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SPACE SHUTTLE SORTIE PAYLOAD CREW SAFETY AND SYSTEMS COMPATIBILITY CRITERIA

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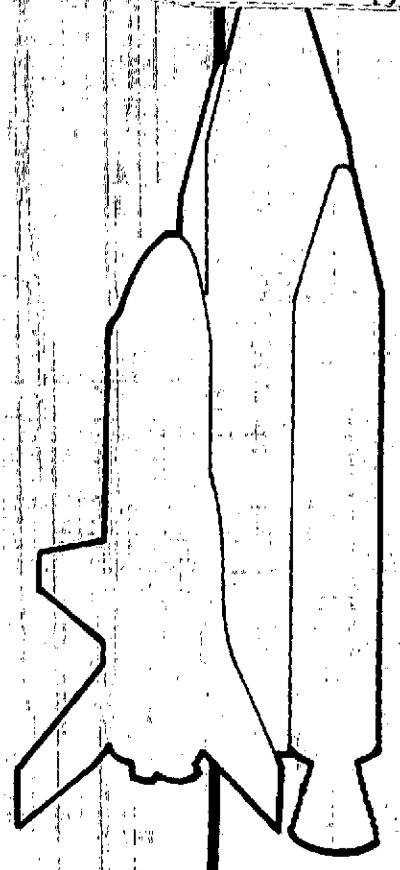

Volume III

Systems Compatibility Design and Verification Criteria

15 MAY 1973

FINAL REPORT

TRW
SYSTEMS GROUP

22215-H014-R0-00

SPACE SHUTTLE SORTIE PAYLOAD
CREW SAFETY AND SYSTEMS COMPATIBILITY CRITERIA

VOLUME III - SYSTEMS COMPATIBILITY DESIGN AND VERIFICATION CRITERIA

Prepared for

National Aeronautics and Space Administration
Lyndon B. Johnson Space Center
Houston, Texas 77058

Under Contract
NAS9-12741

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TRW
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ABSTRACT

This study final report is submitted to NASA/JSC by TRW Systems Group in accordance with contract NAS9-12741. As part of the effort to reduce the costs of shuttle payloads, this study was performed to determine the minimum, mandatory design and verification criteria necessary to insure that sortie payloads are compatible with the space shuttle system; distinguishing them from those criteria related primarily to mission success, configuration choices, management prerogatives, or other cost-benefit variables which are, therefore, discretionary to payload project management. Results from an investigation of past practices in spacecraft and aircraft programs served as a baseline of information used to identify and determine candidate criteria and also to develop a design and verification categorization methodology which distinguishes candidate criteria as mandatory or discretionary. This study concluded that utilization of the mandatory design criteria, presented in this report, as the basis for sortie payload specifications will produce basic systems compatibility between the orbiter and its sortie payloads at reduced costs. Also, when additional criteria are generated due to changes in subsystems, designs, or guidelines, the categorization methodology developed can aid managerial decision-making concerning these criteria. To a limited degree, the compatibility criteria as defined in this study reflect a portion of the total system safety effort involved in a manned space program.

FOREWORD

Space shuttle characteristics are expected to allow selective easing of many cost-inducing criteria now required of payloads placed in orbit by expendable launch systems. Of particular interest is the prerequisite of identifying and differentiating between the minimum, mandatory design and verification criteria for sortie payloads and all other criteria for payload projects.

The TRW Systems Group under two concurrent contracts to NASA/JSC (NAS9-12741 and NAS9-12742) has performed a combined study effort entitled "Space Shuttle Sortie Payload Crew Safety and Systems Compatibility Criteria" for the express purpose of addressing the determination of mandatory and discretionary design and verification criteria applicable to sortie payloads from operational space shuttle management viewpoint. The study projects were performed during the period from 16 May 1972 through 15 May 1973.

The studies were sponsored jointly by NASA Headquarter's Mission and Payload Integration Office of the Office of Manned Space Flight, and the Lyndon B. Johnson Space Center's Engineering and Development Directorate. Study direction was provided by Mr. Earle M. Crum of the Future Programs Division, Payloads Engineering Office. He was assisted by a NASA Management Team representing NASA Headquarters, Johnson Space; Kennedy Space; Langley Research; Lewis Research; and Marshall Space Flight Centers.

The results of these studies are documented in the following three volumes:

Space Shuttle Sortie Payload Crew Safety and Systems Compatibility Criteria Documentation

Volume	Title	Document No.
I	Executive Summary	22214/22215-H013-R0-00
II	Crew Safety Design and Verification Criteria	22214-H014-R0-00
III	Systems Compatibility Design and Verification Criteria	22215-H014-R0-00

TABLE OF CONTENTS

TABLES

FIGURES

NOMENCLATURE

AC	Alternating Current
A/C	Aircraft
AFSC	Air Force Systems Command
ALSEP	Apollo Lunar Surface Experiment Package
ARC	Ames Research Center
ASP	Airborne Science Program
ASPO	Apollo Spacecraft Program Office
c.g.	Center of Gravity
COMM	Communications
CO_2	Carbon Dioxide
CSM	Command and Service Module
CV	Convair
D	Discretionary
DAC	Douglas Aircraft Company
DC	Direct Current
D&C	Displays and Controls
DH	Design Handbook
DOD	Department of Defense
DP&S	Data Processing and Software
ECLS	Environmental Control and Life Support
ELEC	Electrical
EMC	Electromagnetic Compatibility
EMI	Electromagnetic Interference
EOS	Earth Orbiting Shuttle
ERAP	Earth Resources Aircraft Program
EVA	Extravehicular Activity
FOV	Field-of-View

NOMENCLATURE (Continued)

g	Gravity
GDCA	General Dynamics Convair Aerospace Division
GEN	General
GFE	Government Furnished Equipment
G&N	Guidance and Navigation
GN&C	Guidance, Navigation and Control
GSFC	Goddard Space Flight Center
GSE	Ground Support Equipment
HEAO	High Energy Astronomical Observatory
HTS	Heat Transport System
HV	High Voltage
ICD	Interface Control Document
INST	Instrumentation
IVA	Intravehicular Activity
JSC	Johnson Space Center
KSC	Kennedy Space Center
LM	Lunar Module
LED	LM Engineering Document
LEM	Lunar Excursion Module
LSP	LM Specification
LV	Low Voltage
M	Mandatory
MIL	Military
MOL	Manned Orbiting Laboratory
MSC	Manned Spacecraft Center
MSCM	Manned Spacecraft Center Manual

NOMENCLATURE (Continued)

MSF	Manned Space Flight
MSFC	Marshall Space Flight Center
MSS	Mission Specialist Station
NAS	National Aeronautics and Space
NASA	National Aeronautics and Space Administration
NHB	NASA Handbook
NR	North American Rockwell
O&C	Operations and Checkout
OBCO	On-Board Checkout
OGO	Orbiting Geophysical Observatory
P&F	Particles and Fields
P&I	Performance and Interface
PCDS	Payload Command Decoder Subunit
PGA	Pressurized Garment Assembly
P/L	Payload
PLE	Payload Environment
PSS	Payload Specialist Station
PYRO	Pyrotechnic
RAM	Research and Applications Modules
RAU	Regional Acquisition Unit
R&D	Research and Development
RF	Radio Frequency
R&QA	Reliability and Quality Assurance
RMS	Remote Manipulator System
SD	Space Division of Rockwell
SIM	Scientific Instrument Module
SOAR	Shuttle Orbital Applications and Requirements

NOMENCLATURE (Concluded)

SP	Special Publications
SPEC	Specification
STD	Standards
STRU	Structures
TDDS	TV Data Display Systems
THER	Thermal
TM	Technical Manual
TOR	Technical Operating Report
TV	Television
U	Unclassified
VAC	Vacuum

1. INTRODUCTION

1.1 BACKGROUND

NASA is currently examining shuttle payload costs in an effort to both more accurately predict and reduce such costs. History indicates that the criteria applied by NASA to previous space payloads caused them to be quite expensive. This practice was acceptable considering the costs associated with the launch and the necessity for a high probability of mission success. However, when these costs are used to estimate the cost of future shuttle payloads, it is evident that there would soon be a cost factor limiting the use of the shuttle.

Fortunately, the shuttle characteristics will allow selectively easing many of the cost-inducing criteria now placed on expendable launch system payloads. Relaxing these criteria is expected to greatly reduce the cost of space payload development.

Central to those cost-reducing efforts must be the capability to identify and differentiate between the minimum, mandatory design and verification criteria for shuttle sortie payloads and all other candidate criteria for payload projects. Accordingly, this study will contribute to lower sortie payload costs by producing a methodology capable of defining the minimum criteria required for a compatible sortie payload. The resulting criteria will form the basis of future specifications to be developed when quantitative shuttle data are available.

1.2 OBJECTIVES

The prime objective of this study was to identify the minimum, mandatory payload design and verification criteria necessary to insure that sortie payloads are compatible with the space shuttle system, distinguishing them from those criteria related to mission success, configuration choices or management approaches which are, therefore, discretionary to payload project management as variables in cost-benefit trades. Specific study objectives are tabulated in Table 1-1.

Table 1-1. Specific Study Objectives

- Research, identify, and analyze past compatibility design practices in analogous payload situations to establish a historical perspective and to utilize available experience.
- Establish categorizing processes for distinguishing between shuttle mandatory and discretionary compatibility design and verification criteria.
- Identify the mandatory design and verification criteria that are required by shuttle management to insure systems compatibility of sortie payloads with the space shuttle system.
- Identify the compatibility design and verification criteria that are discretionary to payload management as variables in cost-benefit trades.

1.3 SCOPE

The scope of this study is bounded by the sortie payload philosophy shown in Figure 1-1. A shuttle sortie payload may consist of one or more major elements. These elements remain attached to the orbiter at all times and therefore do not include propulsion systems nor free-flying satellites. A given sortie payload may interface with the shuttle mission specialist station (MSS) and payload specialist station (PSS) and excludes a remote manipulation system. Several pallets of experimental equipment may reside in the payload bay as well as piggy-back package(s). Additionally, as in Skylab, some experiment equipments may also be included in the orbiter crew compartments.

Accordingly, the criteria derived by this study are applicable to sortie payload elements carried in the shuttle payload bay or in the crew compartments.

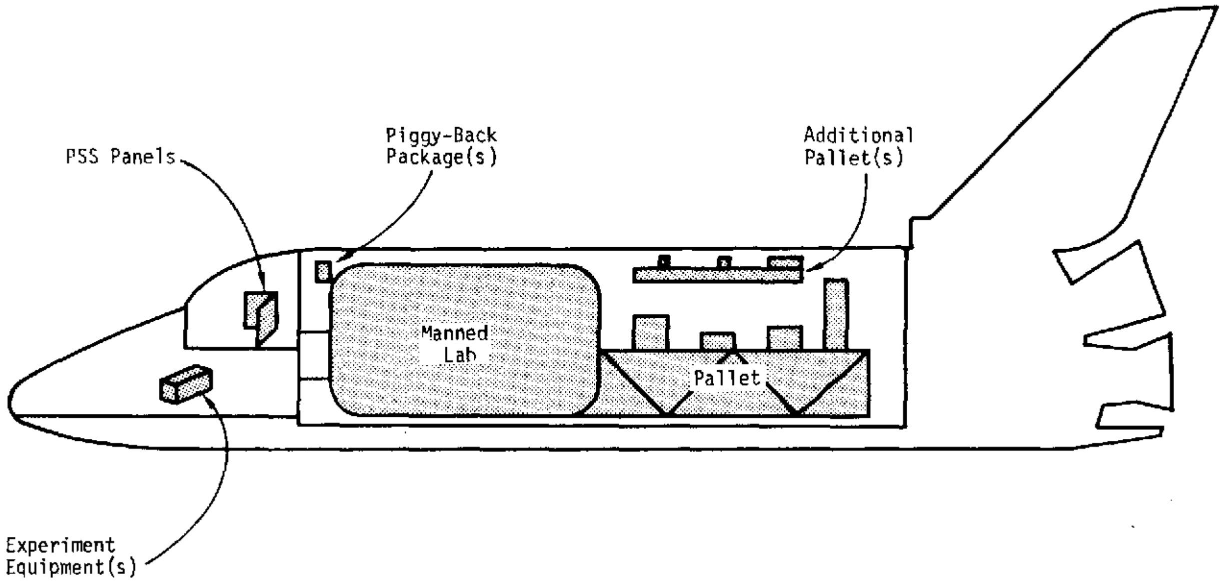

Figure 1-1. Shuttle Sortie Payload Philosophy

Since sortie payloads are pre-phase A in development, a generalized sortie payload was conceived against which an interface design analysis could be made. This generalized payload model contains the subsystems, instruments, and considerations known to be included in representative sortie payloads and is defined in Section 4.

The basic guidelines employed in the study are summarized in Table 1-2.

Table 1-2. Study Guidelines

- This study addresses the post R&D, operational shuttle era assuming a mature, fixed-design, "shuttle airlines" flight operations capability oriented to low-complexity, low-cost operations.
- Design and test considerations include only those imposed by the space shuttle for mission purposes and are confined within the limits from terminal countdown through a normal landing.
- Whether payload equipment is from the civilian sector or GFE should not alter the applicability of the shuttle imposed mandatory criteria. The payload should be given maximum possible latitude.
- Extravehicular activity (EVA) requirements are not excluded from a sortie payload. However, shuttle EVA equipment are excluded from assignment to the payload.
- Study definitions:
  - Criteria are general rules by which the acceptability of shuttle payloads may be determined.
  - Specifications are the translations of criteria into explicit, usually quantitative, statements suitable for detailed design and test purposes. A criterion may translate into several specifications.
  - Requirements may be criteria or specifications which have been imposed by appropriate administrative authority.
  - Orbiter/payload interface is a point (or area) where a physical relationship exists between the orbiter and payload, or between major payload elements, wherein physical and/or functional compatibility is required.
  - Systems compatibility involves those payload interface design features that must be satisfied so that the payload elements and the orbiter can function together within acceptable degrees of mutual tolerance. Compatibility between payload elements is defined to encompass the same considerations as those between the payload and the orbiter.
  - Mandatory systems compatibility design criteria and verification levels are defined, levied and controlled by shuttle management and are obligatory to all sortie payload elements. However, certain of these criteria that affect only the payload may be controlled by payload management.
  - Discretionary design criteria make up all other criteria. Implementation and verification of these criteria are subject to payload project management prerogatives.

2. PRECEDENT PRACTICES RESEARCH

An investigation of past practices in spacecraft and aircraft programs was accomplished to establish a historical perspective and a baseline of information in the form of conclusions and recommendations applicable to this study.

2.1 APPROACH

The basic standard for selection of programs for investigation was that they be analogous to the shuttle-payload situation. This basic standard was expanded into a set of guidelines to be used in the selection of past programs. Table 2-1 itemizes these guidelines and indicates the rationale or analogy to the shuttle for each guideline.

A wide variety of programs were selected based upon the guidelines. Twelve programs were addressed and are presented in Table 2-2 along with comments on their applicability. Although not considered as past programs, two shuttle-related study reports, Research and Applications Module (RAM) and Shuttle Orbital Applications and Requirements (SOAR) studies (References 1 and 2), were provided by NASA to give current perspective concerning some sortie payloads, payload integration and other pertinent planning details. These programs and studies were considered to cover an adequate cross section of applicable programs necessary to obtain a comprehensive understanding of the practices, procedures, and methods of analogous programs.

Utilizing the available information sources shown in Table 2-3, a plan was formulated for researching the selected programs. This plan consisted of a series of requirements, shown in Table 2-4, obtained from each of the selected programs. These requirements, along with appropriate documentation, provided a comprehensive insight as to how the compatibility problem was handled on these programs. In addition, a basis for recommending those past practices and procedures which should not be carried forward into the shuttle era was established.

Table 2-1. Past Program Selection Guidelines

• Programs were either manned or unmanned.	- Shuttle is a manned program. Payloads were integrated onto unmanned programs as will be done on shuttle. Further, many techniques of unmanned programs may be applicable to the shuttle.
• Payload carrier was an aircraft or spacecraft.	- The shuttle is a spacecraft but has many of the attributes and characteristics of aircraft.
• Payload was a scientific experiment.	- Shuttle payloads, for the most part, will be scientific in nature.
• Preferable that the carrier vehicle accommodated several independent payloads.	- The shuttle will carry a variety of independent payloads.
• Carrier vehicle levied compatibility requirements on the payloads.	- The shuttle will require that payloads be compatible with the shuttle vehicle.
• Select the most recent and most accessible of the past programs.	- It was not feasible to research all programs; the most recent programs provide the latest technology.

Table 2-2. Past Programs Selected for Historical Research

PROGRAMS	APPLICABILITY
Manned Spacecraft	
• Apollo SIM Bay	A major manned program. Payloads were controlled from crew cabin. EVA activities. Several payloads integrated
• Apollo Lunar Surface Experiments Package (ALSEP)	A major manned program. EVA considerations
• Apollo Particles and Fields Subsatellite	As part of SIM bay experiments, gave more detailed view of integration problems by considering an individual payload
• Skylab Experiments	Aspects of sortie lab. Many experiments integrated
Unmanned Spacecraft	
• High Energy Astronomical Observatory (HEAO)	A large payload that was scheduled to be a shuttle payload
• Orbiting Geophysical Observatory (OGO)	Integrated approximately 27 different experiments
• Pioneer	Interplanetary vehicle considerations; met other guidelines
• Scout • Thor-Delta	Scout and Delta were low-cost utility-type vehicles which carried a variety of payloads.
• Vela	Highly successful spacecraft program which was typical of many others with respect to documentation methods
Aircraft Programs	
• Earth Resources Aircraft Program (ERAP) • Airborne Science Program (ASP) (CV-990 Aircraft)	These aircraft programs have cost-effective aspects that could be adopted by the shuttle.

Table 2-3. Historical Research Information Sources

DATA SOURCE	PROGRAM
NASA	
Johnson Space Center	
Engineering and Development Directorate	ALSEP (3, 4)*, Apollo SIM Bay Experiments (5), ERAP (6), RAM (1), SOAR (2)
Skylab Program Office	Skylab Experiments (7)
Ames Research Center	ASP (CV-990) (8)
Langley Research Center	Scout (9)
Marshall Space Flight Center	Skylab Experiments (7), Shuttle (10)
Contractors	
North American Rockwell	Apollo SIM Bay Experiments (5)
McDonnell Douglas Corporation	Thor-Delta (11, 12), Shuttle (13)
Vought Missiles and Space Company	Scout (9)
Boeing Aerospace	Skylab Experiments (7)
TRW	OGO (14), Pioneer (15, 16), Vela (17, 18), HEAO (19), P&F Subsatellite
Documentation (Other than from above sources)	
Aerospace Corporation	Shuttle (20)
Lockheed Missiles and Space Corporation	Shuttle (21)
Grumman Aerospace Corporation	ALSEP (22)

*Documentation references in parentheses

Table 2-4. Precedent Practices Research Requirements

1. Determine the criteria used to write payload design specifications that were placed upon experimenters to assure compatibility. If not available, obtain payload specifications. Determine the rationale or justification for implementing each criterion or specification.
2. Determine the payload testing criteria or specifications used to achieve design compatibility with the payload carrier vehicle or with other payloads.
3. Determine the payload design and test criteria or specifications designated as mandatory. Determine the guidelines used to classify these criteria as mandatory.
4. Which of these design and test criteria or specifications were relaxed or revised from their original requirement as problems arose in order to meet the compatibility requirement? What was the original requirement and what caused the change?
5. Determine which criteria or specifications resulted in high production or testing costs with respect to overall costs.
6. Determine the significant payload integration problems and how they were solved. This includes both payload-to-vehicle and payload-to-payload compatibility problems.
7. Determine how successful the payloads were and if any failures were due to integration problems.
8. Determine the criteria and philosophy concerning off-the-shelf or standard components used in the payloads.

2.2 CONCLUSIONS

Conclusions from the historical research effort evolved into statements which applied to one or more of the programs investigated. These statements, itemized in Table 2-5, represent a summary of the information gained from the research requirements and the documentation that was reviewed. From these conclusions, recommendations for application to subsequent study requirements were formulated.

An additional result of the historical research was an accumulation of specifications, requirements, guidelines, and criteria utilized by these programs to guide payload development and integration. This accumulation became the baseline for sortie payload criteria determination and development which is discussed in Section 4.

2.3 RECOMMENDATIONS

The recommendations resulting from the analysis of past practices, shown in Table 2-6, were presented to and approved by the NASA Management Team at the study formal mid-term review. Where applicable, the recommendations were formulated employing the terminology of the study. They were geared toward being utilized as a baseline for the development of design and verification criteria as well as the categorization processes (see Section 3) that were developed to distinguish between mandatory and discretionary criteria. Therefore, each recommendation is reflected in the categorization processes, in the manner criteria were developed, or in philosophies which would contribute to overall cost reduction of payloads in the shuttle era.

Table 2-5. Conclusions from Investigation of Previous Programs

CONCLUSIONS	PROGRAMS: MANNED SPACECRAFT				UNMANNED SPACECRAFT						AIRBORNE	
	APOLLO SIM BAY	APOLLO P&F SUBSAT.	ALSEP	SKYLAB	SCOUT	THOR-DELTA	PIONEER	VELA	HEAO	OGO	ERAP	ASP
1. Procedures, methods, philosophy, etc., utilized in the past resulted in successful programs.	X	X	X	X	X	X	X	X	X	X	X	X
2. Programs had "one-chance" to assure that payloads were compatible with the spacecraft; therefore, previous practices were geared toward mission success of the payloads on first attempt. For this reason, functional requirements were not separated from compatibility design and verification requirements.	X	X	X	X	X	X	X	X	X	X		
3. Common practice is for NASA to fly only equipment that meets all government specifications.	X	X	X	X	X	X	X	X	X	X	X	
4. Experimenters were supplied with guiding documents (such as P&I specs, ICD's, or handbooks) which gave design and test requirements to various levels of detail with the type of program determining this level.	X	X	X	X	X	X	X	X	X	X	X	X
5. The number of payload requirements and specifications levied were directly proportional to the cost of payload delivery.												
• Highest Complexity: MSF & Interplanetary Programs	X	X	X	X			X					
• Lower Complexity: Unmanned Programs								X	X	X		
• Lowest Complexity: A/C and Certain Unmanned Programs					X	X					X	X

Table 2-5. Conclusions from Investigation of Previous Programs (Continued)

CONCLUSIONS	PROGRAMS: MANNED SPACECRAFT				PROGRAMS: UNMANNED SPACECRAFT						PROGRAMS: AIR-BORNE	
	APOLLO SIM BAY	APOLLO P&F SUBSAT.	ALSEP	SKYLAB	SCOUT	THOR-DELTA	PIONEER	VELA	HEAO	OGO	ERAP	ASP
6. Compliance with the requirements levied was considered mandatory. However, if original requirements could not be met, a compromise or waiver would be granted based upon a cost vs. benefit analysis rather than deleting the experiment or causing extensive redesign. Therefore, many "mandatory" requirements were actually "discretionary" when it was determined the payload could not meet the requirement.	X	X	X	X	X	X	X	X	X	X	X	X
7. Programs relied heavily on generally accepted design standards.											X	X
8. Programs were R&D in nature and, from the standpoint of integrating experiment payloads, seemed to become more complex as experience was gained. Manned spacecraft programs levied even more requirements on payloads for subsequent missions rather than fewer ones.	X	X	X	X				X		X		
9. Design requirements for payload-to-spacecraft and payload-to-payload compatibility were intermeshed with the functional requirements.	X	X	X	X	X	X	X	X	X	X	X	X

22215-H014-R0-00

Table 2-5. Conclusions from Investigation of Previous Programs (Continued)

CONCLUSIONS	PROGRAMS											
	MANNED SPACECRAFT				UNMANNED SPACECRAFT						AIR-BORNE	
	APOLLO SIM BAY	APOLLO P&F SUBSAT.	ALSEP	SKYLAB	SCOUT	THOR-DELTA	PIONEER	VELA	HEAO	OGO	ERAP	ASP
10. Programs on which the spacecraft was designed or built before the payloads were known levied minimal interface requirements on the prospective payloads.					X	X				X		X
11. Programs relied heavily on formal "paperwork systems" rather than informal agreements to achieve compatibility of payloads.	X	X	X	X			X	X	X	X		
12. Insuring systems compatibility with the spacecraft was not as difficult, nor did it cause as many problems, as insuring functional reliability of the payloads.	X	X	X	X	X	X	X	X	X	X	X	
13. When the payload-to-spacecraft interface is strictly physical (i.e., the payload does not operate from the spacecraft but is merely carried by the spacecraft), compatibility requirements are minimized.		X	X		X	X		X				
14. Inflight maintenance and adjustments by operators increased payload reliability.											X	X

Table 2-5. Conclusions from Investigation of Previous Programs (Concluded)

CONCLUSIONS	PROGRAMS											
	MANNED SPACECRAFT				UNMANNED SPACECRAFT						AIR-BORNE	
	APOLLO SIM BAY	APOLLO P&F SUBSAT.	ALSEP	SKYLAB	SCOUT	THOR-DELTA	PIONEER	VELA	HEAO	OGO	ERAP	ASP
15. Nonexpendable payload carriers had re-fly and/or inflight maintenance capability which permitted flight testing rather than ground testing to assure compatibility.											X	X
16. NASA procuring regulations (traditions) dictate much testing. Essentially, the same sequence of design and testing requirements was levied regardless of application or complexity of the hardware.	X	X	X	X	X	X	X	X	X	X	X	
17. Extensive ground testing of the payloads was required by the spacecraft management to insure mission success.	X	X	X	X			X	X		X		
18. Testing was the primary method of verification of payload design, compatibility, and functional reliability.	X	X	X	X	X	X	X	X	X	X	X	
19. Testing to assure interface compatibility was an indiscrete subset of functional testing.	X	X	X	X	X	X	X	X	X	X	X	X
20. There was no such thing as "safety testing". Meeting compatibility requirements insured safety. Therefore, safety requirements became design requirements and were tested as such.	X	X	X	X	X	X	X	X	X	X	X	X

Table 2-6. Recommendations from Investigation of Previous Programs

RECOMMENDATIONS	CONCLUSION REFERENCES
1. The following recommendations should be considered prefaced with the phrase "In order to minimize the overall cost of shuttle payloads..." because past methods were successful and a prime reason for change is to reduce costs.	1
2. Minimize and standardize requirements, criteria, guidelines, etc., imposed by the space shuttle on experimenters who design and test payloads.	3, 4, 6, 7, 8, 10
3. Shuttle payload design and verification criteria should be stated in general terms and mandatory requirements should be minimal.	3, 4, 5, 6, 7, 9, 10
4. Since shuttle will not be in a "one chance for success" situation with respect to payloads, criteria and requirements once considered mandatory should be evaluated in a different perspective.	2, 6
5. Criteria levied on payloads by the orbiter to assure compatibility should be distinguishable from those criteria levied to assure payload reliability or crew safety.	2, 9
6. Compatibility criteria should also be further distinguishable as either mandatory or discretionary to shuttle management.	2, 9
7. Mandatory compatibility design criteria levied on space shuttle payloads should be only those that are imposed by the shuttle management and involve a payload-orbiter or payload-payload interface or interaction. They are the minimum criteria which permit the payload to operate in the orbiter without causing unacceptable interference with the operations or performance of the orbiter or another payload. Typically, mandatory criteria should not be waiverable or subject to negotiation.	10, 12, 13
8. Mandatory compatibility verification criteria should be required by shuttle management only for mandatory design criteria. However, every mandatory design criteria should not necessarily require a test for verification. Another verification method may suffice.	16, 17, 18, 19, 20

Table 2-6. Recommendations from Investigation of Previous Programs (Concluded)

RECOMMENDATIONS	CONCLUSION REFERENCES
9. Rely on past experience to reduce the number and severity of mandatory design and verification criteria and stress methods of design verification other than testing such as: • Similarity • Inspection • Analysis • Demonstration Experience plus intentional overdesign of interfaces (where economical and commensurate with orbiter capabilities) will eliminate much testing.	10, 12, 13, 16, 17, 18, 19, 20
10. Discretionary compatibility design criteria give payload program management additional assurance that payload reliability or operation is enhanced above a minimum acceptable level and may be made as a result of cost-benefit analyses.	6
11. Discretionary verification criteria are those levied to give additional assurance (above some minimum acceptable level that another verification method would give) that a design feature is acceptable.	6
12. Summarily, mandatory compatibility criteria should be levied by JSC shuttle management and discretionary criteria levied by payload management.	3, 4, 5, 6

3. DETERMINATION OF CATEGORIZATION PROCESSES

The objective of categorization processes determination was to develop tools which could be utilized to 1) determine if a candidate design criterion was part of the minimum, mandatory set or the discretionary set for systems compatibility, 2) generate a rationale to support the determination, and 3) determine the minimum acceptable verification method for a mandatory criterion. Two processes were developed. The first to be discussed, the design categorization process, was structured to utilize the boundaries of the study to systematically determine those criteria which are the minimum required for systems compatibility. These mandatory criteria are distinguished by the process from all other criteria because they are required for nominal payload/orbiter operation. The other methodology, the verification process, was structured to determine the minimum level of verification necessary to verify a mandatory design criterion. The remainder of this section details the general approach utilized in this development along with specific and detailed descriptions of the processes.

3.1 APPROACH

A "logic tree" methodology consisting of a series of analytical questions was utilized for formulating the categorization processes. The processes were developed based upon guidelines and assumptions which were derived from analysis of the objectives and scope of the study, Precedent Practices Research recommendations, and other NASA recommendations and directives. Table 3-1 itemizes these basic guidelines and assumptions which, in addition to the general Study Guidelines in Table 1-1, are reflected in the structure and statements within the processes.

3.2 DESIGN CATEGORIZATION PROCESS

The objective of the design categorization process was to systematically determine for each candidate sortie payload criterion whether it is mandatory or discretionary with respect to systems compatibility. The following subsections detail the approach and results of this methodology.

Table 3-1. Categorization Processes Guidelines and Assumptions

Design Process
• Orbiter design remains fixed and the design criteria generated from the study will only affect payload design. Payload operation procedures will not be considered applicable to the study. • Compatibility design criteria involve interfaces and interactions between the orbiter and the payload. • The processes should apply to payloads already developed as well as those that will be developed in the future. • The orbiter management will levy mandatory design criteria upon payload projects that will ensure payload and orbiter compatibility for nominal operations. • Compatibility design criteria levied to prevent or circumvent a contingency or non-nominal situation will not be considered mandatory. These types of criteria will be either discretionary compatibility or crew safety criteria.
Verification Process
• The verification process will determine if a design criterion must be verified by test or by another method of verification. • The shuttle program management will require some verification level of all mandatory design criteria. • Shuttle program management will not require verification of discretionary design criteria. • Commensurate with accumulated manned space flight (MSF) experience, verification techniques other than testing will be emphasized to reduce costs.

3.2.1 General Approach

The logic diagram approach to structuring the design process is shown in Figure 3-1. Each diamond represents a significant aspect to the overall categorization problem. The first three steps of the methodology will determine if a criterion affects payload design, is applicable to a sortie payload, and if the criterion is crew safety oriented. These steps are somewhat straightforward but are necessary to meet overall study objectives and eliminate criteria that have previously been imposed but are not part of the minimum set of criteria for basic compatibility. The remaining areas of concern require more extensive analysis.

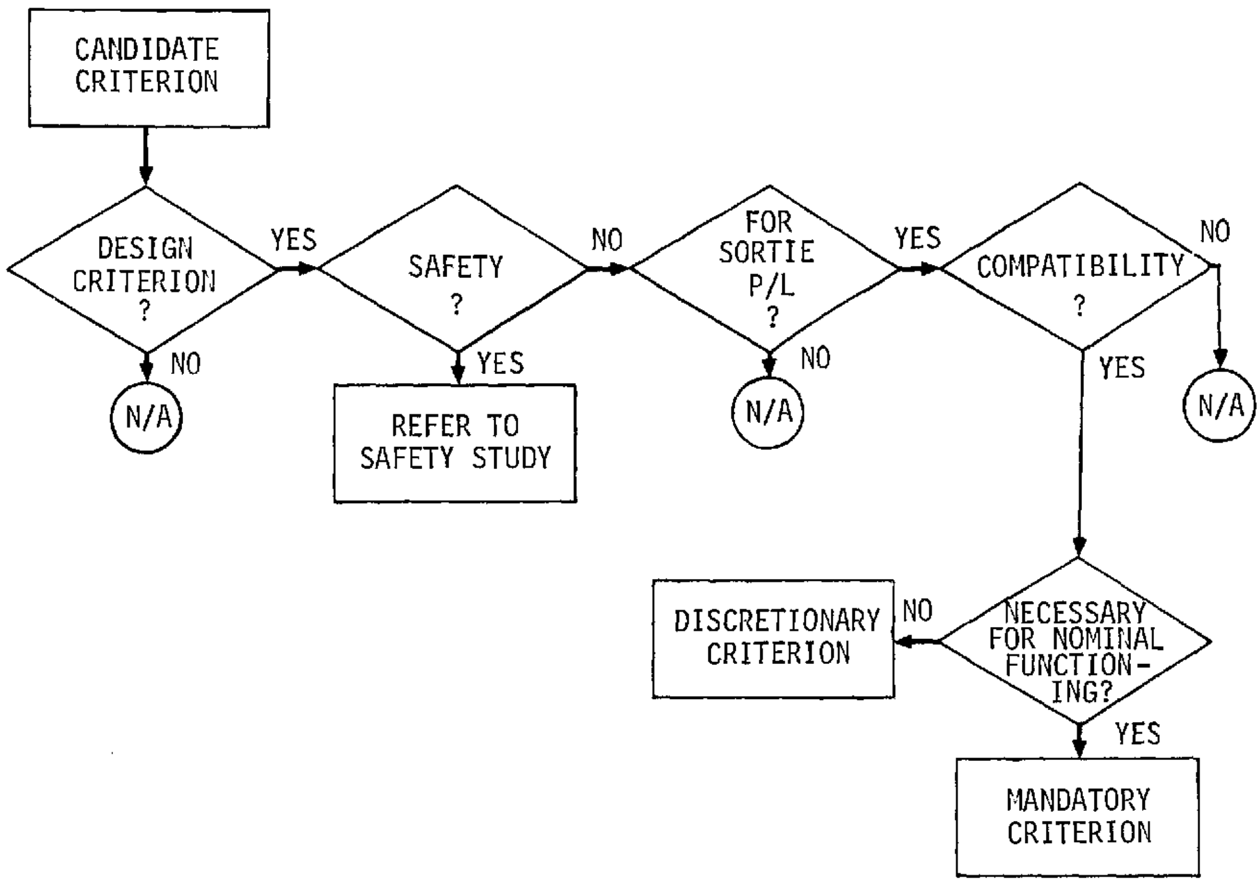

Figure 3-1. General Approach to the Design Categorization Process

Each criterion must be examined to determine if it affects an orbiter-payload interface and then if nominal operation of either the payload or orbiter is impacted by the criterion. The analysis surrounding each of these areas will yield a rationale that will logically categorize the criterion.

Because of the variation in criteria purposes and the many considerations surrounding each segment of the process, this general approach process was expanded to facilitate analysis.

3.2.2 Detailed Methodology

Expanding the general design process resulted in the detailed logic flow shown in Figure 3-2. A necessary accompaniment to this detailed methodology is further explanation and underlying considerations associated with each area of concern. The following is a block-by-block discussion of the flow.

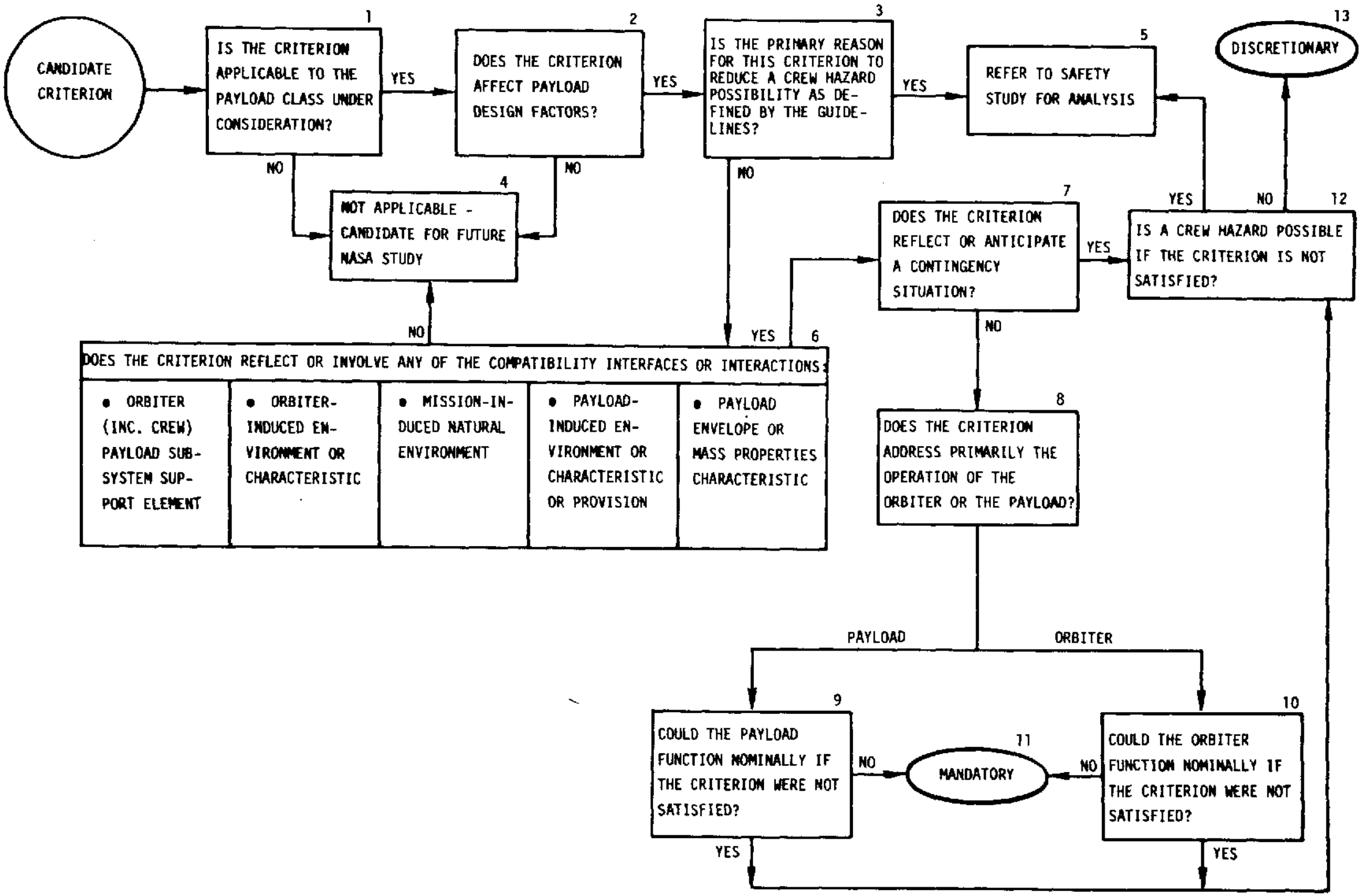

Figure 3-2. Design Categorization Process Logic Flow

22215-H014-R0-00

Block 1: Is the criterion applicable to the payload class under consideration?

A basic consideration of this study was that the design process and criteria development would consider only sortie payloads. The study definition of sortie payloads (discussed in Section 1.3) was utilized as the basis for the analysis. Specific hardware considerations precluded from investigation in this study were payloads with propulsive or kick stages, free-flyer payloads, and other ejected payloads.

Block 2: Does the criterion affect payload design factors?

A basic tenet of this study is that the criteria will be used as a basis for writing design specifications for payloads. This question is directed toward assuring that the criterion, in fact, affects payload design rather than indicating how the payload will be operated or other procedural considerations. If the criterion in question does not affect a design factor, it is not considered applicable to this study because it would lie outside the minimum mandatory set and therefore would increase mandatory compatibility costs. As shown by Block 4, the criterion is retained for possible future NASA use.

Block 3: Is the primary reason for this criterion to reduce a crew hazard possibility as defined by the guidelines?

The study was directed solely at criteria utilized for the purpose of assuring systems compatibility and not crew safety. The purpose of this question is to eliminate all criteria that are obviously safety oriented and to refer them to the associate Crew Safety Study (NAS9-12742) as directed by Block 5. Criteria context will indicate, in most cases, if the primary reason is to protect the crew from a hazard. The process has provisions in later stages to identify subtle safety criteria or those that were questionably safety oriented and permitted to proceed for further analysis.

Block 6: Does the criterion reflect or involve any of the compatibility interfaces?

- Orbiter (including crew) payload-subsystem support element
- Orbiter-induced environment or characteristic
- Mission-induced or natural environment
- Payload-provided provisions for the interface
- Payload-induced environment or characteristic
- Payload envelope or mass properties characteristic

A guideline of the compatibility study was that compatibility criteria involve interfaces and interactions. Compliance with this guideline contributes to the limitation of the mandatory compatibility criteria population and therefore to the reduction of payload integration costs. An analysis of this guideline prompted the considerations shown in Figure 3-3. Analysis of these factors, as the following paragraphs explain, resulted in the structure of the Block 6 question.

The orbiter will provide support elements to the payload such as electrical, physical attachment, and pointing/stabilizing which the payload can utilize if necessary. These support features provide an interface between the orbiter and the payload that affects payload/orbiter operation and must be considered in payload design.

Within these support elements are intrinsic characteristics which the payload must tolerate to assure proper payload operation. For example, the payload must be designed to tolerate electrical support transient characteristics. Physical attachment support includes characteristics such as shock and vibration which the payload design must tolerate.

The payload will be subjected to environmental factors from the orbiter and from natural or mission-induced sources intrinsic to the space environment. The orbiter will induce environments such as radiation, magnetic fields, and other potentially undesirable elements of which the payload designers must be made aware to assure proper payload operation. Similarly, natural or mission-induced environments such as low gravity and pressure, meteoroid impact, and atmospheric contamination must be considered.

The payload will also be required to provide accommodations to assure that the payload-orbiter interface is complete. A case in point is payloads requiring EVA to complete mission operations. Special tools or mobility aids must be provided as necessary. The payload will also be required to provide certain instrumentation such as recorders and special display equipment. These payload-provided equipments will interface with the orbiter and must be specified so that proper interface design is assured.

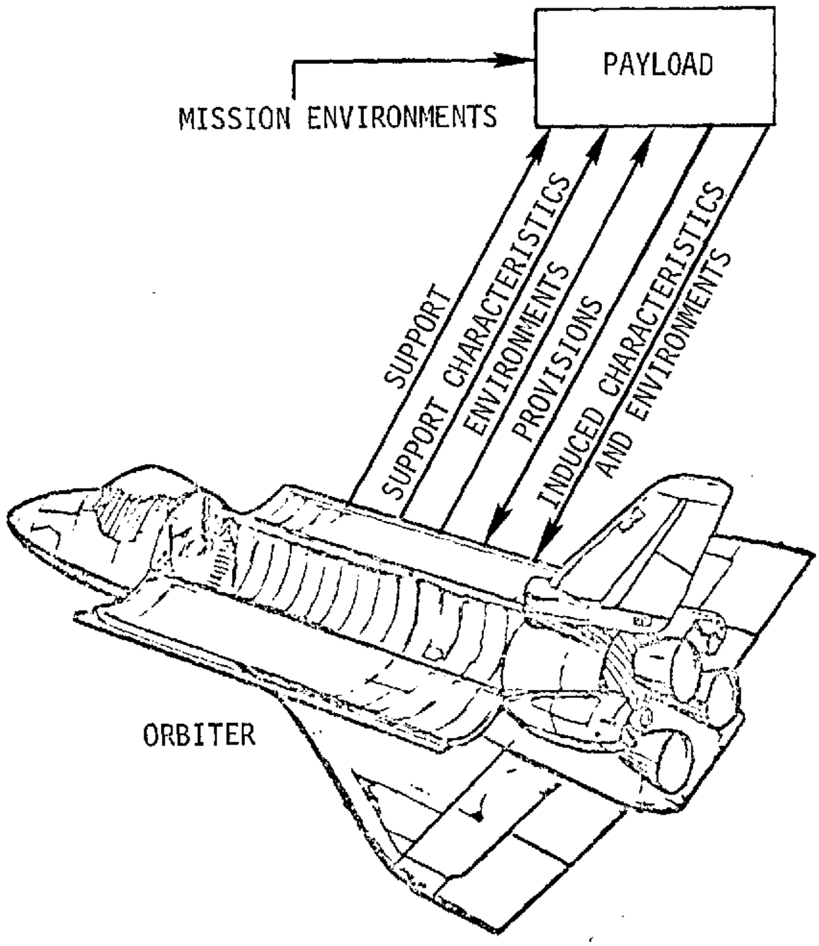

Figure 3-3. Interfaces and Interactions Considered for Compatibility

Assuring compatibility is a two-sided coin. Not only must efforts be directed toward assuring proper payload operation, but equal concentration must be made to assure that orbiter operations are not impaired by omitting certain payload criteria. These criteria fall into the general category of criteria which are ofter called "hardware safety" criteria or requirements. This study addresses a subset of that category; specifically, those criteria levied on payloads to assure that nominal orbiter operations are not impared by the payload. Typically, these criteria involve vehicle operations interference resulting from support interface with the payload. Also, nominal vehicle operation rather than crew safety is of first concern in these criteria. (Volume II of this study addresses that aspect of "hardware safety" criteria where each criterion involves crew safety as the prime consideration). Payload-induced characteristics and environments such as size, weight, and payload-generated contamination are examples of criteria elements pertinent to this category of criteria and must be considered for systems compatibility.

Utilizing the considerations of Block 6 will determine if a given criterion is, in fact, an applicable candidate compatibility criterion. Criteria not falling into one of these compatibility categories are not applicable to this study and are retained for future NASA use.

Block 7: Does the criterion reflect or anticipate a contingency situation?

A primary objective of this study is to determine the minimum, mandatory set of compatibility criteria. In doing so, prime consideration is given to those design features that assure only basic compatibility of an interface thereby bounding minimum costs. This means the minimum criteria necessary for nominal operation and functioning of the payload or the orbiter through the interface are of major concern. Then, all supplementary design features that are cost-benefit in nature can be levied at the discretion of management to avoid possible problems or abnormal influences that could impact operations. These criteria either assure crew safety or enhance payload performance or mission success. Criteria of this type receive a "YES" to the Block 6 question and are passed on to Block 12 for further analysis. Those criteria which receive a "NO" may be mandatory for compatibility and are passed to Block 8 for analysis.

Block 8: Does the criterion address primarily the operation of the orbiter or the payload?

This branching block is utilized to determine which side of the orbiter-payload interface is being primarily affected so that further, more detailed analysis can be made.

Blocks 9 and 10: Could the payload/orbiter function nominally if the criterion were not satisfied?

The most appropriate test for determining if a candidate criterion is mandatory is to analyze the consequence of not imposing the criterion. If not imposing the criterion could prevent nominal, planned operation of either the payload or the orbiter, the criterion must be considered mandatory for systems compatibility and go to Block 11. Criteria which receive a "YES" to this question are not considered mandatory and pass to Block 12 for further analysis.

Block 12: Is a crew hazard possible if the criterion is not satisfied?

One of the initial steps in this process (Block 3) checked for obvious safety criteria. Block 12 provides for another check so that, after analysis, those criteria that emerge as subtle safety oriented can be referred to the Safety Study for further analysis.

Block 13: Discretionary

The final block of the design process describes discretionary criteria--those criteria subject to cost-benefit analysis. Criteria which reach this point in the process are discretionary to shuttle management and involve the following considerations:

- Configuration choices of components, assemblies, systems, etc., not required to assure compatibility
- Enhancement of payload mission success probability over and above that provided by basic systems compatibility
- Enabling payload performance at levels which would exceed the performance levels dictated by baseline orbiter accommodations
- Other cost-benefit trades

This area completes the analysis of a candidate design criterion. As mentioned at the beginning of the design process discussion, an additional requirement of the process is to produce a rationale with each categorization determination. This is accomplished by documenting the path each criterion takes through the process. The analysis surrounding each block to which the criterion is subjected then becomes the rationale that supports the final categorization.

3.3 VERIFICATION CATEGORIZATION PROCESS

The objective of verification is to assure shuttle management that the payload has complied with a mandatory design criterion. The verification process determines for each mandatory design criterion which verification technique is considered sufficient by shuttle management as minimum, mandatory design verification. In light of past spaceflight experience coupled with the capabilities and low-cost objectives of the shuttle, verification methods other than testing can and should be emphasized. This is accomplished, as shown in Figure 3-4, by systematically analyzing the mandatory design criterion to determine if one of the other standard verification methods (similarity, analysis, inspection, demonstration) will suffice. Utilization of these other verification methods is not new, (References 6 and 7); however, as brought out here and in the recommendations from Precedent Practices Research, with the experience already obtained from space flight, employment of these methods to a greater extent should be possible. Since these methods are generally less costly to apply than testing, an overall cost-savings can be realized.

If the verification method determined is other than testing, then testing to verify the criterion is considered discretionary. Testing may be performed at the discretion of payload management to further substantiate the adequacy or reliability of the design. The following is a detailed explanation of each of the verification methods specified in Figure 3-4.

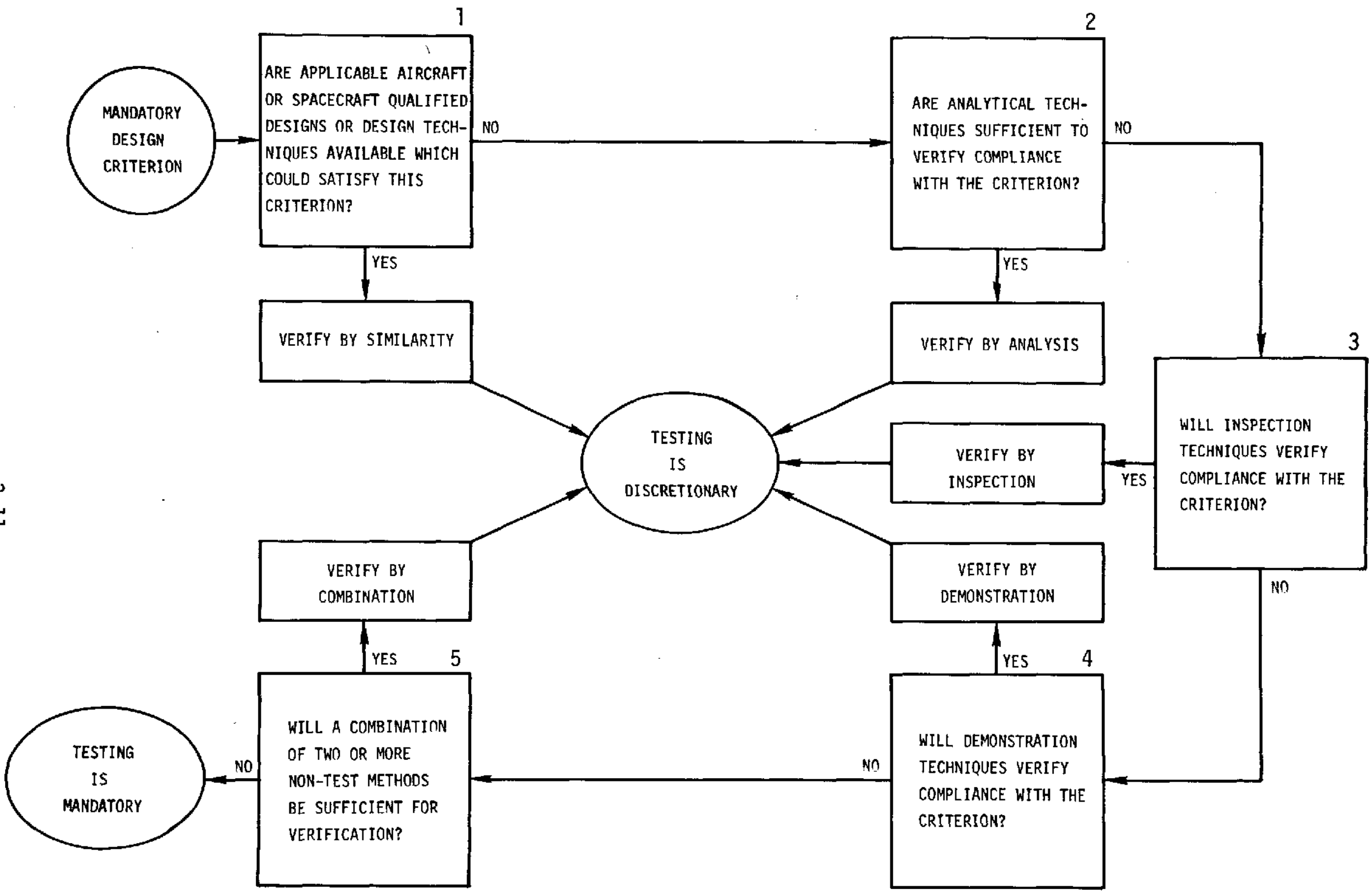

Figure 3-4. Verification Categorization Process Logic Flow

22215-H014-R0-00

Block 1: Similarity

Verification by similarity is used when the article or payload is substantially similar or identical in design, manufacturing processes, and quality control to another article that has been previously qualified to equivalent or more stringent standards. Verification by similarity may pertain to characteristics such as material, configuration, functional element or assembly. As indicated by the JSC R&QA Office Test Section, for example, equipment verified for flight on manned aircraft (such as the ERAP program) could be sufficiently qualified by similarity for spaceflight.

Block 2: Analysis

Analysis may be used in lieu of testing whenever it can be shown by generally accepted analytical techniques that an article will meet the applicable technical requirements. Increased design margins, made possible by shuttle weight and volume capabilities, will allow verification by analysis where testing was previously required.

Block 3: Inspection

Inspection can be used to verify the construction features, compliance with drawings, workmanship, and physical condition of the article. This method is utilized at design reviews and customer acceptance readiness reviews to verify design requirements.

Block 4: Demonstration

Demonstration can be used to verify such requirements as service and access, handling, convenience, and ease of operation. This method is used extensively in verifying designs that involve a man-machine interface such as crew-payload interface during EVA activities.

Block 5: Combination

Verification by combining two or more of the previously discussed methods may be utilized if one method does not provide minimum acceptable verification.

If these verification methods are not sufficient to verify a mandatory design criterion, then testing must be employed as the verification method.

4. CANDIDATE CRITERIA DETERMINATION

The objective of this portion of the study was to identify, define, and structure compatibility design criteria which would be subjected to the categorization process, discussed in Section 3, for categorization as either mandatory or discretionary. The following subparagraphs discuss the approach taken in this effort.

4.1 APPROACH

One of the initial tasks of this effort was to define, within the context of the study, the structure and general characteristics of a criterion. It was determined that a criterion should possess the characteristics noted in Table 4-1 in order for the study results to meet study objectives.

Table 4-1. Criterion Characteristics

- A criterion should be removed from a strict specification statement, i.e., non-quantitative and should be a standard to which payloads would be designed.
- The criterion should indicate that imposing the criterion will require compliance with detailed specifications and what the general content of the specifications will be.
- A criterion should clearly identify the incompatibility and/or interface being addressed.
- A criterion should be user oriented.

Before criteria could actually be structured, the data and information that would eventually form the basis of the criteria had to be collected and evaluated. A comprehensive orbiter-payload subsystem analysis was also performed to assure that the elements of compatibility between the orbiter and the payload had been considered. Finally, criteria were structured to conform to the study requirements. Each of these steps is discussed in detail in the remainder of this section.

4.2 DATA COLLECTION AND EVALUATION

The bulk of supporting data and information that subsequently comprised the criteria was gathered during the Precedent Practices Research portion of the study. Few systems compatibility criteria were found to exist in the documentation. The information consisted primarily of specifications, requirements, guidelines, and other specific program information (see Table 2-3) along with relevant, non-program data sources (References 6 and 23). Of the non-program data sources, the Manned Spacecraft Criteria and Standards document, MSCM 8080, was particularly relevant because of its significance as a stand-alone guiding document for present and past manned spacecraft programs. This information, coupled with the NASA-supplied shuttle model and appropriate shuttle payload studies documentation (References 1 and 2), formed the basis for criteria determination.

Approximately 350 data items were accumulated. Within these data items, much redundancy and overlap existed. However, by researching many programs, some assurance that coverage of the interface areas, subsystems, and other compatibility elements between payload and orbiter was realized.

Additionally, an interface design analysis was performed to add to this assurance as discussed in Subsection 4.3.

4.3 INTERFACE DESIGN ANALYSIS

The orbiter-payload interface consists of the following general considerations defined in Subsection 3.2:

- Orbiter payload-subsystems support
- Orbiter-induced environments or characteristics
- Payload-provided provisions for the interface
- Payload-induced environments or characteristics
- Mission-induced or natural environmental factors
- Payload envelope or mass properties characteristics

In order to develop criteria associated with each of these interface areas, an interface design analysis was performed to determine the design elements within each interface area.

At present, the family of sortie payloads which will fly on the shuttle does not exist. Although individual, proposed sortie payloads do exist, these few payloads do not exhibit the complete set of interface characteristics that the family of sortie payloads might possess. Therefore, an analysis was made to determine the typical subsystems, characteristics, and other considerations conceivable of any given sortie payload. The results of this analysis, shown in Table 4-2, provided a generalized view of a sortie payload and formed the baseline for a detailed interface design analysis. Initial direction for structuring, classifying, and managing the information that had previously been gathered also resulted from the generalized sortie payload effort.

Utilizing the generalized payload analysis, an in-depth analysis was performed of the subsystem interface parameters and characteristics which impact the design and performance of spacecraft payloads. The results of this analysis, shown in Table 4-3, comprise a complex interrelationship of design elements and considerations. These elements and considerations, along with substantiating design rationale and required verification methods, are shown within each subsystem/interface area.

These two analyses, together with the information obtained from Precedent Practices Research, provided the supporting data necessary to structure criteria for each of the sortie payload interface areas except for some specific orbiter-provided and required payload-provided support provisions and equipment. The NASA-provided shuttle information model and the Space Shuttle Baseline Accommodations for Payloads document (Reference 24) were utilized to determine these elements. The orbiter remote manipulator system (RMS) was examined as part of this effort and adjudged not to be applicable to this sortie payload criteria study. Also, the crewmen's pressure garment assemblies, although weight-chargeable to payloads, are not payload equipment and thus are inappropriate for interface definition within the sortie payload scope of this study.

The results of the interface design analysis accomplished two purposes. First, it established a basis for payload subsystem and interface area selection used for classification and control of criteria. Second, the analysis identified the elements of interface within each subsystem or interface area that were subsequently used in criteria determination. These two items are discussed further in the following two subsections.

Table 4-2. Generalized Sortie Payload Subsystems and Considerations

<u>FLUID SYSTEMS</u> - Liquid Loop - Valves & Lines - Hydraulics	<u>CONTROLS & DISPLAYS</u> - Control Stimuli - Display Responses - Computer Operations	<u>ENERGY SOURCES</u> - X-Ray - Intense Magnetic Flux - Radio Frequency (RF) - Onboard Nuclear Particles - Meteoroids	<u>ELECTRICAL/ELECTRONIC</u> - Power Circuitry - Batteries - LV + HV Supplies - AC Supplies - Vac/Solid-State - RF Transmitters - Redundant Circuitry - Filters - EMI - Fuel Cells - Solar Arrays
<u>OPTICAL SYSTEMS</u> - Optics - Film	<u>THERMAL</u> - Conduction - Liquid Loop/ Cold Plate - Heaters - Insulation - Radiation	<u>TOXIC AGENTS</u> - Reagents - Microbes - Fuels & Oxidizers - Operating Fluids	<u>CREW INVOLVEMENT</u> - EVA/IVA - D&C Interface - Direct Operation - Touch Temperatures
<u>MECHANICAL</u> - Hatches - Structures - Cryogenic Coolers - Extendable Booms - Antenna - Gyros - Shields	<u>PNEUMATICS</u> - Pressure Vessels - Extending Mechanisms - Valves & Lines	<u>POINTING/AIMING</u> - Gimballed Platforms - State Vector Circuitry - CMG	<u>ENVIRONMENT</u> - Pressure - Vibration - Acceleration - Thermal - Humidity - Acoustical - Natural Radiation - Contamination - Shock
	<u>INSTRUMENTATION/TLM</u> - Data Circuitry - Transducers - Isolation	<u>PYROTECHNICS</u> - Device Actuators - Boom Jettison - Equipment Protection	

Table 4-3. Payload Interface Design Analysis

SUBSYSTEM/ INTERFACE AREAS	ELEMENT SET	RATIONALE	VERIFICATION METHOD
COMMUNICATIONS/ DATA	A. FREQUENCY ALLOCATIONS 1. Carriers 2. Modulation 3. Side Bands 4. Filter/Attenuation Requirements 5. Interfering Signal Level Limits	The communications subsystem designers will require these definitions to select components. Since a manned vehicle will have voice, beacon and telemetry frequencies, the interference problem must be considered in the selection of center frequencies, as well as the side-banding effects. A consideration in the definition of antennas and power levels is the percent of communication coverage desired throughout the orbit. Since the ground stations' locations and capabilities are known, the orbiter equipment is selected accordingly.	Analysis, test
	B. ANTENNA REQUIREMENTS 1. Gain Characteristics 2. Main Lobe Pattern 3. Allowable Side-Lobes 4. Polarization/Phasing 5. Orientation of Axis a. Fixed b. Drive Pattern c. Tolerance of Alignment		Analysis
	C. TRANSMITTER POWER 1. Carrier-to-Noise Ratio 2. Beamwidth 3. Single Carrier Power 4. Multi-carrier Power Degradation Rate 5. Beacon Modes 6. Amplitudes a. Peak b. Modulation c. Attenuation requirements 7. Modulation Losses		Test
	D. RECEIVER POWER 1. Up-link Threshold 2. Noise Figure 3. Sensitivity 4. Center-Frequency Stability		Analysis, test
	E. ELECTRICAL REQUIREMENTS 1. DC Voltages 2. Power Consumption a. Turn-on b. Peak c. Average	Electrical requirements must be stipulated to allow power budget to be formulated.	Analysis

Table 4-3. Payload Interface Design Analysis (Continued)

SUBSYSTEM/ INTERFACE AREAS	ELEMENT SET	RATIONALE	VERIFICATION METHOD
COMMUNICATIONS/ DATA (Continued)	F. DATA HANDLING 1. Data Gathering Rate 2. Data Transmitting Rate 3. Data Storage Requirements 4. Data Conversions a. Analog-to-Digital b. Digital-to-Analog c. Encoding (encrypting) d. Decoding (decrypting) e. Minimum Conversion f. Format(s) 5. Maximum Allowable Data Loss a. Storage Overflow b. Modulation Loss c. Signal Degradation • Low power • Interference	The data gathering rate and data transmission rate relate to ground station coverage. If the ground station(s) accepting data cannot record all of the data on a single orbital pass of the vehicle, data storage capability must increase to preclude excessive loss of data. The format of transmitted data, i.e., bits per word and words per frame, establish the required hardware capability and data rates.	Analysis
CREW	A. CONSTRAINT REQUIREMENTS 1. Launch Profile 2. Work-Station/ Walkway Aids 3. Extra-Vehicular Activities 4. Re-entry & Landing Profile	Crew constraints must be provided to allow personnel to move about the vehicle and to operate the experiments in a reduced-gravity environment. Such constraints are for both safety and convenience of task performance.	Analysis
	B. PERSONNEL TASKS 1. Orbiter Functions 2. Experiment Operation 3. Experiment Deployment 4. EVA	The demands upon personnel time must be budgeted to provide a balance of work/ rest without extending the task requirements of any crew member. The tasks must be analyzed against the mission timeline to eliminate conflicts.	Task analysis
	C. PAYLOAD STRUCTURE 1. Crew Access Requirements a. Monitor b. Adjust c. Deploy 2. Intra-Vehicular Mobility a. Walk-Way/Crawl-space b. Safety c. Strength	The payload structure and orbiter-to-payload interface will be designed to facilitate the required personnel movements and tasks.	Analysis

Table 4-3. Payload Interface Design Analysis (Continued)

SUBSYSTEM/ INTERFACE AREAS	ELEMENT SET	RATIONALE	VERIFICATION METHOD
CREW (Continued)	D. PAYLOAD LAYOUT 1. Visibility 2. Display/Readout Devices 3. Task Analysis and Facility of Access	The payload must be arranged to maximize personnel efficiency at experiment tasks.	Analysis
	E. ENVIRONMENT 1. Vehicle/Payload a. Pressurized/air-locked configurations b. Thermal extremes allowable c. Acoustic limits d. Oxygen system e. Lighting requirements	The primary concern of the vehicle-to-payload environment design is crew safety and comfort without undue expenditure of space, weight and funds. Lighting must be adequate for flight duties such as monitoring displays, adjusting/calibrating equipment and recording flight/experiment data.	Analysis
	F. FACILITIES 1. Storage a. Rations b. Water c. PGA 2. Comfort a. Waste disposal b. Rest	The crew facilities must provide adequate storage, comfort, and safety features to support the crew for the duration of the mission.	Analysis and inspection of drawings
ELECTRICAL	A. VOLTAGE 1. DC a. Nominal Level(s) b. Maximum c. Minimum d. Allowable Ripple e. Regulated Bus Requirements	The electrical subsystem is the primary system during orbital operations since it provides power for communications, experiments and life support system.	Test
	B. POWER CAPACITY 1. Peak Wattage 2. Normal Usage 3. Minimum Requirement	The electrical system must produce enough power to sustain minimum operations and critical functions. The total mission success will depend a great deal upon the adequacy of power.	Test
	C. CURRENT 1. Peak a. Cold In-rush b. Hot In-rush 2. Steady-State Average	Current values are a design guide, both for electrical requirements and for overload protection devices.	Test
	D. TRANSIENTS 1. Frequency 2. Amplitude 3. Duration	Electrical transients should not produce a critical failure in the system nor a major degradation of mission data.	Test

Table 4-3. Payload Interface Design Analysis (Continued)

SUBSYSTEM/ INTERFACE AREAS	ELEMENT SET	RATIONALE	VERIFICATION METHOD
ELECTRICAL (Continued)	E. FREQUENCIES 1. Clocking a. Nominal b. Allowable Variation c. Digital Rates	Frequencies should be maintained stable to allow other subsystem components to function regularly.	Test
	F. SOURCE 1. Orbiter 2. Self-Contained 3. Test Access	The selection of power source should consider mission length, power requirements, source weight and the environment. Backup/complementary sources should be evaluated.	Test
	G. OVERLOAD PROTECTION	Overload at subsystem components should not cause failure of the source, the main bus, nor other subsystems.	Test
	H. CABLE DESIGNS, INTERFACE 1. Connectors 2. Shielding a. Protective b. EMC	Cables should be designed to distribute the power as required to other subsystems in a reliable, non-interfering manner.	Test
ELECTROMAGNETIC COMPATIBILITY (EMC)	A. SIGNAL INTEGRITY 1. Data Degradation a. Allowable dB margin 2. False Clock Signals 3. Frequency Variation a. Allowable system range b. Ordnance compatibility range c. Transient variations, allowable limits 4. Pulse Shape Variation	The degree of allowable EMI is stipulated by the signal integrity required in the system/subsystem.	Analysis, test, drawing inspection
	B. SOURCE CONTROL 1. Internal Self-generated EMI 2. External Source Susceptibility	Self-generated EMI will be suppressed by design and fabrication; external requires shielding and grounding techniques.	Analysis, test
	C. GROUNDING REQUIREMENTS 1. Telemetry 2. Primary Power 3. Heater Circuits 4. Command/Control Circuits 5. Ordnance Circuits 6. Data Lines 7. RF/Communication Lines 8. Sensor Circuits	Individual subsystems require different grounding designs, dependent upon the respective frequency.	Analysis

Table 4-3. Payload Interface Design Analysis (Continued)

SUBSYSTEM/ INTERFACE AREAS	ELEMENT SET	RATIONALE	VERIFICATION METHOD
(EMC) (Continued)	D. PARTS, MATERIALS & PROCESS CONTROLS 1. RF Bonding a. Maximum joint impedance b. Joint cleanliness c. Mechanical strapping 2. Signal Separation a. Cable routing b. Cable configuration c. Shielding d. Surface coating e. Grounding f. Filtering	The specification of approved parts, materials and processes will largely dictate the level of EMC achieved at the system level.	Analysis, test
	3. Electrochemical Corrosion Control a. Isolation or Non-Use of Dissimilar Metals • Coating • Bonding	Protecting against electrochemical corrosion is a design requirement and can be controlled by proper materials selection.	Analysis
FLUID SYSTEMS	A. PRESSURE 1. Operating Limits 2. Maximum Allowable Surge 3. Maximum Allowable Leakage 4. Control Function Levels 5. Relief Levels	Fluid systems present a design problem where leakage allowances are zero or very low. Fluid leaks are difficult to repair; if the fluid is an oil or fuel leak, the mission can be endangered by improper design.	Test
	B. CIRCUIT REQUIREMENTS 1. Reservoir Capacity 2. Supply Line Routing/ Size Limits 3. Return Line Routing/ Size Limits 4. Vent and Drain Accommodations 5. Filtration 6. Flow Control Devices 7. Slosh Control	Circuit components are mutual; each component size/capacity relates to the subsystem capacity and operating demands on the subsystem.	Test
	C. ELECTRICAL REQUIREMENTS a. Primary Power b. Heater Power D. THERMAL INSULATION REQUIREMENTS	The fluid system may require electrical power for pumping or circulating action. Liquids may require heater protection against solidifying temperatures or a thermal insulation plan.	Test

Table 4-3. Payload Interface Design Analysis (Continued)

SUBSYSTEM/ INTERFACE AREAS	ELEMENT SET	RATIONALE	VERIFICATION METHOD
ALIGNMENT/ POINTING	A. FIXED ATTITUDE 1. Reference Location and Axes 2. Allowable Error Limit	Payload alignment may be critical, since it orients the experiments to their design plane and to the various mission profile forces.	Drawing inspection and test
	B. CONTROLLED ATTITUDE 1. Primary Reference 2. Backup/Secondary Reference 3. Axial Excursion Limits 4. Precession or Drive Rate Requirements 5. Damping Ratio 6. Correction Rate 7. Nominal Attitude	Some payload components may require a stabilized or driven attitude to maintain vertical, target reference or a skewed-axis orientation. Such requirements increase design complexity of structures/components and influence experiment layout and power requirements.	Test
	C. POINTING COORDINATES 1. Reference 2. Elevation Limits 3. Azimuth Limits 4. Pointing Error Limits 5. Scheduled Target Changes 6. Frequency of Pointing Change 7. Drive Rates Required to Maintain Point	Some payload experiments will require aiming/tracking on a reference to produce proper results. These requirements will specify some structure designs for access or vision fields and will necessitate close control of either the reference or the pointing device.	Test
PAYLOAD CHECKOUT	A. CHECKOUT MODES 1. Pre-Launch 2. Ascent 3. Orbital 4. Re-Entry 5. Descent	The checkout of the payload will occur in phases throughout the system schedule. Flight conditions can be simulated for checkout of the payload prior to launch.	Test
	B. FREQUENCY 1. One-Time Check 2. Cyclic/Periodic 3. Event-Related	The frequency and sequence of checkout are specified to allow an accurate checkout procedure to be written.	Analysis
	C. SEQUENCE OF ACTIONS		Analysis, test.
	D. SPECIAL INTERFACES 1. Test Cables, Umbilicals, In-flight Jumpers 2. Instrumentation 3. Calibrate/Simulate Fixtures	Special interfaces will require special test equipment and possibly structural designs to permit access.	Inspection, test

Table 4-3. Payload Interface Design Analysis (Continued)

SUBSYSTEM/ INTERFACE AREAS	ELEMENT SET	RATIONALE	VERIFICATION METHOD
PAYLOAD CHECKOUT (Continued)	E. ACCEPTANCE CRITERIA 1. Parameter/Result List 2. Acceptable Limits	The acceptance criteria will provide a decision on payload readiness and performance during checkout.	Analysis, test
	F. DATA REQUIREMENTS 1. Hard-Copy Records 2. Magnetic Records 3. Photographic Data 4. Computer Storage/ Transfer 5. Analog-to-Digital Conversion 6. Digital-to-Analog Conversion 7. Visual Display	Payload checkout will require printout/ readout devices to report in-process or final results.	Documentation
ENVIRONMENTAL	A. TEMPERATURE 1. Ground transport, storage and handling a. Maximum b. Minimum c. Duration 2. Mission a. Maximum b. Minimum c. Periodic excursions ● Differential ● Period	The environment determines to a large extent the design of the subsystem components. Temperature extremes affect the choice of materials and special heating/insulating techniques.	Analysis
	B. PRESSURE 1. Maximum Level 2. Orbital Level a. Internal Minimum b. Internal Ambient c. Venting/Equalization Levels d. Stop-Vent Level e. Allowable (maximum) Leakage Rate	The pressure environment ranges from sea level static pressures to low pressure orbital values. The control of pressures dictates seal selection, material strength and special pressurization components.	Analysis, test
	C. SHOCK 1. Maximum G-Loading 2. Characteristic Shape a. Rise Time b. Delay Time 3. Plane of Application a. Discrete Axis b. Random	The shock environment establishes special component mounting to protect fragile or precision elements.	Analysis, test

Table 4-3. Payload Interface Design Analysis (Continued)

SUBSYSTEM/ INTERFACE AREAS	ELEMENT SET	RATIONALE	VERIFICATION METHOD
ENVIRONMENTAL (Continued)	D. VIBRATION 1. Frequency Range 2. Amplitude(s) 3. Duration 4. Octave Rate(s) 5. Plane of Application a. Discrete Axis b. Multi-Axis c. Random	Vibrations can destroy the accuracy and even abort the mission if not considered fully during design phases.	Analysis, test
	E. RADIATION 1. Permissible Ambient Level 2. Sources a. On-Board Equipment b. External Impingement • Nominal Rate • Maximum Rate • Duration	Radiation levels from all sources have to be considered since radiation has a cumulative effect upon personnel.	Analysis, test
	F. FOREIGN OBJECTS, IMPACTING 1. Source 2. Size 3. Velocity 4. Occurrence Internal	The incidence of foreign objects such as dropped tools, launch-thrown debris and meteorites should not endanger the mission.	Analysis
	G. FOREIGN SUBSTANCE, CONTAMINATING 1. Material 2. Density/Size 3. Source 4. Longevity/Duration 5. Residue 6. Humidity Limits 7. Salt Spray Limits 8. Dust Limits 9. Outgassing from Internal Components, Limit	Contamination of experiment samples, payload equipment and crew support devices can reduce mission success and should be considered during the design phase.	Analysis, test
	H. ACOUSTIC 1. Maximum Ambient Noise Level • Octave Band Portion • Center Frequency Versus Noise Spectra 2. Maximum Peak Level a. Flight Buffeting b. Ordnance Activities c. Equipment Operating Modes	Noise levels are controlled to reduce crew fatigue and preclude hearing impairment.	Test

Table 4-3. Payload Interface Design Analysis (Continued)

SUBSYSTEM/ INTERFACE AREAS	ELEMENT SET	RATIONALE	VERIFICATION METHOD
ENVIRONMENTAL (Continued)	J. MAGNETIC 1. Stray Fields a. Flux Density b. Duration 2. Periodic/Permanent Fields a. Operating • Permeability of Materials • Remanence • Maximum Acceptable Flux Density or Field Strength b. Non-Operating • Residual Field 3. Mapping Test Requirements	Magnetic fields will be encountered; in the case of computer memory cores, propagated. These fields should not influence experiment data and should be controlled as far as possible to prevent communication interference.	Test
	K. OXYGEN LEVEL 1. Crew a. Minimum Requirement • Rate of Supply • Total Volume b. Maximum Allowable 2. Experiment Requirements	Oxygen levels are essential to crew members and could be required for biological experiments.	Analysis, test
	L. LIGHT LEVELS 1. Source a. Solar b. Orbiter-Generated c. Experiment Component-Generated 2. Wavelength(s) 3. Minimum Requirements 4. Allowable Variations a. Periodic b. Maximum Level	Light will be required for crew operations; the level can be designed to be controlled for optimum task lighting.	Analysis and test
ORDNANCE	A. ACTUATION METHOD 1. Automatic Sequence 2. Command a. Crew b. Ground Station 3. Dual Requirement a. Selective b. Required	The ordnance subsystem is a critical category since its performance is usually required for mission success and its presence presents a safety hazard. Positive actuation is designed into the system by redundancy of circuits and explosive devices.	Analysis, test

Table 4-3. Payload Interface Design Analysis (Concluded)

SUBSYSTEM/ INTERFACE AREAS	ELEMENT SET	RATIONALE	VERIFICATION METHOD
ORDNANCE (Continued)	B. ACTUATION SEQUENCE 1. Safing/Arming 2. All-Fire 3. Discrete Fire 4. Fire Intervals Schedule		Analysis and test
	C. VOLTAGE REQUIREMENTS 1. Minimum Firing Level 2. Sustained Voltage Level 3. Minimum Rise Time at Initiation		Sample test
STRUCTURAL/ MECHANICAL	A. ENVELOPE SIZE, LIMITS B. INSTALLATION 1. Method 2. Interface Requirements 3. Attitude/Position	The structure and mechanical subsystem supports the total mission. System elements are maintained in specified relationships to each other by the structure; the crew safety depends on the structure; and flight attitudes are influenced by the structure moments and center-of-gravity.	Drawing inspection, part inspection, assembly test
	C. MASS PROPERTIES/WEIGHT ORIENTATION DYNAMICS		Test
	D. CENTER-OF-GRAVITY REQUIREMENTS		Test
	E. ACCESS REQUIREMENTS 1. Ground Operations 2. Flight Operations		Drawing inspection, test
	F. MAINTAINED ATTITUDE OR ORTHOGONALITY REQUIREMENTS		Test
	G. DEPLOYMENT REQUIREMENTS 1. Excursion Axis/Plans 2. Travel Limit(s) 3. Frequency of Deployment and Schedule 4. Rate of Deployment/ Retraction	Requirements for extending or ejecting experiments increases the structural/ mechanical design complexity. The stipulated limits of such deployments allow the design to be adequately prepared.	Test
	H. MATERIALS 1. Non-allowable Structures/Materials 2. Requirements and Allowances a. Coatings b. Bondings and Adhesives c. Paints 3. Strength	Material selection should exclude incompatible materials, separate or eliminate dissimilar metals with galvanic potentials, control the use of coatings and bondings, and assure adequate strength for all environmental requirements.	Analysis, test
	J. MARKINGS AND IDENTIFICATIONS		Inspection
	K. RESONANCE 1. Natural Frequencies 2. Transmissibility	Structures and mechanisms should not demonstrate natural frequencies and resonances in the range of operating vibration frequencies.	Test

4.4 SUBSYSTEM DETERMINATION

The subsystems and considerations of the interface design analyses were necessarily general because sortie payloads have not yet been fully specified. In order to more closely correspond to the orbiter subsystem and interface area nomenclature, the following categories for payload criteria management and control were selected:

- Communications
- Cryogenics
- Data Processing and Software
- Displays and Controls
- Electrical Power
- Environmental Control and Life Support
- Extravehicular/Intravehicular Activity
- Guidance, Navigation and Control
- Instrumentation
- Onboard Checkout
- Payload Environment
- Pyrotechnics
- Structures
- Thermal Control
- General

This selection should aid in understanding the criteria categories and therefore assist in the usability of the criteria.

4.5 CRITERIA SYNTHESIS

The preponderance of information gathered to support the criteria determination task were not criteria. The data consisted primarily of specification statements, guidelines, and other requirements. This information was sorted into appropriate subsystem categories and the redundant and overlapping information was deleted (which reduced the volume of information considerably). At this point, those data which were obviously not applicable to the compatibility study were also omitted. For instance, information which involved ground support equipment, safety, procedures, or non-sortie elements was rejected or referred to the Crew Safety Criteria Study (Volume II). In effect, the first three blocks of the design categorization process were implemented to a certain degree. Those items deleted during this effort, as well as all other rejected information, were retained for NASA use.

The iterative process of criteria determination continued by combining data elements where appropriate, and structuring the information into proper syntax for criteria presentation. Concurrent with the latter stages of the synthesizing effort, candidate criteria were subjected to the categorization process. This accomplished two purposes. It enabled the criteria syntax and categorization processes to be adjusted for clarity and completeness. It also enabled cross-correlation between the processes and criteria to assure that the basic interfaces for systems compatibility were being addressed.

The synthesizing task reduced the original data from Precedent Practices Research and the interface design analyses to approximately 50 criteria. These criteria were then subjected to the categorization processes (Section 3) for further analysis and categorization as mandatory or discretionary criteria.

5. SYSTEMS COMPATIBILITY DESIGN AND VERIFICATION CRITERIA

The principal results of this study are presented in this section. They are the recommended minimum set of criteria considered mandatory, at any cost, to achieve orbiter-payload systems compatibility. A partial listing of the unbounded set of discretionary criteria (see Table 1-2) are also presented. As required, rationale for each criteria categorization is included along with the recommended minimum verification level for mandatory criteria.

The total of 34 mandatory and 7 discretionary criteria are distributed within the 15 subsystem/interface areas as shown below. The criteria are

Subsystem/Interface Area	Table 5-1 Mandatory	Table 5-2 Discretionary
• Communications	4	--
• Cryogenics	1	--
• Data Processing and Software	1	--
• Displays and Controls	1	--
• Electrical Power	4	--
• Environmental Control and Life Support	1	--
• Extravehicular/Intravehicular Activity	1	--
• Guidance, Navigation and Control	2	--
• Instrumentation	1	5
• Onboard Checkout	1	1
• Payload Environment	1	--
• Pyrotechnics	1	--
• Structures	9	1
• Thermal Control	2	--
• General	4	--

presented in summary in Table 5-1 and in their entirety in Tables 5-2 and 5-3. Specific MSCM 8080 (Reference 23) standards which contributed to criteria development are referenced. Also, to denote whether orbiter or payload operation is of primary concern, the word "orbiter" or "payload" is underlined in the rationale of each criterion. Criteria which address only payload operation are further identified with the note "This criterion may be controlled by payload management". This indicates that even though mandatory criteria are levied by shuttle management to provide for nominal operation, actual control and management of the criteria after being levied may be exercised by payload management. The criteria and rationale presented are the result of the criteria structuring effort described in Section 4 and the subsequent subjection of these criteria to the design and verification processes discussed in Section 3.

Table 5-1. Systems Compatibility Design Criteria Summary

COMMUNICATIONS (4)		
	• Commands	1M,--
	-Uplink	
	-PCDS	
	-Onboard	
	• TV Payloads	1M,--
	-Hardware	
	-Signal Characteristics	
	• Voice	1M,--
	• Carrier Frequencies	1M,--
CRYOGENICS (1)		
	• Reactants	1M,--
	-Purity	
	-Cleanliness	
DATA PROCESSING & SOFTWARE (1)		
	• Computation Support	1M,--
DISPLAY & CONTROL (1)		
	• Panels	1M,--
	-Hardware	
	-Electrical Characteristics	
ELECTRICAL POWER (4)		
	• Power Sources	1M,--
	-Hardware	
	-Voltage	
	-Transients	
	-Impedance	
	-Grounding	
	• EMC and RF	1M,--
	-Conducted	
	-Radiated	
	• P/L-Induced Characteristics	1M,--
	-Load Impedance	
	-Transients	
	-Capacitance	
	-Feedback	
	• Corona	1M,--
ECLS (1)		
	• Atmospheric Maintenance	1M,--
EVA/IVA (1)		
	• Astronaut Capabilities	1M,--
	-Reach	
	-Visibility	
	-Torque/Force	
	-Transferables	
GN&C (2)		
	• Realtime Data	1M,--
	-Data Characteristics	
	• Pointing/Stabilizing	1M,--
	-Accuracy	
	-Stability	
	-Deadband	
INSTRUMENTATION (6)		
	• Downlink	1M,--
	-RAU	
	-Hardware	
	-Signal Characteristics	
	• Transducers	--,1D
	-Operating Range	
	-Resolution	
	• Telemetry	--,4D
ONBOARD CHECKOUT (2)		
	• Go/No-Go Criteria	1M,--
	-Checkout Command Decoder	
	-Stored Program Processor	
	• Payload Viewing	--,1D
P/L ENVIRONMENT (1)		
	• Natural Environment	1M,--
	-Low-g & Pressure	
	-Space Radiation	
	-Space Thermal	
	-Meteoroid	
	-Space Magnetic Fields	
	-Humidity	
	-Solar Illumination	
	-Contaminations	
PYROTECHNICS (1)		
	• Generated Environment	1M,--
	-Contamination	
	-Shock	
	-Thrust	
STRUCTURES (10)		
	• Mounting Provisions	1M,--
	-Location, Attachment	
	• Orientation & Alignment	1M,--
	• Orbiter-Induced Environ.	1M,--
	-Acceleration	
	-Shock	
	-Vibration	
	-Acoustical	
	-Thermal	
	-Nuclear Radiation	
	-Magnetic Fields	
	-Contamination	
	-Structural Distortion	
	• P/L Envelope & Mass Properties	1M,--
	• Boom-Mounted Equipment	1M,--
	• Fields-of-View	1M,--
	• Materials	1M,--
	• Flaking	1M,--
	• Service Panels	1M,--
	• Decompression	--,1D
THERMAL CONTROL (2)		
	• Heat Transport	1M,--
	-Coldplate Hardware	
	• Temperature Limits	1M,--
GENERAL (4)		
	• Orbiter Support Limits	1M,--
	• P/L-Induced Forces, Impulses	1M,--
	• P/L Induced Environments	1M,--
	• Waste Storage	1M,--

M = Mandatory D = Discretionary

Table 5-2. Mandatory Compatibility Design Criteria

DESIGN CRITERION	CATEGORIZING RATIONALE	VERIFICATION
	COMMUNICATIONS	
COMM-1.* Payloads that require ground and/or orbiter commands must be designed to interface with the GFE Payload Command Decoder Subunit (PCDS). The standard PCDS interface requirements are: interconnecting hardware and locations; cable type and size; command signal levels, both on and off states; number and type of commands required; and impedance matching.	This design criterion is applicable to sortie payloads that require orbiter support for payload commanding. Crew hazards are not a consideration of this criterion nor is a contingency situation involved. Adhering to this criterion assures that the payload can be commanded in a nominal manner and is therefore mandatory.	Test
COMM-2.* Payloads requiring orbiter support for display and/or downlink transmission of TV signals must interface with specified orbiter design configuration. This interface must be compatible with the interconnecting hardware and the following electrical signal characteristic/requirements: data formats, bit rates, operational modes, coding accuracy, input/output load impedance, duty cycle, and the active and quiescent operating voltages.	This design criterion for sortie payloads which produce TV signals is applicable to those payloads that require orbital support to transmit those signals to ground or to the orbiter displays. This criterion would be a normal requirement for payloads which require this support and is not imposed to circumvent a contingency or abnormal situation. If the payload design for this interface is improper, payload operation would be non-nominal; therefore, the criterion is mandatory.	Test
COMM-3.* Sortie payload elements, requiring two-way voice communications with the orbiter crew and/or ground, must be designed to interface with the orbiter Mission Specialist Station through the standardized audio stations located in the payload bay with respect to interconnecting hardware, impedance matching, and driver voltage.	This orbiter payload-support element is provided for those payloads which require voice communications. Sortie payload design is affected by this support element in that hardware connection, cable size, length, and type along with signal characteristics must interface properly with the standardized orbiter equipment in order to receive and transmit voice communications. Voice support would be used in the normal operation of the payload and it is mandatory that payloads adhere to this criterion.	Test
COMM-4. Payload-transmitted carrier frequencies must be utilized that allow sufficient bandwidth separation between payload and orbiter carrier frequencies to preclude interference. Orbiter carrier frequencies and permissible payload carrier frequencies will be specified to assure proper allocation.	Carrier frequencies of payloads and the orbiter that are too close could cause interference to occur in orbiter-to-ground voice and data transmission or in payload communications transmissions. This interference could prevent nominal operations of either the orbiter or the payload and it is therefore mandatory that payloads be designed to adhere to this criterion.	Inspection/ Test

*This criterion may be controlled by payload management.

Table 5-2. Mandatory Compatibility Design Criteria (Continued)

DESIGN CRITERION	CATEGORIZING RATIONALE	VERIFICATION
	CRYOGENICS	
CRYO-1.* Payload elements which utilize cryogenic reactants supplied by the orbiter must be designed to interface with the interconnecting hardware and must be able to operate at specified reactant purity and systems cleanliness levels. (See MSCM 8080, No. 78.)	Payloads, like sortie laboratories, may utilize fuel cells to provide power. These power sources utilize cryogenic reactants and can be simultaneously loaded from common shuttle/payload umbilicals. The payload must be designed to assure that the reactant plumbing interfaces properly with the orbiter plumbing so that the payload reactant storage tanks can be loaded. If the payload fuel cells utilize orbiter reactants, the plumbing hardware must also be proper to assure that reactants are supplied to the payload fuel cells. Payload systems cleanliness requirements must meet and reactant purity requirements must not exceed the orbiter specifications. The considerations of this criterion, therefore, impact nominal operation and are mandatory for payloads that employ fuel cells.	Inspection
	DATA PROCESSING AND SOFTWARE	
DP&S-1.* Payloads requiring the orbiter payload and performance monitoring computers for computation support must be designed to interface with the orbiter data processing and software subsystem through the input/output units with respect to all hardware and software specifications.	Payloads may utilize the orbiter computer for real-time data computation and manipulation for data display and other purposes. In order to utilize the orbiter computer support, the payload will have to properly interface with the orbiter computer system through input/output units. The payload must be designed to orbiter standards for each of the specifications or nominal payload operation will not be possible. Therefore, the criterion is mandatory.	Test
	DISPLAYS AND CONTROLS	
D&C-1.* Instrumentation and control panels provided by the payload for location in the Mission Specialist Station, Commander/Pilot, or Payload Specialists Stations that require orbiter support for power or data distribution must be designed to interface with orbiter configuration and must be compatible with the orbiter space allocated. The orbiter power configuration will specify the maximum power, voltage levels, ripple and transients, source impedance, and return grounding requirements. The data distribution configuration will specify the cable size and type, signal levels, duty cycle, number of functions, and impedance matching requirements.	Sortie payload design must be compatible with orbiter space allocation and electrical characteristics in order for the payload hardware to fit and operate properly with the orbiter. Incompatibility at this interface could prevent payload information from being received and/or the payload from being controlled. Since nominal payload operation would be impaired if this interface was improper, the criterion is mandatory.	Test

*This criterion may be controlled by payload management.

Table 5-2. Mandatory Compatibility Design Criteria (Continued)

DESIGN CRITERION	CATEGORIZING RATIONALE	VERIFICATION
	ELECTRICAL POWER	
ELEC-1.* Payloads requiring DC power to be supplied by the orbiter must be designed to interface with specified orbiter DC power source characteristics such as: type of interfacing cables and connectors, maximum power available, types and levels of voltages, voltage ripple and transient requirements, source impedance, and power return ground concepts.	The primary reason for this design criterion for a sortie payload is to assure nominal operation of the payload. This criterion reflects an orbiter subsystem support element along with the accompanying orbiter-induced characteristics of that support element and is therefore applicable. Each of the design elements or characteristics listed in the criterion is expected to be encountered during normal operation; therefore, the criterion is being imposed to assure nominal payload operation. Nonconformance to any element of this criterion would prevent the payload from functioning nominally; therefore, the criterion is mandatory.	Test
ELEC-2. Payloads must not generate conducted or radiated electromagnetic or RF interference which will cause adverse effects on the orbiter subsystems during any operating mode. The conducted and radiated EMI levels acceptable for normal orbiter operations will be specified in a separate EMC document. This document will also specify the levels of EMI generated by the orbiter that the payload must be designed to operate within.	This characteristic of the electrical system must be controlled within acceptable limits so the orbiter and payload can function nominally. Failure to meet this criteria could cause unacceptable interference in electrical, communications, G&N, and other avionics systems. Potential interference from these sources is anticipated whenever electrical systems are used. Shielding, selection of proper components, suppression and filtering are usually used to prevent such interference which would impair nominal orbiter operation. It is mandatory that payloads adhere to this criterion.	Similarity/ Analysis
ELEC-3. The payload electrical system interface with the orbiter shall be designed to assure the load impedance, distributed capacitance, in-rush current transients, ripple, and interference feedback will not compromise normal orbiter operations.	Payload-induced electrical characteristics listed in this criterion will be limited by the orbiter's capability to accommodate these characteristics and still operate nominally. If the sortie payload fails to meet these limitations, the orbiter electrical system could be adversely affected causing abnormal operation, or the payload could be prevented from operating by the orbiter. In either case, nominal operation is impaired; so the criterion is mandatory.	Test
ELEC-4.* Payload electrical and electronic systems must be designed so that the nominal functioning will not be impaired by the anticipated levels and frequency of corona discharge and arcing. (See MSCM 8080, No. 37.)	Corona effects could distort the data being gathered by a payload. Corona discharge or arcing is a normal occurrence with electrical systems in space and sortie payloads must be designed for this effect in order for the payload to function nominally. Corona may be generally avoided or eliminated by lowering potential differences, increasing the gap or length of the current path between points of different potential, increasing or decreasing the ambient gas pressure, or lowering the voltage stresses in gas spaces by selecting insulations with low dielectric constants. This criterion is mandatory for sortie payloads which could be impacted by corona discharge.	Analysis/ Inspection

*This criterion may be controlled by payload management.

Table 5-2. Mandatory Compatibility Design Criteria (Continued)

DESIGN CRITERION	CATEGORIZING RATIONALE	VERIFICATION
	ENVIRONMENTAL CONTROL AND LIFE SUPPORT	
ECLS-1. Manned payload elements interfacing with orbiter atmospheric capabilities must be designed to insure the following environmental requirements are compatible with the orbiter system: pressure, temperature, humidity, CO_2 control, and leak rate.	Failure to meet this design criterion would cause excessive utilization of the orbiter support provisions which could lead to crew discomfort and possibly to non-nominal operations. Therefore, to assure nominal orbiter mission operations, the criterion is considered mandatory.	Analysis/Test
	EXTRAVEHICULAR/INTRAVEHICULAR ACTIVITY	
EVA-1.* Payloads requiring EVA/IVA support to complete their missions must be designed to conform to the applicable man-machine interface standards with respect to crew capabilities such as reach, visibility, maximum torque and force limitations, and ability to handle the size and weight of transferable payloads.	In order for the sortie payload to receive crew support, it must be designed so the crew interface systems can be operable in the space environment. This criterion reflects a nominal situation when crew support is required for necessary payload operation. To provide for nominal payload and crew operation, this criterion is categorized as mandatory.	Demonstration
	GUIDANCE, NAVIGATION AND CONTROL	
GN&C-1.* Payloads requiring orbiter guidance and navigation real-time data must be designed to interface with the orbiter GN&C computer. This interface requires that the payload be capable of connecting to the hardware provided by the orbiter and accepting the data format (timing, state vector initialization and extrapolation, and spacecraft attitudes and attitude rates) along with the characteristics of the data provided.	Sortie payloads will utilize GN&C data for real-time purposes such as for pointing accuracy determination and data correlation. This criterion will affect how the payload is designed in order to utilize the orbiter support element properly. Nominal payload operation or data correlation would be affected if this payload interface were not designed properly. Therefore, the criterion is mandatory.	Analysis/Test
GN&C-2.* Payloads which must be pointed/stabilized for data gathering or other purposes must be designed to operate and interface with the orbiter considering the orbiter capabilities for pointing accuracy, stability rate, and deadband.	If a sortie payload must be pointed toward some area of interest for data gathering purposes in order for the payload to accomplish its purpose, this criterion must be considered in payload design. A definite interface exists since the orbiter is providing a support element (pointing) with certain limitations which the payload must consider in its design. Payloads may incorporate additional gimballing systems to effect greater accuracy than the orbiter alone provides. Nonetheless, these systems also must interface satisfactorily with the orbiter capabilities for pointing. The limitations on accuracy, etc., are expected and are specified to allow design for nominal payload operation; therefore, the criterion is mandatory.	Analysis

*This criterion may be controlled by payload management.

Table 5-2. Mandatory Compatibility Design Criteria (Continued)

DESIGN CRITERION	CATEGORIZING RATIONALE	VERIFICATION
	INSTRUMENTATION	
INST-1.* Payloads that generate data to be downlinked must interface with the orbiter Stored Program Processor through the GFE Regional Acquisition Unit (RAU). Payloads that generate wideband data to be downlinked must interface with the orbiter FM transmitter. These interfaces require that the hardware and data signal characteristics of the payload instrumentation conform to the specifications of the orbiter equipment.	In order for sortie paylods to transmit data to earth through the orbiter in a nominal manner, the design of interfacing instrumentation must be proper. This orbiter support element is provided for normal payload data transmission and therefore primarily affects payload operation. Improper design at this interface could prevent payload data transmission and therefore render the payload useless. Therefore, the criterion is mandatory.	Test
	ONBOARD CHECKOUT	
OBCO-1.* Payloads that require inflight checkout must be designed to interface with the standardized Checkout Command Decoder and the Stored Program Processor with respect to hardware connection, checkout commands and data characteristics and formats.	Prior to liftoff, the payload can be checked out via the Checkout Command Decoder for serial digital checkout commands and data and via the Stored Program Processor for payload narrowband checkout data. The Decoder and Processor are connected to the ground by hardwire. The sortie payloads must interface with these checkout units in order to determine if the payload is capable of flight operation. This criterion reflects an orbiter support element used to determine if the payload is capable of nominal operation and is mandatory.	Test
	PAYLOAD ENVIRONMENT	
PLE-1.* Payloads must be designed to operate nominally under the influence of expected levels of these environmental elements: low gravity and pressure, space radiation, space thermal characteristics, meteoroid impact, space magnetic fields, solar illumination, and atmospheric contaminations such as humidity, dust, fungus, and ozone.	The primary reason for this sortie payload design criterion is to assure nominal operation while under the influence of mission-induced natural environments. Since certain levels of each of these elements is expected during a mission, payload design must include utilization of shielding, insulation, and other protective devices to allow nominal operation. If the payload did not meet this criterion, nominal operation would be jeopardized and thus the criterion is considered mandatory.	Similarity/ Analysis

*This criterion may be controlled by payload management.

Table 5-2. Mandatory Compatibility Design Criteria (Continued)

DESIGN CRITERION	CATEGORIZING RATIONALE	VERIFICATION
	PYROTECHNICS	
PYRO-1. Payloads requiring operation of pyrotechnic devices must be designed such that pyrotechnic actuation will not produce contamination, shock, thrust, and other stimuli or debris that could interfere with orbiter operation.	Pyrotechnic devices expend contaminants and impart shock to the structure when actuated. Sortie payloads which utilize these devices must design these systems so that the induced characteristics from the explosion are either controlled or of such magnitude as not to impact the operation of orbiter systems. Since the characteristics of pyrotechnic detonation could adversely impact nominal orbiter operation and functioning, the criterion is mandatory.	Similarity/ Analysis
	STRUCTURES	
STRU-1.* Payloads must be designed to conform to the orbiter standardized payload attachment point provisions for payload mounting with respect to attachment design and location; and load transfer and distribution.	This sortie payload design criterion is imposed to assure that the payload will attach to the orbiter so that the payload can be supported and carried by the orbiter during the mission. The criterion involves an orbiter payload-subsystem support element (structural attachment) and is therefore an applicable criterion. Since all sortie payloads must attach to the orbiter, the criterion does not reflect a contingency situation. The criterion must be satisfied in order for the payload to be transported by the orbiter and, therefore, the criterion is mandatory.	Test
STRU-2.* Payloads requiring specific orientation and alignment within the payload bay must be designed to be compatible with orbiter provisions for this support along with the associated accuracy afforded by the orbiter for these accommodations. (See MSCM 8080, No. 8, Rev A.)	This design criterion for sortie payloads is required by payloads which are pointed toward some area of interest for data gathering and require knowledge of, and are therefore sensitive to, orientation with respect to the orbiter guidance axes. Since this criterion reflects nominal orbiter support to the payload, it is an applicable criterion. This payload interface must be designed properly or payload data could be less than nominal or even useless based upon inability to correlate or interpret the data because of alignment errors. Therefore, this criterion is mandatory.	Analysis/ Inspection
STRU-3.* Payloads must be designed to withstand specified levels of the following orbiter-induced environments: acceleration, shock, vibration, acoustical, thermal, nuclear radiation, magnetic fields, effluent and debris contamination, and structural distortion.	The orbiter will subject the payload to predictable levels of each of these orbiter-induced environments. The sortie payload must be designed to tolerate these characteristics of the orbiter so that nominal payload operation will be possible. Since certain levels of these characteristics are expected, the payload will be protecting against a nominal, rather than a contingency situation. Therefore, the criterion is mandatory in order for sortie payloads to be capable of operating nominally under the influence of these characteristics.	Similarity/ Analysis

*This criterion may be controlled by payload management.

Table 5-2. Mandatory Compatibility Design Criteria (Continued)

DESIGN CRITERION	CATEGORIZING RATIONALE	VERIFICATION
STRU-4. Payloads must comply with specified orbiter payload bay clearance envelopes and adhere to the limitations placed on payload mass properties (weight, center of gravity) by the orbiter.	A payload too large for the payload bay obviously could not be carried by the orbiter. Payload size must be within the acceptable clearance envelope of the bay walls to prevent contact due to orbiter deflection. Payloads must adhere to the mass properties limitations imposed by the orbiter to keep from impacting the orbiter operational capabilities for launch and landing.	Analysis/ Inspection
STRU-5. Payloads with extendable/retractable sensors/transmitters (using booms or other methods) must be designed in size, weight, structural rigidity, and extension length so that, when extended, the orbiter is able to perform normal guidance and control functions.	Sortie payloads with extendable sensors will induce characteristics upon the orbiter vehicle GN&C and structural systems by virtue of imparting a change in vehicle configuration and c.g. location. The payload must be designed such that the physical characteristics of the extended sensor do not interfere with required orbiter stabilization and control functions. The requirements of this criterion are associated with the nominal operation of the orbiter and the payload system. Payloads designed beyond the limits of orbiter capability would impact normal orbiter operation; therefore, the criterion is mandatory.	Similarity/ Analysis
STRU-6.* Payloads must be designed to comply with the orbiter provisions for payload field-of-view (FOV) from the payload bay with respect to direction and degree.	With the payload bay doors open, the orbiter provides a field-of-view for sortie payloads that require pointing or sighting to gather data. This criterion requires that the payload be designed to operate nominally within the orbiter limitations. Payloads requiring a FOV for data gathering could not function nominally if the payload sensor was not designed to point correctly or if the sensor FOV angle was too large. Failure to meet this criterion would affect payload operation and prevent nominal operation. Therefore, the criterion is mandatory.	Analysis
STRU-7.* Payloads must not utilize materials that could react adversely with orbiter materials and affect the operation of the orbiter-payload interface. (See MSCM 8080, Nos. 63 and 101.)	When certain materials are placed together, a chemical reaction occurs which is detrimental to the bond or connection. For example, metals which differ enough in electrical potential could cause galvanic corrosion. Also, contact surfaces of electrical connectors, electroplated with gold, have developed semiconducting or insulating films in the presence of sulfur-bearing atmosphere. Payload-induced characteristics of this type could affect nominal payload operation. Therefore, the criterion is mandatory.	Similarity/ Analysis
STRU-8.* Payloads must be designed to interface with standard and payload-peculiar service panels attached to the orbiter and located in the payload bay with respect to hardware connection, mounting location, and subsystem specific interface characteristics.	After payloads have been installed into the payload bay (but prior to launch), payload services such as electrical power, fluid and gases filling, venting, and draining will be provided through service panels. The sortie payloads must be designed to interface properly with these panels in order to prepare the payload for nominal operation. Therefore, this criterion is mandatory.	Analysis

*This criterion may be controlled by payload management.

Table 5-2. Mandatory Compatibility Design Criteria (Continued)

DESIGN CRITERION	CATEGORIZING RATIONALE	VERIFICATION
STRU-9. Surfaces of payload equipment in the spacecraft crew compartment or in manned sortie labs which are expected to be exposed to extensive or continuous abrasion by the spacecraft crew must not be painted or coated with materials which are subject to flaking. (See MSCM 8080, No. 43.)	This criterion indicates a payload-induced environment resulting from crew contact with payload surfaces. The flaking from these surfaces could result in contaminating particles "floating" in the zero-g environment. This contamination could then impact nominal orbiter electrical and environmental control and life support subsystems operation and could possibly cause irritation to the (orbiter) crew, further interfering with operations. Therefore, the criterion is mandatory.	Analysis/ Inspection
	THERMAL CONTROL	
THER-1.* Payloads which require orbiter active thermal control must be designed to operate with the orbiter heat exchanger by assuring that the coldplate interconnection type, size, and location are proper and that the payload thermal control requirements do not exceed the specified orbiter capability for all mission phases.	This criterion is imposed primarily to assure nominal payload support from the orbiter HTS. Meeting the requirements of this criterion impacts sortie payload design. The requirements of this criterion do not reflect a contingency situation but rather a necessity for nominal payload operation. The criterion is therefore categorized as mandatory.	Analysis
THER-2.* The payload must be capable of withstanding the anticipated thermal limits expected to occur during the various flight phases of pre-launch, launch, on-orbit (bay door open and closed), and entry and post-landing.	The orbiter will subject the sortie payload to various temperature environments during the flight phases. The payload must be designed to withstand these expected temperatures by utilizing the orbiter heat transport system, insulation, shielding, and other thermal protection devices. Since these temperature limits are anticipated, nominal payload operation would be jeopardized if measures were not taken to protect against this environment. Therefore, the criterion is mandatory.	Similarity/ Analysis
	GENERAL	
GEN-1.* Normal payload support requirements which are not within the specified orbiter capabilities must be provided by the payload.	If, in fact, the accommodations of the orbiter are not sufficient for normal payload operations, the payload would not be able to function nominally unless it is designed for this required additional accommodation. For example, if the payload required AC or some different input voltage than the orbiter supplied, the payload must provide the DC to AC rectifying equipment or transformer to be able to function nominally. Or, if the payload required more accurate pointing capability than the orbiter could provide, the payload must be designed for this additional accuracy capability. This criterion reflects an absence of orbiter provisions for nominal payload operation and assumes that the payload data would be essentially useless unless this additional capability is designed into the payload. Therefore, the criterion is mandatory.	Analysis

*This criterion may be controlled by payload management.

Table 5-2. Mandatory Compatibility Design Criteria (Concluded)

DESIGN CRITERION	CATEGORIZING RATIONALE	VERIFICATION
GEN-2. Payloads must not generate forces, impulses or momentum changes which will produce adverse effects on the orbiter GN&C capability.	Since sortie payloads remain attached to the orbiter during payload operation, the angular momentum from moving components or impulse from propulsive sources such as gas vents could affect orbiter attitude control functions to the extent of interfering with nominal orbiter operation. Therefore, the payloads must be designed to assure that these payload-induced characteristics are within acceptable limits for nominal orbiter operations. This criterion is mandatory to assure nominal orbiter operation.	Analysis
GEN-3. Payloads must be designed to assure that the following payload-induced characteristics or environments are not above specified levels that would adversely impact orbiter operations: contamination such as nuclear radiation, magnetic fields, sound pressure levels, leakage (hydraulic and other fluid systems), metallic particles, thermal, and gaseous venting. (See MSCM 8080, Nos. 9 and 62.)	The various types of payloads that will fly on the orbiter will produce these types of environments on the orbiter. The sortie payload must be designed to control these induced characteristics to levels acceptable to the orbiter vehicle and crew. Failure to meet this criterion could impact orbiter nominal operation and is, therefore, mandatory.	Similarity/ Analysis
GEN-4.* Payloads that generate liquid and/or gaseous waste materials above specified levels must be designed to process and expend and/or store the waste materials to preclude contamination of orbiter systems.	This design criteria for sortie payloads would probably not cause a crew hazard (unless the payload was contained within the crew area), but the payload-induced environment could possibly impact orbiter mechanical and electrical subsystems so they would not function nominally. If the payload was expected to generate this waste, a non-nominal situation would not exist and the design criterion would be for the purpose of nominal payload operation and would, therefore, be mandatory.	Analysis/ Inspection

*This criterion may be controlled by payload management.

Table 5-3. Discretionary Compatibility Design Criteria

DESIGN CRITERION	CATEGORIZING RATIONALE	VERIFICATION
	INSTRUMENTATION	
INST-2. Transducers must be selected to monitor at least the nominal operating range of the parameter to be measured. Also, to enhance problem resolution, transducer ranges must extend far enough beyond expected ranges to allow monitoring of off-nominal conditions, but not so far as to degrade the granularity (resolution) of the measurement.	This criterion is a choice of components used to monitor the payload. This choice does not assure compatibility with the orbiter but possibly enables corrective action for a non-nominal occurrence. The effects of this criterion enhance mission success from a ground flight control standpoint and is discretionary.	
INST-3. All parametric readouts and displays required by the crew must be telemetered for independent ground observation.	This criterion is a configuration choice which is utilized to increase the possibility of mission success through ground mission-control activities.	
INST-4. Instrumentation must be provided to monitor and indicate to the crew that a non-observable function is either taking place or has been completed.	This criterion is designed to preclude a non-nominal occurrence from impacting mission success. Since this criterion is not required for basic compatibility or nominal operation, it is considered discretionary.	
INST-5. Commands affecting critical equipment status must have associated telemetry direct from the commanded end item to provide a positive functional verification.	This design is a configuration choice to insure payload mission success and is therefore categorized as discretionary.	
INST-6. Payload operation, normally checked by direct human senses, must be instrumented for shuttle missions.	This orbiter (crew) support element is a configuration choice of payload monitoring capability and is discretionary.	
	ONBOARD CHECKOUT	
OBCO-2. Payloads must be designed recognizing that payload viewing from the Mission Specialist Station will be available to payloads for operational checkout.	Payload developers may utilize this method of payload checkout in lieu of instrumentation or other checkout devices; thus affecting how the payload is designed. This is a configuration choice subject to cost-benefit analysis and is, therefore, discretionary.	
	STRUCTURES	
STRU-10. Payloads which will be located within pressurized compartments of the orbiter must be designed to withstand rapid decompression to vacuum without damage to the payload equipment. (See MSCM 8080, No. 2, Rev A.)	This sortie payload design criterion would be imposed to protect the payload from an orbiter-induced environment (decompression). Since rapid decompression is not a nominal or planned occurrence, then the primary reason for the criterion is to assure payload mission success probability if this contingency situation does occur. Therefore, the criterion is discretionary.	

6. CONCLUSIONS

The results of this study will form the basis for detailed sortie payload specifications to be written when quantitative shuttle data are available. Utilization of the mandatory design criteria will help assure that future shuttle sortie payloads will be compatible with the space shuttle vehicle and help assure crew and hardware safety.

Since shuttle program management may concentrate only on those criteria and specifications considered mandatory, considerable cost savings can be realized by reduced manpower, less need for shuttle program managerial cognizance over certain criteria, and less paperwork. Also, when new criteria are generated due to changes in subsystems, designs, or guidelines used by this study, the categorization processes can be used to aid in managerial decision-making concerning these criteria.

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