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Paper Session IV-A - Common Interfaces

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COMMON INTERFACES

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Abstract

Operational flexibility of a launch system can be increased with a common interface between a launch vehicle and the family of compatible satellites. This improvement in flexibility, which enhances launch responsiveness, is achieved via the ability to rapidly replace or exchange a satellite (or select a different launch vehicle) during the launch preparation process.

This study focused on concepts for interface commonality with a selection of Air Force launch vehicles and payloads. Currently, among the launch vehicles examined, there is limited interface commonality. Historical interfaces and attempts at commonality were reviewed to determine constraining factors. Concepts for providing interface commonality in both the near and far term are recommended for further study. However, implementation and maintenance of common interfaces will require increased launch vehicle performance, adequate performance margins and a cultural change which permits control of interfaces and payload weight limits.

Introduction

Launch responsiveness cannot be easily achieved. Many changes to the current launch systems and operational philosophy will be required. One of the most important improvements needed is increased standardization of the interfaces between the spacecraft, upper stage (if one is required) and booster. The interfaces for past and current DOD expendables have been studied and an assessment made of the impact of these interfaces on two goals of launch responsiveness - the ability to substitute one payload for another with little or no delay and the ability to change launch vehicles without incurring significant delays. Current shortfalls were identified and concepts for increasing interface commonality in both the near and far term were developed. The study was completed for SD/CL (Space Division/Launch Systems) but does not represent an official Space Division position.

The study addressed DOD spacecraft are to be launched on Titan IV/IUS (Inertial Upper Stage), Titan IV/Centaur, Delta II, Atlas E or Titan II, and Atlas II respectively. A historical assessment was also completed. It included primarily Atlas and Titan boosters with their associated upper stages.

For each spacecraft/launch system pair, spacecraft to upper stage and upper stage to booster (or, in the case of no upper stage, spacecraft to booster) interfaces were examined in detail. The interfaces examined included: structural interfaces, power conditioning and distribution, guidance and navigation, command and control, telemetry and data processing, payload fairings, separation systems, destruct systems, and fluids. Launch pad AGE to upper stage/spacecraft interfaces and launch control center interfaces were also assessed in less detail.

Historical

The historical segment of the study included an assessment of: past use of common interfaces, reasons these interfaces were designed to be common, benefits derived from standardization, and, in the instances where common interfaces had not been retained, the forces which caused changes. Detailed histories were generally not available, but some patterns did become apparent.

One program which was able to achieve a degree of standardization was the Agena. The standard Agena achieved significant production cost savings while meeting program peculiar requirements through the use of booster adapters and optional equipment kits. The Agena flew on Thor, Atlas and Titan boosters through the use of a separate booster adapter for each vehicle. It met unique satellite requirements primarily through the use of over 30 optional equipment kits.

The Titan IIIC was one of the few vehicles which retained a significant amount of interface standardization. This was driven primarily by user requirements for flexibility and was possible because the primary users could utilize similar configurations. Titan IIIC programs used the Transtage upper stage and the same payload fairing. Electrical and mechanical interfaces were common. The Transtage guidance software was mission peculiar, but this could be developed ahead and stored on tape.

The Titan 34D, which had improved performance, later flew the same payloads, but the commonality which had existed was not retained. Only the eight point mechanical interface between the payload and Transtage remained common. In fact, this same interface is used for IUS on Titan 34D, STS and Titan IV. The electrical interface began as a common interface with unused harnesses tied back. However, unique spacecraft requirements coupled with performance constraints resulted in the removal of unneeded harnesses and the addition and modification of others. The result of these changes was a vehicle usable only by the single spacecraft for which the vehicle had been adapted. Payload fairings were also unique to each spacecraft because of unique physical dimensions, access requirements, and environmental requirements. Each upper stage, IUS and Transtage, also had its own version of the booster. This was achieved by welding either a Transtage 12 foot adapter or a short IUS adapter to stage II. AGE was also user unique and the IUS fairing is 6" larger than the Transtage fairing.

IUS also unsuccessfully attempted standardization. The original IUS concept was to have standard interfaces with the booster (STS) via IUS ASE (Airborne Support Equipment); with the spacecraft via generic structural, power and avionics accommodations; with checkout AGE via and automated checkout stations and standard power and interface racks; and with the range and SCF (Satellite Control Facility) through autonomous operations. The addition of Titan 34D and Titan IV changed the booster checkout AGE and range interfaces. Performance considerations dictated unique configurations including the use of an interstage and tailored SRM (solid rocket motor) and RCS (reaction control system) propellant loads. Spacecraft interfaces changed to accommodate specific spacecraft needs for power, secure communications, contamination protection and software sequencing.

Although most vehicles achieved only limited interface standardization, it was generally recognized that for most launch vehicles interface commonality was preferable since it led to reduced costs and increased operational flexibility. The drive to achieve spacecraft goals was, however, a stronger influence than operational flexibility. For boosters, some commonality, primarily mechanical, was achieved within a given family at the booster to upper stage interface. Electrical, telemetry, guidance & navigation and command & control were generally unique because of spacecraft needs. Payload fairings, although attempts at standardization were made, have almost always been payload unique. The fact that commonality was seldom achieved even though it was intended offers a valuable lesson for current and future systems. It is necessary not only to design standardized interfaces, but to implement procedures to ensure that the interfaces remain standard.

Current Systems

The assessment of current interface commonality was restricted to five spacecraft, two large sized satellites and three medium sized satellites, and those launch vehicles planned to be used for one or more of these spacecraft - Titan IV, Titan II, Atlas E, Atlas II, and Delta II. Both planned and potential spacecraft/launch vehicle combinations were investigated. The options examined are depicted in Figure 1. Planned launch vehicles are shown with a solid arrow and potential launch vehicles with a dashed arrow.

While the magnitude of the problem varies with satellite and launch system, it currently requires approximately two to four years to prepare a spacecraft to be compatible with a new launch vehicle. Much of this time is devoted to analyses related to the integration effort, but hardware redesign has usually also proved necessary. Hardware modifications can be made to the spacecraft, the upper stage, the booster or some combination of these three. Modifications of the upper stage are the most common. Booster changes are sometimes required. Spacecraft are redesigned usually only if environmental considerations, such as loads, mandate change.

Most of the tasks involved in this lengthy effort can be completed in anticipation of launch and the products stored until needed. This is true of analyses, software development, and hardware redesign. For instance, to modify the targeting software for a Titan IV/IUS currently requires 155 days lead time, but this can be done and stored. Launch responsiveness cannot be achieved, however, if any hardware changes are such that they cannot be accomplished in advance. For example, if a spacecraft requires that the booster be customized in such a way that other spacecraft cannot use it and a booster is not going to be dedicated to this spacecraft, then the customization can be accomplished only after a firm decision is made to use the launch vehicle in question. It is necessary, therefore, to identify the currently existing incompatibilities and to assess which of these can be accommodated in advance of need.

The Titan IV is the newest and largest in the family of Titan vehicles. There are currently five distinct configurations of its two stage core vehicle. Titan IV - 401 is the configuration designed for use with the Centaur upper stage. Titan IV - 402 is used with the IUS upper stage. Titan IV - 403 and Titan IV - 404 are both based on the IUS (402) design and are to be launched from VAFB with payloads with no upper stage (NUS). Titan IV - 405 was designed to be used from ETR for NUS payloads. Only those three configurations used from ETR - 401, 402 & 405 - are relevant to this study. These Titan IV configurations differ from each other both in the internals of Stage II and in the interface used between the core vehicle and the upper stage or satellite. Because of these differences, the stage II configurations are not readily interchangeable. Significant time and effort would be required to reconfigure to a different payload.

The most significant difference between the Titan IV 401 (Centaur) configuration and the 402 and 405 configurations is the avionics placement. Essentially all avionics in the 401 configuration reside in the Centaur. The antennas which would normally be on stage II are instead on both the Centaur and on the payload fairing. Separation and destruct circuitry are also unique to this configuration. These differences mandate significant cabling differences between the 401 configuration and the other configurations. In addition, there are several PLF related differences.

The Titan IV 402 (IUS) configuration is closer to the NUS (405) configurations than is the 401 version. It uses Titan 34D/IUS avionics modified to reflect booster vehicle autonomous guidance and control. IUS ISDS (Inadvertent Separation Destruct System) safing discretes from the Titan vehicle have been added as has an IUS telemetry antenna switching interface. Six antennas are on stage II.

The Titan IV 405 (NUS) configuration is similar to the 402 but has a SV flight termination system (explosive formed projectile system) within stage II. An external conduit was added for the ETA (explosive transfer assembly) lines. There are also other electrical system differences including variations in umbilicals and an additional dynamic signal conditioner.

The operational flexibility of the three ETR launched configurations - 401, 402 and 405 - would be considerably enhanced if they could each be made compatible with a wider range of satellites. This flexibility could be achieved through stage II commonality but is not now available because of the substantial hardware differences between configurations.

Two problems common to switching any of these payloads to another configuration or exchanging payloads on a particular vehicle are the PLF and AGE. The PLF varies with both the configuration and the payload. The length varies from 56 feet to 86 feet in 10 foot increments. There are payload peculiar access doors and upper stage peculiar access doors. The Centaur configuration has antennas. The Centaur and NUS versions have a stiffened boattail. This means that it is not normally possible for a fairing meant for one payload to be used for another or for a fairing meant for one configuration to be used on another. The appropriate payload fairing will, in most instances, need to be built and stored if a payload or booster switch is to be possible in a timely manner. With the AGE the problem is somewhat similar. The AGE is unique to a specific payload and will vary if that payload were to be flown on a different upper stage. The AGE for the alternate combination to be flown would have to be available and an exchange procedure specified.

For some payloads a degree of flexibility can be fairly easily achieved. For other payloads the options are limited.

One of the large satellites, called LARGE SAT #1 in this study, can only be flown with a Centaur upper stage. This limits flexibility, but simplifies the interface analysis. The only practical method of utilizing another Titan IV configuration to this satellite is to make the alternate configuration resemble the 401 (Centaur) version. Concepts for accomplishing this are discussed in the section titled "Near Term Concepts."

The other large satellite, LARGE SAT #2, is normally launched on a 402 (IUS) configuration, but has additional options. In addition to making either a 405 (NUS) or a 401 (Centaur) look like a 402 (IUS), this spacecraft could possibly be flown with a Centaur upper stage. This would definitely involve electrical modifications and might require structural changes to the satellite to withstand the different loads associated with the Centaur launch.

The other satellites under discussion - denoted MEDIUM SAT #1, #2 and #3 will be launched by medium launch vehicles. The same sort of flexibility that is advantageous for the Titan IV is useful for these payloads. Although different launch vehicles are involved, the problem is in some respects less complex than for the Titan IV.

The Atlas II is the baseline launch vehicle for MEDIUM SAT #1's. It has two liquid stages and a Centaur as the third stage. The Atlas II is based on the existing Atlas design but has uprated engines, lengthened propellant tanks, a N_2H_4 roll control system and modern avionics. The Centaur II is also changed from the previous version and is 3 feet longer. MEDIUM SAT #1 requires an adapter or adapters to fly on the Atlas II. Two different solutions were considered. The baseline is to have both a spacecraft supplied adapter and an General Dynamics supplied adapter. The two adapters would fit together. An alternative solution is to have a single adapter supplied by the spacecraft.

Two other spacecraft could potentially fly on the Atlas II. MEDIUM SAT #2 might be able to achieve spin velocity beyond the 5 rpm which the Centaur can provide by utilizing the spacecraft reaction control system, otherwise it would require a spin table attached to the Centaur front end or some other spin mechanism. It should not require much other adaptation. MEDIUM SAT #3 could possibly be launched by a two stage (that is, without the Centaur) version of the Atlas II. A specially designed two stage version of the Atlas (to probably be denoted Atlas J) may prove necessary, but a simpler approach is worth further study. This alternative would involve having the spacecraft steer the vehicle which would require software modifications and the addition of an interface box. To fly either Atlas version from VAFB would require pad modifications.

Another possible launch vehicle for MEDIUM SAT #3 is the Delta II without the third stage. This would require a modification of the pad at VAFB to accept the larger Delta II, but should entail few interface problems. The only electrical interface which would be required by the satellite is a separation signal.

Although Titan II was not considered because of performance for any satellite within the study scope other than MEDIUM SAT #3, it should be mentioned that adapting payloads to this vehicle requires relatively little effort. This is due primarily to the relative simplicity of the vehicle/payload interfaces. Electrical connectors are routed to Stage II compartment 2A and kits exist to support a variety of payloads. Payload access doors have been standardized. There are only 8 analog and 8 bilevel channels available to payloads, so that payload unique usages are minimized. Payload specific adaptations are generally limited to thermal and acoustic blankets, air ducts and/or diffuser systems, and batteries.

As can be seen from the above, there is currently very little standardization primarily because of the pressure to meet spacecraft needs. Launch responsiveness was neither a hardware design goal nor a major consideration when deciding on specialized launch vehicle changes. The driving concern has always been spacecraft needs and many current systems have been optimized to meet spacecraft peculiar requirements. If the spacecraft can be made to accept less optimization it will be possible in the near term to increase responsiveness through a degree of commonality, but full interface standardization will take more time.

Near Term Concepts

The most feasible, assuming sufficient performance is available, near term (through 1994) approach to interface standardization is the development of adapters. (For the Titan IV sufficient performance is expected from the uprated solid rocket motors under development. Most other vehicles under discussion currently have enough performance margin.) These adapters would be either at the spacecraft/upper stage separation plane or at the booster/payload (note: here payload is the spacecraft with or without an upper stage) separation plane. The adapter would be designed to accommodate as many interface differences as possible, but in some instances the adapter may not be sufficient.

Adapters would have to be able to handle physical differences, differences in commodity requirements, and power and signal conditioning and distribution. Physical variations include variations in the diameter of booster and payload, structural/mechanical requirements, load paths, and attachment patterns. Electrical, telemetry and communication requirements differ as do fluid and environmental requirements. Plugs and fittings vary in location and type. The variations in separation systems and destruct systems also have to be taken into account.

Concepts have been developed for several adapters. These are not, however, meant to be design recommendations. Designs should properly result from detailed contractor studies. The adapter descriptions are instead meant only to illustrate possible approaches.

For the Titan IV vehicle an adapter could be built utilizing the existing CP2490 skirt structure. This would position it between the existing upper stage adapters (CP2491 for IUS or CP2492 for Centaur) and the stage II core. To accommodate the new adapter it will be necessary to add a field joint at vehicle station 203.151. Spacecraft may still necessitate separate adapters and additional work on stage II is required at the launch site when the substitution is being made to terminate and tie back unused harnesses and to deactivate unused equipment as appropriate when changing between booster or payload configurations.

The adapter for launching LARGE SAT #2 on a NUS core vehicle must contain: all baseline IUS mission requirements and kits; an IUS umbilical; a harness to interface the IUS TIU to the stage II electrical system either directly or through the NUS interface panel; a harness to interface the IUS destruct and separation systems to the stage II destruct and separation systems. An adapter for this satellite on a Centaur core vehicle is similar but must also contain all of the baseline IUS equipment not contained in the 401 configuration.

The adapter for launching LARGE SAT #1 on an NUS or IUS core could be built in a similar manner. The design of the adapter, however, would be different since it must contain the Centaur baseline mission requirements and kits rather than the IUS equipment. Again there would be separate versions for the NUS and IUS cores.

The problem of launching MEDIUM SAT #3 on an Atlas II (without Centaur) could also potentially be solved through the use of an appropriate adapter. The design of the adapter would be less complex than those for Titan IV's. This adapter would have two basic functions - accommodating the physical differences and providing an interface for the guidance provided by the spacecraft to the Atlas II replacing the Centaur guidance used in the standard Atlas II configuration.

Far Term Concepts

The first step in designing interfaces for the future should be to develop standard configurations between boosters, upper stages and spacecraft. This will require an assessment of all of the requirements of the individual spacecraft, all of the launch vehicle constraints and a careful assessment of all of the possible trades. Among the most important tradeoffs will be increased equipment weight vs performance. Carrying unused hardware uses performance that would otherwise be available to the spacecraft. It may be more advantageous to decide not to meet some satellite requests. Once the standards have been defined, coordinated and approved, procedures must be established to permit these standards to influence the design of the next generation of both spacecraft and launch vehicles. Adapters could be designed to accommodate any residual differences, but differences requiring adapters should be strongly discouraged.

Figure 2 depicts some potential approaches. One adapter may allow the Atlas II to be used without the Centaur for programs not requiring an upper stage. This adapter's main function would be to handle vehicle guidance. Another adapter could accommodate the differences between a two stage and three stage Delta II. The Titan IV situation will be considerably less complex in the far term because of two planned developments. The future Titan IV's will be built to have Stage I and Stage II common to all vehicles. In addition, upgraded solid rocket motors will provide substantially increased performance. These together should permit the development of an adapter which will allow rapid substitution of payloads.

Standards must also be developed for the interfaces between AGE and all flight elements. These standards should require the use of BITE (Built In Test Equipment) to the maximum extent possible to minimize AGE interfaces and to allow increased automation of pre-flight processing.

In order for standardization to become a reality, planning must begin now. The planned Titan IV changes are the first of many necessary launch vehicle changes. There must be corresponding concepts developed and implemented in the satellite arena. Standardization concepts must be reflected in the satellite block changes currently under study.

The Advanced Launch System (ALS) which is planned to be implemented in the late 1990's may serve to facilitate interface standardization. It is planned to have only a simple mechanical interface between the vehicle and the payload. Once satellites have adapted to this, it should be possible to simplify the interfaces for the other vehicles in the fleet as well.

Conclusions

Design and implementation of standard interfaces are only the first steps. History has shown that in the absence of firm controls, commonality soon erodes under the pressure of spacecraft unique requirements. A high degree of launch responsiveness cannot be achieved without a significant amount of interface commonality. The required commonality cannot be maintained without cultural change within the spacecraft community. The historical emphasis on optimization on an individual spacecraft basis must be replaced by the willingness to give priority to operational considerations.

This type of change will not come easily. There are no institutional mechanisms in place in the DOD community through which standardization decisions can be made and enforced. Furthermore, intelligent designs must involve not only the DOD but also spacecraft and launch vehicle contractors. Many conflicting interests must be balanced and once a proper balance is achieved implementation will require a high level of cooperation among diverse elements. If this is to ever be achieved, now is the time to begin.

COMMONALITY STUDY SCOPE
LAUNCH OPTIONS

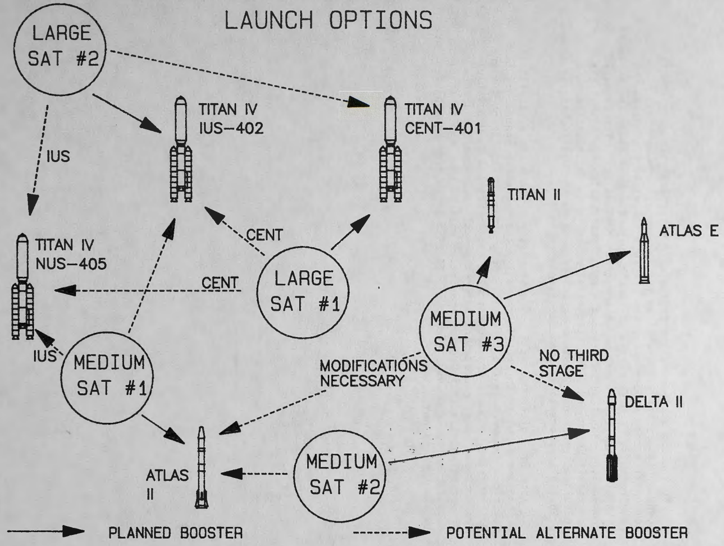
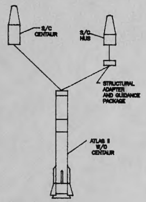


Figure 1

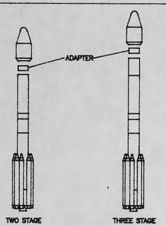
COMMON INTERFACES
FAR TERM
PROPOSED OPTIONS

ATLAS II



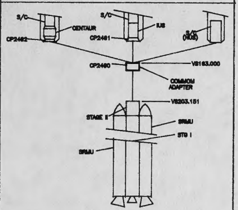
- O PROVIDE STRUCTURAL ADAPTER WITH GUIDANCE EQUIPMENT AND I/F FOR USE WITH S/C THAT DO NOT REQUIRE CENTAUR
- O NEW GUIDANCE S/W WILL BE REQD FOR S/C USING THE NUS CONFIG OF THE ATLAS II
- O MOD LAUNCH PADS AT VAFB AS REQUIRED TO SUPPORT ATLAS II LAUNCHES

DELTA II



- O S/C TO PROVIDE ADAPTER WITH APPROPRIATE STRUCTURAL & MECHANICAL INTERFACES TO MATE WITH COMMON BOOSTER PROVIDED INTERFACE

TIV



- O STG I & STG II COMMON TO ALL CONFIGURATIONS
  - / DEACTIVATE UNUSED STG II EQUIPMENT IN PLACE
  - / TERMINATE & TIE BACK UNUSED HARNESSES
- O SRMU PERFORMANCE SHOULD ACCOMMODATE INCREASE BOOSTER WEIGHT

Figure 2