ADVANCED TRANSPORTATION SYSTEM STUDY

Manned Launch Vehicle Concepts for Two Way Transportation System Payloads to LEO

Work Breakdown Structure and Work Breakdown Structure Dictionary

(DR-5)

Contract NAS8-39207

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FORWARD

This report is submitted in compliance with DR-5 of Contract NAS8-39207, Advanced Transportation System Studies for the National Aeronautics and Space Administration, George C. Marshall Space Flight Center. The report describes the Work Breakdown Structure (WBS) and its associated WBS Dictionary for Task Area 1. This WBS format is consistent with the preliminary design level of detail employed by both Task Area 1 and Task Area 4 in the ATSS study and is intended to provide an estimating structure for parametric cost estimates.

ADVANCED TRANSPORTATION SYSTEMS STUDY (ATSS)
TASK AREA 1 (TA1)

WORK BREAKDOWN STRUCTURE (WBS)

A single WBS format has been agreed to by MSFC, Rockwell International - Huntsville Operations (TA1 contractor) and General Dynamics (TA 4 contractor) to provide a compatible basis for cost estimates made by, or used by, either task area. This DR-5 is consistent with the conceptual- and/or preliminary- level of technical design definition that characterizes both TA 1 and TA 4 efforts , and is intended to provide an estimating structure for rough-order-of-magnitude (ROM) parametric cost estimates.

1.0 SPACE TRANSPORTATION SYSTEM
- **1.1 LAUNCH VEHICLE SEGMENT**
  - 1.1.1 Launch Vehicle Integration , Assembly & Checkout (IACO)
  - 1.1.2 Booster (strap-on) stage.
  - 1.1.3 Core Stage (Stage 1).
    - 1.1.*i*.1 Stage *i* Integration, Assembly and Test
    - 1.1.*i*.2 Stage *i* Structures less Tanks
    - 1.1.*i*.3 Stage *i* Propellant & Pressurant Tanks
    - 1.1.*i*.4 Stage *i* Separation Devices
    - 1.1.*i*.5 Stage *i* Recovery & Landing System
    - 1.1.*i*.6 Stage *i* Thermal Protection
    - 1.1.*i*.7 Stage *i* Main Propulsion Engines
    - 1.1.*i*.8 Stage *i* Auxiliary Propulsion
    - 1.1.*i*.9 Stage *i* Propulsion Feed & Propellant Management
    - 1.1.*i*.10 Stage *i* Power Generation & Distribution
    - 1.1.*i*.11 Stage *i* Flight /Thrust Vector Control
    - 1.1.*i*.12 Stage *i* Avionics
    - 1.1.*i*.13 Stage *i* Environmental Control & Life Support
    - 1.1.*i*.14 Stage *i* *Stage Unique* Software
    - 1.1.*i*.15 Stage *i* *Stage Unique* Ground Support Equipment
    - 1.1.*i*.16 Stage *i* *Stage Unique* Tooling
    - 1.1.*i*.17 Stage *i* *Stage Unique* Systems Engineering
    - 1.1.*i*.18 Stage *i* *Stage Unique* Program Management
    - 1.1.*i*.19 Stage *i* Spares & Repair Parts
    - 1.1.*i*.20 Stage *i* Major Overhauls
  - 1.1.4 Second Stage (Stage 2)
  - 1.1.5 Third Stage (Stage 3).
  - 1.1.*n* Upper Stage (aka Kickstage,Orbital Transfer Stage, Space Transfer Vehicle).
- **1.2 TRANSPORTATION NODE SEGMENT** *(not applicable for ATSS TA1 WBS)*
  - 1.2.1 to 1.2.*n* ELEMENTS (1 thru *n*)
    - 1.2.1.1 Integration, Assembly, & Test
    - 1.2.1.2 Structures
    - 1.2.1.3 Hangers
    - 1.2.1.4 Docking & Berthing Equipment
    - 1.2.1.5 Thermal Protection
    - 1.2.1.6 Propulsion/Reaction Control
    - 1.2.1.7 Power Generation & Distribution
    - 1.2.1.8 Avionics
    - 1.2.1.9 Environmental Control & Life Support
    - 1.2.1.10 Crew Accommodations
    - 1.2.1.11 Software
    - 1.2.1.12 Support Equipment
    - 1.2.1.13 Tooling
    - 1.2.1.14 Systems Engineering

1.2.1.15 Program Management
1.2.1.16 Spares & Repair Parts
1.2.1.17 Major Overhauls

1.3 TEST SEGMENT

1.3.1 System Test & Evaluation
1.3.1.1 Development Test & Evaluation (DT&E)
1.3.1.2 Operational Test & Evaluation (OT&E).
1.3.1.3 Test Facilities, Equipment and Support

1.4 OPERATIONS SEGMENT

1.4.1 Launch Operations
1.4.1.1 Launch Processing, Cargo Integration, & Landing/Recovery Operations
1.4.1.2 Launch Operations Systems Engineering & Program Management
1.4.1.3 Base Operations & Maintenance
1.4.1.4 Liquid Propellants
1.4.2 Flight (Mission) Operations
1.4.2.1 Flight (Mission) Planning & Design
1.4.2.2 Real-Time Mission Control
1.4.2.3 Analytical Payload Integration
1.4.2.4 Crew Operations & Training

1.5 SOFTWARE SEGMENT

1.5.1 Flight Software
1.5.1.*i* Flight Software Computer Program (aka configuration item)
1.5.2 Ground Software
1.5.2.*i* Ground Software Computer Program (aka configuration item)

1.6 GROUND SEGMENT

1.6.1 Facilities & Special Purpose Equipment
1.6.1.1 Launch Pad
1.6.1.2 Vertical Processing Facility
1.6.1.3 Horizontal Processing Facility
1.6.1.4 Launch Control Center
1.6.1.5 Mission Control Center
1.6.1.6 Communications Network
1.6.1.7 Test Facilities
1.6.1.8 Government Owned/Contractor Operated (GOCO) Manufacturing Facilities
1.6.1.9 Other Facilities
1.6.2 Common Ground Support Equipment (GSE)

1.7 PROGRAM SEGMENT

1.7.1 System Engineering & Integration (SE&I)
1.7.2 Program (Project) Management (PM)
1.7.3 NASA-provided "Wrap" Factors
1.7.3.1 Contractor Fee
1.7.3.2 Government Support
1.7.3.3 Contingency

ADVANCED TRANSPORTATION SYSTEMS STUDY (ATSS)

TASK AREA 1 (TA1)

WORK BREAKDOWN STRUCTURE (WBS) DICTIONARY

1.0 SPACE TRANSPORTATION SYSTEM

The term "space transportation system" refers to that set of launch vehicle hardware, software, facilities, equipments, and operations which constitute a capability to launch a manned and/or unmanned (cargo) spacecraft into orbit, to transfer a spacecraft within or between orbits, and/or to recover a spacecraft from orbit.

For WBS-based cost estimating purposes, an individual space transportation system (e.g., Delta, Atlas, Titan or Space Shuttle) may consist of as many as seven primary levels of WBS indenture that correspond to system *segments*,: a launch vehicle segment (WBS 1.1) ; an on-orbit transportation node segment (WBS 1.2); a test segment (WBS 1.3); an operations segment that includes both launch operations and flight (mission) operations (WBS 1.4); a software segment (WBS 1.5); a ground segment that includes facilities and equipment (WBS 1.6); and a program segment which includes program-level "wraps" that are indirectly estimated as a "wrap" on other directly-estimated hardware/software costs (WBS 1.7) .

However, it is <u>not</u> necessary for a space transportation system's WBS to include all seven segments; it is acceptable to include just those segments that are sufficient to completely describe the work to be accomplished. For example, since TA1's primary focus is manned launch vehicles, it is <u>not</u> expected that TA1 will be required to generate cost estimates for on-orbit transportation nodes (WBS 1.2); however, TA1's WBS reserves a "placeholder" for the transportation node segment so that it will be comparable, on a line-item by line-item basis, to WBSs used by other ATSS contractors. And, since technical descriptions of software in conceptual studies such as those

planned for TA1 are sketchy, at best, it is anticipated that software costs will be implicitly included in the ROM estimates based on other available parameters (e.g., weights, complexities, et.al.); however, TA1's WBS includes a "placeholder" for the software segment, again so that WBSs will be completely comparable between ATSS task areas.

Within each segment-level WBS, at a greater (second) level of WBS indenture, there may be one or more elements that are related to the development, production and/or operations necessary to place, transfer, and/or recover spacecraft. For DR-5 purposes, these elements may be generally designated as *"element 1"* through *"element n"*, (e.g., within the launch vehicle segment, WBS 1.1, its *1st* through its *nth* stages may be designated as WBS 1.1.*1* through WBS 1.1.*n* , respectively) as necessary to describe the complete space transportation system.

Generally, the elements within the launch vehicle segment may be defined by physical entities such as stages (e.g., booster, core, kick stage, et.al.) or by other identifiable hardware/software items (e.g., shrouds/fairings, crew modules, cargo carriers, recovery capsules, et.al.) needed for a complete, integrated launch vehicle. For example, elements within the launch vehicle segment may include propulsive stages (e.g., boosters, core), upper stages (e.g., orbit transfer vehicles or space transfer vehicles), recovery vehicles and other elements that are necessary to provide an operational space transportation system.

At an even greater (third) level of WBS indenture (e.g., WBS 1.*1.i.x*), each launch vehicle element (stage) may include airframe structures, thermal protection, propellant and pressurant tankage, separation and/or recovery devices, main and auxiliary propulsion engines & feedlines, electrical power, thrust vector control, avionics, environmental control & life support, and other installed subsystems and components.

1.1 LAUNCH VEHICLE SEGMENT

The launch vehicle segment refers to that combination of elements which provides a sufficient velocity increment to place a spacecraft (containing its payload/cargo and/or its crew) into its operational environment. For cost estimating purposes, WBS 1.1 includes all resources required to design, develop, test, evaluate and produce either complete or partial units of the launch vehicle (either prototype or operationally configured) regardless of their end use. The launch vehicle segment may consist of one or more elements (stages) that provide propulsive force and protect the payload during its ascent through Earth's atmosphere.

1.1.1 Launch Vehicle Integration , Assembly & Checkout (IACO)

Launch vehicle integration, assembly and checkout includes all those resources, except those consumed at the launch site, needed to integrate and assemble stage elements "*i*" through "*n*" into a complete launch vehicle , such as structural, mechanical, electrical and/or fluids interfaces, adapters and/or mating sections. (WBS 1.4.1, launch operations, includes pre-launch integration, assembly and checkout activities at the launch site.). All efforts directly chargeable to individual stages of the launch vehicle are accounted for at the element-level and are specifically excluded from this WBS.

1.1.2 Booster (strap-on) stage.

The booster (strap-on) stage includes solid propellant booster(s) and/or liquid propellant booster(s) that, if used, provide supplementary propulsive thrust, in addition to the core stage's main propulsive thrust, during the launch vehicle's initial lift-off and atmospheric ascent phases. All efforts related to designing, developing, testing, evaluating and producing either complete or partial units of the booster (strap-on) stage, as an entity, are included in WBS 1.1.2 (e.g., structural casings, propellant/fuel nozzles, ignition devices, mounting structures, et.al.). However, this WBS specifically excludes those resources necessary to integrate and assemble the stage into a complete launch

vehicle (see WBS 1.1.1 and /or WBS 1.4.1) and also excludes those resources necessary to test and evaluate the integrated launch vehicle (see WBS 1.3.1) of which the booster (strap-on) stage is only one part.

1.1.3 Core Stage (Stage 1).

The core (stage 1) or first stage, which may be supplemented by strap-on boosters, provides the main propulsive thrust for the launch vehicle/cargo unit combination from launch vehicle lift-off through atmospheric ascent. All efforts related to designing, developing, testing, evaluating and producing either complete or partial units of the core stage, as an entity, are included in this WBS (e.g., core airframe structures and propellant tanks, thermal protection coverings and insulation, main propulsion engines and feedlines, thrust vector and flight controls, instrumentation, electrical and/or fluids interfaces, separation devices, and other installed equipment).

Since the degree of design definition available to ATSS TA1 can best be characterized as conceptual (ROM parametric) and/or very preliminary, it is expected that cost estimates will be based on element-level technical data at best. However, should the need arise, major subsystems and components within any element (stage) "*I*" may be included within the element "*I*" WBS by extending its level of indenture further, as indicated for a typical stage:

1.1.*I*.1 Stage *I* Integration, Assembly and Test

1.1.*I*.2 Stage *I* Structures less Tanks

1.1.*I*.3 Stage *I* Propellant & Pressurant Tanks

1.1.*I*.4 Stage *I* Separation Devices

1.1.*I*.5 Stage *I* Recovery & Landing System

1.1.*I*.6 Stage *I* Thermal Protection

1.1.*I*.7 Stage *I* Main Propulsion Engines

1.1.*I*.8 Stage *I* Auxiliary Propulsion

1.1.*1*.9 Stage *1* Propulsion Feed & Propellant Management

1.1.*1*.10 Stage *1* Power Generation & Distribution

1.1.*1*.11 Stage *1* Flight /Thrust Vector Control

1.1.*1*.12 Stage *1* Avionics

1.1.*1*.13 Stage *1* Environmental Control & Life Support

1.1.*1*.14 Stage *1* *Stage Unique* Software

1.1.*1*.15 Stage *1* *Stage Unique* Ground Support Equipment

1.1.*1*.16 Stage *1* *Stage Unique* Tooling

1.1.*1*.17 Stage *1* *Stage Unique* Systems Engineering

1.1.*1*.18 Stage *1* *Stage Unique* Program Management

1.1.*1*.19 Stage *1* Spares & Repair Parts

1.1.*1*.20 Stage *1* Major Overhauls

1.1.4 Second Stage (Stage 2)

The second stage (stage 2) , if used, provides sustaining propulsive thrust, after separation of the first or core stage, for the launch vehicle/cargo unit combination. This element may include, for example, airframe structure and tankage, propulsion, flight control, instrumentation, structural/electrical and/or fluids interfaces, separation devices, and all other installed equipment (see stage "*1*" WBS indenture above) integral to the stage as an entity . All efforts related to designing, developing, testing, evaluating and producing either complete or partial units of the second stage, as an entity, are included in this WBS; however, this WBS specifically excludes those efforts necessary to integrate or assemble the second stage (stage 2) into a complete launch vehicle (see WBS 1.1.1 and WBS 1.4.1) and also excludes those efforts necessary to test and evaluate the integrated launch vehicle (see WBS 1.3.1) of which the second stage (stage 2) is only one part.

1.1.5 Third Stage (Stage 3).

The third stage (stage 3) element, if used, provides continuing propulsive thrust, after separation of the second stage, for the launch vehicle/cargo unit combination. This stage may include, for example, structure, propulsion, flight control, instrumentation, interfaces, separation devices, and all other installed equipment integral to the stage as an entity within itself. All efforts related to designing, developing, testing, evaluating and producing either complete or partial units of the third stage, as an entity, are included in this WBS; however, this WBS specifically excludes those efforts necessary to integrate or assemble the third stage into a complete launch vehicle (see WBS 1.1.1 and WBS 1.4.1) and excludes those efforts necessary to test and evaluate the integrated launch vehicle (see WBS 1.3.1) of which third stage is only one part.

1.1.*n* Upper Stage (aka Orbital Insertion Stage, Kickstage, or Orbital Transfer Stage, Space Transfer Vehicle). The upper stage (element *n*) refers to the final propulsive stage of the launch vehicle which typically inserts the mission spacecraft into its operational environment. This element may include, for example, structure, propulsion, flight control, instrumentation, interfaces, separation devices, and all other installed equipment integral to the stage as an entity. All efforts related to designing, developing, testing, evaluating and producing either complete or partial units of the upper stage, as an entity, are included in this WBS. However, this WBS specifically excludes those efforts necessary to integrate or assemble the upper stage into a complete launch vehicle (see WBS 1.1.1 and WBS 1.4.1) and excludes those efforts necessary to test and evaluate the launch vehicle (see WBS 1.3.1) of which the upper stage is only one part.

*1.2 **TRANSPORTATION NODE SEGMENT** (not applicable for ATSS TA1 WBS Dictionary)*
1.2.1 to 1.2.n ELEMENTS (1 thru n)
1.2.1.1 Integration, Assembly, & Test
1.2.1.2 Structures
1.2.1.3 Hangers
1.2.1.4 Docking & Berthing Equipment
1.2.1.5 Thermal Protection
1.2.1.6 Propulsion/Reaction Control
1.2.1.7 Power Generation & Distribution
1.2.1.8 Avionics
1.2.1.9 Environmental Control & Life Support
1.2.1.10 Crew Accommodations
1.2.1.11 Software
1.2.1.12 Support Equipment
1.2.1.13 Tooling
1.2.1.14 Systems Engineering
1.2.1.15 Program Management
1.2.1.16 Spares & Repair Parts
1.2.1.17 Major Overhauls

1.3 TEST SEGMENT

1.3.1 System Test & Evaluation

WBS 1.3.1 includes segment-level hardware (e.g., prototype or specially fabricated hardware) and services used to obtain or validate engineering data. However, launch vehicle hardware articles which are complete operational units (i.e., configured for an operational mission) are specifically excluded as is that testing which can be uniquely associated with stage-level hardware . In addition to those hardware items that are consumed in the conduct of system tests, WBS 1.3.1 includes test planning, test conduct, test support, test data reduction and reports from such tests. This WBS also includes all effort associated with the design and production of models, specimens, fixtures and instrumentation in support of the test program.

1.3.1.1 Development Test & Evaluation (DT&E)

Development tests and evaluations are conducted to demonstrate that the design and development process is complete and/or to demonstrate that the system will meet

specifications. WBS 1.3.1.1 includes scale models and special-purpose tests such as , for example, subsystem integration test, flight and/or ground aerodynamic, thermal, vibro/acoustic, and static and dynamic structural tests.

1.3.1.2 Operational Test & Evaluation (OT&E).

Operational tests and evaluations of the integrated launch vehicle may be conducted to assess its prospective utility, effectiveness, supportability and/or the need for modification. This WBS includes, for example, flight tests, orbital tests, and initial operational test & evaluations conducted during development.

1.3.1.3 Test Facilities, Equipment and Support

Test facilities, equipment and support includes special test facilities or sites required for development tests including, for example, propulsion test fixtures, clean rooms, test chambers, etc.; however, brick-and-mortar-type facilities allocable to industrial facilities are excluded. This WBS includes, for example, operation and maintenance during tests, instrumentation, repairable spares, repair of repairables, test and support equipment, contractor technical support, surveillance aircraft, tracking vessels, et.al..

1.4 OPERATIONS SEGMENT

1.4.1 Launch Operations

Launch operations comprise those activities required to receive and inspect individual stage elements (1 through *n*) at the launch site, to integrate and assemble these stage elements into a complete launch vehicle, to integrate the payload/cargo spacecraft into the launch vehicle, to test (checkout) the launch vehicle as an integrated unit, and to launch the launch vehicle/cargo spacecraft combination. WBS 1.4.1 includes, for example, logistics for launch operations, pre/post flight data reduction & analysis,

countdown & launch, and launch pad refurbishment. Where appropriate, launch operations may be defined by type of resource consumed at the third level of WBS indenture (as indicated below) and identified with specific types of hardware/software item (e.g., launch vehicle, spacecraft, etc.)

1.4.1.1 Launch Processing, Cargo Integration, & Landing/Recovery Operations

1.4.1.2 Launch Operations Systems Engineering & Program Management

1.4.1.3 Base Operations & Maintenance

1.4.1.4 Liquid Propellants

1.4.2 Flight (Mission) Operations

Flight (mission) operations consist of those resources required to command, control, track and communicate with the launch vehicle/cargo spacecraft during its mission. Flight (mission) operations both precede and follow of the launch vehicle lift-off (conventionally, the handoff point between launch operations and flight operations) and include, for example, preflight mission planning and flight design, real-time mission control, telemetry, communications, data reduction & analysis, and logistics support for ground-based flight equipment. Flight operations also include those activities necessary to effect recovery of spacecraft, reusable launch vehicles or other mission equipment such as recovery operations , logistics support to recovery operations, and post-recovery transportation of recovered equipment. Where appropriate, flight operations may be defined at a greater level of WBS indenture (as indicated below) by type of operation or resource consumed and further identified with specific types of hardware/software item (e.g., launch vehicle, spacecraft, etc.)

1.4.2.1 Flight (Mission) Planning & Design

1.4.2.2 Real-Time Mission Control

1.4.2.3 Analytical Payload Integration

1.4.2.4 Crew Operations & Training

1.5 SOFTWARE SEGMENT

Depending on its end use or application, software can be categorized as either flight software or ground software at the second level of WBS indenture. For example, flight application software (e.g., Space Shuttle's backup flight system) might provide autonomous, real-time guidance, navigation & flight control functions for the launch vehicle . Generally, ground software (e.g., KSC's launch processing system for Space Shuttle) is installed on ground-based computers, and may be much larger (dimensioned in software lines of code) and/or complex than is flight software. For either flight or ground software that is not stage-unique , WBS 1.5 includes both nonrecurring costs (e.g., design, coding, testing & debugging and independent verification & validation) and recurring efforts (e.g., software maintenance & flight-to-flight reconfiguration) and identified by specific computer program .

1.5.1 Flight Software

1.5.1.*i* Flight Software Computer Program (aka configuration item)

1.5.2 Ground Software

1.5.2.*i* Ground Software Computer Program (aka configuration item)

1.6 GROUND SEGMENT

1.6.1 Facilities & Special Purpose Equipment

Ground facilities and special purpose equipment needed to test, manufacture and operate any individual space transportation system tend to be constructed, activated,

operated and maintained specifically for that system with, generally, little or no co-mingling of facilities and equipment between systems. For each facility identified at the WBS 1.6.1.*i* level, both non-recurring costs (e.g., architecture & engineering (A&E) services, construction of real-estate facilities (CoF) and site activation (SA) activities including installation of permanent mission equipment and support equipment into the site facility) and recurring costs (e.g., operation and maintenance (O&M) of the facility and its installed special purpose equipment) are included.

1.6.1.1 Launch Pad

1.6.1.2 Vertical Processing Facility

1.6.1.3 Horizontal Processing Facility

1.6.1.4 Launch Control Center

1.6.1.5 Mission Control Center

1.6.1.6 Communications Network

1.6.1.7 Test Facilities

1.6.1.8 Government Owned/Contractor Operated (GOCO) Manufacturing Facilities

1.6.1.9 Other Facilities

1.6.2 Common Ground Support Equipment (GSE)

Common ground support equipment (GSE) is equipment, including tools, needed to operate and maintain the elements of the space transportation system prior to its mission, or subsequent to completion of its mission. GSE can be characterized as general purpose, multi-application equipment used to support launch and/or mission operations. WBS 1.6.2 includes, for example, power generators, power distribution systems, environmental control, cabling, malfunction detectors, fire prevention devices and other common-usage items not uniquely identifiable with specific elements or stages of the launch vehicle.

1.7 PROGRAM SEGMENT

The program segment WBS 1.7 comprises three cost elements -- system engineering (WBS 1.7.1), program management (WBS 1.7.2) and other "wrap" factors (WBS 1.7.3) -- that, since they cannot be directly associated with specific units of hardware or software, are generally estimated as a percentage of (or "add-on" to) the directly estimated hardware/software costs.

1.7.1 System Engineering & Integration (SE&I)

System engineering & integration (SE&I) provides technical direction and control of project hardware and/or software as it progresses from its conceptual and preliminary design phases through engineering & manufacturing development, through test & evaluation, and into production and full operational capability. SE&I defines, directs, and controls the development and production of system hardware and software including logistics, maintenance, facilities, testing, and activation of a system. System engineering & integration efforts that can be specifically associated with stage-level hardware elements is excluded, unless that effort is of special contractual or engineering significance (e.g., an associate contractor).

1.7.2 Program (Project) Management (PM)

Project management refers to those business planning, organizing, directing, coordinating, controlling, and approval actions that are not associated with specific hardware elements and that are not included in system engineering including, for example, logistics management, cost/schedule/performance management, contract management, data management, vendor liaison, etc.

1.7.3 NASA-provided "Wrap" Factors

This WBS element consists of NASA provided wrap-around factors -- for contractor fee, government support and contingency -- that, for consistency, the ATSS TA4 contractor will apply to cost estimates generated by other ATSS task area contractors.

1.7.3.1 Contractor Fee

1.7.3.2 Government Support

1.7.3.3 Contingency