Appendix B: Work Breakdown Structure (WBS)

B.1. Introduction

The WBS and WBS dictionary are effective management processes for planning, organizing, and administering NASA programs and projects. In accordance with NASA directives NPR 7120.5E ("NASA Space Flight Program and Project Management Requirements"), NPR 7120.7 ("NASA Information Technology and Institutional Infrastructure Program and Project Requirements"'), and NPR 7120.8 ("NASA Research and Technology Program and Project Management Requirements"), the WBS and WBS Dictionary are mandatory elements of a project's management baseline. The goal is to develop a WBS that defines the logical relationship among all program elements to a specified level. The WBS integrates technical, cost, and schedule parameters, giving the Project or Program Manager (PM) a tool to forecast cost and schedule performance, among other management objectives.

With respect to the NASA cost estimator, a project's WBS will significantly affect two areas: the development of the Cost Breakdown Structure (CBS) and the generation of the required inputs into the Cost Analysis Data Requirement (CADRe) database. The development of a WBS with those requirements considered in the early stages will save significant "mapping" and reconciliation efforts for the cost estimator at a later stage. Accordingly, these items are the focus of this appendix. For complete WBS development guidance that includes the WBS as a basis for assigned project responsibilities, provides project schedule development, simplifies a project by dividing the total work scope into manageable units, and provides a common reference for all project communication, refer to NASA's WBS Handbook,[1] which follows the guidelines found in NPR 7120.5E[2].

B.2. Developing a Product-Oriented WBS

A Product-Oriented WBS, which is what is commonly meant by "WBS," is a hierarchical organization of all of the hardware, software, services, and other deliverables necessary to successfully complete a space flight project.[3] The purpose of the WBS is to allocate the work content into manageable segments to enable the planning and control of cost, schedule, and technical content. The typical space flight system WBS is product oriented. The product-oriented WBS begins with the end product at the highest level (such as spacecraft) and subdivides the work content into lower-level elements until sufficient detail is achieved for management (or cost estimating) purposes. A WBS relates the elements of work to one another and to the end product. The WBS is the foundation that relates all project disciplines to a common framework that supports the planning, monitoring, and control of progress and status of engineering efforts, cost and schedule resources, and technical progress and performance.

[1] NASA Work Breakdown Structure Handbook, SP-2010-3404, *http://evm.nasa.gov/handbooks.html*.
[2] NASA NPR 7120.5E, NASA Space Flight Program and Project Management Requirements, w/ Changes 1–10, *http://nodis3.gsfc.nasa.gov/displayDir.cfm?Internal_ID=N_PR_7120_005E_&page_name=AppendixB&search_term=7120%2E5E*.
[3] References to WBSes of varying types may be confusing. For the purposes of this document, and due to common usage, a WBS refers to a Product-Oriented Work Breakdown Structure, an FBS refers to a Functional Work Breakdown Structure, and an OBS refers to an Organizational Work Breakdown Structure.

One of the first tasks that must be performed by the cost estimator when developing a new cost estimate is to either obtain or develop the WBS (step 2 in NASA's 12 step cost estimating process). The WBS is critical because it is the primary source for development of a CBS. If composed with cost information, a WBS may serve directly as a CBS. Otherwise, it may be loaded with cost information attributed to its respective elements to create the CBS. If the project has advanced into Phase B, the Project Manager should be able to provide a WBS. If, however, the project is in the early concept study phase (including Analysis of Alternatives [AOA]), the cost estimator may need to develop a WBS.

When the project or study lead provides the WBS, the cost estimator needs to determine if the WBS addresses the total scope of work and is suitable for cost estimating. Depending on the specific cost models or estimating approaches the analyst has chosen, the project WBS may not have sufficient granularity, or misalignment may exist between the WBS and the estimating methods. Any adjustments that are made to the project WBS must be coordinated with the project or study lead to ensure that the changes will not cause issues with understanding or communicating the estimate. If adjustments to the WBS are not feasible, it is the responsibility of the analyst to make whatever

CADRe WBS

The NASA Standard WBS required by NPR 7120.5E only proceeds to level 2. This increases the degrees of freedom for the Program/Project Manager to construct a WBS that best facilitates project accomplishment. However, the cost estimator and project lead must be aware that there are managerial data demands that must map from the project's WBS. Construction of a WBS that considers these requirements may alleviate significant PM level of effort at stages of the project beyond initial WBS formulation.

For each Agency project, the WBS established by the project must use the NSM numbering scheme and also must correlate exactly through level seven to the corresponding financial accounting structure utilized for each project within the NASA Core Financial System.

In addition to the NASA Core Financial System requirements, projects must submit data into the CADRe system under the CADRe WBS format, shown at right. These data are used by the Agency for reference in future cost estimates. Construction of a project WBS that mirrors or easily maps to the CADRe structure will achieve savings in future level of effort and is considered a "best practice."

NASA WBS Elements	Level
System Name	1
Project Management	2
Systems Engineering	2
Safety and Mission Assurance	2
Science/Technology	2
Payload(s)	2
Payload Management	3
System Engineering	3
Payload Product Assurance	3
Instrument n	3
Instrument n Management	4
Instrument n Systems Engineering	4
Instrument n Assurance	4
Antenna	4
Optics	4
Sensors/Detectors	4
Structures & Mechanisms	4
Thermal Control	4
Electronics	4
Power	4
Pointing Subsystem	4
Harness & Cabling	4
C&DH	4
Ground Support Equip	4
Integration, Assembly Test & Check out	3
Flight System \ Spacecraft	2
Flight System Project Management	3
Flight System Systems Engineering	3
Flight System Product Assurance	3
Spacecraft	3
Spacecraft Management	4
Spacecraft Systems Engineering	4
Spacecraft Product Assurance	4
Spacecraft Structures & Mechanisms	4
Spacecraft Thermal Control	4
Spacecraft Electrical Power &	4
Spacecraft GN&C	4
Spacecraft Propulsion	4
Spacecraft Communications	4
Spacecraft C&DH	4
Spacecraft Software	4
CSCI Name 1	5
CSCI Name 2	5
Software Subsystem I&T	5
Spacecraft I&T	4
Entry/Decent/Lander	3
Rover	3
Spacecraft Retirement & Disposal	3
Launch Vehicle/Services	2
Mission Operations System (MOS)	2
MOS Management	3
MOS Systems Engineering	3
Mission Operations Center	3
Science/Data Operations Center	3
Data Distribution & Archival	3
Communications/Network Infrastructure	3
Training	3
Ground Data System (GDS)	2
GDS Management	3
GDS Systems Engineering	3
Mission Operations Center	3
Science/Data Operations Center	3
Data Distribution & Archival	3
Ground Stations	3
Communications/Network Infrastructure	3
GDS Integration & Test	3
System Integration, Assembly, Test & Check	2
Education & Public Outreach	2
Reserves	1
CM&O	1
G&A	1

accommodations are necessary to the cost estimates in order to provide the alignment between estimating methods and the WBS.

NASA WBS models have been provided in the NASA Air Force Cost Model (NAFCOM) and other Center sources to assist the analyst by furnishing a WBS for the costs estimated by the model. NASA uses NAFCOM for various cost estimating purposes and is transitioning to the Project Cost Estimating Capability (PCEC), as described in the box on page B-3. However, use of the NAFCOM template has resulted in ambiguity when attempting to map the results onto the NASA 7120.5 WBS. Figure B-1 depicts this ambiguity. PCEC addresses this issue by having options for multiple WBSes, including a WBS consistent with the NASA standard WBS and the lower level CADRe standard WBS.[4]

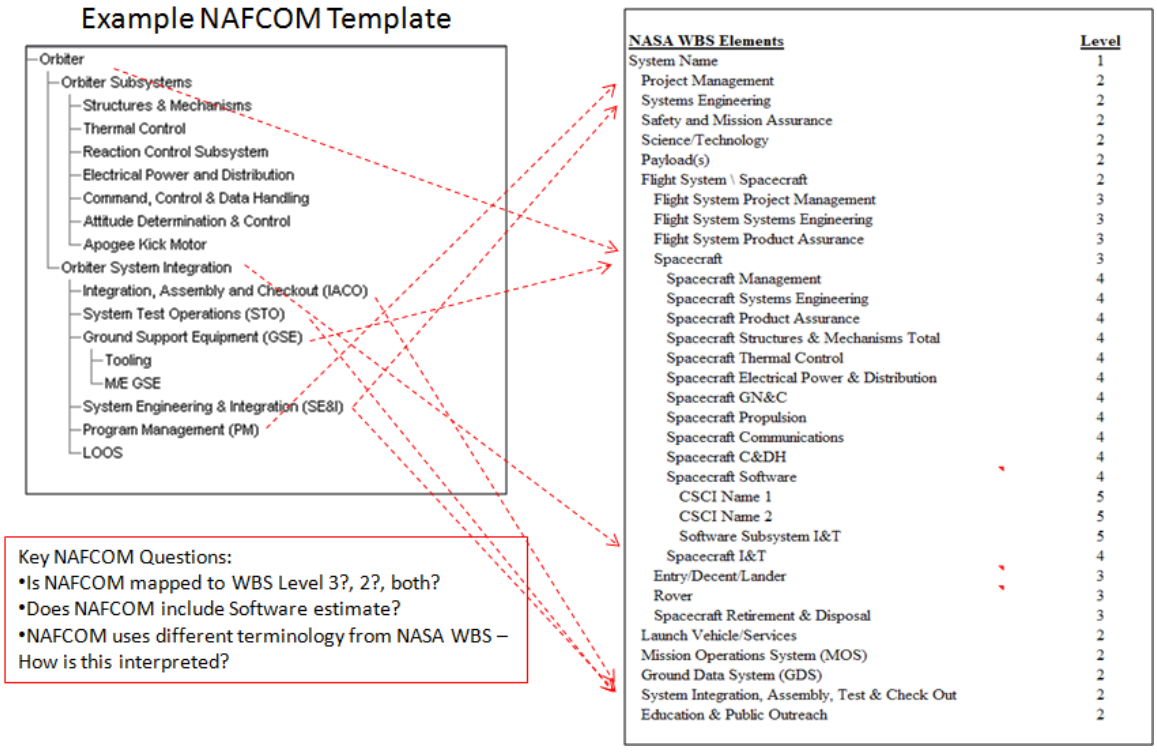

Figure B-1. Mapping the NAFCOM Template to NASA WBS Created Ambiguity[5]

As can be seen in Figure B-1, much of the terminology used in NAFCOM differs from that of the NASA WBS. For example, Program Management is listed in the NAFCOM template. The NASA WBS does not include the term 'Program' with 'Management' and lists three levels of Project Management: Project Management (Level 2), Flight Systems Project Management (Level 3), and Spacecraft Management (Level 4). A second example is NAFCOM System Engineering & Integration (SE&I). The NASA WBS contains the following entries: System Engineering (Level 2) and System Integration, Assembly, Test & Check Out (Level 2). Careful examination of Figure B-1 reveals many other inconsistencies.

Due to the ambiguity of mapping between NAFCOM and the NASA WBS, there is concern about the possibility of misinterpreting the NAFCOM output and mapping the results to the incorrect NASA WBS elements. There is also concern about mapping some NAFCOM higher-level elements to the NASA WBS

[4] The templates for a standard CADRe WBS can be found at *http://www.nasa.gov/offices/ooe/CADRe_ONCE.html*.
[5] Taken from NAFCOM, version 2012. Originally developed for NASA by SAIC.

Spacecraft Level and then double-costing when applying mission wraps to the spacecraft results. The cost analysis must take care to avoid these pitfalls.

The CBS should be consistent with other functions and data sources, such as the budget, the Master Equipment List (MEL), and the Project Management Plan (PMP). The CBS should also be consistent with the appropriate NASA Standard Level 2 WBS template. The analyst must be aware that Pre–Phase A studies may not address all elements in a NASA Standard WBS or provide a cost categorization consistent with the standard WBS terminology.

Per the requirements in NPR 7120.5E, a project should have a preliminary WBS and WBS dictionary by Phase A. The WBS dictionary defines all of the elements in the WBS and is a highly useful document for aligning the project's structure for tracking resources to the content of the cost models. Identifying and resolving differences between these elements is necessary to produce an estimate that accurately reflects the project content.

PCEC replacing NAFCOM

At the time of this report's publication, NAFCOM is still heavily used by the NASA cost estimating community. However, NAFCOM users are in the process of transitioning to the Project Cost Estimating Capability (PCEC), which contains additional information and tools. PCEC incorporates NAFCOM models, as well as models developed by various NASA Centers and directorates. Since most users at this time are more familiar with NAFCOM, this handbook will continue to reference it. The expectation is that the functionality provided to users by NAFCOM and referred to here will continue with PCEC.

Once the estimate is complete, the analyst will need to coordinate with the project or study lead to identify the proper WBS level for reporting. Generally speaking, reporting is done at a higher level than the estimate (e.g., reporting the spacecraft estimate at the total level when the estimate is performed at the subsystem level). The costs at the more detailed WBS levels need to be available as backup material to address questions and provide substantiation.

When performing a full Life Cycle Cost (LCC) estimate, the analyst must consider the temporal aspects of the WBS. Ideally, all elements of the WBS will be defined at the beginning of the project life cycle. However, if the project is in the formulation phase, the focus may be on near-term activities such as system development, with less attention being paid to other aspects of the project life cycle. It is incumbent upon the analyst to ensure that all content of a project's life cycle is adequately addressed.

The NASA Space Flight Project Standard WBS, as defined in the NASA Work Breakdown Structure Handbook,[6] is an acceptable approach to ensuring that all LCCs are captured. Since all projects are required to use the NASA Standard WBS, the project's WBS and WBS dictionary must be compatible. The NASA Standard WBS is shown below in Figure B-2.

[6] *http://ntrs.nasa.gov/archive/nasa/casi.ntrs.nasa.gov/20110012671_2011013098.pdf*

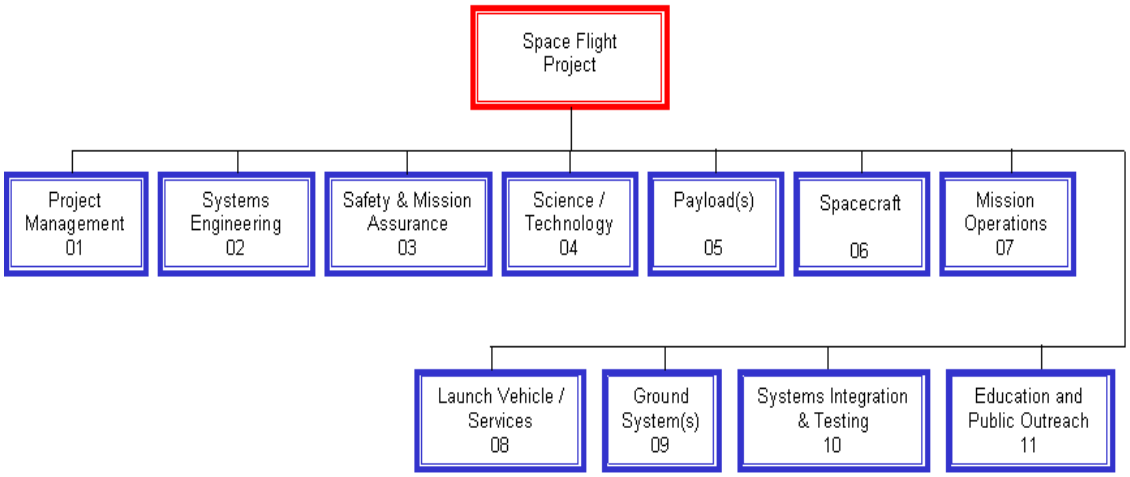

Figure B-2. NASA Standard Space Flight Project WBS

Note that Figure B-2 only proceeds to level II in its depiction. The standard does not intend that this is the lowest level required. Rather, the standard grants significant freedom to the Project or Program Manager to select which branches require lower levels. In addition to the Flight Projects Standard WBS, there are lower-level standard WBSes defined in NPR 7120.8, Appendix K.[7] The standard CADRe WBS is also consistent with the NASA Standard WBS but goes to more detailed levels. MIL-STD-881C[8] is another resource. PCEC has multiple standard WBS templates that may be helpful to the analyst.[9]

B.3. Alternative WBSes

In addition to the product- or cost-oriented WBS, there are alternative ways of organizing the work and presenting the cost. This section discusses three of these approaches: the Organizational Work Breakdown Structure (OBS), the Functional Work Breakdown Structure (FBS), and Elements of Cost (EOC). The relationship between these different breakdown structures is shown in Figure B-3.

[7] *http://nodis3.gsfc.nasa.gov/displayDir.cfm?Internal_ID=N_PR_7120_0008_&page_name=AppendixK*
[8] MIL-STD 881C Work Breakdown Structure for Defense Materiel Items, 3 October 2011, *https://acc.dau.mil/CommunityBrowser.aspx?id=482538*
[9] PCEC will contain the following WBS templates: NASA NPR 7120.5, NASA CADRe, NC12 Earth Orbiting Spacecraft, NC12 Planetary Spacecraft, NC12 Uncrewed Spacecraft, NC12 Crewed Spacecraft, NC12 Launch Vehicle Stage

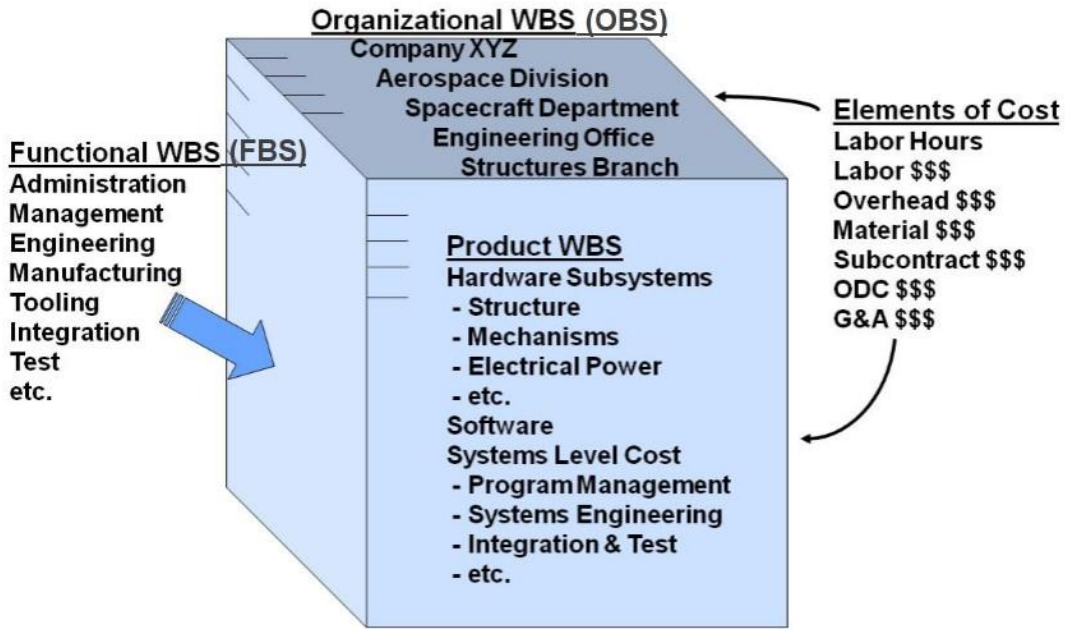

Figure B-3. Multidimensional WBS Relationships

Each WBS approach draws on the same cost data but applies a different categorization. Therefore, each dollar spent can be assigned to a product WBS element, an organizational unit, and a function and identified with an element of cost.

It is important for the cost engineer to understand and appreciate these different views. While the estimate is typically tied to the product WBS, other reporting and management systems may use an Organizational Work Breakdown Structure or Functional Work Breakdown Structure, or a combination of the three. Note that performance management systems such as Earned Value Management (EVM) will establish control accounts at a level where individual products intersect with individual organizations, thus linking the product to the OBS.[10]

The following subsections explain each of these alternative WBSes in greater detail.

B.3.1. Organizational Work Breakdown Structure (OBS)

The OBS accounts for the costs via the individual organizational units that perform the work. Since most organizations are structured hierarchically, this approach mimics a WBS in appearance. However, the OBS is used by the performing organization to track fiscal performance, whereas the WBS is the project manager's approach to organizing and tracking the work. For large projects of long duration, it is common for the performing organization to reorganize so that the WBS and OBS are aligned.

B.3.2. Functional Work Breakdown Structure (FBS)

The FBS organizes work by activity (or function). For example, the work to design an avionics box may consist of the following functions: engineering, procurement (of materials), assembly (of the test unit), and testing. The FBS is independent of both product and organization, though there may be overlaps with those two structures. Most WBSes contain enabling functions within their breakdown structure. Typical enabling functions include project management, systems engineering, mission assurance, and systems integration. In NAFCOM, these crosscutting functions are captured as systems integration costs.

[10] More information on the use of EVM at NASA can be found at *http://evm.nasa.gov/*.

FBSes are typically seen in recurring activities. Both mission operations and ground processing lend themselves to an FBS, where the work required to either prepare flight hardware for launch or operate the hardware post launch is best described using action (or functional) terms (vehicle processing, for example).

An FBS is sometimes referred to as an activity-oriented structure. An activity-oriented structure contains all the activities needed to develop a mission. It is also usable for any subset of the mission. It focuses on work that must be done, rather than on end products. The activity-based structure is not tied to any particular architecture because it is a list of the needed functions, not the elements, of the architecture.[11]

The following is an example of an activity-based structure:

- Project Management
- Systems Engineering
- Systems Design
- Detailed Design
- Prototype/Brassboard Manufacturing
- Prototype/Brassboard Integration
- Prototype/Brassboard Qualification Testing
- Protoflight Manufacturing
- Protoflight Recurring Engineering
- Protoflight Quality Assurance
- Protoflight Integration
- Protoflight Testing and Checkout

It should be noted that these activities are performed in support of a number of the aforementioned WBS elements (e.g., payload, spacecraft, and ground systems). Each of the above activities is a part of each of the WBS elements and can even be assigned to individual subsystems or components. The activities are typically performed by different organizations, with engineering performed by the engineering organization and manufacturing by the manufacturing organization. Contractor or civil service labor may be recorded in systems that are first organized by function and then by end item. Data may be available for both. Every contractor manages its projects differently. Some manage by products, some by functional activities, and others by both.

The estimating community has traditionally focused on the cost by WBS, but the activity-based or FBS may be utilized to either develop a grassroots estimate or to normalize data for inclusion in a parametric cost model. With the introduction of JCL (see Appendix J), obtaining actual costs by both WBS and activities will become more critical. So as more data are collected, the Agency will have better historical data to improve future JCL estimates. During project execution, use of activity- or function-based data displays may also provide very useful insight into both plans and actuals and offer analysts the ability to quickly identify problems or disconnects between planned expenditures or staffing and project schedules.

[11] The Functional Breakdown Structure and its Relationship to Life Cycle Costs," DeHoff, Levack, and Rhodes, 45th AIAA/ASME/SAE/ASEE Joint Propulsion Conference, August 2009.

B.3.3. Elements of Cost (EOC)

An EOC structure is unique in that it can be used as a standalone approach to organizing cost data, or it can be used to provide more detail for other WBS forms. Because it is relatively standard, elements of cost are often aligned with the accounting system and focus on capturing cost and other resource data at the lowest possible level. A typical EOC breakdown will look similar to the NAFCOM EOC shown in Figure B-4.

Example: EOC in NAFCOM: In addition to estimating by WBS, cost models such as NAFCOM, PCEC, PRICE, and SEER can produce cost estimates by EOC. NAFCOM assumes a standardized cost element breakdown, including cost for labor, material, overhead, subcontracts, Other Direct Charges (ODCs), and General and Administrative (G&A) expenses for each element in the WBS. The cost element breakdown is computed using default labor, overhead, and G&A rates, as well as average percent-of-total factors derived from an analysis of historical missions. The analyst is able to further refine the cost estimate with user-defined labor, G&A, and overhead rates. In addition to cost, labor is also reported in hours separated into engineering, manufacturing, and other (quality control, tooling, facilities labor) categories.

Standard Elements of Cost in NAFCOM

- Labor Hours
  - Engineering Labor Hours
  - Manufacturing Labor Hours
  - Other Labor Hours
- Labor $
  - Engineering Labor $
  - Manufacturing Labor $
  - Other Labor $
- Overhead $
- Material $
- Subcontracts $
- ODCs $
- G&A $

Figure B-4. Standard Elements of Cost Used in NAFCOM

The data and research performed result in the default labor rates; percent-of-total factors for engineering labor, manufacturing labor, other labor, material, and Other Direct Charges; default make percentage; G&A percentage; and overhead percentage. Data are obtained representing different spacecraft types, agencies, and reporting methods. The standard cost elements identified above provide consistency for allocating various reporting types into similar groupings. Definitions for these elements of cost are provided in the next subsection.

B.3.4. Cost Element Definitions

Engineering Labor—Engineering labor is generally defined as the direct labor expended by engineering employees while performing all scientific investigations, technical processes, research, development and design, system engineering, testing, logistics, and support for the manufacturing process of a specific product.

G&A—General and administrative costs are indirect expenses, including the costs required to maintain a company's general and executive offices; the cost of staff services such as legal, accounting, public relations, financial, and similar expenses; and other general expenses related to the overall business that are not assignable to overhead areas.

Labor Hours—The skill or labor categories that can be used for analysis are divided into three suggested groupings: engineering, manufacturing, and other.

Manufacturing Labor—Manufacturing labor is generally defined as the direct labor performed on the end item or the processing of parts used in the finished product, as well as the functional testing of the product. It normally covers fabrication, assembly, and manufacturing support activities. Manufacturing labor also sometimes includes tooling and quality control labor; however, for the functional breakdown analysis, tooling and quality control labor are considered other labor.

Materials—The raw materials, purchased parts, and overhead costs that are attributable to purchasing, receiving, storing, warehousing, delivering, or expediting materials.

Other Direct Charges—ODC covers costs not usually listed under direct material, labor, or overhead, including such things as computer usage, travel, freight, consultants, remote activities, taxes, and interdivisional support costs.

Other Labor—Other labor includes program management, data labor tooling, quality control labor, and facilities labor.

Overhead—Overhead includes costs that, because of their incurrence for common or joint objectives, are not readily subject to treatment as a direct cost. Such indirect cost is incurred to benefit the total direct cost or business base of a contractor. In NAFCOM, fringe benefits are included in overhead and not in labor.

Subcontracts—Subcontracts include the procurement of major components or subsystems that require the subcontractor to do extensive design, development, engineering, and testing to meet a prime contractor's procurement specifications. This cost category does not include the procurement cost for the buy percentage of the subsystem—such cost must be added separately as throughputs.