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Abstract

The International Space Station Alpha adapted an approach to management that is referred to as the Integrated Product Team/Analysis and Integration Team process. This approach organizes around the products that are built in the Integrated Product Teams. In the case of the Space Station Program, these are the major components of the Space Station that are launched into space and assembled. The organization also includes Analysis and Integration Teams that perform System Engineering and Integration functions across the product teams. A major tenet in this organization is to formalize a "tiger team" or "concurrent engineering" approach in which the skills and disciplines needed are brought together to get the job done. Having assembled the proper skills, the teams are trusted and authorized to carry out their responsibilities; if it can be done within team resources, and where it does not impact other teams. Since all interested parties are represented on the team, issues are addressed as they are identified and worked in-process, rather than waiting for major program reviews. The teams are held accountable for their work. They are expected to communicate their internal decisions and elevate decisions that they cannot resolve within their means. This gives the people who know the most about the product more responsibility in making the decisions affecting it.
Introduction

In 1992, NASA conducted an internal review of the Space Station Freedom management structure and found that there were significant problems in lines of authority and accountability. The Program Office had no direct authority over the projects. The project offices reported to different NASA Center Directors who reported outside the program to different Associate Administrators. The organizational structure is shown in figure 1. The projects themselves were responsible for a mixed collection of products. There were many organizations, forums and working groups, who often claimed similar responsibilities and worked at cross purposes. Lines of responsibility and accountability were not identifiable. The program could succeed only if all parties were completely cooperative. As a result, the program processes were cumbersome and contentious. There were major cost overruns, and continuing schedule slips. In 1993, NASA conducted an effort outside the Space Station Freedom Program to cut program costs through redessign of the Space Station and redefinition of the management structure and processes. The Integrated Product Team/Analysis-and Integration Team concept for management was researched and adopted for use on the program. This approach was reviewed with the Vast oversight committee, and was endorsed by them.

SSF Line & Programmatic Chain of Command

Figure 1
The Integrated Product Team/Analysis and Integration Team concept has been used on a number of programs, including the 767 AWACS, F22, Comanche helicopter, V-22 tilt rotor aircraft, and a variant was used on the 777 program. When the Boeing Company was selected to be the prime contractor, they brought significant experience in this management approach through these programs.

**Generic Integrated Product Team/Analysis and Integration Team Structure**

Integrated Product Teams are just what the name implies. They are teams that are focused on developing a product. They are integrated in the sense that they employ people with the complete complement of skills needed to accomplish the team's responsibilities. These teams are delegated authority and allocated budget and schedule to perform their assigned work. This set of people may be permanently assigned to the team, or may be matrixed from other organizations on a full or part time basis.

Analysis and Integration teams perform system engineering and integration tasks across Integrated Product Teams. Through analysis, development of system and hardware architectures, development of Interface Control Documents, assessments of effectiveness parameters, development of verification and test requirements and verification traceability, the Analysis and Integration Teams function to integrate the Integrated Product Teams at one level to successfully form an Integrated Product Team of these sub-elements. Figure 2 shows this generic structure, which provides a complete and easily understood relationship between product development and system engineering and integration responsibilities.

![Diagram of Generic Structure](image)

**Figure 2**

FUNCTIONS:
- IPT = PRODUCES PRODUCT
- AIT = SYSTEM ENGINEERING
As a part of the Integrated Product Team/Analysis and Integration Team formal documentation, a hierarchy of team charters and Team Execution Plans are written for teams. It begins at the top with a Program Execution Plan, that flows down to the Team Execution Plans. This ensures clear definition of roles, responsibilities, organizational relationships, products, and team membership.

International Space Station Alpha Structure and Responsibilities

The overall International Space Station Alpha organization is shown in figure 3. The development of the hardware is concentrated in the Vehicle Team. Space Station operations planning, development and training are the responsibility of the Operations Team. The International Partners Team is responsible for developing policy relating to the International Partners and negotiating agreements with them. There is a Business Management Office responsible for implementation of the Space Station Configuration Management, procurement, metrics, and Information Systems. There are also offices responsible for representing the customers of the Space Station. These are the Utilization Integrated Product Team, the Strategic Utilization and Operations Integrated Product Team, and the Research Management Integrated Product Team. The Safety and Mission Assurance Integrated Product Team provides a focus within the program to assure that a safe vehicle is designed and built. The Space Station Analysis and Integration Team provides the top level program integration function across all the major teams at the top levels of the program.

Since the emphasis of the program at this point in time is in the development of the hardware, the focus of the discussion will be on the Vehicle Team. Because of this emphasis, the largest number of teams and people in the Program Office are in the Vehicle team. The Vehicle Team has 154 people out of the 338 in the Program Office. The Analysis and Integration Team at the Vehicle level (Vehicle Analysis and Integration Team) was chosen to have the most resources within the program for system engineering and integration functions. Most of the integration activity within the program is focused within this organization.

Teams consist of NASA and contractor personnel, and where appropriate, International Partners. Both NASA and the prime contractor are organized together within this team structure. Personnel from Operations, Safety and Mission Assurance, Science and Utilization, Program Control, and other support from the major offices of the Station Program to the vehicle Analysis and Integration Teams and Integrated Product Teams is obtained through the appropriate Integrated Product Team Manager. This support is required to assure a balance in requirements and to raise and work issues in a timely manner, consistent with Concurrent Engineering practices.

As the program progresses and development of the products is completed, the emphasis of the program will migrate over to the Operations Team, and the size of the Vehicle office will be reduced. The intent is that these people who have the most complete product knowledge base will move to the Operations team to participate in the sustaining engineering and operation of the hardware they have developed.
Figure 4

NASA has overall government management and oversight responsibility for the program. The responsibilities for the hardware development and performance lies with the Prime contractor and its subcontractors. NASA personnel participate in the team
processes to represent the NASA program manager and the government as the customer. This responsibility includes representing the government’s requirements and assuring that they are complied with. Another responsibility is to bring NASA technical expertise to the team to contribute to the team’s products. There are specific developments of supporting hardware that are being provided by NASA. These developments require commitments to the Prime that this hardware and associated documentation and reporting are provided in a timely manner to meet overall program need dates.

The Vehicle teams utilize matrix support from the field centers for analyses, in-house hardware development, use of facilities, etc. The Launch Package/Stage Integrated Product Teams and Vehicle Analysis and Integration Team each develop their requirements for support and develop candidate Space Station Task Agreements with technical representatives from the centers.

The NASA personnel on the Program teams are located at the Johnson Space Center. Some are located at contractor and International Partner facilities. All these personnel who are administratively assigned to the Program Office are badged as NASA Headquarters employees.

Vehicle Team Responsibilities

The Vehicle Integrated Product Team responsibilities include:

1. Analysis, design, development, fabrication, assembly, systems engineering and integration, verification and testing, and delivery of US. Vehicle elements, sub-elements, support hardware and software; and their integration into Launch Packages/Stages, leading to the completed Space Station.

2. Analysis and integration of International Partner systems and elements into launch packages/stages.

3. Overall flight vehicle verification, including ground-based integrated stage testing.

4. On-orbit performance verification for each stage in the incremental Station build up.

Launch Package/Stage Teams

Space Station hardware development is organized according to the physical entities that are launched into space. These are developed by Launch Package/Stage Integrated Product Teams. There are teams responsible for US, Russian, European Space Agency, Italian, Canadian, and Japanese launch packages. The Vehicle Team is also comprised of Subsystem Provider Integrated Product Teams, a Phase 1 Integrated Product Team, a ground facility development team, and a Vehicle Analysis and Integration team. The International Space Station Alpha Vehicle Integrated Product Team structure is shown in figure 4.
Each individual Launch Package/Stage Integrated Product Team manages assigned integrated stages, including development of all associated flight hardware and software, integration and verification, delivery to orbit, assembly, activation, checkout, and validation of on-orbit performance as a part of the assembled station. The Launch Package/Stage Integrated Product Team focus on launch packages and stages emphasizes the delivery of functional spacecraft. Launch packages that are similar are handled by one team, where practical, to minimize duplication and synergize the Integrated Product Team activities. The Launch Package/Stage Integrated Product Teams are responsible for the physical assembly of their hardware and for development of specific hardware not supplied by subsystems Integrated Product Teams. At the next level down, Integrated Product Teams are organized that are responsible for the contract end items, which make up the launch packages and the major subsystems.

The Launch Package/Stage Integrated Product Team managers have the delegated authority for product decisions that are within their approved requirements, schedule and cost. The Analysis and Integration Team prepares sufficient material to enable informed decisions by the Integrated Product Team manager that they work for. The solutions are implemented within the authority of the Integrated Product Teams. Decisions are brought to the Vehicle Manager if consensus cannot be reached within the Launch Package/Stage Integrated Product Teams and Analysis and Integration Teams. Documentation and communication of decision details is the responsibility of all Integrated Product Teams.

The US. hardware elements of station are developed at the first tier subcontractors, known as Product Groups in an Integrated Product Team structure directly supporting the Launch Package/Stage teams. There are NASA members of the Launch Package/Stage teams that work at the Product Groups and work directly with the hardware teams. The Product Groups are developing the Node, Pressurized Mating Adapters, Joint Airlock, Cargo Transportation Hardware, Cupola, Laboratory, Habitation Module, S0 Truss, S1 Truss, P1 Truss, S3 Segment, S4 Segment, Photo voltaic arrays, S5 Segment, S6 Segment, photo voltaic array, P3 Truss, P4 Truss, photo voltaic array, P5 Segment, P6 Segment, photo voltaic array, Z1 Segment. The Canadian developed Mobile Servicing System and the Italian developed Mini Pressurized Logistics Module will be integrated at the Product Groups.

Each Launch Package Integrated Product Team ensures the development of the hardware is controlled within the approved budget and schedule. Responsibilities of these teams include technical/schedule status monitoring; issue resolution facilitation; and cognizance of technical, cost, and schedule status of each of the Product Groups' element Integrated Product Teams. The NASA members of the Launch Package/Stage teams have the additional responsibility to ensure that the Launch Package is integrated into the Space Shuttle.

Subsystem Integrated Product Teams are responsible for development of the systems hardware that spans across Launch Packages. This ensures end-to-end design and continuity of the subsystems within the Station. The subsystems encompassed by this Integrated Product Team are the Command and Data Handling, Extra-Vehicular Activity, Flight Crew Systems, Electrical Power, Communication and Tracking, Guidance, Navigation and Control, Propulsion, Thermal Control, Life Support, and Structures & Mechanisms. Their customers are the Launch Package/Stage Managers.
and must provide their hardware according to required schedules, weight allocations, and interfaces.

For Integrated Product Teams that are further decomposed into lower level products, an Analysis and Integration Team is formed to facilitate the system engineering and integration of the product and across all lower level products. Through the Analysis and Integration Team, Launch Package/Stage integrated Product Teams develop and manage their specific requirements, Interface Control Documents, resources and engineering master schedule.

The Phase 1 Integrated Product Team is responsible for development of experiments that are to be flown on Space Shuttle flights to the current Russian MIR Space Station. These experiments are designed to prove out concepts that will ensure a successful Station in the International Space Station Alpha Program.

Team 1 (RSA) is responsible for the integration of the Russian hardware developed for the program. The Team 6 Integrated Product Team will integrated the Japanese and European elements into the program. This includes the Japanese Experiment Module and outfitting hardware, and the European module and outfitting hardware.

Ground Facilities Team 8 Integrated Product Team ensures that the ground, verification, development & test, and launch facilities are available in a timely manner to accomplish the on-orbit assembly process.

Assembly Mission Integration Analysis and Integration Team

This team is responsible for developing consistent processes for Launch packages associated with the International Space Station Alpha. Members of this team will be matrixed to the Launch Package/Stage Teams to perform the Prime responsibilities associated with the Launch Package/Stage team role.

Vehicle Analysis and Integration Team

The Vehicle Analysis and Integration Team performs Systems Engineering and Integration tasks to develop the overall Vehicle architecture, ensure that each Launch Package can be integrated into the assembly, and ensure that it fits and performs the required functions for each stage of assembly. It is responsible for proposing resolution of design and integration issues.

The Vehicle Analysis Team is responsible for analyzing and ensuring the performance and design integration of the overall vehicle at each stage. This team is responsible for developing a workable assembly sequence that is functional at each stage of build up. The Subsystem Architecture and Analysis Team provides the system engineering that develops the subsystem design architectures and resolves design and performance issues across all stages and systems. The Vehicle Integration Team provides the set of top level requirements for the integrated vehicle, and allocates those requirements to the flight elements. It is also responsible for development of an Engineering Master Schedule, Interface Control Documents, and managing Vehicle technical resources. The effectiveness of the vehicle, e.g. safety, reliability and maintainability, is performed by the Vehicle Effectiveness Team to ensure compliance with system requirements and
uniform implementation across all Integrated Product Teams. A consistent and comprehensive test and verification program is developed by the Vehicle Test and Verification Team to be executed by the appropriate Integrated Product Team. They manage the system by which compliance with requirements is verified.

Most System Engineering and Integration processes, such as requirements, architecture, resource management, utilize a similar approach consisting of a flow down of requirements and a roll-up of implementations. For example, the Vehicle Analysis and Integration Team allocates the vehicle-level technical resources (weight, power, volume, crew time, etc.) to the launch packages. These resources are further allocated by the Integrated Product Teams, as appropriate, to control their hardware development. The implementations are then successively rolled up for assessment at the next higher levels.

The Vehicle Analysis and Integration Team includes both permanent members as well as heads of the Launch Package/Stage Integrated Product Teams, Subsystem Integrated Product Teams, or Ground Facility Integrated Product Teams as needed. Personnel from the Vehicle Analysis and Integration Team provide analyses as needed to the lower level Integrated Product Teams and their Analysis and Integration Teams, as well as to the Space Station Analysis and Integration Team.

Processes

The Integrated Product Teams and Analysis and Integration Teams conduct their own meetings to get their work done. If they cannot reach agreement on an issue, if a change requires funding outside their established budget, or if a decision they need affects another team with which they cannot negotiate an acceptable agreement; then they are obligated to raise the issue to the next level Analysis and Integration Team. The Vehicle Analysis and Integration Team holds regular sessions to resolve issues and integrate changes. The Vehicle Integrated Product Team holds weekly sessions to resolve issues at the Vehicle level. The Space Station Analysis and Integration Team also holds weekly meetings to resolve issues at the program level. Configuration Management supports this process with the appropriate documentation and process control. NASA Civil Service and contractor managers responsible for the products of these teams lead these meetings and work together to reach a consensus. A Space Station Control Board is held as a more formal meeting with all Program Participants when major scheduled reviews are held. Figure 5 illustrates the relationship of the primary decision forums to the program structure.
Weekly video con program reviews and monthly visits to major subcontractors are used to gain regular visibility into the hardware development and tasks at lower tiers of the program. All teams are responsible for providing visibility to management through program metrics, schedule and task performance, and issue reporting.

Hardware reviews, such as Preliminary Design Reviews, and Critical Design Reviews are held by the hardware teams. Results and remaining issues are reported in a timely manner to upper levels of the program. The results and hardware status are also reflected and reviewed at Incremental Design Reviews, which are held yearly at the program level.

The contractual relationship is shown in figure 6. The former prime contractors to the three Space Station Freedom Work Packages now report contractually through the Boeing Prime contractor. This is obviously not aligned exactly with the team structure. It was necessary to arrange the contracts in this way to retain the same hardware responsibilities that had been in place for years in the Freedom program. This has created some initial complications in transitioning working relationships and responsibilities. However, hardware element and technical teams have been formed at the subcontractors that report according to the team structure and process.

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**Budget/Financial Management**

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**Figure 6**
Similarities and Differences with Past Human Space Programs

There are many parallels to the way programs have been run in the past and some important differences.

The Program Office at JSC has similar responsibilities to former human space flight programs, in terms of their system engineering and integration responsibilities. It has teams responsible for hardware development similar to project offices in the past. As an example, project offices in the Shuttle Program include those for the Orbiter, External Tank, Boosters, Main Engines, etc. The equivalent Program/project relationships for International Space Station Alpha are shown in figure 7. A difference in Space Station Program is that these offices are included in the Program office and are collocated. There are direct lines of organization responsibility and accountability to the Program Manager rather than to Center Directors as was done in previous programs. This is necessary to closely match responsibilities of the contractors, who now report through a prime contractor. Numbers of civil service personnel within this combined program/project office are significantly reduced from what was in place during Freedom for the equivalent functionality, with an attendant reduction in equivalent teams offices, and, working groups. There are to be 338 people in the current Space Station Program Office versus 937 as counted for Space Station Freedom in 1992 for the same set of program and project functions.

![Figure 7](image-url)
Unlike the Shuttle program, there is a true Prime contractor that integrates all the contracted Space Station hardware through its subcontractors. The Shuttle Program has an integration contractor that has its contract with the program office. Contractors for the Shuttle hardware have contracts directly the NASA project offices. These project offices report to Center Directors at Johnson Space Center and the Marshall Space Flight Center rather than to the program office.

The Vehicle Analysis and Integration Team structure was closely fashioned after the system engineering and Integration model documented in the System Engineering Management Guide that was published by the Defense Systems Management College. The specific functions and responsibilities of these teams closely relate to those listed in this guide. The system engineering organization proposed by this guide is shown in figure 8. It can be compared to the Vehicle Analysis and Integration Team organization shown in figure 4.

**System Engineering Organization**

![Diagram of System Engineering Organization](image)

The teams themselves formalize an approach used by NASA for years to solve critical problems. They have been called "Tiger Teams," "Skunk works," etc. More recent terminology has called it concurrent engineering. The basic approach is to gather the most knowledgeable people that can be found from needed discipline and functional areas to work together and resolve issues in a timely manner. The Integrated Product Teams and Analysis and Integration Teams are organized to do this through their own
employees from both NASA and Boeing, matrixed support from other Program office teams, and NASA institutional organizations. The Prime provides experts from other parts of its company to help in critical problem areas.

There is a recent addition of a chief engineer, who reports to the Program Manager. He and his representatives working through the Program Teams will perform traditional technical peer reviews on engineering analyses and by institutional experts.

Conclusions

The current Space Station management structure has provided an environment that has enabled significant progress in reaching a program baseline and resolving long standing issues. It has provided a logical reporting structure with clear lines of responsibility and accountability. For the first time in this program all elements of the program are working together in a reporting chain of command that will not allow internal contentious organizational battles and standoffs. This organization has been functional for only a year. There have been and are still a few rough spots that arise. These are being resolved as they occur. However, concurrent engineering concepts are in place and understood by the teams. Already people feel ownership and responsibility for their products, and are working together to solve problems.

The government force managing this program has been significantly streamlined. Duplication in responsibilities between organizations has been eliminated. This is attributable to the simplified organizational lines of reporting and the creation of a prime contract relationship with the other tiers of contractors. Program and project level teams are in one organization and are collocated. This facilitates communication and participation among all elements of the program. It also facilitates timely decisions, issue resolution, and efficient program operation.

A key philosophy for the program is to have teams that are made up of all the necessary people to identify and resolve issues as they arise. This keeps problems from arising later and creating costs that could otherwise be avoided. The Integrated Product Team/Analysis and Integration Team structure formalizes the tiger team approach that has been used by NASA for years to solve critical problems.