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**Training Manual for Elements of Interface
Definition and Control**

Vincent R. Lalli
*Lewis Research Center
Cleveland, Ohio*

Robert E. Kastner
*Vitro Corporation
Rockville, Maryland*

Henry N. Hartt
*Vitro Corporation
Washington, DC*



National Aeronautics and
Space Administration

Office of Management
Scientific and Technical
Information Program

Preface

This technical manual was developed under the Office of Safety and Mission Assurance continuous training initiative. The structured information contained in this manual will enable the reader to efficiently and effectively identify and control the technical detail needed to ensure that flight system elements mate properly during assembly operations (both on the ground and in space).

Techniques used throughout the Federal Government to define and control technical interfaces for both hardware and software were investigated. The proportion of technical information actually needed to effectively define and control the essential dimensions and tolerances of system interfaces rarely exceeded 50 percent of any interface control document. Also, the current Government process for interface control is very paper intensive. Streamlining this process can improve communication, provide significant cost savings, and improve overall mission safety and assurance.

The primary thrust of this manual is to ensure that the format, information, and control of interfaces between equipment are clear and understandable, containing only the information needed to guarantee interface compatibility. The emphasis is on controlling the engineering design of the interface and not on the functional performance requirements of the system or the internal workings of the interfacing equipment. Interface control should take place, with rare exception, at the interfacing elements and no further.

There are two essential sections of the manual. The first, Principles of Interface Control, discusses how interfaces are defined. It describes the types of interface to be considered and recommends a format for the documentation necessary for adequate interface control. The second, The Process: Through the Design Phases, provides tailored guidance for interface definition and control.

This manual can be used to improve planned or existing interface control processes during system design and development. It can also be used to refresh and update the corporate knowledge base. The information presented herein will reduce the amount of paper and data required in interface definition and control processes by as much as 50 percent and will shorten the time required to prepare an interface control document. It also highlights the essential technical parameters that ensure that flight subsystems will indeed fit together and function as intended after assembly and checkout.

Acknowledgments

In 1992 the NASA Reliability and Maintainability Steering Committee recognized the need to provide its engineers, especially its design engineers, with a practical understanding of the principles and applications of interface definition and control documentation. A working group was formed and met at Goddard Space Flight Center to discuss how some of the NASA centers were handling this topic. Four centers and NASA Headquarters participated in the meeting: Headquarters—NASA handbook methods; Johnson Space Center (JSC) and Marshall Space Flight Center (MSFC)—space station; Lewis Research Center—space station and launch vehicles; Jet Propulsion Laboratory (JPL)—Mars Observer; and Goddard Space Flight Center (GSFC)—space experiments.

To satisfy the need for a short, informative interface definition and control training manual, Robert E. Kastner and Henry N. Hartt of the Vitro Corporation prepared the manual using material from the working group meeting. Harvey L. Schabes and William J. Taylor of Lewis Research Center served as the final NASA project office reviewers. Their suggestions improved the usefulness of the text for flight projects. The dedication, time, and technical contributions of Jack Remez/GSFC; Donald Bush (retired)/MSFC; David Oberhettinger/SYSCON (JPL); Daniel Deans/LORAL (JSC); and Ronald Lisk/NASA Headquarters (Code Q) in the preparation of this manual are appreciated. Without the support of their individual centers and their enthusiastic personal support and willingness to serve on the NASA Reliability and Maintainability Steering Committee, this manual would not have been possible.

The following NASA members of the steering committee may be contacted for more information about the processes and products discussed in this manual:

James F. Clawson
Jet Propulsion Laboratory
California Institute of Technology
MS 301-456, SEC 505
4800 Oak Grove Drive
Pasadena, CA 91109
Office: (818) 354-7021
Facsimile: (818) 393-4699
E-mail: james.f.clawson@ccmail.jpl.nasa.gov

John Greco
NASA Langley Research Center
MS 421, Bldg. 1162A, Rm. 125
5A Hunsaker Loop
Hampton, VA 23681-0001
Office: (804) 864-3018
Facsimile: (804) 864-6327
E-mail: j.a.greco@larc.nasa.gov

Wilson Harkins
NASA Headquarters, Code QS
300 E. Street SW
Washington, DC 20546
Office: (202) 358-0584
Facsimile: (202) 358-3104
E-mail: wharkins@cc.hq.nasa.gov

Vincent R. Lalli
NASA Lewis Research Center
Code 0152, MS 501-4
Cleveland, OH 44135
Office: (216) 433-2354
Facsimile: (216) 433-5270
E-mail: rqlalli@lms01.lerc.nasa.gov

Michael E. Langley
NASA George C. Marshall Space Flight Center
CR-10, Bldg. 4203
Marshall Space Flight Center, AL 35812
Office: (205) 544-0056
Facsimile: (205) 544-4155
E-mail: michael.langley@msfc.nasa.gov

Dan Y. Lee
NASA Ames Research Center
MS 240A-3, P.O. Box 1000
Moffet Field, CA 94035-1000
Office: (415) 604-5962
Facsimile: (415) 604-0399
E-mail: dan_lee@qmgate.arc.nasa.gov

Leon R. Migdalski
NASA Kennedy Space Center
RT-SRD-2 OSB3309
Kennedy Space Center, FL 32899
Office: (407) 861-3284
Facsimile: (407) 861-4314
E-mail: lmigdals@srqa.ksc.nasa.gov

Donald L. Wiley
NASA Lyndon B. Johnson Space Center
Code NS3, Bldg. 45, Rm. 616B
Houston, TX 77058
Office: (713) 483-4084
Facsimile: (713) 483-3045
E-mail: dwiley@gp101.jsc.nasa.gov

Jack W. Remez
NASA Goddard Space Flight Center
Code 302, Bldg. 6, Rm. S240
Greenbelt, MD 20771
Telephone: (301) 286-7113
Facsimile: (301) 286-1701
E-mail: remez@gsfc.nasa.gov

Contents

Chapter	
1. Introduction	1
1.1 Training	2
2. Principles of Interface Control	3
2.1 Purpose of Interface Control	3
2.2 Identifying Interfaces	3
2.3 Categorizing (Partitioning) and Defining Interfaces	4
2.3.1 Electrical/Functional	4
2.3.2 Mechanical/Physical	4
2.3.3 Software	5
2.3.4 Supplied Services	5
2.4 Documenting Interfaces	6
2.5 Identifying Steady-State and Non-Steady-State Interfaces	6
2.6 Selecting a Custodian	6
2.7 Analyzing for Interface Compatibility	7
2.8 Verifying Design Compliance With Interface Control Requirement	7
2.9 Verifying Contract-Deliverable Item	7
2.10 Training	8
3. The Process: Through the Design Phases	13
3.1 Program Phases	13
3.1.1 Concept Definition	13
3.1.2 Requirements Definition	13
3.1.3 Systems Integration	16
3.2 Preparing and Administering Interface Control Document	16
3.2.1 Selecting Types of Interface Control Document	16
3.2.2 Tracking and Resolving Missing Interface Design Data	16
3.3 Initial Issuance of ICD	17
3.4 Document Review and Comment	17
3.4.1 Resolving Comments	17
3.4.2 Interface Control Working Group	17
3.4.3 Approval/Signoff Cycle	19
3.4.4 Technical Approval	19
3.4.5 Baselineing	19
3.5 Change Notices	19
3.5.1 Initiating Changes	19
3.5.2 Requesting Changes	21
3.5.3 Proposed Change Notice Review and Comment Cycle	21
3.5.4 Processing Approved Changes	21
3.5.5 Distributing Approved Changes	21
3.5.6 Configuration Control Board	21
3.5.7 Closing the Loop	22
3.6 Training	22

Appendixes:

A: Electrical/Functional Interface Example	24
B: Mechanical/Physical Interface Examples	29
C: Software Interface Example	38
D: Supplied Services Interface Example	39
E: Compatibility Analysis	43
F: Bracket System for Interfaces	46
G: ICD Guidelines	48
H: Glossary	49
 References	 50
Bibliography	50
Training Answers	51

Chapter 1

Introduction

This technical manual resulted from an investigation of techniques used throughout NASA and other Federal Government agencies to define and control technical interfaces for both hardware and software. The processes described herein distill the requirements for interface definition and control into a concise set of parameters that control the design of only the interface-related elements rather than providing extraneous design detail that must subsequently be configuration managed.

The purpose of this manual is to provide guidelines for establishing and conducting the interface control process so that items produced by different design agencies satisfactorily mate and operate in a way that meets mission requirements. These guidelines were drawn from the methodologies of a number of highly successful programs and therefore represent a compilation of "lessons learned."

The principles and processes of interface definition and control presented in this document apply to all projects and programs but may be tailored for program complexity. For example, the interface control process may be less formal for a project or program that requires only one or two end items and has few participants; however, the formal interface control document is still necessary. For a project or program that requires a number of end items and where several participants are involved, a carefully followed interface control process is imperative, with comments, decisions, agreements, and commitments fully documented and tracked. Individual managers should provide the implementation criteria for their interface control processes early in the project or program (ref. 1).

This manual covers the basic principles of interface definition and control: how to begin an interface control program during the development of a new project or program, how to develop and produce interface documentation, how to manage the interface control process, and how to transfer interface control requirements to hardware and software design.

Interface definition and control is an integral part of system engineering. It should enter the system engineering cycle at the end of the concept development phase. Depending on whether the system under development is designed for one-time or continuous use, the process may continue for the full life cycle of the system. Interface definition and control should not be equated to configuration management or configuration control. Rather it is a technical management tool that ensures that all equipment will mate properly the first time and will continue to operate together as changes are made during the life cycle of the system. Figure 1.1 depicts the elements of the system engineering cycle and is used in chapter 3 to describe the application of the interface discipline at different parts of the life cycle (ref. 2).

Establishing a system that ensures that all interface parameters are identified and controlled from the initial design activities of a program is essential. It is not necessary that the fine details of these parameters be known at that time, but it is very important that the parameters themselves are identified, that everything known about them at that time is recorded and controlled, and that voids¹ are identified and scheduled for elimination. The latter requirement is of primary importance to the proper design of any interface. Initial bounding of a void and scheduled tightening of those bounds until the precise dimensions or conditions are identified act as a catalyst to efficient design and development. An enforced schedule for eliminating voids is one of the strongest controls on schedule that can be applied (ref. 3).

The process of identifying, categorizing, defining, and documenting interfaces is discussed in the following chapter. Guidance for the analysis of interface compatibility is also provided.

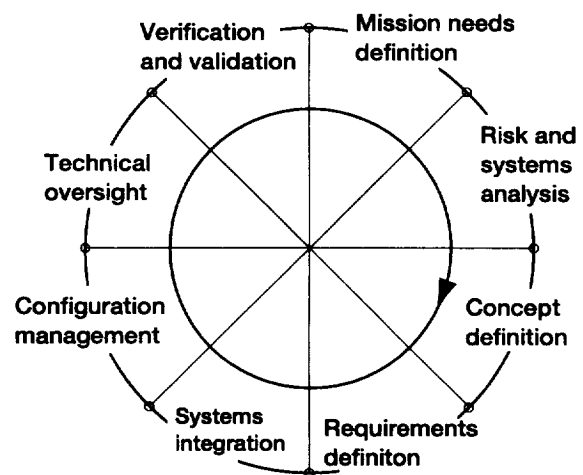


Figure 1.1—System engineering cycle. (The requirements definition phase must include the requirements for the interfaces as well as those which will eventually be reflected in the interface control document.)

¹ A "void" is a specific lack of information needed for control of an interface feature. Control and elimination of voids is fundamental to a strong interface definition and control program.

1.1 Training²

1. The processes explained in this manual for interface definition and control are
 - A. A concise set of parameters that control the design of the interface-related elements
 - B. A set of design details needed for configuration management
 - C. Mission needs definition, risk and systems analysis, concept and requirements definitions, system integration, configuration management, technical oversight, and verification and validation
2. The process is very important for projects that require
 - A. A number of end items
 - B. Involvement of several participants
 - C. Comments, decisions, agreements, and commitments that must be fully documented and tracked
 - D. All of the above
3. What elements does the system engineering cycle contain?
 - A. Mission needs, requirements, and integration
 - B. Technical oversight, core design, and system configuration
- 4a. What is a void?
 - A. Bracketed data
 - B. Wrong data
 - C. Lack of information needed
- 4b. How should voids be handled?
 - A. Voids should be identified and their elimination scheduled.
 - B. Data should be analyzed.
 - C. Supplier should be guided.
- 4c. Name a strong control needed for voids.
 - A. Precise dimensions
 - B. Enforced schedule
 - C. Identified catalysts

²Answers are given at the end of this manual.

Chapter 2

Principles of Interface Control

2.1 Purpose of Interface Control

An interface is that design feature of a piece of equipment³ that affects the design feature of another piece of equipment. The purpose of interface control is to define interface requirements so as to ensure compatibility between interrelated pieces of equipment and to provide an authoritative means of controlling the design of interfaces. Interface design is controlled by an interface control document (ICD).

These documents

1. Control the interface design of the equipment to prevent any changes to characteristics that would affect compatibility with other equipment
2. Define and illustrate physical and functional characteristics of a piece of equipment in sufficient detail to ensure compatibility of the interface, so that this compatibility can be determined from the information in the ICD alone
3. Identify missing interface data and control the submission of these data
4. Communicate coordinated design decisions and design changes to program participants
5. Identify the source of the interface component

ICD's by nature are requirements documents: they define design requirements and allow integration. They can cause designs to be the way they are. They record the agreed-to design solution to interface requirements and provide a control mechanism to ensure that the agreed-to designs are not changed by one participant without negotiated agreement of the other participant.

To be effective, ICD's should track a schedule path compatible with design maturation of a project (i.e., initial ICD's should be at the 80% level of detail at preliminary design review, should mature as the design matures, and should reach the 99% mark near the critical design review).

2.2 Identifying Interfaces

Identifying where interfaces are going to occur is a part of systems engineering that translates a mission need into a configured system (a grouping of functional areas) to meet that need. Each functional area grouping is assigned certain perfor-

mance requirements. These performance requirements are translated into design requirements as the result of parametric studies, tradeoff studies, and design analyses. The design requirements are the basis for developing the system specifications. The boundaries between the functional areas as defined in the system specifications become the interfaces. Early interface discussions often contribute to final subsystem specifications. Interface characteristics, however, can extend beyond the interface boundary, or interface plane, where the functional areas actually come together. The interface could be affected by, and therefore needs to be compatible with, areas that contribute to its function but may not physically attach. For example, it may be necessary to define the path of a piece of equipment as it traverses through another piece of equipment and rotates and articulates to carry out its function. Electrical characteristics of a transmitter and receiver separated by an interface plane may have to be defined for each to properly function. Similarly, the acoustic energy produced by one component and transmitted through the structure or onto another component may need a corresponding definition.

Identifying interfaces early in a program is essential to successful and timely development. Functional analyses are used for analyzing performance requirements and decomposing them into discrete tasks or activities (i.e., decomposing the primary system functions into subfunctions at ever increasing levels of detail). Functional block diagrams are used to define data flow throughout the system and interfaces within the system. Once the segments and elements within a system have been defined, a top-level functional block diagram is prepared. The block diagrams are then used in conjunction with *N*-squared diagrams to develop interface data flows. The *N*-squared diagram is a technique used extensively to develop data interfaces but can also be refined for use in defining hardware interfaces. However, use of this tool in this manual will be restricted to interface categorization. Additional description is provided in section 3.1.1.

In summary, identifying where interfaces are going to occur begins the systems integration component of systems engineering and must start early in design planning. The interface boundaries or planes vary from program to program depending on how design and development responsibilities are assigned. Interface control can occur within a functional area of other design and development agents. Therefore, interfaces can be identified at many levels, for example,

1. Center to center
2. Discipline to discipline (e.g., propulsion to guidance, sensor to structure, or power to users)
3. Contractor to contractor

³For purposes of this manual, a piece of equipment is a functional area assigned to a specific source. Thus, a piece of equipment can be an element of the space station, a system of a spacecraft, a work package assigned to a contractor, or a subsystem.

4. Center to contractor to discipline
5. Program to program (e.g., shuttle to National Launch System)

Once interface boundaries or planes are established, the interfaces must be categorized and defined.

2.3 Categorizing (Partitioning) and Defining Interfaces

Categorizing, or partitioning, interfaces separates the interface features by technical discipline and allows each category, in most cases, to proceed through the definition process independently.

The following basic interface categories (defined by the types of feature and data they encompass) are recommended for use in most programs:

1. Electrical/functional
2. Mechanical/physical
3. Software
4. Supplied services

During the early phases of systems engineering, interfaces may be assigned only the high-level designation of these categories. As the system becomes better defined, the details of the physical and functional interface characteristics become better defined and are documented.

An interface can be assigned to one of these categories by a number of processes of elimination. The one recommended for use is the *N*-squared diagram (ref. 4), which is currently being used by some NASA centers.

2.3.1 Electrical/Functional

Electrical/functional interfaces are used to define and control the interdependence of two or more pieces of equipment when the interdependence arises from the transmission of an electrical signal from one piece of equipment to another. All electrical and functional characteristics, parameters, and tolerances of one equipment design that affect another design are controlled by the electrical/functional ICD. The functional mechanizations of the source and receiver of the interface electrical signal are defined, as well as the transmission medium.

The interface definition includes the data and/or control functions and the way in which these functions are represented by electrical signals. Specific types of data to be defined are listed here:

1. Function name and symbol
2. Impedance characteristics

3. Shielding and grounding
4. Signal characteristics
5. Cable characteristics
6. Data definition
7. Data transmission format, coding, timing, and updating
8. Transfer characteristics
9. Circuit logic characteristics
10. Electromagnetic interference requirements
11. Data transmission losses
12. Circuit protective devices

Other data types may be needed. For example, an analog signal interface document would contain function name and symbol, cable characteristics, transfer characteristics, circuit protective devices, shielding, and grounding; whereas a digital data interface would contain function name and symbol, data format, coding, timing and updating, and data definition.

Additional data types under the electrical/functional heading are

1. Transmission and receipt of an electrical/electromagnetic signal
2. Use of an electrically conductive or electromagnetic medium

Appendix A shows recommended formats for electrical and functional interface control drawings.

2.3.2 Mechanical/Physical

Mechanical/physical interfaces are used to define and control the mechanical features, characteristics, dimensions, and tolerances of one equipment design that affect the design of another subsystem. They also define force transmission requirements where a static or dynamic force exists. The features of the equipment that influence or control force transmission are also defined in this ICD. Mechanical interfaces include those material properties of the equipment that can affect the functioning of mating equipment, such as thermal and galvanic characteristics. Specific types of data defined are

1. Optical characteristics
2. Parallelism and straightness
3. Orientation requirements
4. Space or provisions required to obtain access for performing maintenance and removing or replacing items, including space for the person performing the function
5. Size, shape, mass, mass distribution, and center of gravity
6. Service ports
7. Indexing provisions
8. Concentricity
9. Surface finish
10. Hard points for handling

11. Sealing, pressurization, attachment, and locking provisions
12. Location and alignment requirements with respect to other equipment
13. Thermal conductivity and expansion characteristics
14. Mechanical characteristics (spring rate, elastic properties, creep, set, etc.)
15. Load-carrying capability
16. Galvanic and corrosive properties of interfacing materials

Other data types may be needed. For example, an ICD controlling a form-and-fit interface would generally contain such characteristics as size and shape of the item, location of attachment features, location of indexing provisions, and weight and center of gravity of the item. However, an ICD controlling a structural load interface would contain weight and center of gravity, load-carrying capability, and elastic properties of the material if applicable to the loading conditions. Not all ICD's controlling a form-and-fit interface would have to contain all types of data given in this example, but some form-and-fit interface definitions contain more than the 16 types of data listed. Indexing definitions may require angularity, waviness, and contour definitions and tolerances.

Additional data types under the mechanical/physical heading would be

1. Dimensional relationships between mating equipment
2. Force transmission across an interface
3. Use of mechanically conductive media
4. Placing, retaining, positioning, or physically transporting a component by another component
5. Shock mitigation to protect another component

Appendix B (from ref. 5) shows a mechanical/physical drawing.

This extensive variety of possibilities and combinations prevents assigning a standard set of data types or level of detail to a form-and-fit interface. Each interface must be analyzed and the necessary controlling data identified before the proper level of interface definition and control can be achieved. This holds true for all examples given in this chapter.

2.3.3 Software

A software interface defines the actions required when interfacing components that result from an interchange of information. A software interface may exist where there is no direct electrical interface or mechanical interface between two elements. For example, whereas an electrical ICD might define the characteristics of a digital data bus and the protocols used to transmit data, a software interface would define the actions taken to process the data and return the results of the process. Software interfaces include operational sequences that involve

multiple components, such as data-processing interactions between components, timing, priority interrupts, and watchdog timers. Controversy generally arises in determining whether these relationships are best documented in an electrical/functional ICD, a software ICD, or a performance requirements document. Generally, software interface definitions include

1. Interface communication protocol
2. Digital signal characteristics
3. Data transmission format, coding, timing, and updating requirements
4. Data and data element definition
5. Message structure and flow
6. Operational sequence of events
7. Error detection and recovery procedures

Other data types may be needed. Appendix C provides an example of a software interface signal.

2.3.4 Supplied Services

Supplied services are those support requirements that a piece of equipment needs to function. Supplied services are provided by an external separate source. This category of interface can be subdivided further into electrical power, communication, fluid, and environmental requirements. The types of data defined for these subcategories are

1. Electrical power interface:
 - a. Phase
 - b. Frequency
 - c. Voltage
 - d. Continuity
 - e. Interrupt time
 - f. Load current
 - g. Demand factors for significant variations during operations
 - h. Power factor
 - i. Regulation
 - j. Ripple
 - h. Harmonics
 - l. Spikes or transients
 - m. Ground isolation
 - n. Switching, standby, and casualty provisions
2. Communication interface:
 - a. Types of communication required between equipment
 - b. Number of communication stations per communication circuit
 - c. Location of communication stations
3. Fluid interface:
 - a. Type of fluid required
 - i. Gaseous
 - ii. Liquid

- b. Fluid properties
 - i. Pressure
 - ii. Temperature
 - iii. Flow rate
 - iv. Purity
 - v. Duty cycle
 - vi. Thermal control required (e.g., fluid heat lost or gained)
- 4. Environmental characteristic interface:
 - a. Ambient temperature
 - b. Atmospheric pressure
 - c. Humidity
 - d. Gaseous composition required
 - e. Allowable foreign particle contents

Other data types may be needed. Appendix D shows an example of a supplied services interface for air-conditioning and cooling water.

2.4 Documenting Interfaces

Once an interface has been categorized and its initial contents defined, that interface definition must be recorded in a document that is technically approved by the parties (designer and manager) and the owners of both sides of the interface. The document then is approved by the next higher level in the project management structure and becomes the official control for interface design.

The program manager must ensure that compliance with the approved interface control document is mandatory. Each level of program management must ensure that the appropriate contractors and Government agencies comply with the documentation. Therefore, technical approval of the interface control document indicates that the designated approving organization is ready to invoke the interface control document contractually on the approving organization's contractor or supporting organization.

The interface categories can be grouped together in one document, or each category can be presented in a separate document (i.e., electrical ICD's, mechanical ICD's, etc). The format for interface control documents is flexible. In most cases a drawing format is the easiest to understand and is adaptable to the full range of interface data.

The specification format (ref. 6) can also be used. The use of this type of format enables simple changes through the removal and insertion of pages; however, the format is often difficult to use when presenting complex interface definitions that require drawings, and normally requires many more pages to convey the same level of information.

In either case there must be agreement on a standard for data presentation and interpretation. ANSI standard Y14.5 (ref. 7) can be used for dimensions, along with DOD-STD-100

(ref. 8), for general guidance of a drawing format. The specification format should use MIL-STD-490 (ref. 6) for paragraph numbering and general content.

Some large programs require large, detailed ICD's. Maintaining a large, overly detailed document among multiple parties may be more difficult than maintaining a number of smaller, more focused documents. Grouping small documents by major category of interface and common participants is one of the most effective and efficient strategies. It minimizes the number of parties involved and focuses the technical disciplines, greatly streamlining the decision process and permitting much shorter preparation time. However, interfaces can be multidisciplinary and separate documents can result in miscommunications.

2.5 Identifying Steady-State and Non-Steady-State Interfaces

Interfaces can vary from a single set that remains constant for the life of a program to a multiple set of documents that reconfigures during specific events in the life of a system. The first category would be used for an interplanetary probe. The interfaces of its instruments with the basic spacecraft structure would remain the same from assembly for launch throughout the life of the experiment. However, a continually evolving platform, such as a lunar base, would perhaps be controlled in a series of interface documents based on the assembly sequence of the base. An initial base would be established and later made more complex with additional structures and equipment delivered by subsequent lunar flights. Pressurized elements, logistic elements, power-generating sources, habitats, laboratories, and mining and manufacturing facilities might be added and reconfigured over time. Each configuration would require a set of interface control documents to ensure compatibility at the construction site as well as with the transportation medium from Earth to Moon. Interfaces that remained constant during this process might be termed steady state and require no further consideration once the interface was verified and delivered; whereas interfaces that would evolve from the initial configuration through multiple iterations would require multi-coordination of interface parameters and schedules. The selection of interface categories should identify the steady-state or non-steady-state nature of interfaces as well as their initial designations (ref. 9).

2.6 Selecting a Custodian

Selecting an ICD custodian can depend on several factors (e.g., percentage of interface ownership, relative mission importance of interface sides, and relative investment of interface sides). However, it is generally most effective if the custodian

selected has an objective point of view. An example of this would be someone who is independent of either side of the interface (i.e., without any “vested interest” in the interface hardware or software). Objectivity permits unbiased control of the interface, involvement of the custodian as an objective mediator, and documentation of the interface on a noninterference basis with program/project internal design. Selecting an independent interface custodian should be the first step in establishing an interface control organization. A set of criteria should be used to select the custodian by weighting the content and interests of the interface with the needs of interface control. One set of criteria is as follows:

1. Integration center: Is one center accountable for integrating the interfaces controlled by this ICD? This criterion is considered the most important because the integration center will have the final responsibility for certifying flight readiness of the interfaces controlled in the ICD.
2. U.S. center: Is the participant a U.S. center? This criterion is considered the next most important because of agency experience and projected responsibility.
3. Flight hardware or software: Is the interfacing article flight hardware or software (as opposed to support hardware or software)? Flight hardware or software takes precedence.
4. Flight sequence: Does one side of the interfacing equipment fly on an earlier manifest than the other? An earlier flight sequence takes precedence over follow-on interfacing hardware.
5. Host or user: Is the interfacing article a facility (as opposed to the user of the facility)? Procedure in this criterion is guided by the relative priority of the interfacing articles.
6. Complexity: How complex is the interfacing equipment (relative to each side)? The more complex side of the interface normally takes precedence.
7. Behavior: How active is the interfacing equipment? The active side normally takes precedence over the passive side.
8. Partitions: How are the partitions (categories) used by the interfacing equipment? The relative importance of the partitions to the interface is acknowledged, and selection of the custodian is sensitive to the most important partition developers.

Scores are assigned to each piece of interfacing equipment for each criterion. These scores can be determined by many different methods. Discrete values can be assigned to the first four criteria. A score of 1.0 is assigned if the interfacing piece of equipment is unique in meeting the criterion, the other piece of equipment then receives a score of 0.0. Scores of 0.5 are assigned to both sides if both (or neither) of them meet the criterion. There is no definitive way of assigning scores to the last four criteria; however, verbal consensus or an unbiased survey can be used to assign scores. Also, the partition criteria can be scored by partition evaluation analysis (ref. 4).

2.7 Analyzing for Interface Compatibility

The interface definitions to be documented on the ICD's must be analyzed for compatibility before the ICD is authenticated. Appendix E provides guidance on how compatibility analyses may be performed. They vary in their complexity from a simple inspection of the interface definitions to complex mathematical analyses where many variables are involved.

Regardless of complexity, the compatibility analysis should be documented and maintained as backup information for the ICD. It can be used to expedite any changes to the interface definition by providing a ready means for evaluating the compatibility of the proposed change. The compatibility analysis also can be used to document how the interface definition was arrived at and why the definition is presented as it is on an ICD.

2.8 Verifying Design Compliance With Interface Control Requirement

The ICD can only fulfill its purpose if the contractors' detailed design drawings and construction practices adhere to the limits imposed by the ICD. Verifying compliance of the design as well as of the construction process is an integral part of interface control.

Each contractor should be assigned the responsibility of denoting on their manufacturing and inspection drawings or documents those features and characteristics that, if altered, would affect interfaces controlled by the ICD's. To ensure that all ICD requirements are covered, the contractor should select, at the highest assembly level at which the equipment is inspected, the features and characteristics to be denoted. Any design change affecting an ICD-controlled feature or characteristic would be clearly identified even at the assembly level (ref. 10).

Entries identified as “to be resolved” (TBR) can be bracketed or shaded to indicate preliminary interface information or an interface problem. This information is subject to further review and discussion and is an interim value for use in evaluating effects. Entries identified as “to be supplied” (TBS) represent data or requirements to be furnished. Appendix F shows a typical bracket system.

2.9 Verifying Contract-Deliverable Item

Each contract-deliverable item that is a mating side to an ICD interface should also be tested or measured to verify that the item complies with the requirement as specified in the ICD. The

responsibility for administering and reporting on this verification program could be assigned to the design agent, the contractor, or an independent third party. If feasible, an independent third party should be selected for objectivity.

The verification methods should include analysis, measurement and inspection, demonstration, and functional testing. The specific methods employed at each interface will depend on the type of feature and the production sequence. Compliance should be verified at the highest practical assembly level. To preclude fabrication beyond the point where verification can be performed, an integrated inspection, measurement, and demonstration test outline of both hardware and software should be developed. This verification test outline will provide a schedule, tied to production, that allows all interface requirements to be verified. The resultant data and inspection sheets should become part of the verification data in the history jacket retained by the contractor for NASA.

2.10 Training²

1. What is the purpose of interface control?
 - A. To define interfaces
 - B. To ensure compatibility between interrelated equipment
 - C. To provide an authority to control interface design
 - D. All of the above
2. How is an interface identified?
 - A. By boundaries between functional areas
 - B. By functional analyses of performance requirements
 - C. By design features of a component that can affect the design features of another component
- 3a. How can interfaces be categorized?
 - A. Mechanical, electrical, software, and services
 - B. Electrical/functional, mechanical/physical, software, and supplied services
 - C. Electrical, physical, software, and supplies
- 3b. What is one method of assigning an interface to one of the four basic categories?
 - A. Functional flow block diagram
 - B. Timeline analysis
 - C. *N*-squared diagram
- 4a. How can an interface be documented?
 - A. By drawing format
 - B. By specification format
 - C. By both of the above
- 4b. Who approves the interface control document?
 - A. Designer or manager
 - B. Owners of both sides
 - C. Both of the above
- 4c. Who ensures compliance with the approved ICD?
 - A. Designer or manager
 - B. Owners of both sides
 - C. Project manager
- 5a. What is a steady-state interface?
 - A. A single set that remains constant for the life of the project
 - B. A multiple-set suite that reconfigures during specific events in the life of the system
- 5b. Give an example of a steady-state interface.
 - A. An interplanetary probe
 - B. A lunar base
- 5c. What features make this a good example of a steady-state interface?
 - A. The basic structure of the spacecraft would remain the same from assembly for launch throughout the life of the experiment.
 - B. An initial base would be established and subsequently made more complex with additional structures and equipment delivered by subsequent lunar flights.
- 6a. How should an ICD custodian be selected?
 - A. Percentage of ownership of the interface
 - B. Relative investment of interface sides
 - C. An objective point of view
- 6b. What criteria should be used to select a custodian?
 - A. Integration or U.S. center, flight hardware or software, flight sequence, host or user, complexity, behavior, and partitions
 - B. Integration hardware, sequence user, and partitions
- 6c. What scoring system can be used for these criteria?
 - A. Zero to 1.0, verbal consensus, unbiased survey, and partition evaluation analysis
 - B. One to 100, priority ranking, and voting
- 7a. What is the purpose of an ICD compatibility analysis?
 - A. Demonstrates definitions and provides mathematical analysis
 - B. Demonstrates completeness of an interface definition and provides a record that the interface has been examined and found to be compatible

²Answers are given at the end of this manual.

- 7b. What are the four categories that require interface analysis?
- A. Electrical/functional, mechanical/physical, supplied/ services, and hydraulic/pneumatic
 - B. Electrical/functional, mechanical/physical, software, and supplied services
- 7c. The hardware for mounting the satellite vehicle (SV) adapter to the Titan IV Centaur is shown in figures 2.1 to 2.3.
- A. Is there sufficient data to perform a compatibility analysis?
 - i. Yes
 - ii. No
 - B. Can the Jet Propulsion Laboratory specify the SV adapter ring?
 - i. Yes
 - ii. No
 - C. What items need to be bracketed?
 - i. Shear pin material and SV attachment view
 - ii. SV panel and view C–C
- 8a. What does a bracket on an ICD represent?
- A. Verification of design compliance
 - B. An interface problem
- 8b. What interface deficiency rating does a bracket discrepancy have?
- A. S & MA impact A > 1 or understanding of risk B > 2
 - B. S & MA impact A < 1 or understanding of risk B < 2
- 9a. How are mating sides of an ICD interface verified?
- A. Testing or measurement to meet requirements
 - B. Analysis, measurement or inspection, demonstration, and functional testing
- 9b. What does the verification test outline provide?
- A. Schedule, tied to production, that allows interface requirements to be verified
 - B. Process controls, tied to manufacturing, for meeting schedules
- 9c. Where is the resultant test and inspection data stored?
- A. Contractor files for use by an independent third party
 - B. History jackets for use by NASA

ICD-TIV/SV-24027 REV A
25 JANUARY 1994
APPENDIX A

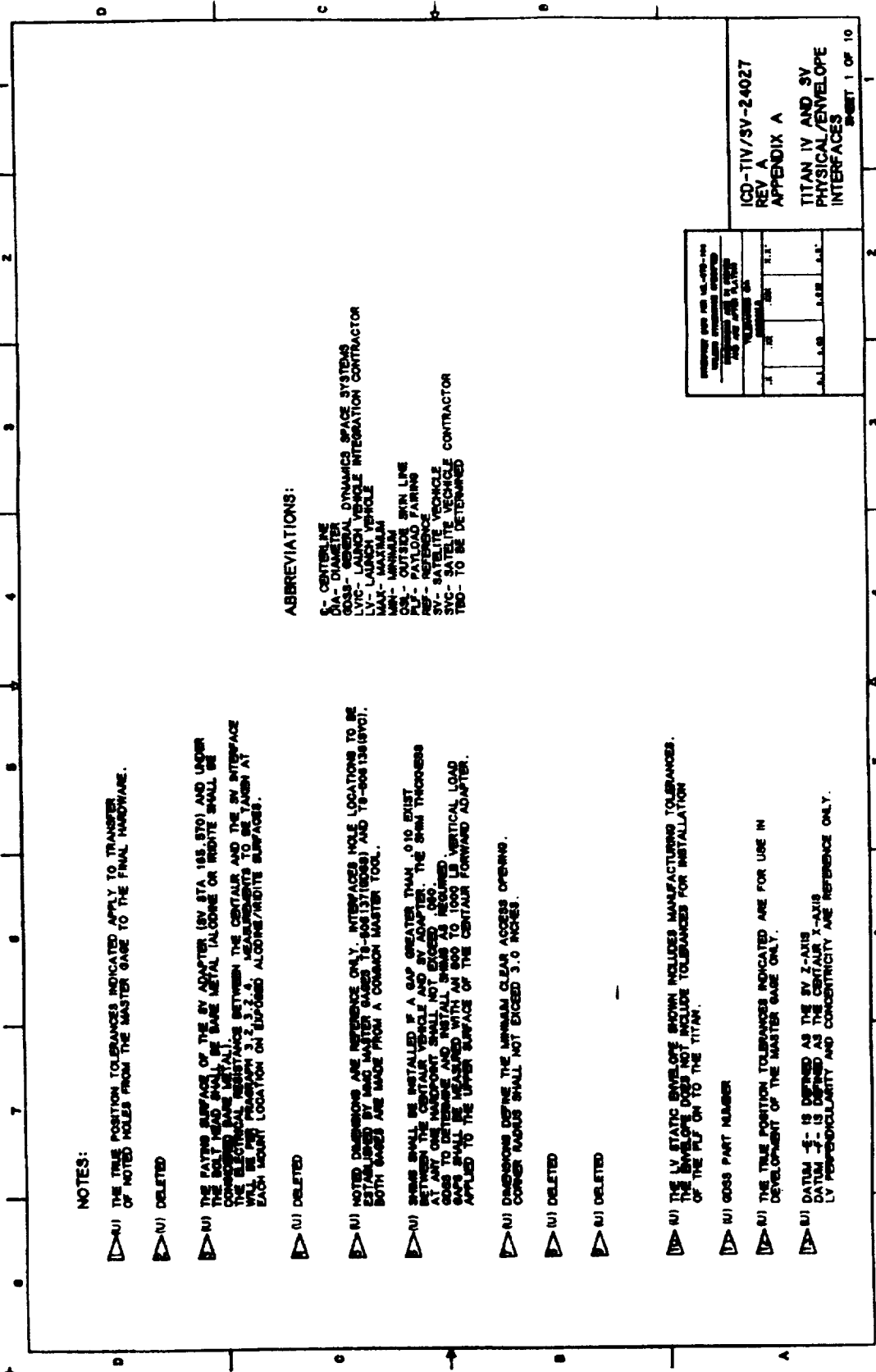
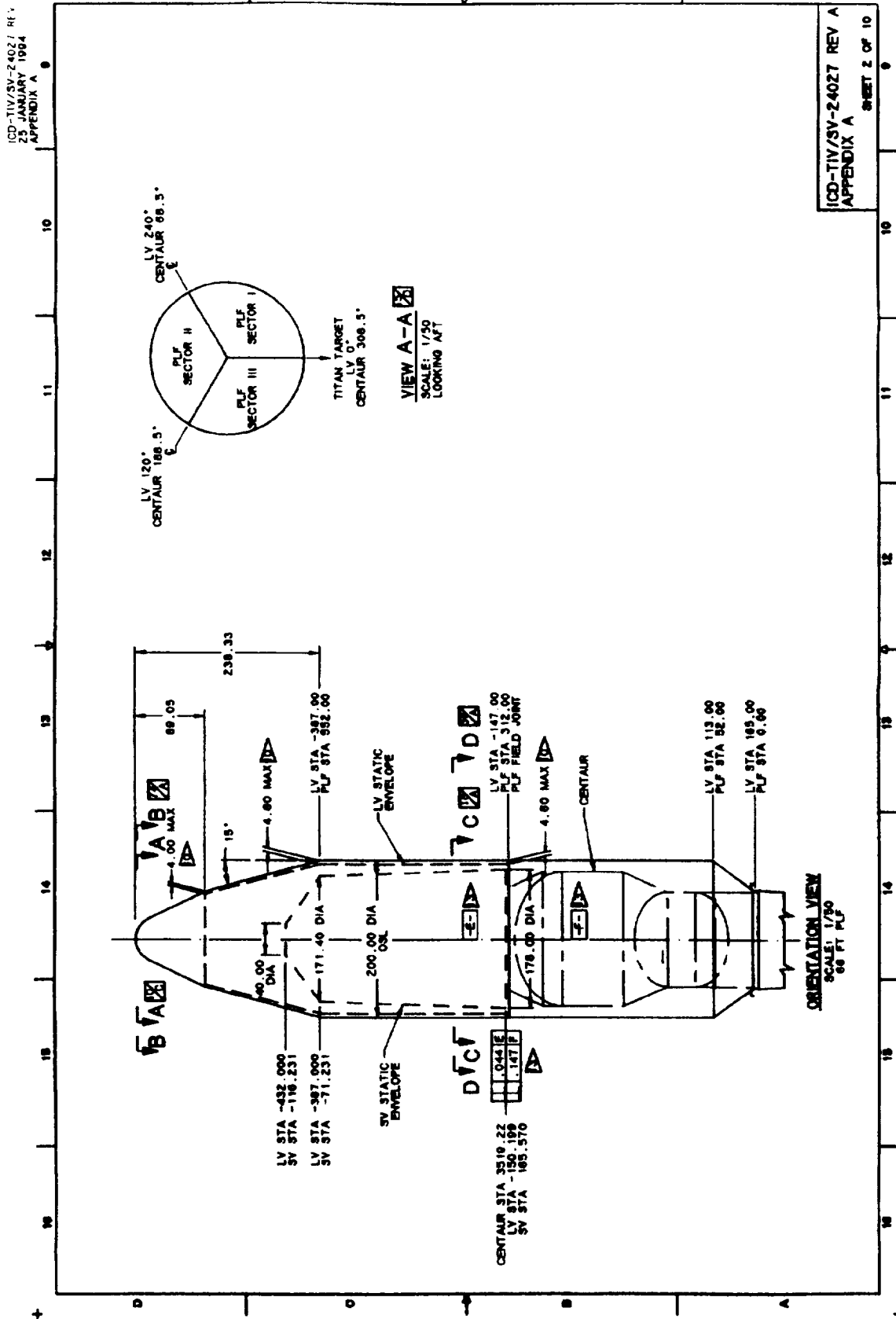


Figure 2.1.—Titan IV and satellite vehicle physical/envelope interfaces.



ICD-TIV/SV-24027 Rev A
25 JANUARY 1994
APPENDIX A

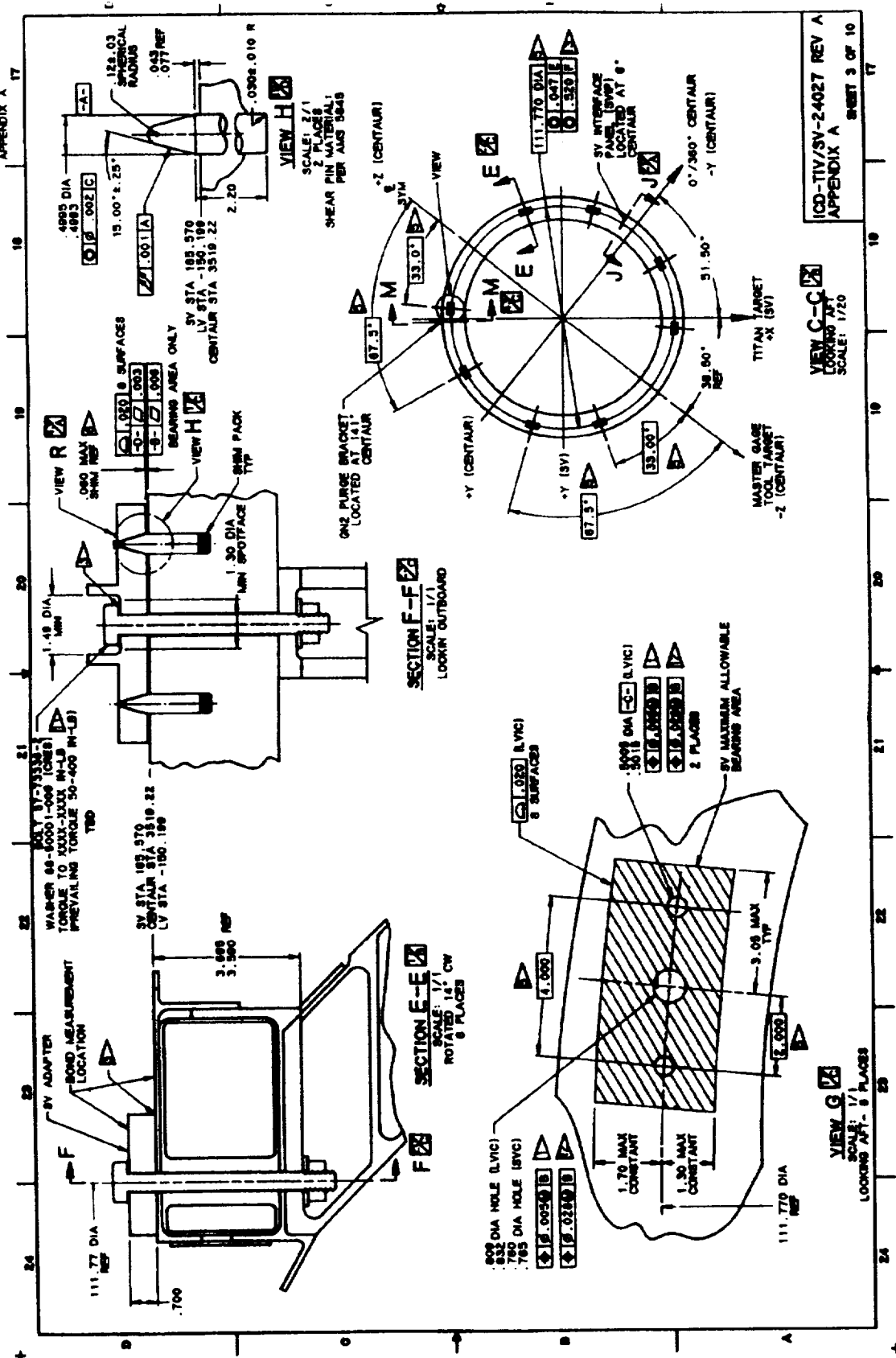


Figure 2.3.—Titan IV and satellite vehicle adapter ring.

Chapter 3

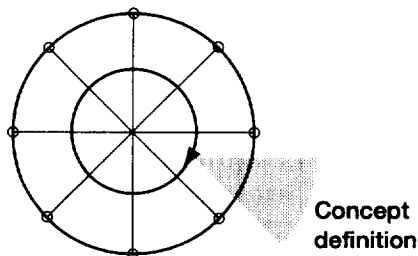
The Process: Through the Design Phases

Interface control should be started when a program begins. This process eventually will define all interface design and documentation responsibilities throughout the life cycle of the program. Each program phase from concept development to project construction is directly related to the maturity level of interface control.

3.1 Program Phases

3.1.1 Concept Definition

During the system engineering concept definition phase (from fig. 1.1), basic functional areas of responsibility are assigned for the various pieces of equipment that will be employed by the project (electrical power, environment control, propulsion, etc.); see figure 3.1. At this point the design responsibilities of the responsible organization and related contractor (if chosen) should be defined to establish a set of tiered, traceable requirements. From these requirements the interfaces to be designed are identified by category (electrical/functional, mechanical/physical, software, and supplied services) and by type of data that must be defined. This categorization will include a detailed review of each requirement to determine which requirements or features will be controlled by the interface control process. (What is important for this item to fulfill its intended function? On what *interfacing* equipment is this function dependent?) Once the interfaces to be controlled are selected, the formal procedures for interface control need to be established. These procedures include identifying the par-



- Assign basic functional areas of responsibility.
- Define design responsibilities.
- Categorize interfaces.
- Define interfaces to be controlled.
- Establish formal interface control procedures.
- Disseminate scheme, framework, traceability.

Figure 3.1.—Establishment of interface control process during concept definition.

ticipants responsible for the interface control documentation, the approval or signoff loop for documentation, and the degree to which all participants have to adhere to interface control parameters and establishing a missing design data matrix, change procedures, etc. (See section 3.2.)

Early development of the interface process, products, and participants provides a firm foundation for the design engineer to use the correct information in designing his or her portion of an interface. It minimizes the amount of paper to be reviewed, shortens the schedule, and concentrates the efforts of the designer on his or her area of responsibility.

Initial selection of interfaces generally begins with listing of all pieces of equipment in a system and then identifying the extent of interrelation among them. One tool used to help in this process is the *N*-squared diagram. Details of this process can be found in reference 4. The *N*-squared diagram was initially used for software data interfacing; however, some centers are using it for hardware interfaces. If the diagram is not polarized initially (input/output characteristics not labeled), it is a convenient format for identifying equipment interfaces and for categorizing them. An example of this form is shown in figure 3.2. This diagram can be further stratified to identify the interfaces for each of the categories; however, detailed stratification is best applied to electrical/functional, software, and supplied services interfaces. Using the *N*-squared diagram permits an orderly identification and categorization of interfaces that can be easily shown graphically and managed by computer.

By the end of this phase the basic responsibilities and management scheme, the framework for the interface control documentation, and the process for tracking missing interface design data (see section 3.2.2) should be established and disseminated.

3.1.2 Requirements Definition

During the requirements definition phase (fig. 3.3; from fig. 1.1), the definitions of the mission objectives are completed so that each subsystem design can progress to development. Here, the technology to be used in the project will be defined to limit the risk associated with the use of new, potentially unproven technologies. Defining requirements and baselining interface documents early in the design process provides information to the designer needed to ensure that interface design is done correctly the first time. Such proactive attention to interfaces will decrease review time, reduce unnecessary paperwork, and shorten schedule times. By the end of requirements definition all interface control documents should be prepared, interfaces defined to the most detailed extent possible, and ICD's presented for baselining.

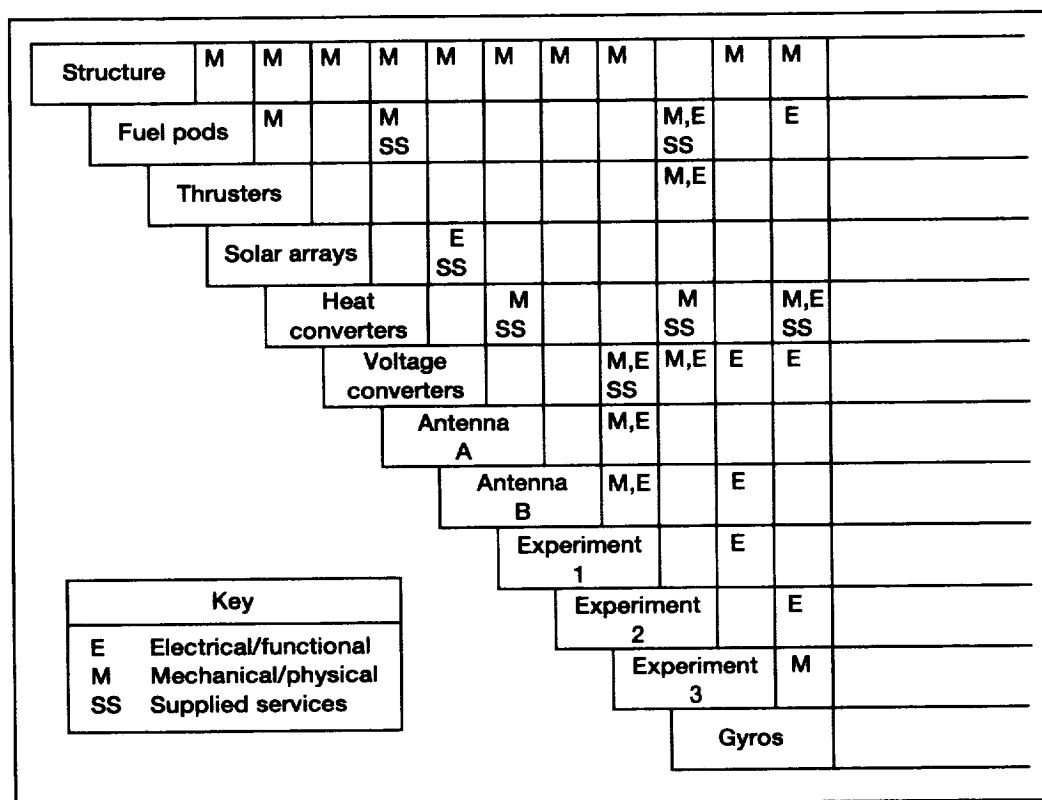
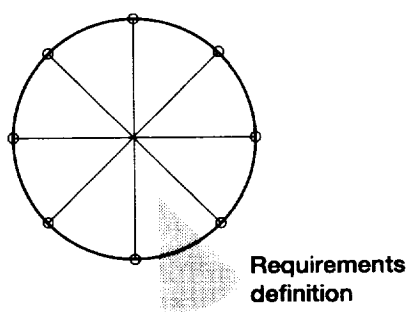


Figure 3.2.—N-squared diagram for orbital equipment. (Entries not polarized.)



- Define technologies to be used.
- Define and categorize all interfaces.
- Prepare all interface control documents.
- Identify all voids and assign both responsibilities and due dates.
- Bound voids when possible.
- Baseline interface documents.

Figure 3.3.—Development and control of interfaces during requirements definition.

Baselining is the act by which the program manager or designated authority signs an ICD. That signature establishes the ICD as an official document defining interface design requirements. The term “baselining” is used to convey that the ICD is *the only* official definition and that this officiality comes from the technical management level. Not only is the initial version of the ICD baselined, but each subsequent change or update to an ICD is also baselined.

The baselined version of the ICD will identify (by a “void”) any missing design data that cannot be included at that time. Agreed-to due dates will be noted on the ICD for each data element required. Each void will define the data required and specify when and by whom such data will be supplied. Where possible, the data to be supplied should be bounded initially on the ICD. These bounds will be replaced by detailed data when the void is filled. The initial bounds give the data user (the other side of the interface) a range that can be used without risk, until the detailed data are supplied. Establishing these voids on ICD’s provides a means of ensuring that interface design data are supplied when they are required by the data user. Yet it allows design freedom to the data supplier until the data are needed. A recommended form for use in identifying the data needed is shown in figure 3.4. The criteria for choosing due dates are discussed in section 3.2.

Interface Design Data Required (IDDR)

(Drawing/document number + Void number)

Data required: Brief description of information needed
to define interface element currently
lacking details

Data supplier: (Project center/code/contractor)

Data user(s): (Project center/code/contractor)

Date due: (Date design data are needed, either actual
date or a period of time related to a specific
milestone.

Figure 3.4.—Format for interface design data required (IDDR).

**Interface Design Data Required (IDDR)
Program Status Report**

Drawing/doc # _____	Sheet/page _____	Short title _____	Supplier(s) _____	User(s) _____	Due date _____	Remarks
IDDR #	/Zone	Data required	Center/code/ contractor	Center/code/ contractor	Yr/Mo/Day	

Figure 3.5.—Format for monthly report on IDDR status.

Documents should be baselined as early as possible, as soon as the drawings contain 10% of the needed information. The significance of early baselining is that both sides of the interface have the latest, most complete, official, single package of information pertaining to the design of the interface.

The package includes all agreed-to design data plus a list of all data needed, its current level of maturity, and when it is to be supplied by whom to whom.

Technical information voids in interface documents must be accounted for and tracked. Otherwise, there is no assurance that the needed information is being provided in time to keep the design on schedule. The status of these voids must be reported, and the owners of the interface-design-data-required forms (IDDR's) must be held responsible for providing the needed information. It is recommended that the status be reported monthly to all parties having responsibility for the interfaces.

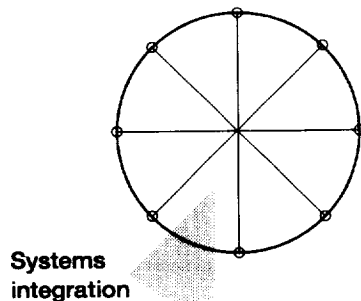
A consolidated report is the most efficient, consumes the least paper and mail services, and allows the program manager to track areas important to the integration of the system components. The basic form shown in figure 3.5 is recommended for reporting and tracking IDDR's.

3.1.3 Systems Integration

The interface control program continues to be active during the systems integration phase (fig. 3.6; from fig. 1.1). Design changes that establish a need for a new interface will follow the interface control change procedures as defined in section 3.2.

Proposed design changes that affect existing interfaces are not given final approval until all participants' and the cognizant center's baselinings have been received through the ICD change notice system.

During the various design reviews that occur in the full-scale engineering development phase, special attention should be given to design parameters that if altered, would affect interfaces controlled by the ICD. It is strongly recommended that each design activity denote, on design and manufacturing documentation at the preliminary design review, through a bracket or some highlighting system, those features and characteristics that would affect an interface (see section 2.8). At the critical design review all voids should be resolved and all detailed design drawings should comply with interface control documentation (see section 2.9).



- Manage and satisfy voids.
- Invoke use of brackets on design drawings.
- Ensure resolution of voids by the time of critical design review.
- Verify compliance of design documentation with ICD's.

Figure 3.6.—Development and control of interfaces during systems integration.

3.2 Preparing and Administering Interface Control Document

3.2.1 Selecting Type of Interface Control Document

A drawing, a specification, or some combination format should be selected for the ICD on a case-by-case basis. The drawing format generally is preferred when the ICD has features related to physical dimensions and shapes. The specification format is preferred when the ICD needs tables and text to describe system performance. Combinations are used when both dimensions and tables are needed. Members of the coordinating activity responsible for preparing the ICD determine the format, which is approved by the appropriate project authority. Examples of drawing formats are given in appendixes A and B.

The level of detail shown on the ICD varies according to the type and degree of design dependency at the interface being controlled. The ICD should clearly identify and control interfaces between designs and enable compatibility to be demonstrated between the design areas. The key to a useful ICD is limiting the detail shown to what is required to provide compatibility. Any unnecessary detail becomes burdensome and may confuse the contractors responsible for designing the mating interface. *Again, the ICD should, at a minimum define and illustrate physical and functional interface characteristics in sufficient detail that compatibility, under worst-case tolerances, can be determined from the ICD alone; or it should reference applicable revisions of detailed design drawings or documents that define and bracket or identify features, characteristics, dimensions, etc., under worst-case tolerances, such that compatibility can be determined from the bracketed features alone.*

3.2.2 Tracking and Resolving Missing Interface Design Data

Missing interface data should be identified on the ICD, and the ICD should control the date for its submission. The notation identifying the missing data should indicate the specific data required, how the data are being tracked for resolution, when the data are needed by the interfacing design agent, and by what date the required data will be supplied. Establishing data-required notations (or voids) on ICD's helps ensure that interface design data will be supplied when needed; yet it allows design freedom to the data supplier until the due date. Every attempt should be made to establish realistic due dates and to meet that schedule unless there is a valid and urgent need to change a due date.

These criteria and procedures should be followed in establishing, reporting, and managing data due dates:

1. Choose the due date as the date when the data user will start to be affected if agreed-upon or baselined data have not been received.

2. When establishing a due date, allow time to process and authenticate a change notice to the ICD (i.e., once the due date has been established, include a period of time to establish that due date for the data supplier).

3. The custodian responsible for the ICD should periodically, as determined by the appropriate project authority, prepare and distribute a report on the status of all missing design information for all project activities. The report should contain the following information:

- a. Identification of the data element needed, consisting of the ICD number, the date, and a two- or three-digit number that provides a unique identifier for the data element
- b. A short title for the ICD
- c. The activity that requires the data
- d. The date when the missing data are to be supplied or the period of time after the completion of a program event or milestone when the data are to be supplied
- e. The activity from which the data are due
- f. The status of the data required (i.e., late data, data in preparation, or change notice number)
- g. A description of the data required

3.3 Initial Issuance of ICD

The first issue of an ICD should be a comment issue. The comment issue is distributed to participating centers and contractors for review and comment as designated in the interface responsibility matrix (fig. 3.7).

The interface custodian generates the responsibility matrix for ICD's. The matrix specifies the center and contractor responsibilities for baselining, review and comment, and technical approval. The matrix lists all ICD's applicable to a particular program. Distribution of the ICD's can then be controlled through this matrix as well.

The review and comment process is iterative and leads to agreement on system interface definitions and eventual approval and baselining of the ICD. See figure 3.8 for a flow diagram of the issuance, review and comment, and baselining procedures for ICD's. Concurrent distribution of the comment issue to all participants minimizes the time needed for review and subsequent resolution of differences of opinion.

3.4 Document Review and Comment

As designated in the ICD responsibility matrix, all centers and contractors should submit technical comments through the

appropriate authority to all other activities with review and comment responsibilities for the particular ICD and to the ICD custodian.

Technical comments by all activities should be transmitted to the custodian as soon as possible but not later than 30 working days⁴ from receipt of the comment issue. If the comment issue is technically unacceptable to the Government authority or the interfacing contractor, the rationale for unacceptability should be explained, including technical and cost effects if the interface definition is pursued as presented.

3.4.1 Resolving Comments

The ICD custodian collects review comments and works in conjunction with project management for comment resolution until approval is attained, the comment is withdrawn, or the ICD is cancelled. Information on comments and their disposition and associated resolution should be documented and transmitted to all participants after all comments have been received and dispositioned. Allow two weeks⁴ for participants to respond to the proposed resolution. Nonresponses can be considered concurrence with the resolutions if proper prenotification is given to all participants and is made part of the review and comment policy.

When comments on the initial comment issue require major changes and resolution is not achieved through informal communications, an additional comment issue may be required and/or interface control working group (ICWG) meetings may need to be arranged.

3.4.2 Interface Control Working Group

The ICWG is the forum for discussing interface issues. ICWG meetings serve two primary purposes: to ensure effective, detailed definition of interfaces by all cognizant parties, and to expedite baselining of initial ICD's and subsequent drawing changes by encouraging resolution of interface issues in prebaselining meetings. A major goal of interface control should be that baselining immediately follow a prebaselining ICWG meeting.

All ICWG meetings must be convened and chaired by the cognizant project organization. The project can choose a contractor to act as the chair of an ICWG when Government commitments are not required. In all cases the ICWG members must be empowered to commit the Government or contractor to specific interface actions and/or agreements. In cases where a contractor is ICWG chair, the contractor must report to the Government any interface problems or issues that surface during an ICWG meeting.

⁴The times assigned for commenting activities to respond are arbitrary and should be assigned on the basis of the schedule needs of the individual programs.

Key:

- (1) Major project/program applicability (e.g., NSTS).
- (2) Primary project/program ownership of interfaces.
- (3) Category of interface covered by list (e.g., electrical/functional).
- (4) Review, comment, and information (RC&I) responsibilities by NASA center (listed in (5)).
- (5) Center responsible for RC&I of the interface document.
- (6) Center code or contractor doing RC&I.
- (7) Center having technical approval signature authority (one column for each applicable center).
- (8) NASA organization having authentication responsibility (single organization for authentication of a baselined document following technical approval by the organizations in columns marked by (7)).
- (9) Drawing/document number and short title.

Figure 3.7.—Interface responsibility matrix.

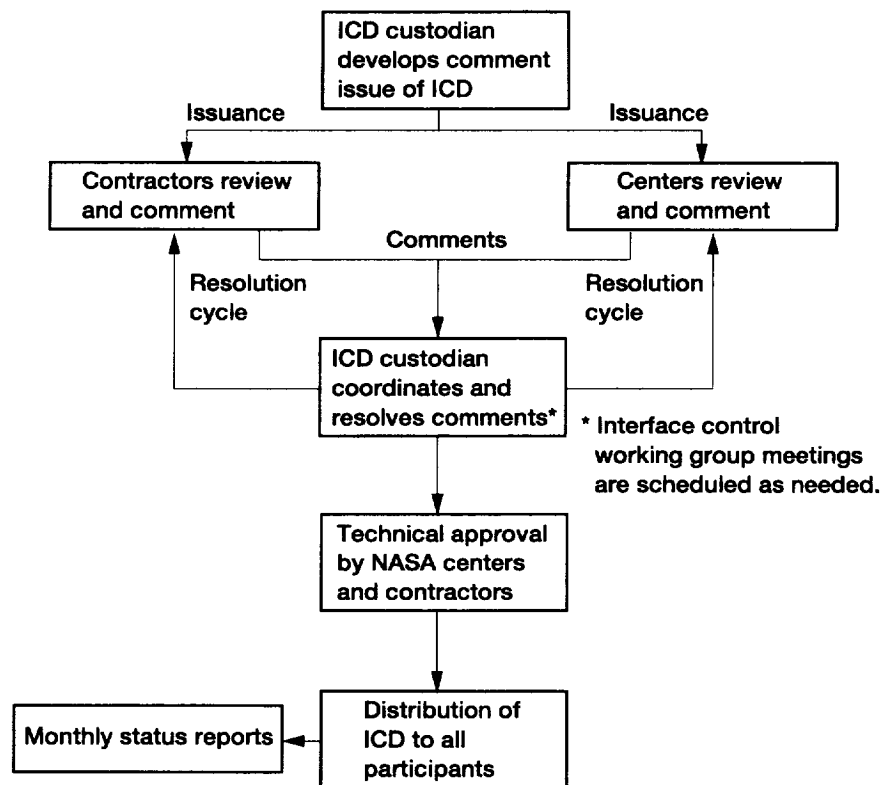


Figure 3.8.—Flow of interface control document production.

The ICWG chair prepares the ICWG meeting minutes or designates one of the meeting participants for this task. The minutes should include discussions of problems, agreements reached, decisions made, and action items. The ICWG chair also ensures that any updated interface control documentation reflecting the ICWG discussions is distributed within the timeframe agreed to by the affected participants.

3.4.3 Approval/Signoff Cycle

The management plan for the project assigns responsibility for each piece of equipment to a specific project authority and its contractor. The signoff loop for each ICD reflects this plan and can be related to the project and the origin of each design requirement. For each ICD, then, the signoff loop follows the sequence of technical approval by the contractors first and then by the appropriate project authority.

3.4.4 Technical Approval

The appropriate project authority and the primary and associate organizations with an interest in a particular ICD are listed in the responsibility matrix. They each sign the ICD to signify technical agreement and a readiness to contractually invoke its requirements.

3.4.5 Baselining

Interface control documents are baselined when the owners of both sides of the interface at the next level up in the program structure come to technical agreement and sign the document.

3.5 Change Notices

The procedure for initiation, review, technical approval, baselining, and distribution of changes to project ICD's (fig. 3.9) should conform to the following guidelines.

3.5.1 Initiating Changes

Any project activity should request a change to an ICD when

1. Data are available to fill a void.
2. Information contained in a data-required note needs to be modified.
3. Additional data are needed (i.e., a new data requirement has been established).
4. A technical error is discovered on the ICD.

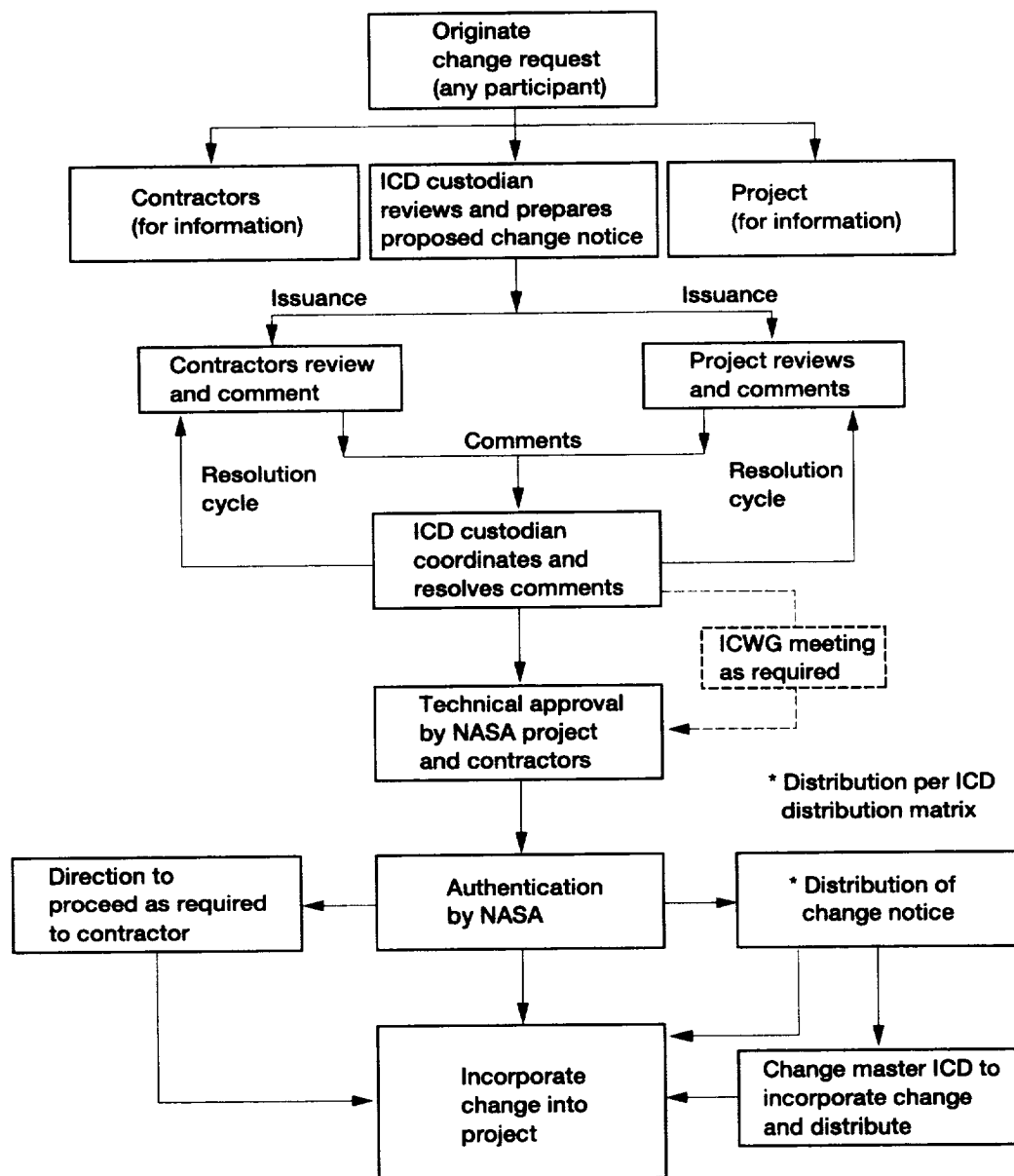


Figure 3.9.—Development and flow of change notices in the ICD revision process.

5. An equipment design change and a system or equipment rearrangement are proposed to improve performance, reduce cost, or expedite scheduled deliveries that would require changes to an interface or creation of new interfaces.

3.5.2 Requesting Changes

All requests for changes should be submitted to the organization responsible for maintaining the ICD, with copies to all activities that will review the resultant change notices and to the appropriate project authority. If baselining is needed in less than 30 days, a *critical* change should be requested. All requests for changes should be submitted in a standard format that includes the following items:

1. Originator's identification number—It is used as a reference in communications regarding the request and should appear on resulting change notices
2. Originating activity—originating project and code or originating contractor
3. Point of contact—name, area code, telephone number, facsimile number, and e-mail address of the person at the originating activity to be contacted regarding the request
4. Document affected—number, revision letter, and short title of each ICD that would be affected by the change
5. Number of data voids (if applicable)—number of data requirements for which data are being provided
6. Urgency—indication of whether this change is critical or routine (project decides whether to use critical route)
7. Detailed description of change—a graphic or textual description of the change in sufficient detail to permit a clear portrayal and evaluation of the request. Separate descriptions should be provided when more than one ICD is affected.
8. Justification—concise, comprehensive description of the need and benefit from the change
9. Impact—concise, comprehensive description of the effect in terms of required redesign, testing, approximate cost, and schedule effects if the requested change is not approved; also the latest date on which approval can occur and not affect cost or schedule
10. Authorizing signature of the organization requiring the change

Upon receipt of a change request to an ICD, the ICD custodian coordinates the issuance of a proposed change notice. First, the ICD custodian evaluates the technical effect of the proposed change on the operation of the system and mating subsystem. If the effect of the change is justified, the ICD custodian generates and issues a change notice. If the justification does not reflect the significance of the change, the ICD custodian rejects the request, giving the reason or asking for further justification from the originating organization. The ICD custodian evaluates an acceptable change request to determine whether it provides data adequate to generate a change notice.

The proposed change notice describes the specific changes (technical or otherwise) to the ICD in detail by “from-to” delineations and the reasons for the changes, as well as who requested the changes and how the change request was transmitted (i.e., by letter, facsimile, ICWG action item, etc.).

3.5.3 Proposed Change Notice Review and Comment Cycle

The review and comment cycle for proposed changes to ICD's should follow the same system as that used for the initial issuance of the ICD (see sections 3.3 and 3.4).

3.5.4 Processing Approved Changes

The baselined change notice should be distributed to all cognizant contractors and project parties expeditiously to promulgate the revised interface definition. The master ICD is revised in accordance with the change notice, and copies of the revised sheets of the ICD are distributed (see sections 3.3 and 3.4). Approval of the change by the project constitutes authority for the cognizant organization to implement the related changes on the detailed design.

3.5.5 Distributing Approved Changes

The custodian distributes the baselined change notice to all cognizant centers and contractors to expeditiously promulgate the revised interface definition. The master ICD is then revised in accordance with the change notice, and copies of the revised ICD sheets are distributed as was the change notice. The responsibility matrix (fig. 3.7) can be used to identify the distribution of change notices as it was used for the distribution of the ICD's.

3.5.6 Configuration Control Board

During development the project's configuration control board is responsible for reviewing and issuing changes to the configuration baseline. The board reviews all class I engineering change proposals to determine if a change is needed and to evaluate the total effect of the change. The configuration control board typically consists of a representative from the chairman, the project management office, customers, engineering, safety assurance, configuration management (secretary), fabrication, and others as required.

Changes to configuration items can only be effected by the duly constituted configuration control board. The board first defines a baseline comprising the specifications that govern development of the configuration item design. Proposed changes to this design are classified as either class I or class II changes. Class I changes affect form, fit, or function. However, other factors, such as cost or schedule, can cause a class I change. Class I changes must be approved by the project before being implemented by the contractor.

All other changes are class II changes. Examples of class II changes are editorial changes in documentation or hardware changes (such as material substitution) that do not qualify as class I changes. Project concurrence, generally, is required for the contractor to implement class II changes. Government plant representatives (Defense Contracts Administration Services (DCAS), Navy Programs Resident Office (NAVPRO), and Air Force Programs Resident Office (AFPRO)) usually accomplish these tasks.

3.5.7 Closing the Loop

A wide range of methods are available for verifying by test that the design meets the technical requirements. During the definition phase analysis may be the only way of assessing what is largely a paper design. Typical methods are testing by similarity, analysis, modeling, and use of flight-proven components; forecasting; and comparison, mathematical modeling, simulation modeling, and using flight-proven experience and decisions. The actual methods to be used are determined by the project office. Each method has associated costs, requires development time, and provides a specific level of performance verification. The Government and industry managers must carefully trade off program needs for performance verification with the related costs.

If any demonstrated or forecast parameter falls outside the planned tolerance band, corrective action plans are prepared by the contractor and reviewed by the Government project office. Each deviation is analyzed to determine its cause and to assess the effect on higher level parameters, interface requirements, and system cost effectiveness. Alternative recovery plans are developed showing fully explored cost, schedule, and technical performance implications. Where performance exceeds requirements, opportunities for reallocation of requirements and resources are assessed.

Although functional and performance requirements are contained in the appropriate configuration item specification, the definition, control, and verification of interface compatibility must be handled separately. Otherwise, the volume of detail will overwhelm both the designers and managers responsible for meeting the functional and performance requirements of the system. Early establishment of the interface definition and control process will provide extensive savings in schedule, manpower, money, and paper. This process will convey precise, timely information to the interface designers as to what the designer of the opposing side is committed to provide or needs and will subsequently identify the requirements for verifying compliance.

Whether the interface is defined in a drawing format or in a narrative format is at the discretion of the program. What is of primary importance is that only the information necessary to define and control the interface should be on these contractual documents to focus the technical users and minimize the need for updating information.

Appendix G provides seven ICD guidelines that have been used by many successful flight projects and programs to provide such a focus on the interface definition and control process.

3.6 Training²

- 1a. When should the ICD process be started?
 - A. Concept definition
 - B. Requirements definition
 - C. Systems integration
- 1b. What are the benefits of early development of the ICD process?
 - A. Assigns basic areas of responsibility
 - B. Provides firm foundation for design, minimizes paper, shortens schedule, and concentrates efforts
- 1c. What tool can be used to list equipment and identify their interrelations in a system?
 - A. Prechart
 - B. *N*-squared diagram
- 2a. What should be done in the ICD process during requirements definition?
 - A. Define mission objectives
 - B. Define technology and interfaces and present for baselining
- 2b. What is baselining?
 - A. The designated authority signing an ICD
 - B. The only official definition
- 2c. How are voids in an ICD accounted for and tracked?
 - A. Procedure or administration report
 - B. Monthly program status report on interface design data required
- 3a. What should be done in the ICD process during development?
 - A. Manage voids, invoke brackets, resolve voids, and verify compliance
 - B. Control interface developments
- 3b. How should proposed design changes be handled?
 - A. Discussed at critical design review
 - B. Discussed and approved by all participants
- 3c. What should be given special attention?
 - A. Design parameters that affect controlled ICD
 - B. Manufacturing documentation

²Answers are given at the end of this manual.

- 4a. When is the drawing format used for an ICD?
 - A. To describe the type and nature of the component
 - B. To describe physical dimensions and shapes
- 4b. When should a specification be used?
 - A. To describe performance with tables and text
 - B. To describe a software function
- 4c. What is the key to providing a useful ICD?
 - A. Give as much detail as possible
 - B. Limit the detail to what is necessary to demonstrate compatibility
- 5a. What is the purpose of the initial issue of an ICD?
 - A. Issuance, review, comment, and baselining
 - B. Review and resolution of differences of opinion
- 5b. Who is responsible for controlling the flow of an ICD?
 - A. Contractor
 - B. Custodian
- 6a. Who should review ICD's?
 - A. Organizations designated in the responsibility matrix
 - B. ICD custodian
- 6b. How are comments resolved?
 - A. By the project office
 - B. By project management and custodian working for resolution and approval or the comment being withdrawn
- 6c. Where are interface issues discussed?
 - A. Project office
 - B. Interface control working group
- 6d. Who approves and baselines an ICD?
 - A. Projects at the next level up in program structure
 - B. The project office
- 7a. When should a project activity request a change to an ICD?
 - A. At the custodian's request
 - B. When data are available, requirements need change, an error is discovered, or the design changes
- 7b. What items should be included in a change notice request?
 - A. Identification number, activity, contact, document affected, number of data voids, urgency, description, justification, impact, and authorizing signature
 - B. Those established by the ICWG
- 7c. Who evaluates and issues a proposed change notice?
 - A. ICD custodian
 - B. Project office
- 7d. What does a proposed change notice describe?
 - A. Specific changes (from-to), reasons, and the requestor
 - B. Project notices
- 7e. How is a change notice approved and distributed?
 - A. By the project authority to all cognizant parties
 - B. By all cognizant parties to the contractors

Appendix A

Electrical/Functional Interface Example

This appendix illustrates elements of a telemetry drawing interface control document showing control of waveform parameters and data rates. This interface example depicts data transfer between a guidance system electronics assembly and a launch vehicle telemetry system. The basic drawing (fig. A.1) covers the isolation elements of the guidance system, the jack and pins assigned, and shielding and grounding on the guidance side of the interface. Bus functions are named (e.g., guidance telemetry data 1(parametric)), and the shielding requirements through to the first isolating elements of the telemetry system are provided (see notes on fig. A.1).

Table A.1 contains the details to be controlled for each bus function. Signal source (electronics assembly) and destination (telemetry system) are identified. The waveform (fig. A.2) and its critical characteristics (table A.2) are provided, as well as data rates and sources and load impedances. Telemetry load impedance is further described by an equivalent circuit (see note 3 on fig. A.1).

The final value of pulse minimum amplitude is missing in this example. This is noted by the design-data-required (DDR)

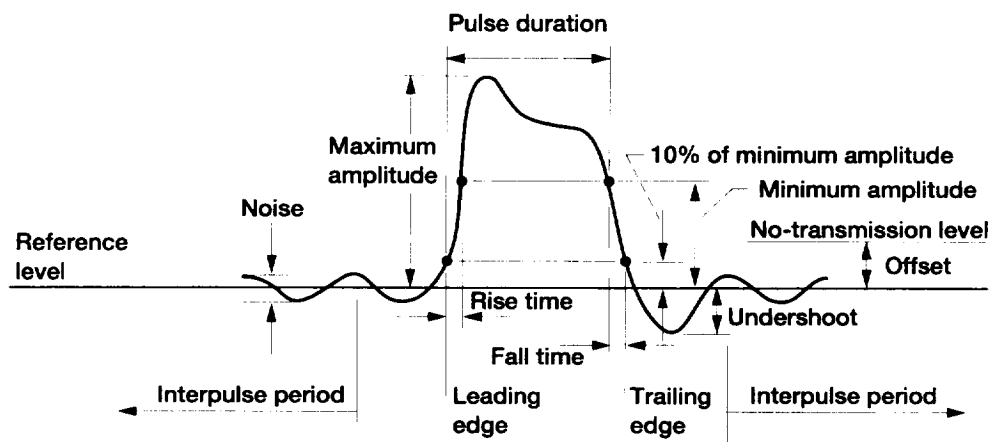
callout in table A.2 and the accompanying DDR block (fig. A.3). The DDR block notes that the responsible parties have agreed on an amplitude band with which they can work until the guidance design becomes firm. However, there is also a date called out that indicates when (45 days after preliminary design review) the telemetry contractor must have the data to be able to complete design and development and deliver the telemetry in time to support launch vehicle flight.

The parameters called out in this example are *only* those needed to control the design of either side of the interface through the first isolating element. Also note that only the shielding and wire gage of the launch vehicle cabling between the two systems are provided. Only pin numbers for the guidance side of the interface are called out and controlled. Connector types and other pertinent cable specifications are as per a referenced standard that applies to all launch vehicle cabling. In this case the same pulse characteristics apply to each of the functions covered; however, table A.2 is structured to permit variation for each function if the design should dictate different values for the characteristics of each function.

Table A.1.—GUIDANCE/LAUNCH VEHICLE TELEMETRY DATA TRANSFER INTERFACE PARAMETERS

[Source, electronic assembly; destination, telemetry; waveform, see fig. A.2; source impedance, 50 Ω maximum during pulse time.]

Function	Data rate	Load impedance	Remarks
Guidance telemetry data 1	Bit rate: 979.2 kilobits per second Word rate: constrained to 153- x 16-bit words per 10-ms frame	110 $\Omega \pm 15\%$ balanced to ground by not less than 5000 Ω and shunted by 200 pF maximum (excluding cabling) (see note 3 on fig. A.1(c))	<ol style="list-style-type: none"> 1. All timing is synchronous with the guidance to telemetry bit synchronization. 2. The guidance telemetry frame synchronization consists of 16 pulses at a rate of (void #3) and occurs at 100 frames per second. 3. The launch vehicle telemetry shall function properly with a guidance telemetry bit synchronization and frame synchronization tolerance of $\pm 0.1\%$. 4. All pulse characteristics are defined at the guidance electronic assembly interface connectors. 5. Guidance signal characteristics are defined for the minimum wire gauge shown.
Guidance telemetry data 2			
Guidance telemetry bit synchronization	Void #3		
Guidance telemetry frame synchronization	100 frames per second (see Remarks)		
Guidance telemetry data 1 word synchronization	Coincident with first bit of each guidance telemetry data 1 word		
Guidance telemetry data 2 word synchronization	Coincident with first bit of each guidance telemetry data 2 word		



Notes:

1. The interpulse period shall be the period from 150 ns after the trailing edge of a pulse until 100 ns prior to the leading edge of the subsequent pulse.
2. The reference level shall be the average voltage for the last 200 ns of the interpulse period.
3. The no-transmission level shall be 0 V differential at the guidance/launch vehicle interface using the test load specified in table A.2.
4. Shielding depicted represents the telemetry shielding requirements only. For cable routing see void #01. Telemetry shielding shall be carried through all connectors between the electronic assembly and the telemetry subsystem.
5. A radiofrequency cap shall be provided on electronic assemblies in all launch vehicles in lieu of this connector.

Figure A.2.—Guidance data pulse characteristics.

Table A.2.—REQUIRED PULSE CHARACTERISTICS AND TEST PARAMETERS

Pulse characteristics (see fig. A.2)	Guidance telemetry					
	Data 1	Data 2	Bit synchronization	Frame synchronization	Data 1 word synchronization	Data 2 word synchronization
Pulse duration	255 + 50 ns					
Minimum amplitude	9 ± 2 V (see V027)					
Maximum amplitude	15 V					
Rise time	75 ns maximum					
Fall time	125 ns maximum					
Undershoot	2.5 V maximum					
Reference level offset	0 to -4.5 V relative to no-transmission level					
Noise	1.4 V maximum peak to peak					
Receiver susceptibility	2.0 V minimum					
Test parameters:						
Test load	$75 \Omega \pm 5\%$ resistive					
Receiver susceptibility	2.0 V minimum					

DDR No. 3288399-V027	
Data required:	Guidance subsystem waveform parameter data (minimum amplitude value to replace coordinated temporary amplitude band currently on ICD-3288399)
Data supplier:	SP-2012/guidance telemetry steering committee
Data user(s):	SP-2732/launch vehicle telemetry contractor/interface coordinator
Date due:	45 days following guidance preliminary design review

Figure A.3.—Typical design data required for table A.2.

Appendix B

Mechanical/Physical Interface Examples

B.1 Mechanical Interface for Distributed Electrical Box

Figure B.1 is an example of an interface development document (IDD) that, from initial inspection, appears to be fairly complete. This figure contains a great amount of detail and just about everything appears to be dimensioned. However, closer examination will reveal serious shortcomings.

First, the basic function of the interface must be defined. The box depicted must be capable of being removed and replaced on orbit, in many cases outside the crew habitat. In some cases it is to be removed and replaced robotically. The box slides along the L-shaped bracket held to the support structure by three mounting bolts labeled “bolt 1,” “bolt 2,” and “bolt 3.” As the box slides along the L-shaped bracket from left to right in the figure, some piloting feature on the box connectors engages the connectors mounted to the support structure by the spring-mounted assembly, and the connector engages fully when the lead screw is completely engaged.

1. The initial interface area to be examined is that of the L-shaped bracket to the support structure (i.e., the interface of the three mounting bolts). The interface is being examined from the perspective of the designer of the support structure. Does figure B.1 contain enough information for a mating interface to be designed? (The area of interest has been enlarged and is presented as figure B.2.)

- a. The dimensions circled in figure B.2 and lettered a, b, c, and d locate the position of the mounting bolts relative to the box data. The following pertinent differences are noted concerning this dimensioning:
 - i. Dimension a locates the holes relative to a “reference datum for coldplate support structure,” but the datum is not defined on the drawing. Is it a line or a plane? What are the features that identify/locate the datum? What is the relationship of this datum to other data identified on the IDD (data A, B, and D)? **This information is required so that the designer of the support structure can relate his or her interface features easily to those of the box IDD.**
 - ii. The IDD states that the tolerances on three-place decimals is ± 0.010 . Dimensions a, b, c, and d are three-place decimal dimensions and would, therefore, fall under this requirement. Elsewhere on the IDD a true position tolerance for bolt locations is indicated. A feature cannot be controlled by both bilateral and true positioning tolerancing. It must be

one or the other. Considering the function of the mounting bolts—to locate the box relative to the electrical connectors, it has to be assumed that dimensions a, b, c, and d are basic dimensions. **Interface control drawings cannot require the designer of the mating interface to assume anything. IDD’s must stand by themselves.**

- b. Figure B.3 depicts initial details of mounting bolts for the L-shaped bracket. On first inspection there appears to be a great amount of detail. However, further examination shows that much of the detail is not related to interface definition. The interface is the bolt. Where is it relative to other features of the box? What is the relationship of bolts 1 and 2 to bolt 3 (datum C)? What is the thread of the bolt? How long is the bolt? The following data on the IDD are not required:
 - i. Counterbore for bolt head
 - ii. Diameter of bolt hole in bracket for bolts 1, 2, and 3
 - iii. Distance of bolt hole to first thread
 - iv. The fact that there is a screw retaining ring

Adding data not required for the interface, even if they are only pictorial, is expensive. It takes time for the organization to develop and present it, and it takes time for the designer of the mating interface to determine that the information is not necessary and discard it. If the extraneous information stays on the IDD, it must be maintained (i.e., changed if the design details change). Only the features of a design that affect the features of the design of the mating interfaces need be placed on the IDD.

- c. Once the unnecessary data are removed, what remains is shown in figure B.4. The data that remain are not complete and are unclear. The true position notations are indicated as being those for the “mounting interface for bolt,” suggesting that the true position applies to the hole in the support structure. However, since the IDD is basically covering the features of the box, it is assumed that these locations apply to the bolts on the box. **It should not be necessary to have to make assumptions about data on an IDD or ICD. The document should stand by itself.**

The only other data left in figure B.4 are the callouts for the locking inserts. These callouts refer to the method used by the designer of the support structure for retaining the bolts. This IDD should not have this callout, since the

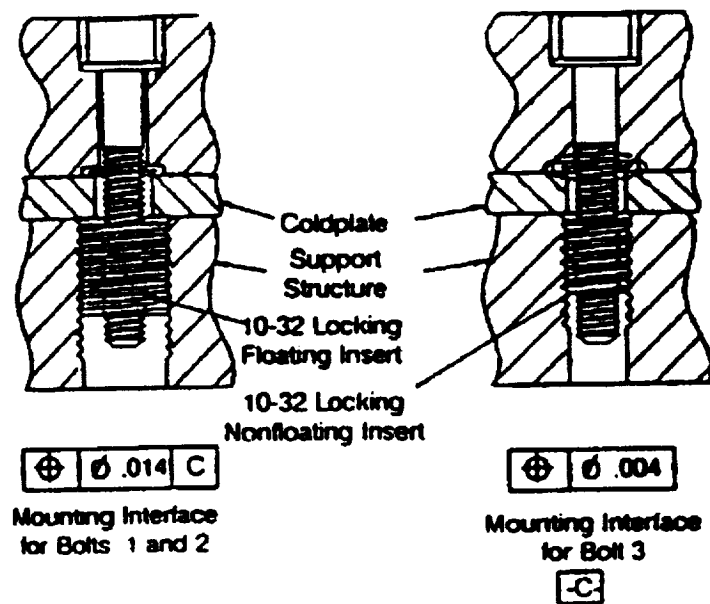


Figure B.4.—Necessary details of mounting bolts.

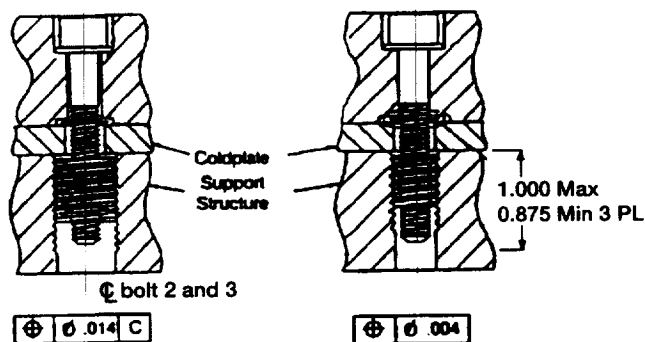


Figure B.5.—Minimal interface definition.

method used for retaining the bolts is not the responsibility of the box designer. **Generally IDD's and ICD's should not specify design solutions, especially when the design solutions are not the responsibility of the one specifying them.**

What is missing is how far the bolts protrude from the box. These data are required so that the designer of the support structure knows how deep to make the mating hole and how much of a mating thread must be supplied to grip the bolts on the box.

Considering all of the above, figure B.5 represents what is really required (along with the locations and thread types already defined in fig. B.1) to define the box side of the interface and for the designers of the support structure to design a compatible interface between the retaining bolts and the support structure.

2. The next area to be examined is that of the connector interface. Since both parts of the connector are being provided by the box designer, the interface is the plate on which the connectors are attached to the support structure. Again, the question is, Does figure B.1 contain enough information for a mating interface to be designed? The answer to that question is, Definitely not! The interface of the plate (holding the connectors) that mates with the support structure is identified as datum D. Again, there is no definition of this datum. Is it a plane passing through the three highest points of the plate or some other features of the connector plate?

If a compatible mating interface is to be designed, the relationship between the surface to which the connector plate is attached and the surface to which the L-shaped bracket is attached must be known. None of these data are supplied in figure B.1. The following are data needed to establish this relationship:

- a. The required perpendicularity of D to A
- b. The required parallelism of D to B
- c. The required angular relationship of the vertical centerline shown in view B–B with the vertical centerline shown in view A–A
- d. The pattern required for the four fasteners holding the connector plate to the support structure. View B–B does contain a dimension of 2.594 for a horizontal spacing of the lower two features but does not indicate that this dimension is applicable to the upper two fasteners. In addition, there is no dimension for the distance between the fasteners in the Z direction.
- e. The required relationship of the hole pattern for the connector plate relative to the box, namely,
 - i. The location of the hole pattern above A in the Z direction
 - ii. The location of the hole pattern relative to C in the X direction
 - iii. The distance of datum D from C in the Y direction when the box is fully installed

Since none of these data are identified as items to be determined (TBD's), it must be assumed either that the data are not required because the connectors can be mated properly with a great deal of misalignment or that the box designer did not recognize that this type of data is required. Designers never wish to freeze a design. The placement of design constraints in an ICD is basically freezing an area of a design or at least impeding the ability to change a design without that design being scrutinized at another level. Therefore, **the tendency of designers is to disclose the minimum that they feel is necessary in the interface for the control process. This is the primary reason for the ICD custodian not to be organizationally a part of the design process.** Yet the ICD custodian must have access to the design function of an agency or contractor organization to ensure the ready flow of the data required for proper interface definition. (Can interface compatibility be demonstrated from the ICD's alone?)

The ICD custodian must always test the data in interface documentation from the viewpoint of another design agent who must develop a compatible mating interface.

The preceding discussion simplifies specification of the L-shaped bracket and the mounting bolts. This redefinition of the interface tied up loose ends and provided needed dimensions and callouts absent from the original document. These portions of the document can now be controlled more easily and related to a 100% mate design.

B.2 Space Reservation and Attachment Features for Space Probe Onboard Titan IV Launch Vehicle

Figure B.6 is an example of an ICD that defines the space envelope available onboard the Titan IV launch vehicle for a payload and the attachment feature details for the launch vehicle side of the interface. The intended payload is the Cassini Mission spacecraft. The Titan payload fairing, as would be expected, is defined. The other side of this envelope (i.e., the spacecraft) must also be defined to show compatibility. When the spacecraft dimensions are established, compatibility should be shown by a comparison of the two envelopes. The Titan documentation defines the available space reserved for equipment (i.e., a stay-out zone for the Titan launch vehicle items). Ideally, this ICD should define a minimum space available for the spacecraft. Therefore, if the spacecraft dimensions are constrained to a maximum size equal to the launch vehicle's minimum, less a value for environmental effects, etc., then the two envelopes are compatible.

Since interface data have been provided for the attachment details for the launch vehicle side of the interface, the design of the Cassini adapter for mounting to the Centaur launch vehicle at station –150.199 can be explained by using the Titan design data.

The following key interface features have been established for this connection:

1. Sheet 1 (fig. B.6(a)), note 5: Location of holes is established by a common master gauge tool with reference dimensions provided.
2. Sheet 3 (fig. B.6(c)), section F–F: Bearing areas are to be flat within 0.006 (units), and per view G the maximum bearing area has been defined.
3. Sheet 3 (fig. B.6(c)), view H: Shape and dimensions of the shear alignment pins have been established.
4. Sheet 1 (fig. B.6(a)), note 4: How loads are to be transmitted is indicated.

The following data elements missing from figure B.6 are mostly related to the lack of spacecraft design data:

1. No apparent tracking of TBD's. **A tracking system should be in place at the beginning of ICD development. Each TBD should have a unique sequential identifier with due dates and suppliers established.**
2. No revision block for tracking the incorporation of changes. Some type of revision record should be placed on each sheet.

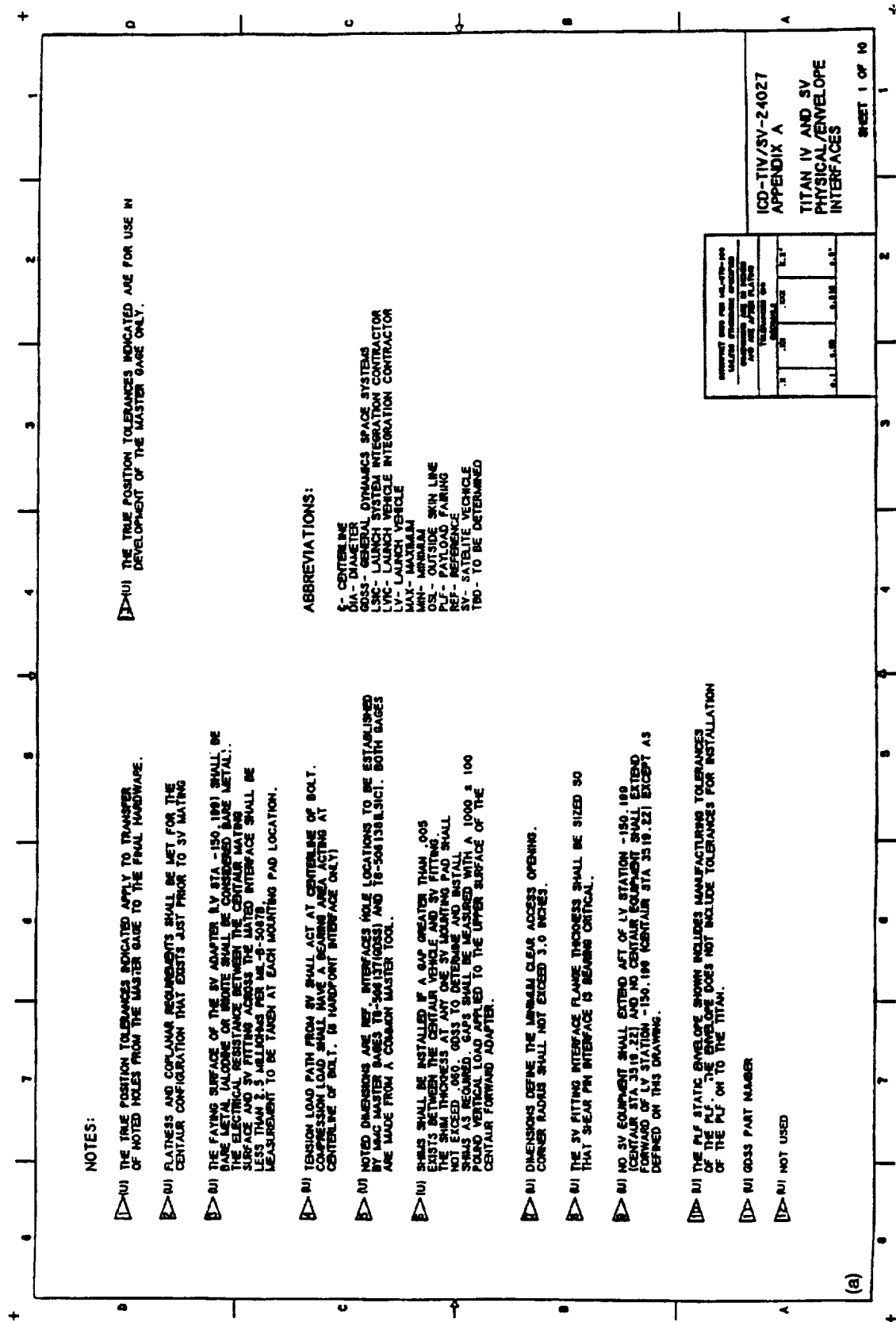


Figure B.6.—Titan IV and space vehicle physical/envelope interfaces. (a) Notes and abbreviations. (b) Orientation view. (c) Section views.

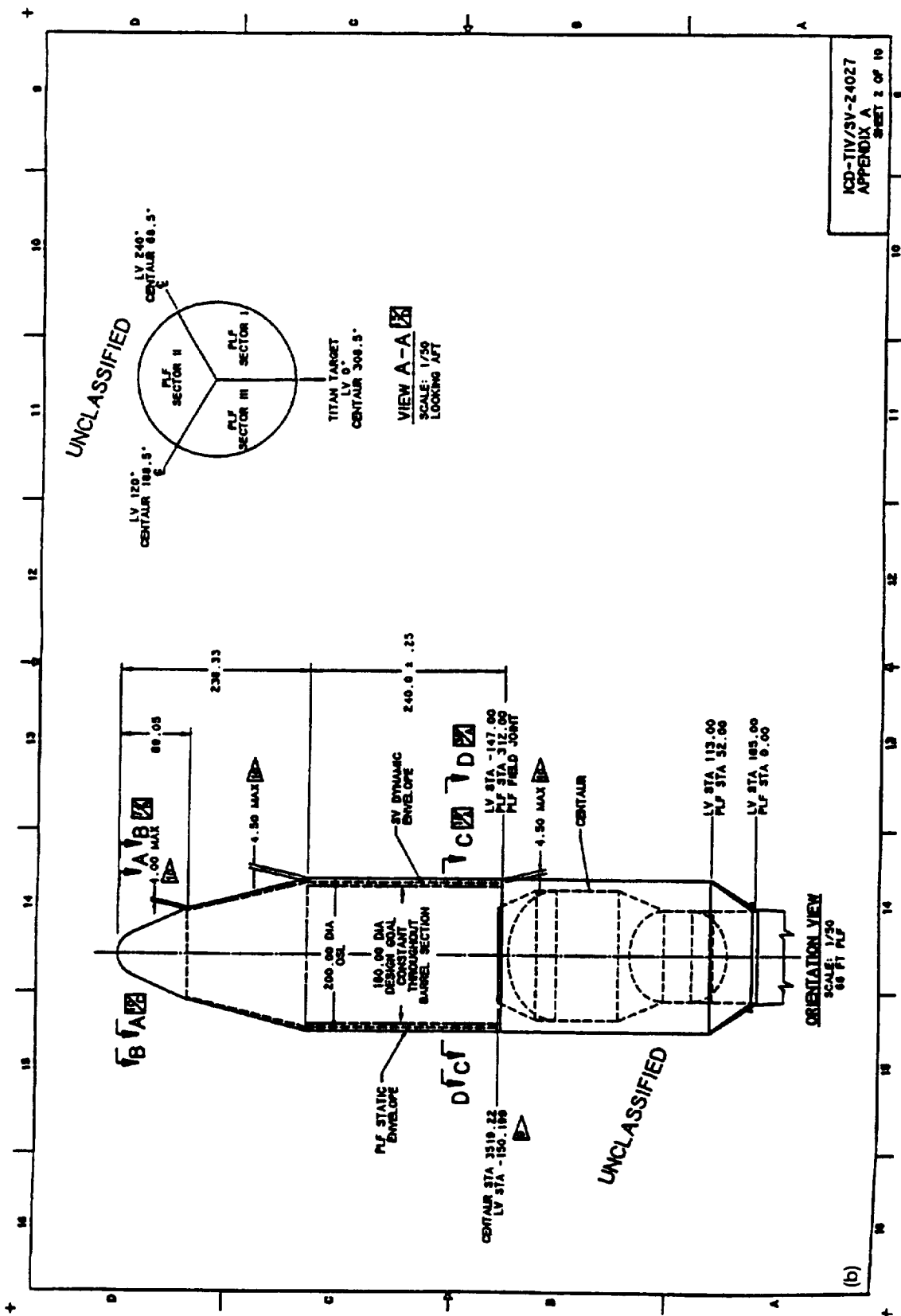


Figure B.6.—Continued. (b) Orientation view.

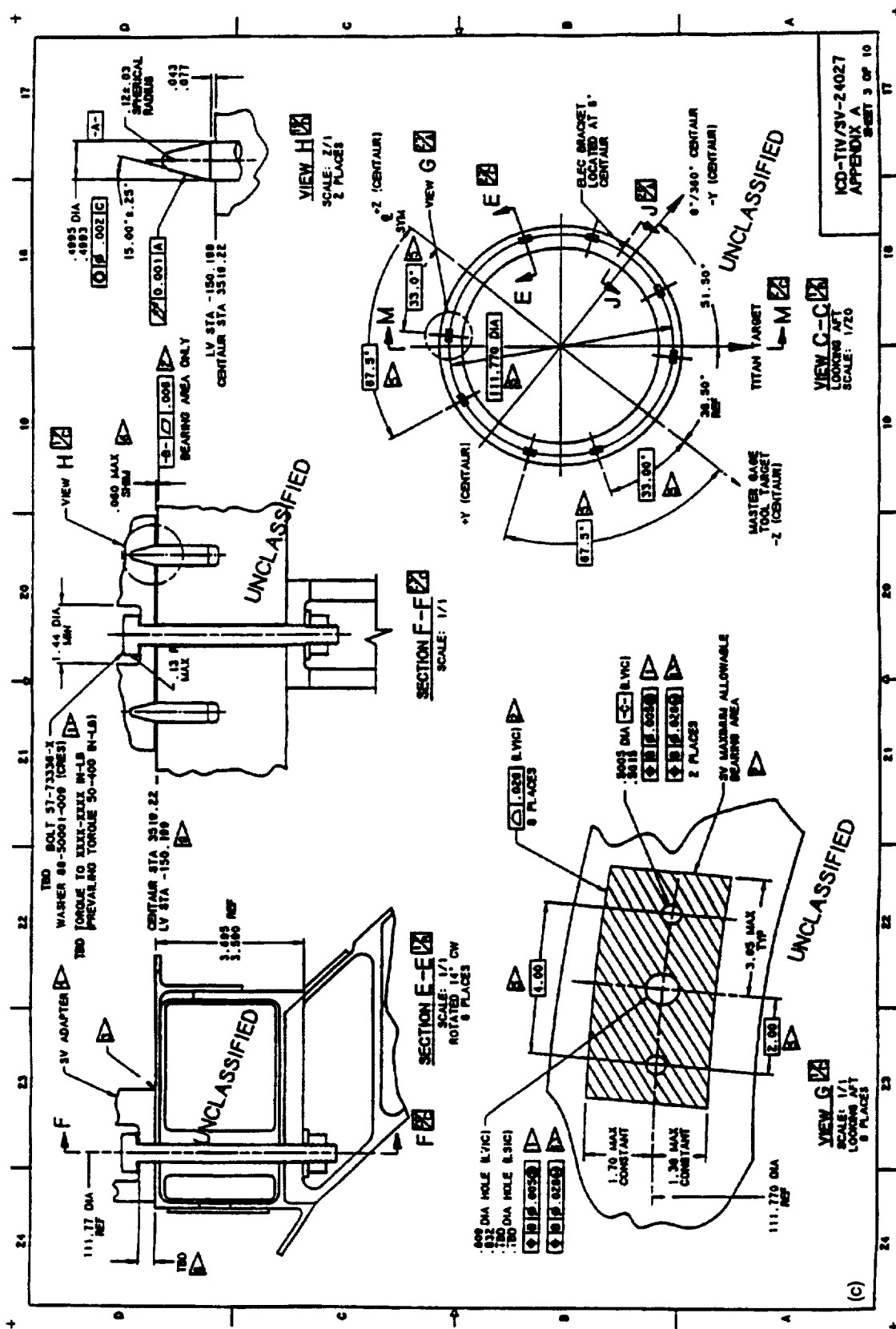


Figure B.6.—Concluded. (c) Section views.

Upon exchange of design data relating to the Cassini probe it would be expected that the probe's maximum envelope would be established and related to the data system of the Titan/Centaur launch vehicle.

This example is basically a one-sided interface. The Titan/Centaur side of the interface is well defined, which is to be expected considering the maturity of the design. The tendency should be resisted, in cases like this, to ignore or place less emphasis on the definition and documentation of the mating interface, given the completeness of the launch vehicle side of the interface. The mating interface, namely, the spacecraft side, should be completely defined. Otherwise, the spacecraft designer will be signing up to design a compatible interface by agreeing with what the interface on the launch vehicle side looks like. Although this approach allows freedom to go off and "do independent things," it lacks the degree of positive control

needed for interface compatibility. The chances for an incompatibility are much less if the spacecraft side of the interface is defined. Space vehicle data, stations, and fasteners must be identified and controlled. The designer of the space vehicle is then able to commit to the design and production of an interface that is defined. The launch vehicle designers can then verify that the spacecraft interface will mate with the launch vehicle available for the spacecraft. Therefore, if the spacecraft dimensions are constrained to a maximum size equal to the launch vehicle's minimum, less a value for environmental effects, etc., then the two envelopes are compatible.

Since interface data have been provided for the attachment details for the launch vehicle side of the interface, the design of the Cassini adapter for mounting to the Centaur launch vehicle at station -150.199 can be explained by using the Titan design data.

Appendix C

Software Interface Example: Definitions and Timing Requirements for Safety Inhibit Arm Signals

Signal definition	Centaur sequence control unit switch number	Initiating event + time	Persistence	Function
Satellite vehicle (SV) pyro unshort (primary)	45	Main engine cutoff (MECO) 2 + 3±0.5 sec	3±0.5 sec	Unshorts SV pyro capacitor banks
SV latch valve arm (primary)	33	MECO2 + 10±0.5 sec	3±0.5 sec	Arms safety inhibit relay for SV main engines
SV pyro unshort (secondary)	89	MECO2 + 15±0.5 sec	3±0.5 sec	Provides redundant unshort of SV pyro capacitor banks
SV latch valve arm (secondary)	88	MECO2 + 17±0.5 sec	3±0.5 sec	Provides redundant arm of inhibit relay for SV main engines
Radiofrequency monopropellant driver backup enable	34	Titan IV/Centaur separation + 24±0.5 sec	3±0.5 sec	Serves backup (redundant to SV ground support equipment command) enable of safety inhibit SV functions (radiofrequency sources and reaction control system thruster drivers)

Appendix D

Supplied Services Interface Example

This appendix provides a simplistic text-based example of a supplied services (air-conditioning and cooling water) interface control document with a typical design-data-required (DDR) block. This example contains elements condensed from a number of service documents originally used for a submarine weapons program; however, the principles contained herein are universally applicable to any complex system of interfaces. Page 1 of the ICD lists the DDR's (table D.1) showing DDR

numbers, location on the drawing, brief description, and due date. The DDR block (fig. D.1) on the drawing expands on this information and identifies supplier, user, and time urgency of the data needed. The DDR numbering convention used here is "V09 = Void #09." Preceding the void number with the ICD number provides a program-unique DDR number that is easily related to its associated ICD and easily maintained in a data base.

TABLE D.1.—DESIGN-DATA-REQUIRED SUMMARY
AND LOCATOR

Void number	Location	Description	Date due
V01			
:			
V09	Sheet 1, zone C-7	Main heating and cooling (MHC) water schedule	30 Days after authentication of data fulfilling DDR 5760242-V12
:			

DDR No. 1466134-V09	
Data required:	Heating and cooling (HC) system upper zone water schedule (supply water temperature versus environmental temperature)
Data supplier:	HC working group
Data user:	Launch vehicle design agent
Date due:	30 days after authentication of data fulfilling DDR No. 2543150-V12

Figure D.1.—Typical design-data-required block.

The following pages present the kinds of data required to fully define the air-conditioning requirements for suites of equipment located in a launch control center. Table D.2 details conditioned-air distribution; table D.3 presents typical interface data required to ensure that a cooling water service is provided to electrical equipment and indicates requirements for the equipment before and after the incorporation of an engineering change.

701. Launch vehicle control center services:

- A. Air-conditioning shall be provided with a dedicated closed-circuit system capable of supplying a minimum total flow of 12 820 scfm with a 50% backup capability.
 1. The conditioned air shall be distributed to each equipment flue as specified in table D.2. The distributed conditioned air at the inlet to the equipment shall satisfy the following parameters:
 - a. Temperature: The minimum temperature shall be 65 °F and the maximum, 70 °F.
 - b. Humidity: The maximum humidity shall be 75 grains per pound of dry air.
 - c. Working pressure: The working pressure shall be enough to overcome equipment pressure drops and to maintain positive pressure at the equipment outlet with respect to compartment ambient pressure. A 10% minimum leakage rate in the compartment shall be assumed.
 - d. Flow resistance: The system shall be able to overcome the pressure drop across the equipment (i.e., from exit of orifice plate to top of equipment) as shown in table D.2.
 - e. Flow profile:
 - (1) The flow distribution for each flue shall be such that the flow velocity between the flue centerline and 1.3 in. from the edge of the flue, and (where equipment permits) 6 in. above the flue gasket, shall not be less than 80% of the achieved average flow velocity. The achieved average flow velocity must equal or exceed velocity based on the minimum flow rate specified in table D.2.
 - (2) Velocity profiling is not required for flues designated 301 through 310, 011 through 015, 446BC, 405-2A, 405-2B, 405-6A, and 405-6B.
 - f. Adjustment capability: The system shall provide flow adjustment from 0 to 300 scfm at each of the equipment flues requiring velocity profiling.

- g. Air quality: Air at the inlet to the equipment shall be equivalent to or better than air filtered through a 0.3- μ m filter with an efficiency of 95%.
2. The closed-loop system shall have the capacity of removing 52.8 kW (minimum) of heat dissipated by equipment using closed-circuit conditioned air. This heat load includes 1.3 kW reserved for launcher equipment in the launch vehicle control center (see note 702 below).

702. The system shall provide the capability of removing 1.65 kW minimum of heat dissipated by equipment by using compartment ambient air as a cooling medium while maintaining the compartment within specified limits.

- A. The ship shall take no action that eliminates the option for launcher equipment to use compartment ambient air or closed-circuit conditioned air for dissipating launcher-generated heat of 1.3 kW.
- B. Heat dissipated to ambient air by equipment using closed-circuit conditioned air is not included.

703. The system shall provide distribution trunks to equipment flues with total flow capacity as designated below for the conditions of table D.2:

Trunk	Minimum flow, scfm
A	2700
B	1620
C	2300
D	3400
E	1300
F	1500

704. Flow at reference designations marked with an asterisk in table D.2 are to be considered flow reserve capabilities. These designated flues do not require verification of flow per table D.2 nor profiling per note 701.A.1.e(1) until these flues are activated. The Government-furnished pipe assemblies and caps will be supplied for flues not activated.

705. The minimum flow for flues 446BC and 447BC is 100 scfm before change 30175 and 250 SCFM after change 30175.

TABLE D.2.—CONDITIONED-AIR DISTRIBUTION

Equipment	Trunk (see note 703)	Flue	Minimum flow, scfm	Flow resistance/ pressure drop at minimum flow (see note 701A.1.d), in. H ₂ O
Data cabinets	A	301B	225	0.54
		301C	260	— — —
		305B	80	.50
		305C	80	.50
		306B	290	.56
		306C	50	.50
Data console	A	308B	100	.50
		308C	50	.50
		309	0*	— — —
		310B	135	.50
		310C	50	.50
Control console	E	405-2A	100	1.0
		405-2B	100	
		405-6A	50	
		405-6B	50	
Power buffer and conversion	B	011	440	2.0
		012	440	
		013-1	150	
		013-2	150	
		015	440	
Control computer group	D	440BC	200	1.0
		440-441D	300	
		444BC	300	
		444-445D	250	
		446BC 447BC	See note 705	
	E	471	200	
Control group	E	450BC	200	
		450-451D	200	
		451BC	100	
	C	452BC	200	
		452-453D	200	
		458BC	200	
		458-459D	200	
		459BC	150*	
	E	472	150*	
Power distribution	F	002BC	150	
		003BC	150	
		004BC	150*	
		004D	150*	
Load	F	271BC	275	1.0
		271D	0*	0
		005BC	100*	1.0
		005D	0*	0

*Flow reserve capability.

TABLE D.3.—WATER FLOW RATE INTERFACE PARAMETERS

[Water inlet temperature: 54 °F max and 48 °F min; temperature alarm set at 56 °F \pm 1 deg F (increasing) and 47 °F \pm 1 deg F (decreasing); see Remarks.
Working pressure: 85 psig max and 57 psig min. Test pressure, 125 psig max with binnacles to be isolated at vehicle hydrostatic test. Pressure drop: nominal differential pressure range, 13 to 23 psid ref. Water quality: dual filters required; filters to 10 μ m with 98% efficiency by weight, 20 μ m absolute.]

Function	Minimum cooling capability	Water flow rate	Remarks
Electrostatically supported gyro navigator (ESGN) and gravity sensor system (GSS) binnacle cooling	2.25-kW gain	^a 6.0-gal/min nominal total flow for two ESGN binnacles and one GSS binnacle. The supply shall maintain constant flow of 2.0 gal/min \pm 10% to each binnacle. ^b A remote, low-flow alarm shall be provided for the ESGN binnacles and the GSS binnacle.	Reliability of water supply shall support a navigation subsystem availability of 0.97. This service requirement shall be continuously available during patrol and refit. The water temperature shall not vary by more than 6 deg F when changing at the rate of 0.25 deg F/sec maximum. This change shall not occur more than once per 30-min period.
Reserve capability for future navigation development	3.25-kW gain	2.6-gal/min minimum	
ESGN binnacle cooling	1.5-kW gain	^a 4.0-gal/min nominal total flow for two ESGN binnacles. The supply shall maintain a constant flow of 2.0 gal/min \pm 10% to each binnacle. ^b A remote, low-flow alarm shall be provided for the ESGN binnacles.	
Reserve capability for future navigation development	4.0-kW gain	4.5-gal/min minimum	

^aThe system shall provide test connections at the inlet and outlet of each binnacle to permit periodic measurement of differential pressure.

^bLocal flow indication shall be provided for each binnacle.

Appendix E

Compatibility Analysis

E.1 Definition

Compatibility analysis of the interface definitions contained in an ICD is a major tool of interface control. It serves a twofold purpose:

1. Demonstrates completeness of interface definition. If any interface data are missing or presented in a manner that cannot be integrated by using the ICD alone as a data source, the ICD is considered deficient.
2. Provides a record (traceability) that the interface has been examined and found to have the right form and fit. This record can then be used in evaluating the acceptability of subsequent change proposals.

E.2 Kinds of Data

The following compilation identifies the kinds of data that must be obtained for a compatibility analysis and outlines the general steps that should be followed for three categories of interface: electrical/functional, mechanical/physical, software, and supplied services:

I. Interface category—electrical/functional

A. Data required to perform analyses

1. The following parameters are required, considering the specific function or signal involved:
 - a. Cabling and connectors
 - b. Power requirements
 - c. Electromagnetic interference, electromagnetic compatibility, electromagnetic radiation, and grounding requirements
 - d. Functional flow and timing requirements
 - e. Signal definition
 - f. Digital data definition to the bit level
 - g. Protocol levels
 - h. Seven-layer International Standards Organization open systems instruction stack definition or its equivalent
 - i. Error recovery procedures
 - j. Startup and shutdown sequences
 - k. Adequacy of standards used or referenced
2. Unique requirements for an interface or a piece of equipment different from overall system requirements (i.e., the hierarchy of specifications required)
3. Adequate definition of all signals crossing the interface. "Adequate" is difficult to define precisely but

depends on the signal type (e.g., analog or digital) and the intended use. In general, the interface must show the characteristics of the isolating device (element) on each side of the interface and define the signal characteristics in engineering terms suitable for the particular type of signal.

4. Timing and other functional interdependencies
5. System handling of error conditions
6. Full definition of any standards used. Most digital transmission standards have various options that must be selected; few, if any, standards define the data that are passed.

B. Steps to be followed

1. Verify interoperability of connectors.
2. Size cables to loads.
3. Determine cable compatibility with signal and environmental conditions.
4. Define data in one document only.
5. Determine adequacy of circuit protection devices and completeness of signal definition.

II. Interface category—mechanical/physical

A. Type of interface—form and fit

1. Data required to perform analysis

- a. A datum (reference) that is common to both sides of the interface (e.g., a mounting hole in one part that will mate with a hole or fastener in the other mating parts or a common mating surface of the two mating parts)
- b. Dimensions and tolerances for all features of each part provided in a manner that gives the optimum interface fit and still provides the required design functions. Optimum interface means dimensioning so that the tolerance accumulation is kept to a minimum.

2. Steps to be followed

- a. Start with the common datum and add and subtract dimensions (adding the tolerance accumulations for each dimension) for each feature of the part interface.
- b. Determine the dimensional location of the interface-unique features by adding and subtracting the tolerance accumulations from resulting dimensions to achieve the worst-case maximum and minimum feature definitions.
- c. Perform the same analysis for the mating features of the interfacing part.
- d. Compare and question the compatibility of the worse-case features of the two mating parts (Will

the maximum condition of one part fit within the minimum condition of the mating part?)

B. Type of interface—structural load

1. Data required to perform analysis

- a. A description of the loading conditions (static or dynamic) and the duration of those conditions
- b. Characteristics of the equipment involved: weight or mass; mass distribution; elastic properties; and sensitivity of elastic properties to temperature, moisture, atmospheric gas content, pressure, etc.

2. Steps to be followed. This analysis involves placing the interfacing items in a position that produces the maximum loads while the items are interfacing. A space experiment is primarily designed for flight loads, yet it must withstand the loads developed during the launch and deployment cycles and perhaps unique loads during launch processing. The complexity of the compatibility analysis will vary depending on the types of interfacing items and environments.

- a. Attachment loads are the simplest, being a statement of the loads applied by the attaching feature (bolt) and the load capability of the component being retained (flange).
- b. Hoisting and handling loads require the calculation of bending moments or shear for various loading scenarios. Dynamic and environmental loads must also be considered. (How quickly is the load applied? What are the wind loading factors?)
- c. A more complex situation will be the loads developed during a dynamic interaction of interfacing items where different material characteristics must be considered along with the reaction characteristics of the materials (e.g., a flexible beam of varying moments of inertia supported by an elastomeric medium where the entire system is subjected to a high-velocity impulse of a few microseconds duration). Such a condition could produce loads that exceed those for which one of the interfacing items is designed. Another interfacing item may have to be redesigned so as not to jeopardize the mission of the primary item (i.e., increasing the strength of the item being supported could increase the weight).

III. Interface category—software

- A. Type of interface—software. The ICD is required to specify the functional interface between the computer program and any equipment hardware with which it must operate. Often, the supplier documentation for standard computer peripherals and terminals is adequate for this purpose. Conversely, it has been found that performance specifications governing the design of new equipment are not satisfactory for use in a

functional ICD. The purpose of an ICD is to communicate equipment interface requirements to programmers in terms that the programmers readily and accurately understand and to require equipment designers to consider the effect of their designs on computer programs.

- B. Type of interface—hardware/software integration. The ICD provides an exact definition of every interface, by medium and by function, including input/output control codes, data format, polarity, range, units, *bit weighting*, frequency, minimum and maximum timing constraints, legal/illegal values, accuracy, resolution, and significance. Existing documentation may be referenced to further explain the effect of input/output operations on external equipment. Testing required to validate the interface designs is also specified.

IV. Interface category—supplied services

A. Type of interface—fluid service

1. Data required to perform analysis

- a. Type of fluid required by the equipment and type of fluid the service supplier will provide. This may be in the form of a Federal or military specification or standard for both sides or for one side of the interface.
 - b. Location of the equipment/service interface (hose connection, pipe fitting, etc.)
 - c. Equipment requirements at the interface location in regard to characteristics (pressure, temperature, flow rate, duty cycle, etc.)
 - d. Capability of the service supplier at the interface location
 - e. Manner in which the equipment can affect the capability of the service supplier (e.g., having a large backpressure that the supplier fluid must push against or a combination of series and parallel paths that the supplier fluid must pass through)
- ##### 2. Steps to be performed. Examine the supplier and equipment requirements to determine
- a. If the supplier capability meets or exceeds the equipment requirements. This may require converting a Federal/military specification or standard requirement into what is specified for the equipment.
 - b. If the supplier capability meets the requirements, considering the effects resulting from the fluid passing through the mating equipment

B. Type of interface—environmental

1. Data required to perform analysis

- a. Conditions required for equipment to function properly. Storage, standby, and operating scenarios need to be established and defined.
- b. Supplier's capability to provide the environment specified in terms of time to reach steady

state from transients resulting from uncontrollable external environments; the limits of the steady-state conditions (maximum/minimum); and monitoring features

2. Steps to be performed. Perform analyses (e.g., thermal) under extreme and nominal environmental conditions to verify that supplier's equipment can maintain the environment required for the equipment. The complexity of the analysis may vary depending on the types of item involved.

- a. Simple inspection, which considers the environment required by an item versus the capability of the ambient in which the item resides
- b. Complex analysis, which must consider uncontrolled external environmental inputs, the thermal properties of intermediate systems that do not contribute to the end environment but act as conduits or resistors in the model, and the interaction of the item and the system that controls the desired environment

Appendix F

Bracket System for Interfaces

Brackets are used on hardware/engineering drawings to flag or identify details controlled by the ICD. Changes cannot be made to the drawings or designs without the effects on the interface being assessed and coordinated through the ICD process.

The process uses a rating similar to that used in the problem/failure reporting bracket system with the same controls and traceability. Once a bracket has been assigned to an interface void or problem, specific analyses and actions are required for the bracketed item to be removed. The bracketed item remains in open status with assignment to the responsible cognizant subsystem or design section until (1) the corrective action or coordinated information has been developed, (2) a proper risk assessment has been performed, (3) ICD change actions have been completed, (4) adequate verification of the interface is planned, and (5) the proper approval signatures have been obtained.

The following ratings are used to establish a category of "bracket" identifiers for interface deficiencies. Any discrepancy having an A rating greater than 1 or a B rating greater than 2 will be designated a bracketed discrepancy (see figure F.1).

- I. Interface deficiency rating A (S&MA impact)
 - A. Rating A1: Negligible effect on interface or mission performance
 1. No appreciable change in functional capability (form, fit, and function are adequate for the mission)
 2. Minor degradation of engineering or science data
 3. Support equipment or test equipment failure but not mission-critical element failure
 4. Support-equipment- or test-equipment-induced failures
 5. Drawing errors not affecting element construction
 - B. Rating A2: Significant degradation to interface or mission performance
 1. Appreciable change in functional capability
 2. Appreciable degradation of engineering or science data
 3. Significant operational difficulties or constraints
 4. Decrease in life of interfacing equipment
 5. Significant effect on interface or system safety
 - C. Rating A3: Major degradation to interface or mission performance or catastrophic effect on interface or system safety
- II. Interface deficiency rating B (understanding of risk)
 - A. Rating B1: Effect of interface deficiency is identified by analysis or test, and resolution or corrective action is assigned and scheduled or implemented and verified. There is no possibility of recurrence.
 - B. Rating B2: Effect of interface deficiency is not fully determined. However, the corrective action proposed, scheduled, or implemented is considered effective in correcting the deficiency. There is minimal possibility of recurrence and little or no residual risk.
 - C. Rating B3: Effect of interface deficiency is well understood. However, the corrective changes proposed do not completely satisfy all doubts or concerns regarding the correction, and the effectiveness of corrective action is questionable. There is some possibility of recurrence with residual risk.
 - D. Rating B4: Effect of interface deficiency is not well understood. Corrections have not been proposed or those proposed have uncertain effectiveness. There is some possibility of recurrence with residual risk.

 Interface discrepancy red flag;
project or task manager approval required

Rating A (S&MA impact)	Numerical rating		Rating B (understanding of risk)
Negligible impact	1	1	Known deficiency with corrective action assigned, scheduled, and implemented
Significant degradation	2	2	Deficiency poorly defined but acceptable corrective action proposed, scheduled, and implemented (low residual risk)
Major degradation	3	3	Known deficiency but effectiveness of corrective action is unclear and does not satisfy all doubts and concerns (residual risk)
		4	Impact not defined with confidence; corrective action with uncertain effectiveness (residual risk)

Figure F.1.—Interface deficiency rating system.

Appendix G

ICD Guidelines

1. Interface control documents should not require the designer of the mating interface to assume anything. ICD's should be compatible with each other and stand alone.
2. Only the definition that affects the design of the mating interfaces need be used.
3. ICD's should not specify design solutions.
4. The ICD custodian should be independent of the design organization.
5. The ICD custodian should verify that the data being controlled by an ICD are sufficient to allow other organizations to develop the interface described by the ICD.
6. An interface control system should be in place at the beginning of system (hardware or software) development.
7. Each void should have a unique sequential identifier establishing due dates, identifying exact data to be supplied, and identifying the data supplier.

Appendix H

Glossary

baseline—The act by which the program manager or a designated authority signs an interface control document (ICD) and by that signature establishes the genuineness of the ICD as an official document defining the interface design requirements. The term “baseline” conveys the idea that the ICD is *the only* official definition and that this officiality comes from the technical management level. Not only is the initial version of the ICD baselined, but each change to an ICD is likewise approved.

comment issue—An issue of an ICD distributed for review and comment before a meeting of the affected parties and before baselining

custodian—The contractor or project assigned the responsibility of preparing and processing an ICD through authentication and subsequently through the change process

data—Points, lines, planes, cylinders, and other geometric shapes assumed to be exact for the purpose of computation and from which the location or geometric relationship (form) of features of a piece of equipment can be established

interface responsibility matrix—A matrix of contractors, centers, and project organizations that specifies responsibilities for each ICD listed for a particular task. Responsibilities are designated as review and comment, technical approval, baselining, and information.

electrical/functional interface—An interface that defines the interdependence of two or more pieces of equipment when the interdependence arises from the transmission of an electrical signal from one piece of equipment to another. All electrical and functional characteristics, parameters, and tolerances of one equipment design that affect another equipment design are specified.

interface—That design feature of one piece of equipment that affects a design feature of another piece of equipment. An interface can extend beyond the physical boundary between two items. (For example, the weight and center of gravity of one item can affect the interfacing item; however, the center of gravity is rarely located at the physical boundary. An electrical interface generally extends to the first isolating element rather than terminating at a series of connector pins.)

interface control—The process of (1) defining interface requirements to ensure compatibility between interrelated pieces

of equipment and (2) providing an authoritative means of controlling the interface design.

interface control document (ICD)—A drawing or other documentation that depicts physical and functional interfaces of related or cofunctioning items. (The drawing format is the most common means of controlling the interface.)

interface control working group—A group convened to control and expedite interface activity between the Government, contractors, and other organizations, including resolution of interface problems and documentation of interface agreements

interface definition—The specification of the features, characteristics, and properties of a particular area of an equipment design that affect the design of another piece of equipment

interoperability—The ability of two devices to exchange information effectively across an interface

mechanical/physical interface—An interface that defines the mechanical features, characteristics, dimensions, and tolerances of one equipment design that affect the design of another subsystem. Where a static or dynamic force exists, force transmission requirements and the features of the equipment that influence or control this force transmission are also defined. Mechanical interfaces include those material properties of the equipment that can affect the functioning of mating equipment or the system (e.g., thermal and galvanic characteristics).

software interface—The functional interface between the computer program and any equipment hardware with which it must operate. Tasking required to validate the interface designs is also specified.

supplied-services interface—Those support requirements that equipment needs to function and that are provided by an external separate source. This category of interface can be further subdivided into environmental, electrical power, and communication requirements.

technical approval—The act of certifying that the technical content in an interface document or change issue is acceptable and that the signing organization is committed to implementing the portion of the interface design under the signer’s cognizance.

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Training Answers

Chapter	Answers
1	1(A); 2(D); 3(C); 4a(C), 4b(A), 4c(B)
2	1(D); 2(C); 3a(B), 3b(C); 4a(C), 4b(C), 4c(C); 5a(A), 5b(A), 5c(A); 6a(C), 6b(A), 6c(A); 7a(B), 7b(B), 7cA(i), 7cB(ii), 7cC(i); 8a(B), 8b(A); 9a(A), 9b(A), 9c(B)
3	1a(A), 1b(B), 1c(B); 2a(B), 2b(A), 2c(B); 3a(A), 3b(B), 3c(A); 4a(B), 4b(A), 4c(B); 5a(A), 5b(B); 6a(A), 6b(B), 6c(B), 6d(B); 7a(B), 7b(A), 7c(A), 7d(A), 7e(A)

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