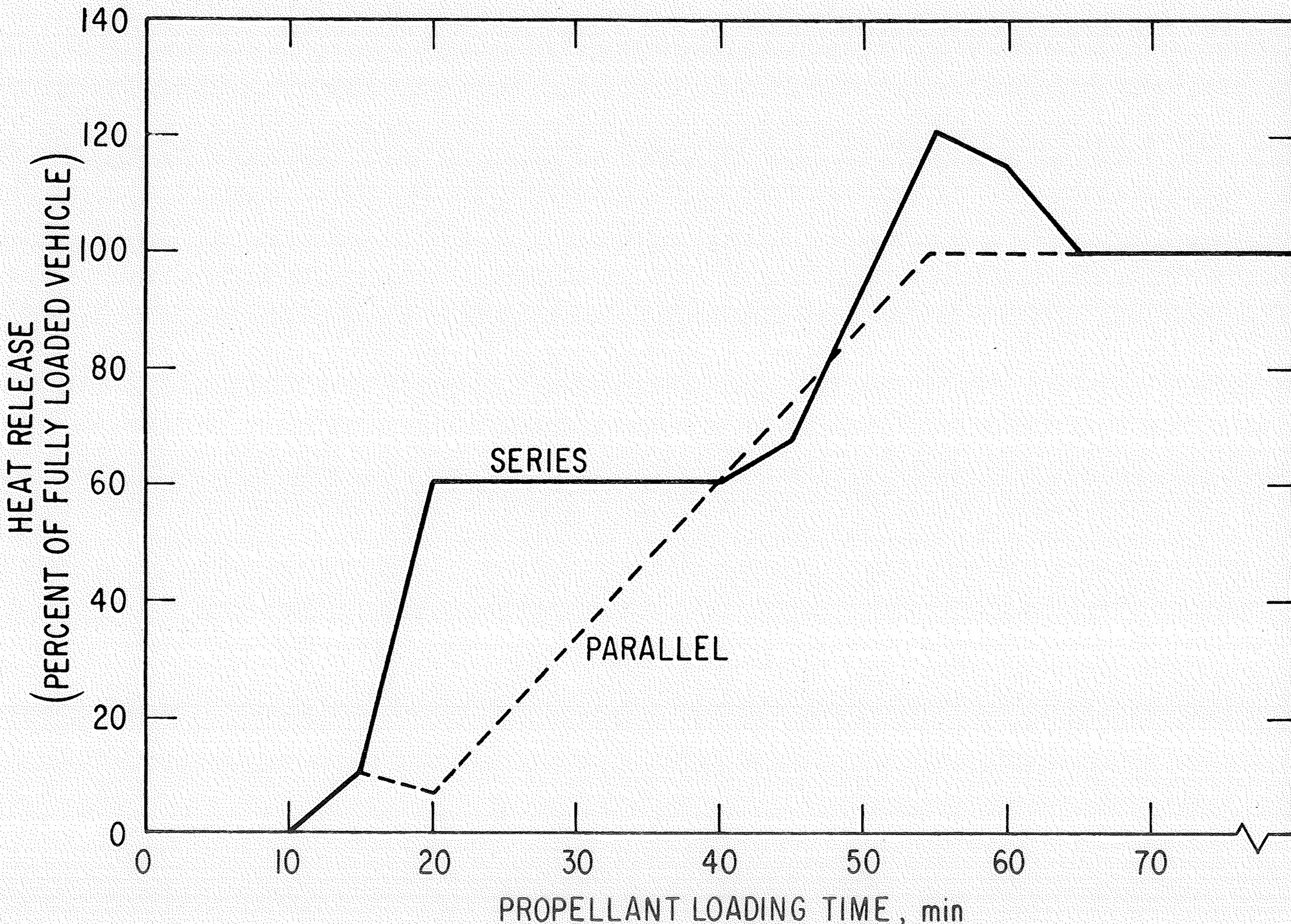
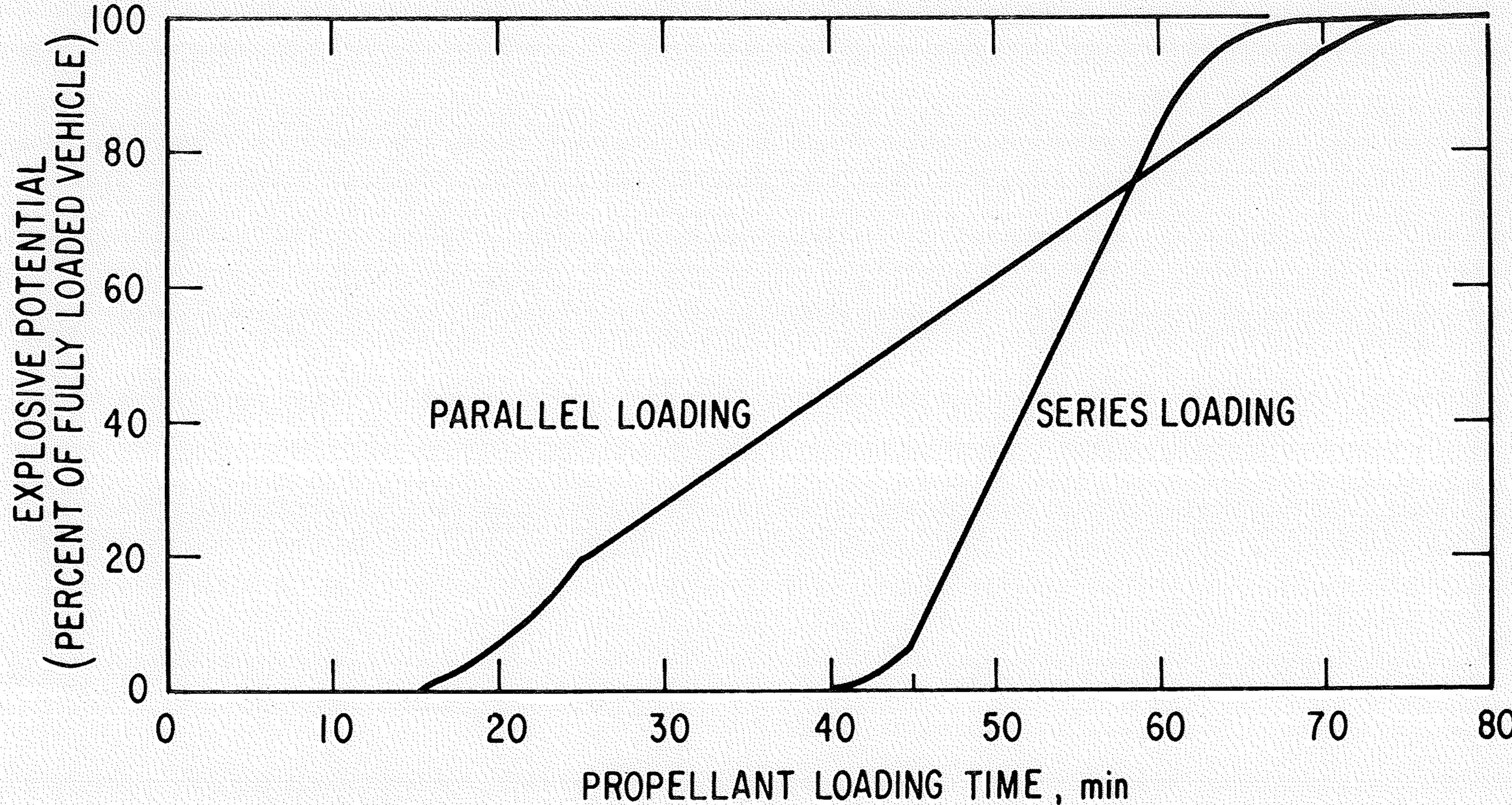


Fig. 3. Vehicle Fire Hazard Versus Loading Time

method (Fig. 4). Furthermore, the backout time to drain vehicle tanks would be greater because of the smaller line size (Fig. 5). In the case of no pressurization, the maximum drain times are in the order of 186 and 115 minutes for LH_2 and LO_2, respectively. A summation of the individual hazards assessments indicates that the parallel loading system is potentially more dangerous.

5.4 EFFECT OF VARYING LOADING TIMES

A reduction of the parallel loading time to approximately one-half of the total series loading time would equalize rapid load rates between series and parallel loading and would, therefore, require equal line sizes for both series and parallel methods. As a result, the explosive hazard of the fluids in the vehicle tank, the backout time, the propellant loading system line spillage, and the structural damage potentials would be equalized between the parallel and the series method. However, the explosion potential of the propellant loading system lines would be increased somewhat since simultaneous rapid flow of the two fluids at a higher rate would occur. The fire hazard due to the fluid stored in the vehicle tank would still be higher for the series method of operation, since LO_2 would be available for combustion with the materials in the vehicle structure.



ASSUMPTION:

1. EXPLOSIVE HAZARD EXISTS ONLY WHEN LH_2 IS ON-BOARD
2. WHEN EXCESS LO_2 IS AVAILABLE, ONLY THE AMOUNT REQUIRED FOR A STOICHIOMETRIC REACTION IS INCLUDED, I.E., 8 lb LO_2/1 lb LH_2

Fig. 4. Vehicle Explosive Hazard Versus Loading Time

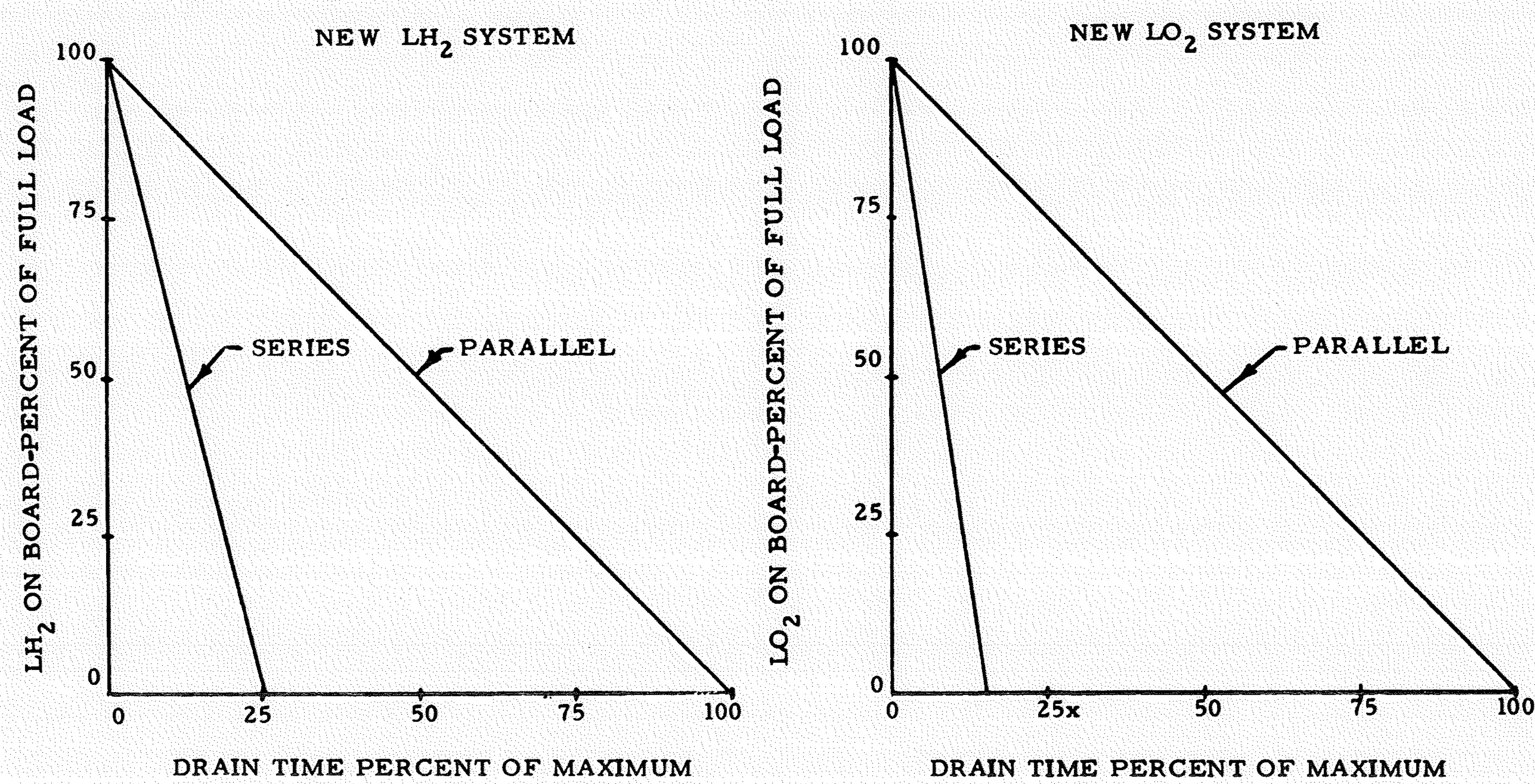


Fig. 5. Relative Propellant Drain Times
(Fully Loaded Vehicle)

6. STUDY LIMITATIONS

The results of this study are constrained by the top level nature of the study and by the vehicle tank and propellant subsystem design details available.

7. CONCLUSIONS

An evaluation of the overall hazards pertaining to the propellant loading of the Space Shuttle lead to the conclusion that for equal total loading times the parallel loading method is potentially more hazardous than the series method of loading.

If desired, the hazard level for the two systems can be made equal for a given overall propellant loading time by utilizing identical hardware in the two systems. The costs of implementing such a change would negate the potential cost savings indicated for the parallel system.

To obtain the best features of both systems at a minimum safety impact it is recommended that the system be designed to operate in either mode with series loading used as the normal mode of operation. To operate in this manner the time allocated for series loading would have to be twice that considered for parallel loading (e.g., 150 minutes for series and 75 minutes for parallel). The rationale for this recommendation assumes that the reaction time for the majority of missions would not be so critical as to require the 75-minute loading capability; however, should an emergency arise, the 75-minute parallel loading capability would be available to reduce the reaction time.

8. SUGGESTED ADDITIONAL EFFORT

This study was confined to a top level analysis of the safety implications of loading propellants into the main propulsion tanks of the Space Shuttle. It is suggested that a study be conducted to determine the safety hazards associated with loading propellants into the various payloads to be carried by the shuttle. Such a study of the payload is considered beneficial since it must also consider the use of propellants other than LO_2 and LH_2, some of which may be hypergolic. The safety implications of a payload malfunction as it impacts the shuttle should also be considered in that study.

AEROSPACE CORPORATION

INTERNAL DISTRIBUTION LIST

(REFERENCE: COMPANY PRACTICE 7-21-1)

REPORT TITLE

STS Parallel vs. Series Propellant Transfer Hazard Analysis

REPORT NO.	PUBLICATION DATE	SECURITY CLASSIFICATION
ATR-71(7233)-1, Vol. I	71 JUN 3Ø	Unclassified

(NOTE: FOR OFF-SITE PERSONNEL, SHOW LOCATION SYMBOL, e.g. JOHN Q. PUBLIC/VAFB)

J. Bazyk
R. M. Coulston
R. J. DeLorenzo
G. M. Kelsey
R. E. Kendall
N. R. O'Brien
A. G. Norem
W. F. Radcliffe
L. R. Sitney
J. R. Smith
J. Steinman
R. Toutant
D. E. Wilkins
D. Willens
R. R. Wolfe

APPROVED BY D E Wilkins DATE 3/25/71

SHEET ______ OF ______

AEROSPACE FORM 2394 REV 7-66

AEROSPACE CORPORATION

EXTERNAL DISTRIBUTION LIST

(REFERENCE: COMPANY PRACTICE 7-21-1)

REPORT TITLE

STS Parallel vs. Series Propellant Transfer Hazard Analysis

REPORT NO.	PUBLICATION DATE	SECURITY CLASSIFICATION
ATR-71(7233)-1, Vol. I	71 JUN 30	Unclassified

MILITARY AND GOVERNMENT OFFICES	ASSOCIATE CONTRACTORS AND OTHERS

(NOTE: SHOW FULL MAILING ADDRESS; INCLUDE ZIP CODE, MILITARY OFFICE SYMBOL, AND "ATTENTION" LINE.)

NASA Scientific and Technical (3 copies)
Information Facility
P. O. Box 33
College Park, Maryland 20740

NASA Headquarters
Washington, D. C. 20546
Attention: New Technology Representative
Code: UT

NASA Headquarters
Washington, D. C. 20546
Attention Code: MT (50 copies)

SAMSO
Air Force Unit Post Office
Los Angeles, Calif 90045
Attn: Lt Col R. S. Bearman (2 copies)

AFR 310-2 DISTRIBUTION STATEMENTS X'd BELOW APPLY

1.	2.	3.	4.	5.

IF LIST COMPRISES TWO OR MORE SHEETS, COMPLETE THIS SIGNATURE BLOCK ON LAST SHEET ONLY

APPROVED BY Robert R. Wolfe (FOR AEROSPACE CORPORATION) DATE 7/2/71

APPROVED BY ______ (FOR COGNIZANT AF OFFICE) ______ (SYMBOL) DATE ______

SHEET ______ OF ______

AEROSPACE FORM 2380 REV 11-66