Project Management Plan for Conceptual Design
Project Name: NASA LSP VCLS
ARO 4200 Section 3 Prof. Dobbs

Astro Chariot **Team # 03-1**

Lead 2: Chase Edwards
Deputy 2: Nicholas Turcios
Sobhan Akhtar,
Tyler Lyman,
Dario Mejia-Solis,
Virginia Sheinkman,
Eliot Khachi

Date: 05 November 2020

1

Table Of Contents

2

Table Of Contents

3

Table Of Contents

4

Table Of Contents

5

Table Of Contents

6

1.1 Needs Analysis

NEED: *Currently the only option for small payload launches is to rideshare payload deliveries due to a limited variety launch vehicles. The NASA Launch Services Program (LSP) Venture Class Launch Service (VCLS) Demo 2 needs a vehicle capable of delivering CubeSats into Low Earth Orbit (LEO) for frequent, flexible, and low-cost access to space. (Hall)*

- The key external stakeholders and their needs are:
  - The NASA Launch Services Program needs a launch vehicle to deliver CubeSats into orbit to obtain Earth temperature data and investigate paths to the moon and scope the lunar surface in 2024.
  - Farmers and water managers are better equipped to optimize water consumption using Earth temperature data acquired from CubeSat (Blumberg).
  - The United States Environmental Protection Agency (US EPA) are better equipped to assess environmental hazards and develop plans of action.
  - Private company Blue Origin benefit with knowledge of ice sample locations.
  - Students are provided the opportunity to design CubeSat missions to further spacecraft research.
  - This system will help NASA send astronauts to the Moon by 2024 to prepare for their first Mars mission (Blumberg).
- The key internal stakeholders and their needs are:
  - Astro Chariot - To win the NASA contract we are proposing a design and the surrounding program for a launch vehicle to complete VCLS mission objectives.
  - NASA Stockholders - Stockholders want to increase stock values and have long-term dividends

7

7

1.2 Program Goals

- Primary Customer Goals are:
  - Overall Goal: Design, develop, and construct a dedicated CubeSat launch platform to bring a multitude of CubeSats into orbit at once
  - Supporting Goals:
    - 1 Develop commercial market for NASA/KSC
    - 2 Continue the CubeSat Launch Initiative to further research at a low cost
- Primary Company Goals are:
  - Overall Goal: Win the NASA/KSC VCLS contract, build a strong reputation for the company, and generate profits totaling 2% of the projected $2 billion lifecycle cost
  - Supporting Goals:
    - 1 Develop technologies to enhance the feasibility of small launch vehicles to orbit
    - 2 Develop a lightweight deployment mechanism for very small satellites

Make a breakthrough in the market for small payload to orbit vehicles by developing practical, mass-efficient technologies.

8

8

1.3 Program Objectives

Customer Objectives	Our Company's Objectives
1: Launch multiple payloads of CubeSats in LEO and 2 constellations of CubeSats into LEO in an SSO	1: Win the VCLS Demo 2 Contract
2: Use dedicated launch service to accelerate with NASA's CubeSat Launch Initiative	2: Demonstrate launch service capability to increase chances of winning future launch service contracts
3: Accelerate NASA educational initiative through student-led spacecraft research	3: Apply Program Manage Plan (PMP) Risk management to minimize risk
4: Select supplier for VCLS that can meet the scheduling, manufacturing, and mission constraints	4: Use this contract as an opportunity to develop and apply innovative technological concepts to further stand out in the market
5: Set up CubeSat Constellation for accurately acquiring information at 550km Low Earth Solar Synchronous Orbit	5: Reduce cost of life cycle by at least 10% by reducing maintenance and manufacturing costs

The primary company objective is to win the VCLS Contract. The primary customer objective is launch CubeSat payload reliably.

9

9

1.4a-1 System Level Requirements

RFP Pg #	Type Ref #	WBS #	FOM	Requirement Statement
2	T1.0-1	0.0	No	A single launch system must be able to complete both Mission 1 and Mission 2 in the VCLS RFP
2	T2.0-1	0.0	No	The system must have the payload capacity for a 30 kg payload for Mission 1
2	T2.0-2	0.0	No	The system must reach a minimum orbit of 500 km and deliver the payload for Mission 1
2	T2.0-3	0.0	No	The system must achieve an inclination of 40-60 degrees for Mission 1
3	T2.0-4	0.0	Yes	The system must carry a 75 kg payload and a 20 kg payload for Mission 2
3	T2.0-5	0.0	Yes	The system must reach a minimum orbit of 550 km sun-synchronous orbit and deliver the 75 kg payload for Mission 2
3	T2.0-6	0.0	Yes	The system must make a minimum 10-degree plane change with a 20 kg payload for Mission 2

The system must deliver a total payload of 30kg to 500 km for Mission 1 and 95 kg to 550 km SSO for Mission 2.

10

10

1.4a-2 System Level Requirements

RFP Pg #	Type Ref #	WBS #	FOM	Requirement Statement
5	T3.0-1	0.0	No	The system must launch from Vandenberg and Kennedy Space Station
3	T4.0-1	0.0	No	The system must be able to carry and deploy CubeSat payload safely for both Mission 1 and Mission 2
3	T1.1-1	1.1	Yes	The system must have a reliability of 1 in 2000 for the success of each mission
5	C1.0-1	2.2	No	The system must abide by adequate price competition as prescribed under FAR15.403-1(C)
3	C2.0-1	2.2	Yes	The system must have a cost per payload to orbit of $22,000 per kg
3	C2.0-2	2.2	Yes	Total program development cost must not exceed $2 billion

The cost per launch and cost per kg of payload to orbit must be less than or equal to current small payload to orbit launch vehicle.

11

11

1.4a-2 System Level Requirements

RFP Pg #	Type Ref #	WBS #	FOM	Requirement Statement
4	P1.0-1	2.1	Yes	The system must be ready for the launch date in the year 2027
4	P2.0-1	2.1	No	The team will conduct periodic design reviews on dates that are TBP
4	P3.0-1	2.1	No	The team will create appropriate documents allowing for the Customer to easily follow the Contractor's work and progress
4	P6.0-1	6.0	Yes	Maintenance cost will 15% lower than the competitor at 12,000,000$/year

The cost per launch and cost per kg of payload to orbit must be less than or equal to current small payload to orbit launch vehicle.

12

12

1.4b-1 Derived Requirements

Req Ref #	WBS #	FOM	Requirement Statement
T4.1	6.1	No	The payload release system must have CubeSat dispensers that will allow for safe release of the satellite configuration within 2 seconds of reaching 10 ft of the target altitude.
T4.2	6.1	No	The system must accommodate the Government's defined combination of CubeSats including 1U, 3U, 6U, 12U and interface features (i.e. rails vs. tabs) that meets the total payload mass required for each mission.
T4.3	6.3	Yes	Mission One and Mission Two shall accommodate at least 12 and 21 CubeSat spacecraft, respectively.
T4.4	4.3	No	The system must recognize the time that the final orbit is achieved and signal the deployment release mechanism accordingly.
T2.1	4.2	No	The system must establish and hold the nominal separation attitude within 0.1 deg tolerance prior to each separation event.

The final stage of the vehicle must house the avionics that releases the fairing and recognizes when the final orbit is achieved to deploy the CubeSats on time.

13

13

1.4b-2 Derived Requirements

Req Ref #	WBS #	FOM	Requirement Statement
T2.2	4.3	No	The system must disable the launch vehicle's reaction control system (RCS) within one second prior to each separation event and remain disabled while the launch vehicle sends redundant separation initiation signals to release each satellite.
T2.3	4.1	No	The system must have a function such that following spacecraft separation, the launch vehicle hardware shall not collide with the spacecraft.
T2.4	4.1	No	The system must have a function such that the spacecraft separation events will be timed and directed to avoid near field collision with any of the other spacecraft deployed from the launch vehicle.
T2.5	4.0	No	The system must have sufficient flight instrumentation to establish that the vehicle launch environments meet the requirements of the ICD (CDRL VCLS 2-2).

The launch vehicle shall have control systems to monitor the trajectory and orientation to orbit as well as obtaining the rotation and orientation for proper payload deployment.

14

14

1.4b-3 Derived Requirements

Req Ref #	WBS #	FOM	Requirement Statement
T2.6	3.1	Yes	The system must provide a Δv of approximately 10 km/s for Mission 1 and 11.3 km/s for Mission 2.
T3.1	3.2	Yes	The system must be able to carry adequate amount of fuel to complete the missions. This includes
T3.2	6.1	Yes	The system must have a payload fairing that is able to house the required number of Cube-Sats.
T2.7	3.1	No	The system must have reaction control systems to maneuver in orbit.
T3.3	2.2	No	The interfaces of the system must be compatible with the Vandenberg Launch Facility, and thus the system must be no bigger than 233 ft in length.
T2.8	6.3	No	The system must be uncrewed and will operate remotely or autonomously .
P3.1	6.1	No	The system must provide appropriate fit check dispensers for use by the CubeSat developers at their integration site.

Both missions will be uncrewed and the payload fairing size will be determined by average CubeSat density and arrangement.

15

15

1.4b-4 Derived Requirements

Req Ref #	WBS #	FOM	Requirement Statement
P2.1	1.2	No	The design must be able to meet NASA requirements for MCRs by date that is TBP.
P2.2	1.2	No	The design must be able to meet NASA requirements for SRRs by date that is TBP.
P2.3	1.2	No	The design must be able to meet NASA requirements for CoDRs by date that is TBP.
P2.4	1.2	No	The design must be able to meet NASA requirements for PDRs by date that is TBP.
P3.2	2.2	No	The design must have design drawing.

The program must address each requirement set forth by NASA and deliver a mission-enabling system by a TBP date to be eligible for contract.

16

16

2.1a.1-1 Launch Vehicle: Program Milestones △ and Task Statements for **Conceptual** Design for ARO 4711 Fall & 4712 Spring Semester

ARO4711L-4721L *Launch Vehicle* Design Tasks,

Progress Review Requirements

You may alter or add to the tasks to suit your own design project's needs.

Fall Semester Design Tasks

Task # System Requirements Review (SRR):

SRR.1 *System Level Requirements Definition Document*

△ **SRR.2 Plan and conduct SDR : Week # 6 Date: 3/03/21**

Task # Minimum due: 1st progress review:

1. Mission profile/analysis/ConOps: Trajectory (graphics), staging/separation events, times of flight; all required *C3* or Δv. Mission profile trades & selection.

1.Preliminary propulsion system requirements. System trades (liquid vs. solid) & selection
2. Trajectory simulations
3. Preliminary mass estimate based on payload and design trades (%Δv split will depend on selected I_{sp}s) (GLOM = 6500 kg)

△ 5. Specification of two design configurations (re-usable & non-re-usable booster) to be pursued.

6. **Plan and conduct OPR1 : Week # 14 Date: 11/25/20**

Spring Semester Design Tasks

Task # Minimum due for EACH of the two designs, for 2nd progress review:

1. Propellant budget calculations.
2. CAD drawings showing internal layout including tanks, engines, interstages, separations, Payload accommodations,
3. Mass & inertia calculations. (GLOM = 7300 kg)

△ 4.Simulation of launch using numerical methods, mission feasibility, wind loads estimation

5. **Plan and conduct OPR2 : Week # 3 Date: 2/08/21**

Task # Minimum due for EACH of the two designs, for 3rd progress review:

1. Estimation of shear & bending moments due to ground & wind loads
2. Calculation of internal loads & stresses for ground & wind loads
3. Attitude control system description; estimation of stability of system.
4. Fault analysis; redundancy assessment

△ 5. Preliminary cost estimation. (~$2 billion USD)

6.Manufacturing, maintenance. For reusable system: "–ilities", EOM disposal.

7. **Plan and conduct OPR3 : Week # 6 Date: 3/01/21**

Task # Due for SDR: above plus

SDR.1 Dimensioned 3-view, mass buildup, internal arrangement (propellants, major subsystems), separation planes, payload.

△ SDR.2 Mission diagram (orbits, trajectories, etc.) SDR.3 Team member photo sheet with names **SDR.4 Plan and conduct SDR**

Task # Due for SDR: Outside Review Evaluation (ORE):

ORE.1 Address judges' comments after SDR. Specify down-selected design for rest of year. : Week # 6 Date: 3/03/21

Design review highlights of Fall 2020 include the first progress review OPR 1 during Week 14 of Fall semester.

17

17

2.1a.1-2 Launch Vehicle: Program Milestones △ and Task Statements for **Preliminary** Design

Spring Semester Design Tasks

You may alter or add to the tasks to suit your own design project's needs.

Task # Minimum due: 4th progress review:

4.1 Mission profile/analysis/ConOps: describe and explain reasons for preferred and a backup trajectory (graphics); all required *C3* or ΔV.

4.2 Final propulsion system selection

4.3 Detailed mass breakdown including propellants

4.4 Launch vehicle selection

△ **4.5 Plan and conduct OPR4 : Week # 9 Date: 03/24/21**

Task # Minimum due: 5th progress review:

5.1 CAD drawings showing internal layout including tanks, engines, interstages, separations, payload accommodations

5.2 Payload and bus layout, FOV plots

5.3 Mass & inertia calculations

5.4 Detailed environmental disturbances

5.5 Heating and thermal analysis

5.6 Structures: quasi-static launch loads stress analysis

5.7 Refined attitude control system

5.8 Telecommunications: hardware description including antennas, emitters. Ground station(s): type needed, scheduling. FTS description

△ **5.9 Plan and conduct OPR5 : Week # 12 Date: 04/19/21**

Task # Due for PDR: above plus

PDR.1 Dimensioned 3-view, final CAD drawings of internal layout (propellants, major subsystems), separation planes.

PDR.2 Structures: revised stress analysis, ground & flight

PDR.3 Command and Subsystems, flight modes, software design, abort sequences

PDR.4 Determine bending moments, shear, stresses for fins and fuselage, fault analysis, redundancy assessment

PDR.5 Detail Cost Analysis

PDR.6 Acoustics and Environmental: Internal and external noise footprints emissions, EOM Disposal

PDR.7 Manufacturing and Maintenance facilities

PDR.8 Team member photo sheet with names

PDR.9 Plan and conduct PDR : Week # 12

△ **Date: 04/21/21**

Design review highlights of Spring 2020 include OPR 4 in Week 9, OPR 5 in Week 12, and PDR in Week 12 of the semester.

18

18

2.1b-1 Integrated Plan Task Statements Conceptual Design

SOW # & Title	WBS# Disciplines Responsible to meet the SOW#	PE Prog. Event from the IMS	SA Significant Accomplishment to meet PE	AC Accomplishment criteria to meet SA	Task #	Task description that produce the Work Products	Work Product that satisfies the SOW #
0.0.1 Program Manage-ment	**1.0** Program Management	**Progra m An-nounce -ment**	**0.0.1-1** PMP followed and updated during Conc. Design **0.0.1-2** EVMS presented at reviews	**0.0.1-1** Implement PMP **0.0.1-2** Update PMP **0.0.1-3** SPI & CPI=1.0 or better	0.0.0.1 0.0.1.2	Conduct Program Management Plan to meet the Program Needs, Goals, Objectives, and Requirements. Utilize the project Org charts, Resource Loaded Schedules, Risk Analysis. Weekly tracking of Earned Value Management schedule % complete, SPI & CPI for corrective actions to maintain I =1.0	**0.0.1-1** Create organization chart and responsibilities **0.0.1-2** SPI/CPI Reports to instructor at all reviews
0.1 Prepare and conduct system require-ments review	**2.0** Systems Engineering	*SRR*	**0.1-1** Systems requirements defined **0.1-2** Systems requirements presented (SDR)	**0.1-1** PgM approves SRR **0.1-2** Customer approves SRR	0.1.1 0.1.2	Write System Level Requirements Definition Document: Define system level mission, architecture, and programmatic requirements defined in RFP # .XXX.X Present Requirements Document at SRR in PPt.	**0.1-1** Requirements Document in Power Point **0.1-2** Oral SRR Briefing
1.1 Design Mission Architecture	**2.0** Systems Engineering	*OPR#* 1	**1.1** Mission Architectures Defined	**1.1-1** Configuration drawings **1.1-2** Mission ConOps outlined	1.1.1 1.1.2	Configuration Drawings Mission profile/analysis/ConOps:	**1.1-2** Mission Profile ConOps defined for each architecture
1.2 Constraint Diagram	**2.0** Systems Engineering		**1.2** Architecture Down-Select and Feasibility Trade Study	**1.2** Constraint diagrams of mission profiles constructed	1.2.1 1.2.2	Define relevant mission profile attributes Construct Constraint diagrams for mission profiles	**1.2-2** Mission profile/ConOps Constraint Diagrams

The program management tasks include conducting the Program Management Plan (PMP) to meet program needs, goals, objectives, and requirements.

19

19

2.1b-2 Integrated Plan Task Statements Conceptual Design

SOW # & Title	WBS# *Disciplines* Responsi-ble to meet the SOW#	*PE Prog. Event from the IMS*	*SA Significant Accomplish-ment to meet PE*	*AC Accomplishment criteria to meet SA*	*Task #*	*Task description that produce the Work Products*	*Work Product that satisfies the SOW #*
1.3 Design Payload Fairing	**6.0** Payload	***OPR #*** **1**	**1.3** Rough design of all payload accommodations	**1.3** Payload harness and attach fitting architectures defined	1.3.1 1.3.2	Define preliminary payload accommodation requirements Define and select the payload harness and attach fitting architectures	**1.3-1** Payload arrangement and fairing volume defined **1.3-2** Payload fairing architecture
1.4 . Propulsion Selection	**3.0** Propulsion		**1.4** Propulsion System Definition	**1.4** Engine architecture characteristics defined	1.4.1 1.4.2	Define preliminary propulsion system requirements Define and select propulsion system architectures	**1.4-2** Selected Propulsion System
1.5 Trajectory Simulations	**4.0** Avionics		**1.5** Record Trajectory Sim data for performance analysis/ candidate selection	**1.5-1** ΔV required **1.5.2** Sensor characteristics **1.5-2** Trajectory sim. data collection **1.5-2** Trade study construction	1.5.1 1.5.2 1.5.3 1.5.4	Determine required ΔV List of sensors' attributes: mass, power, data transmission rate Simulate trajectories for all candidate architectures based on their mission profiles and propulsion system Trajectory trade studies, pork-chop plots, i.e. *C3* vs. transit time & arrival velocity	**1.5-3** Trajectory Simulation Data **1.5-4** Trajectory Charts and FOMS

Payload requirements shall be defined and developed into architectures for the payload harness and attach fitting by the end of November 2020.

20

20

2.1b-3 Integrated Plan Task Statements Conceptual Design

SOW# & Title	WBS# Disciplines Respon-sible to meet the SOW#	PE Prog. Event from the IMS	SA Significant Ac-complishment to meet PE	AC Accomplishment criteria to meet SA	Task #	Task description that produce the Work Products	Work Product that satisfies the SOW#
1.6 Detailed Feasibility Analysis	**2.0** Systems Engineer-ing	***OPR #* 1**	**1.6** Detailed comparison of FOMS	**1.6** List key attributes of each architecture and their cons	**1.6.1**	Conduct trade study based on mission profiles and trajectory simulations to down-select from 3 to 2 architectures: re-usable and non-reusable	**1.6-1** Down-Selected 2 Architectures
1.7 Conduct OPR #1	**1.0** Program Manage-ment		**1.7** Oral & PPT. Pres. Complete	**1.7** OPR docs and present. approved by Prof.	**1.7.1** **1.7.2**	PPT & Rehearsal OPR#1 Briefing	**1.7-1** OPR#1 Summary PPT. **1.7-2** Oral briefing
2.1 Perform CAD Models	**5.0** Frame	***OPR #* 2**	**2.1** CAD Drawings complete	**2.1-1** Four Drawings submit-ted **2.1-2** Approved by Prof.	**2.1.1** **2.1.2**	**2.1-1** Drawings/sketches of vehicle (with separations), bus layout, mass & inertias. **2.1-2** CAD Modeling	**2.1-1** Updated CAD Drawings of system layout & mass
2.2 Perform thermal design	**6.0** Payload, **3.0** Propul-sion		**2.2** Temperature Boundary and Environmental Impact Assessment	**2.2-1** Define subsystem max operating temperature	**2.2.1**	Define thermal limits of avionics, propellant tanks, and all structures subject to extreme temperatures	**2.2-1** Doc. With subsystem operating temp. ranges **2.2-2** Aerodynamics heating Calculations

Sketches of the launch vehicle's internal layout will be drawn and translated into CAD drawings by the beginning of February 2021.

21

21

2.1b-4 Integrated Plan Task Statements Conceptual Design

SOW# & Title	WBS# *Disci-plines* Respon-sible to meet the SOW#	*PE Prog. Event from the IMS*	*SA Significant Ac-complish-ment to meet PE*	*AC Accomplish-ment criteria to meet SA*	*Task #*	*Task description that produce the Work Products*	*Work Product that satisfies the SOW#*
2.3 Propellant Budget Calculation	3.0 Propulsion	***OPR #* 2**	**2.3** Determine engine efficiency, cost of mission	**2.3.1** Propellant Performance and Cost trade study	**2.3.1**	Conduct trade study on various propellant combinations regarding their performance and cost	**2.3-1** Fuel Trade Study
2.4 Mass and Inertia Calculations	**5.0** Frame		**2.4** Projected Mass and Inertia Properties of vehicle body components	**2.4-1** Within customer specifications	**2.4.1**	Calculate projected mass and inertia properties of each section of the vehicle (engine bay, interstage, bulkhead, etc.)	**2.4-1** List of mas and inertia properties
2.5 Trajectory Simulations	**4.0** Avionics		**2.5** Completed Simulation of Launch	**2.5-1** Successful launch simulated	**2.5.1**	Simulate launch using numerical methods	**2.5-1** Development of 6DOF model to simulate launch
2.6 Mission Feasibility Study	**2.0** Systems Engineering		**2.6** Creation of Successful Mission	**2.6-1** Customer approves of final mission	**2.6.1**	Conduct risk analysis and mitigation for down-selected mission profile/ConOps	**2.6-1** Doc. Exploring potential shortcomings in different missions
2.7 Conduct OPR #2	**1.0** Program Management		**2.7-1** CAD Models Completed **5.Oral & PPt. pres. Complete**	**2.7-1** OPR docs and present. approved by Prof.	**2.7.1**	Plan and Conduct **OPR#2**	**2.7-1** OPR#2 Summary PPT. **2.7-2** Oral briefing

Risk statements and mitigations will be developed for the down-selected mission profiles by the beginning of February 2021.

22

22

2.1b-5 Integrated Plan Task Statements Conceptual Design

SOW #	WBS# Disci-plines Respon-sible to meet the SOW#	PE Prog. Event from the IMS	SA Significant Accomplish-ment to meet PE	AC Accomplishment criteria to meet SA	Task #	Task description that produce the Work Products	Work Product that satisfies the SOW #
3.1 Stress Analysis	**5.0** Frame	**OPR # 3**	**3.1** Vehicle Structure Design withstands loads in flight	**3.1-1** Estimation of Ground and Wind Loads **3.1-2** Internal Loads and Stresses Calculations	**3.1-1** **3.1-2**	Calculate Shear, Bending, and Axial loads of the vehicle on the ground and in flight. Calculate internal stresses and loads for skin buckling, bulkheads, propellant tanks, engine mount, etc.	Report of max shear and bending moments, loads, and stresses for all major components
3.2 Control System Design	**4.0** Avionics		**3.2** Control System Architectures	**3.2-1** No major impact on mission	**3.2**	Design and evaluate various attitude control systems	Doc describing potential control systems
3.3 Fault Analysis	**2.0** System Engineering		**3.3** Risks and Faults Identified	**3.3-1** Management Approval	**3.3**	Identify potential faults and risks as well as how to mitigate/eliminate said faults/risks	Doc. Of Risk Waterfall
3.4 Conduct OPR #3	**1.0** Program Management		**3.4** Structural Analysis Completed **3.4-2** Oral &PPt. Pres. Complete	**3.4-1** OPR docs and present. approved by Prof.	**3.4**	Plan and Conduct **OPR#3**	2.6-1 OPR#3 Summary PPT. 2.6-2 Oral briefing

The external loads and internal stresses of major vehicle components will be calculated by the beginning of March 2021 to ensure safe structural tolerances.

23

23

2.1b-6 Integrated Plan Task Statements Conceptual Design

SOW #	WBS# Disci-plines Respon-sible to meet the SOW#	PE Prog. Event from the IMS	SA Significant Accomplish-ment to meet PE	AC Accomplishment criteria to meet SA	Task #	Task description that produce the Work Products	Work Product that satisfies the SOW #
CoDR 1 Dimensioned 3-view	**2.0** Sys. Engineer-ing	**CoDR**	**CoDR 1** - 3-View Diagram Completed	**0.1** Customer approval	**0.1**	Create 3-view drawing for customer evaluation including dimensions of major sections	**0.1** Drawing of proposed architecture complete with all subsystems
CoDR 2 Mission Diagram	**2.0** Systems Engineer-ing		**CoDR 2** - Drawing of mission with all phases submitted	**0.2** Customer approval	**0.2**	Illustrate various phases of planned mission	**0.2** Drawing of mission from beginning to end
CoDR 3 Team Member Photo Sheet	**2.0** Systems Engineer-ing		**CoDR 3** – Team member information documented	**0.3** Customer approval	**0.3**	Document team member contact information and background	**0.3** Team member documentation
CoDR 4 Prepare and Conduct CoDR/SDR	**1.0** Program Manage-ment		**CoDR 4** - Req. doc submitted and CoDR presented	**0.4.1** Req. Doc approved by management and customer **0.4.2** - CoDR approved by management and customer	**0.4-1** **0.4-2**	Write System Level Requirements Definition Document :Define system level mission, architecture,and programmatic requirements defined in RFP Present Requirements Document at SDR in PPt.	**0.4-1** System level requirement definition **0.4-2** Oral SDR Briefing

Preparing for the CoDR presentation in early March entails documentation of the 3-view drawing of the vehicle, the mission diagram, and team member photo/information sheet.

24

24

2.2-1 Contractual Statement of Work for Conceptual Design

SOW #	Req. Ref. #	Related Tasks	Statement of Work Statements
0.0.1	P2.0	0.0.0.1 0.0.1.2	The contractor shall create and present a Program Management Plan to meet the Program Needs, Goals, Objectives, and Requirements as well as track the progress and update the Customer as needed.
0.1	P3.0	0.1.1 0.1.2	The contractor shall write and present System Level Requirements Definition Document during SRR in order to define system level mission, architecture, and programmatic requirements defined in the RFP.
1.1	P3.0	1.1.1 1.1.2	The Contractor shall generate configuration drawings and outline the mission profile.
1.2	T2.0, P3.0	1.2.1 1.2.2	The Contractor shall construct constraint diagrams of the various mission profiles generated.
1.3	T4.0, P3.0	1.3.1 1.3.2	The Contractor shall define and express preliminary payload accommodation requirements along with initial fairing architectures.
1.4	T2.0, P3.0	1.4.1 1.4.2	The Contractor shall define and express preliminary propulsion requirements along with initial propulsion architectures.

The contractor shall create and present the Program Management Plan, System Level Requirements, configuration drawings, and any other preliminary accommodations to meet the customer demands.

25

25

2.2-2 Contractual Statement of Work for Conceptual Design

SOW #	Req. Ref. #	Related Tasks	Statement of Work Statements
1.5	T2.0	1.5.1 1.5.2 1.5.3 1.5.4	The Contractor shall determine and simulate a family of trajectories based on the candidate architectures' mission profiles and propulsion system.
1.6	C2.0	1.6.1	The Contractor shall down-select to 2 architectures which will differ based on whether they are reusable or non-reuseable.
2.1	P3.0	2.1.1 2.1.2	The Contractor shall create CAD models and sketches of the whole vehicle
2.2	T2.0	2.2.1	The Contractor shall define and document the thermal limits of the vehicle in order to further the design of the structure and avionics of the vehicle.
2.3	T2.0, C2.0	**2.3.1**	The Contractor shall conduct a trade study on various propellants in order to find the best performance at the most affordable price.
2.4	T2.0, T3.0, P3.0	**2.4.1**	The Contractor shall calculate and document the mass and inertia properties of the entire launch vehicle.

The contractor shall define trajectories based on the candidate architectures and down-select to 2 architectures, a reusable one and a disposable one.

26

26

2.2-3 Contractual Statement of Work for Conceptual Design

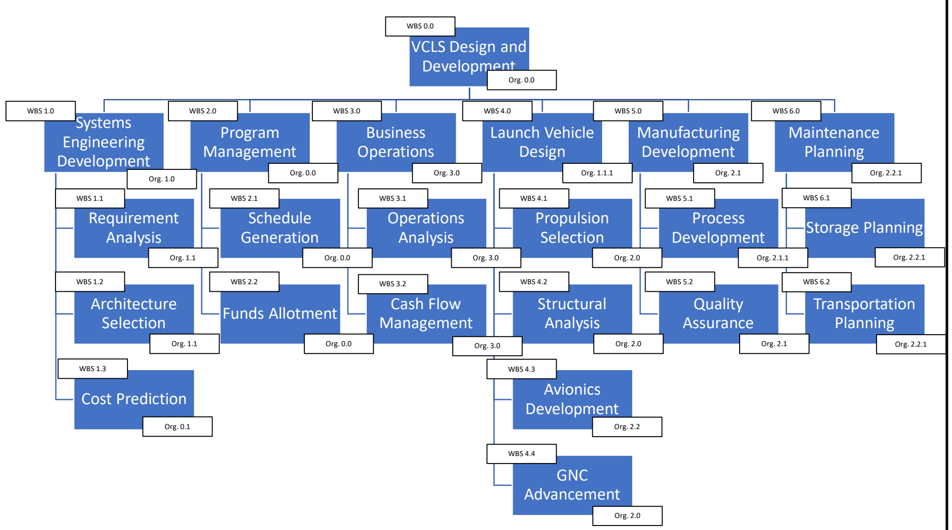
SOW #	Req. Ref. #	Related Tasks	Statement of Work Statements
2.5	T2.0	**2.5.1**	The Contractor shall create a more robust 6 DOF simulation of the launch.
2.6	T2.0, P2.0	**2.6.1**	The Contractor shall identify and mitigate risks for the customer-approved missions.
3.1	T2.0, P3.0	**3.1-1** **3.1-2**	The Contractor shall calculate, and document all expected loads and stress applied to the vehicle both at takeoff and during ascent.
3.2	T2.0	**3.2**	The Contractor shall design and evaluate various attitude control systems.
3.3	T2.0, P2.0	**3.3**	The Contractor shall determine current faults and risks with the mission and launch vehicle and will outline mitigation steps in order to avoid future complications.
1.7, 2.7, 3.4	P2.0	1.7.1 1.7.2	The Contractor shall plan and conduct multiple OPRs following the completion of major program milestones

The contractor shall fulfill all obligations required in the RFP.

27

27

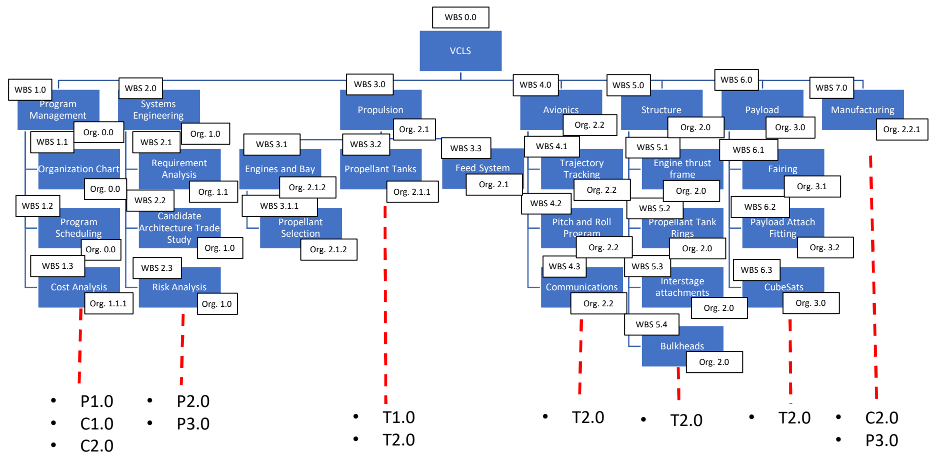
2.3a Functional Work Breakdown Structure



The VCLS System will be planned and executed according to the plan developed in WBS 1.0 Systems Engineering Development. **28**

28

2.3b Product Type Work Breakdown Structure



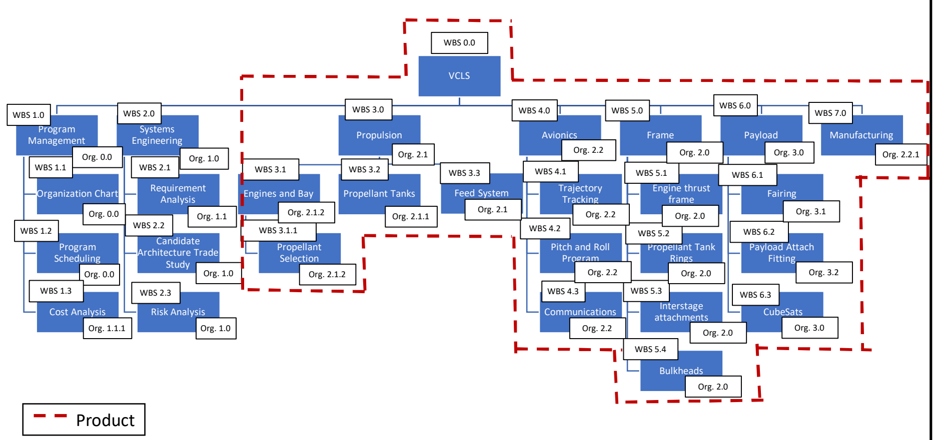
Requirements #s

The General Product Work Breakdown Structure addresses all hardware and software of the launch vehicle necessary for mission success.

29

29

2.3c Product Work Breakdown Structure with Product Tree – General

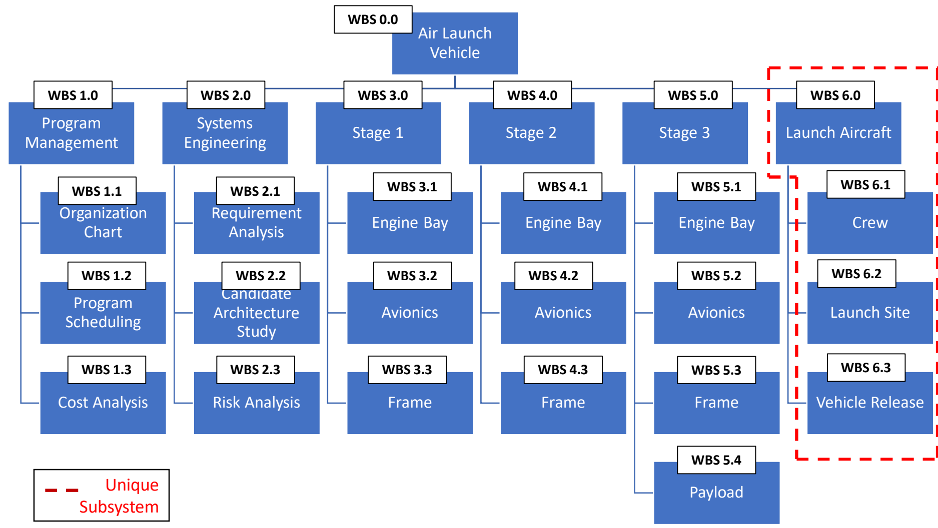


The Product WBS addresses components of the system necessary for the mission's success.

30

30

2.3c-1 Product Work Breakdown Structure of Architecture 1

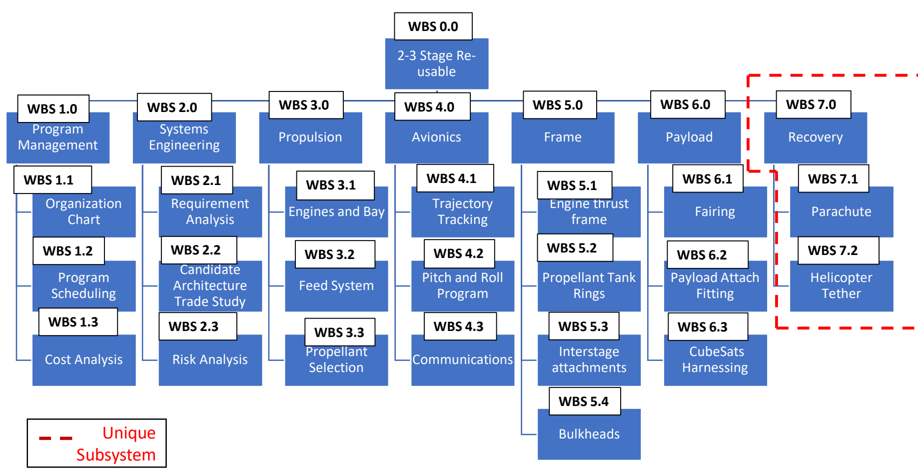


The product work breakdown structure of Architecture 1 includes a launch aircraft which is the carrier of the air launch vehicle.

31

31

2.3c-2 Product Work Breakdown Structure of Architecture 2

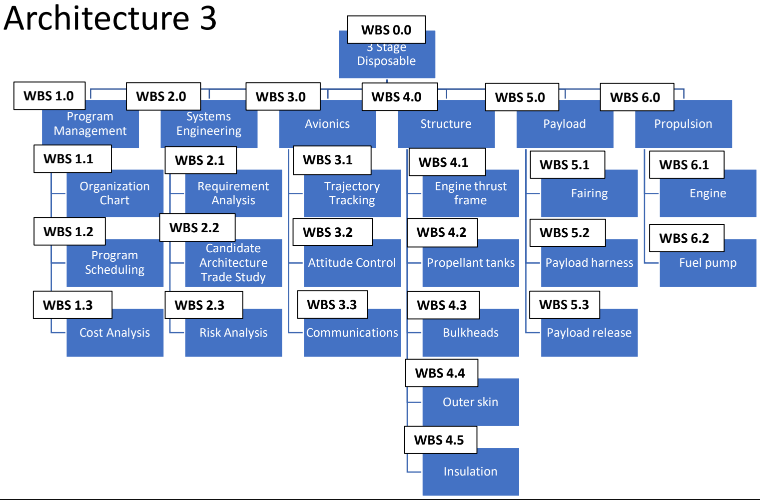


Architecture 2's product work breakdown structure includes a recovery system in addition to all traditional systems required for mission success.

32

32

2.3c-3 Product Work Breakdown Structure of Architecture 3



Architecture 3's product work breakdown structure does not have a recovery system or a special launch since it is a traditional and expendable launch vehicle.

33

33

2.3d-1 Project SOW Cross Reference Matrix

SOW #	REQ #	WBS #	ORG #
0.0.1	P2.0	2.0	1.0
0.1	P3.0	1.0	0.0
1.1	P3.0	1.0	0.0
1.2	T2.0, P3.0	1.0	0.0
1.3	T4.0, P3.0	6.0	3.0
1.4	T2.0, P3.0	3.0	2.1
1.5	T2.0	4.0	2.2
1.6	C2.0	1.0	0.0
1.7	P2.0	2.0	1.0
2.1	P3.0	5.0	2.0

34

34

2.3d-2 Project SOW Cross Reference Matrix

SOW #	REQ #	WBS #	ORG #
2.2	T2.0	3.0, 6.0	2.1, 3.0
2.3	T2.0, C2.0	3.0	2.1
2.4	T2.0, T3.0, P3.0	5.0	2.0
2.5	T2.0	4.0	2.2
2.6	T2.0, P2.0	1.0	0.0
2.7	P2.0	2.0	1.0
3.1	T2.0, P3.0	5.0	2.0
3.2	T2.0	4.0	2.2
3.3	T2.0, P2.0	1.0	0.0
3.4	P2.0	2.0	1.0

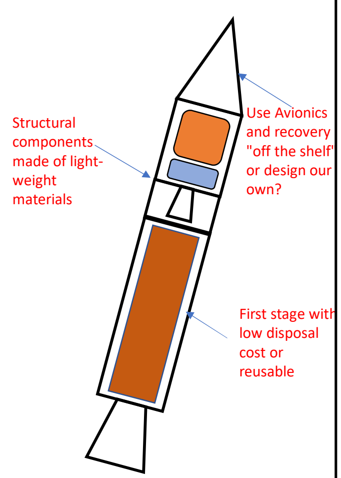
Statement of Work 2.3 involves conducting a trade study for propellant selection, which relates to Propulsion WBS 3.0, and Propulsion Lead 2.1, Ms. Sheinkman.

35

35

3.0a-Technical Approach and Processes System Concept

- It is better to take a pre-existing model and improve upon it.
  - Previous models include Electron Rocket by Rocket Lab
  - Pegasus XL & Stargazer by Northrop Grumman
  - New innovations include: lower operation cost than the existing models
  - Reliable CubeSat delivery system
  - Reusable Rocket Design
- Trade studies for:
  - Narrowing down design concepts
  - Deciding to design our own avionics and recovery subsystems or to purchase existing technologies
- New Possible Technologies:
  - Single column for main and second stage still being matured by SpaceX
  - Helicopter recovery still being matured by Rocket Lab
- Design and Validation Processes
  - CAD modeling & FEA Analysis, CFD Analysis & Wind Tunnel Testing, Control-Surface Hydraulic-Actuation Test, Tank Pressure test, Engine Fire Test, Guidance & Navigation/Trajectory Simulation, Vibration Test



The system will be based on previous architectures such as Electron Rocket and Pegasus XL while incorporating new recovery technologies.

36

36

3.0b-1 Technical Approach and Processes Mission Operations Concept

- Launch Locations are based on locations used for similar SSO missions
- Possible Launch Locations:
  - Vandenberg, CA
  - Kodiak, AK
  - Cape Canaveral, FL
  - Launch Operation Concepts:
  - Aircraft Launch similar to Pegasus
  - Sea Launch for polar orbit

See sketch on next slide

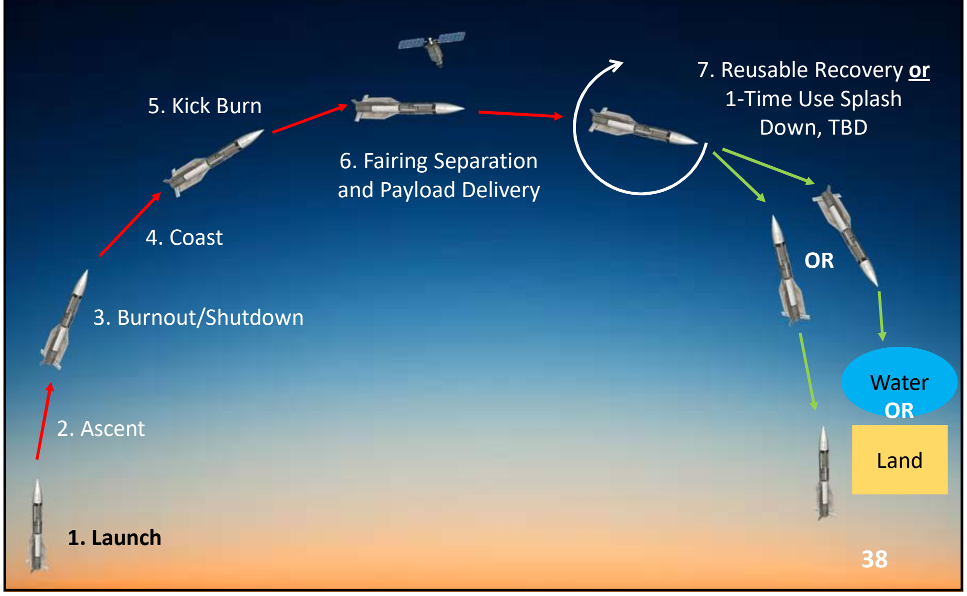
- Trajectory Operation Concepts:
  - Thrust vectoring and pitch and roll program from launch
  - Trade study to determine optimal staging
- New Technologies:
  - Mag-pull launches
  - Propulsive or helicopter recovery
- Mission Design & Validation methods:
  - Trajectory simulations, Six-DOF simulations

Potential launch locations depend on mission requirements, ease of transport, feasible manufacturing, and assembly locations.

37

37

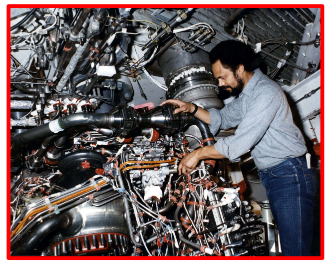
3.0b-2 Technical Approach and Processes Mission Operations Concept



38

38

3.0c-Technical Approach and Processes Maintenance Concepts



- Maintenance is more important for reusable launch vehicles than disposable launch vehicles
- Maintenance should always begin after each recovery
  - Set a dedicated storage location for launch vehicle until next launch.
  - Have a dedicated maintenance team to ensure launch vehicle will be ready for next launch at storage location.
- New Technologies
  - Helicopter delivery to storage facility for maintenance directly after recovery. Facility would require helicopter access.
  - Further develop maintenance techniques for reusable launch vehicles.

- Maintenance Design & Validation methods:
  - Ground test to ensure launch system is still able to function
  - Component testing during re-assembly
  - Fatigue analysis, stiffness testing, structural analysis to ensure components are still usable and will be replaced if not.

Reusable launch vehicles are a modern design concept that require more fine-tuned maintenance techniques than disposable ones.

39

39

3.0d-Technical Approach and Processes Manufacturing Concepts

- Possible Manufacturing Locations:
  - Ideally, near possible launch sites
  - Kennedy Space Center
  - Trade Study Horizontal vs Vertical assembly facilities
  - Facility must 'clean room' for assembly of components that need to be 'oxygen clean'.
- Possible Manufacturers:
  - Northrop Grumman
  - Lockheed Martin
  - Start own manufacturing facility

- New Technologies:
  - Composites structure fabrication
  - Additive Manufacturing – Relativity Space
- Manufacturing Design & Validation methods
  - Post assembly vibration testing , component inspections, quality assurance management
  - Video-scope inspection with ultraviolet dye

Manufacturing concepts depend on the launch site, assembly facility location, available certified manufacturers, and the ability to incorporate new technologies.

40

40

3.0e Technical Approach and Processes Disposal Concepts

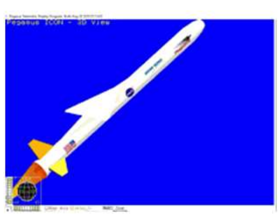
- Reusable launch vehicles require less frequent disposal because of the increased number of missions they are used for
- Second stage is non-reusable and will be designed to burn up upon reentry
  - Enter subterranean-Earth trajectory for remnant disposal
- When launch vehicle is no longer economically feasible to reuse, it will be disposed similarly to SpaceX techniques
  - Transfer launch vehicle main stage to refurbishing facility
  - Detonate vehicle at the end of the life cycle if refurbishment costs outweigh unit production cost
- New Technologies
  - Investigate ecological hazards of disposing carbon fiber
- Disposal Design & Validation methods
  - Return on investment (ROI) analysis
  - Analysis on maintenance cost against manufacturing cost

At the end of a reusable launch vehicle program, disposal techniques are similar to what is currently used by companies such as SpaceX.

41

41

3.1a Technical Approach Summary for VCLS System: 3 Architectures

Air Launch 3 Stage Reusable Launch Vehicle	Series 2-3 Stage Reusable Launch Vehicle	3 Stage Traditional Launch Vehicle
Key Attributes: 1. Two Stages 2. Air Launch 3. LOX-Ethanol 4. Low Risk Technology Readiness Level	**Key Attributes:** 1. 2-3 stage to orbit 2. Medium Risk Technology 3. Liquid propellant 4. Vertical Take-off/Helicopter Recovery	**Key Attributes:** 1. Hydrazine and Solid 2. 3 stage to orbit 3. Low risk technology 4. Vertical Take-off/Expendable
		

The 3 architectures above show possible designs for the RFP, one being an air launch, one being a reusable multi-stage system, and the third being an expendable multi-stage system.

42

42

3.1b-1 Technical Approach Summary for Architecture 1

SLR #	Key System Level Requirements from RFP	Design Driver/Challenge	Design Approach and Key Design Features
0.1	System shall be fully operational and ready to launch by **TBP**	Technology TRL: Medium risk technology requires technology to be finished by launch date	Low Risk Technology Readiness Level: • Technology is already fully developed, therefore launch meeting requirement will be met
1	System capable of launching constellation of CubeSats into 500km, 40-60° inclination.	Minimum Payload Mass: Must deliver 30 kg of payload to orbit with 60° inclination	Key Design Feature: • Rocket is air launched and therefore can meet payload mass requirements • Rocket has propulsive capacity to meet altitude requirement
2	System capable of launching constellation of CubeSats into 550 km SSO with up to 10° plane change between payload deployments.	Minimum Payload Mass: Must deliver 95 kg of payload to orbit ΔV Required: Must meet velocity and thrust requirements to meet orbit	Key Design Feature: • Rocket is air launched and therefore can meet payload mass requirements • Rocket has propulsive capacity to meet altitude requirement

Architecture #1 by having an air launch is more capable of meeting mission requirements by having a high technology readiness level.

43

43

3.1b-2 Architecture 1: Key Design Features, Innovations, and Technologies

Need for System: Dedicated design for small payload delivery to SSO for weather surveillance and communications on a cost-effective, frequent basis.

Key Attributes:

1. 3 stage orbit
2. Air Launch to orbit
3. Wing and tail that provides control

Cons:

- First stage doesn't have a Thrust Vector Control system
- Increased complexity due to requirement of aircraft for launch
- High maintenance cost

Mission 1 will be accomplished through the 2nd stage. Mission 2 will be done through the 3rd stage.

1st stage has a wing and a tail to provide lift and attitude control while in the atmosphere

Architecture #1 is fully capable of meeting mission requirements but suffers from high maintenance costs.

44

44

3.1c-1 Technical Approach Summary for Architecture 2

SLR #	Key System Level Requirements from RFP	Design Driver/Challenge	Design Approach and Key Design Features
0.1	System shall be fully operational and ready to launch by **TBP**	Technology TRL: Medium risk technology requires technology to be finished by launch date	Medium-risk technology and design concepts: • Helicopter recovery of main stage • Electric pump-fed engine • Delicate payload harnessing and deployment method
1	System capable of launching constellation of CubeSats into 500km, 40-60° inclination.	Minimum Payload Mass: Must deliver 30 kg of payload to orbit with 60° inclination	• Main stage falls back to Earth, parachute deployment, and helicopter retrieval • 2nd stage continues to orbit insertion • Main stage uses liquid propellants for reusable tanks and cheap launch costs. • All stages use liquid propellants
2	System capable of launching constellation of CubeSats into 550 km SSO with up to 10° plane change between payload deployments.	Minimum Payload Mass: Must deliver 95 kg of payload to orbit ΔV Required: Must meet velocity and thrust requirements to meet orbit	• Main stage falls back to Earth, parachute deployment, and helicopter retrieval • Liquid propellants for reusable tanks and cheap launch costs. • 2nd stage continues to orbit insertion • Optional 3rd stage for additional maneuverability and payload insertion.

This 2-3 stage architecture utilizes liquid propulsion for all stages and a main stage recovery mission operation via helicopter and parachute.

45

45

3.1c-2 Architecture 2: Key Design Features, Innovations, and Technologies

Need for System: Dedicated design for small payload delivery to SSO for weather surveillance and communications on a cost-effective, frequent basis.

Key Attributes:

1. Two to Three stage to orbit
2. 3D Printed Engines
3. Carbon Fiber Composite
4. Vertical Take-off/Helicopter Recovery

Cons:

- Medium risk technology development of electric pump-fed engines and helicopter recovery of main stage
- Liquid propellants add maintenance procedures and costs such as: storage, retrieval, propellant loading equipment, and engine plumbing cleaning.
- Carbon fiber composite materials pose a higher development cost, but a reusable vehicle will reap its weight-saving benefits over multiple flights.

Key design features include interchangeable 2nd stage, 3D printing of engine components, and utilization of carbon fiber composite manufacturing.

46

46

3.1d-1 Technical Approach Summary for Architecture 3

SLR #	Key System Level Requirements from RFP	Design Driver/Challenge	Design Approach and Key Design Features
0.1	System shall be fully operational and ready to launch by **TBP**	Technology TRL: Low risk technology requires technology to be finished by launch date	Low Risk Technology: • No recovery of parts • Hydrazine engine development • 3 stages increases complexity
1	System capable of launching constellation of CubeSats into 500 km, 40-60° inclination.	Minimum Payload Mass: Must deliver 30 kg of payload to orbit with 60° inclination	• No parallel boosters • First 2 stages fall back to Earth • Tanks are not reusable
2	System capable of launching constellation of CubeSats into 550 km SSO with up to 10° plane change between payload deployments.	Minimum Payload Mass: Must deliver 95 kg of payload to orbit ΔV Required: Must meet velocity and thrust requirements to meet orbit	• No parallel boosters • First 2 stages fall back to Earth • 3 Stages help delta V requirements • Payload insertion provided by 3rd stage • 3rd stage solid fuel provides remaining thrust

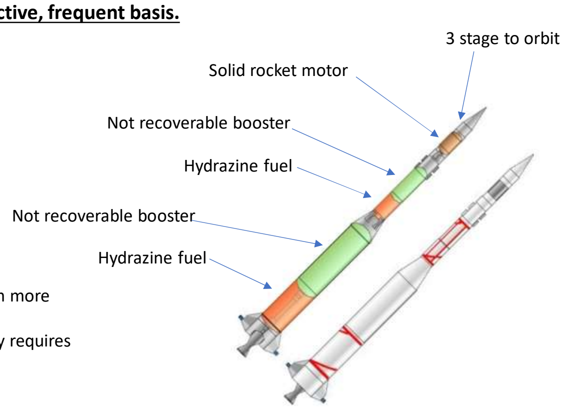
Architecture #3 provides all necessary attributes by having a high TRL level with Hydrazine engines and 3 non-reusable stages but will still reach desired orbit with the payload.

47

3.1d-2 Architecture 3: Key Design Features, Innovations, and Technologies

Need for System: <u>Dedicated design for small payload delivery to SSO for weather surveillance and communications on a cost-effective, frequent basis.</u>

Key Attributes:
- Hydrazine
- 3 Stage to orbit
- Vertical takeoff
- Low risk development



Cons:
- Stages are not reusable making program more expensive
- Vertical launch with horizontal assembly requires technology to lift launch vehicle
- Hydrazine fuel requires special storage

Architecture #3 has a high TRL level and could easily complete the mission, but the rocket is not reusable leading to issues with longevity of system.

48

3.2 Tech Approach: System Level Figures of Merit

FOM No	Description	FOM SLR Requirement Target Value/or characteristic	Import-ance Rank	Weight Factor WF
T1.1-1	Reliability	1/2000	3	2
P1.0-1	Launch Window	Year of 2027	5	1
C2.0-1	Launch Cost	$22,000 per kg payload to orbit	1	3
C2.0-2	Program cost	$80 million	2	3
C6.0-1	Operations cost	$7.8 million per year	4	1

The most important Figures of Merit are Cost per Launch and Cost of the Program while the least important are the Launch Window and Operations Cost.

3.3-1 Architecture Trade Matrix Process

FOM Alt. Archs	T1.1-1 Reliability 1/2000 WF = 2		P1.0-1 Launch Window Jan-Dec 2027 WF = 1		C2.0-1 Launch Cost $22,000/kg WF = 3		Weighted Total
	U	W	U	W	U	W	
Arch 1	1/1750	6	2028	3	$23,000	9	18
	3		3		3		
Arch 2	1/2000	6	2027	3	$17,000	27	36
	3		3		9		
Arch 3	1/3000	18	2025	9	$27,000	3	30
	9		9		1		

The trade matrix suggests that Architecture 2 and 3 are the most likely to meet the important figures of merit and will move forward in the down selection process.

3.3-2 Architecture Trade Matrix Process

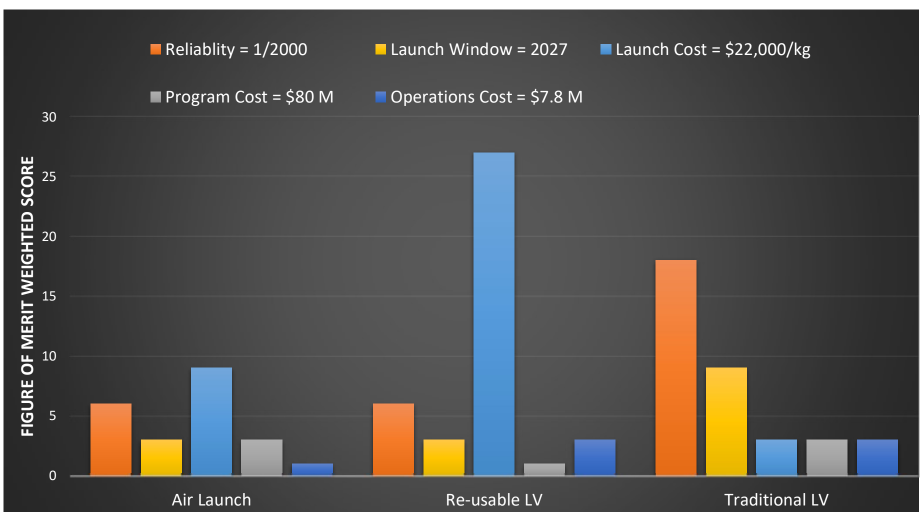
FOM / Alt. Archs	C2.0-2 Program Cost $80 M WF = 1		C6.0-1 Operations Cost $7.8 M/year WF = 1		Weighted Total
	U	W	U	W	
Arch 1	$85 M / 3	3	$9 M/Y / 1	1	22
Arch 2	$95 M / 1	1	$8.5 M/Y / 3	3	40
Arch 3	$75 M / 3	3	$7 M/Y / 3	3	36

The trade matrix suggests that Architecture 2 and 3 are the most likely to meet the important figures of merit and will move forward in the down selection process.

51

51

3.4: Architecture Trade Matrix Bar Graph

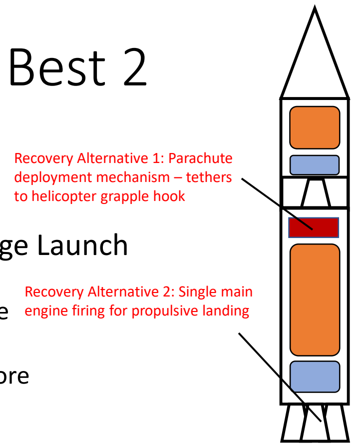


The re-usable launch vehicle drastically reduces launch costs at the expense of program cost and reliability.

52

52

3.5a Selection of Best 2 Architectures



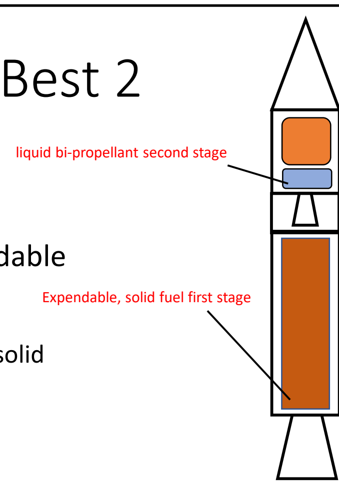
- Description
  - Arch 2: Reusable First Stage Launch Vehicle
    - Stage 1 is entirely reusable
    - TSTO small launch vehicle
    - Liquid fuel with newer, more experimental engines
- Key Rationale

ARCH #1 Selected due to:
- **Low launch cost due to reusable platform**
- **Average reliability**
- **Low operations cost**
- **Adequate launch date**
- **Reusability provides a large advantage**

53

53

3.5b Selection of Best 2 Architectures

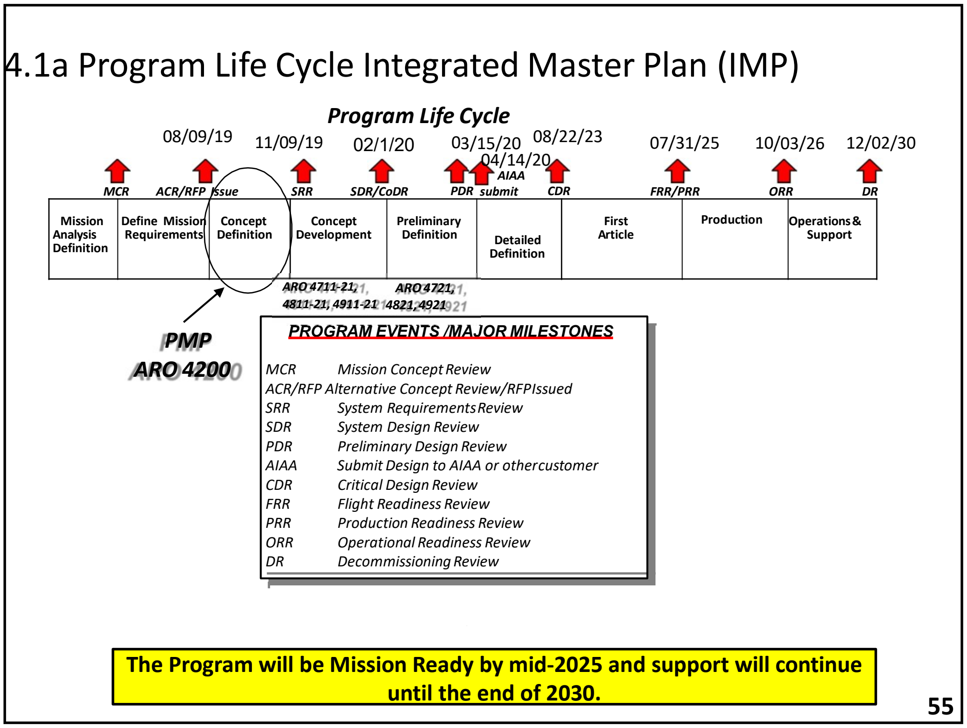


- Description
  - Arch 3: Traditional, Expendable Launch Vehicle
    - All stages are expendable
    - TSTO launch vehicle has a solid rocket 1st stage
    - Proven to work
- Key Rationale

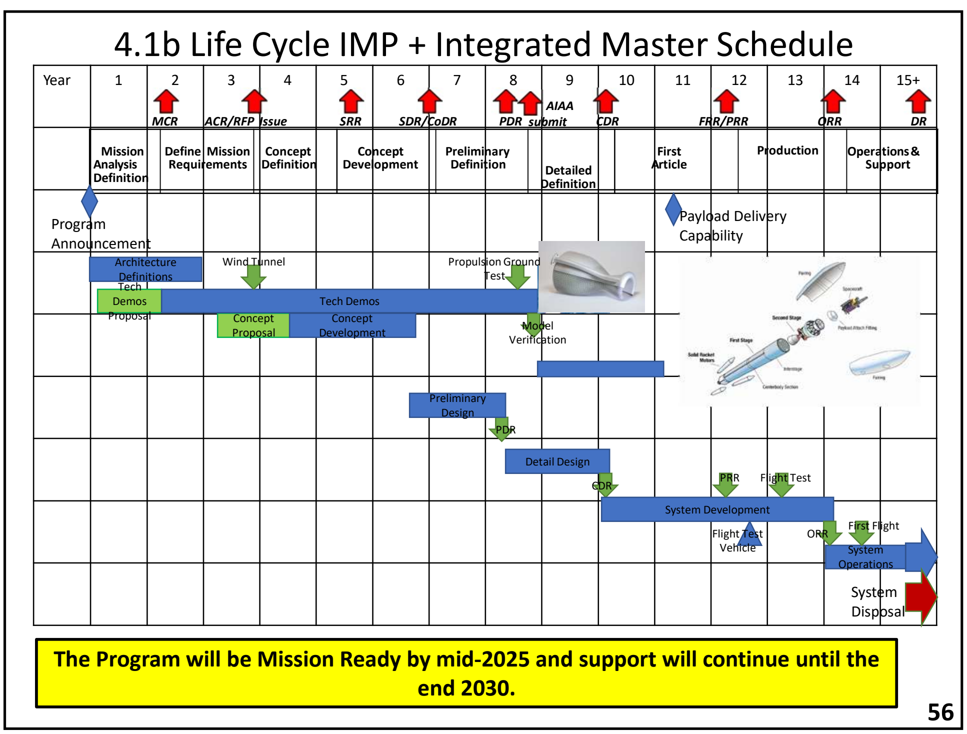
ARCH #2 Selected due to:
- **High reliability**
- **Technological Readiness Level is very high**
- **Early Launch Date**
- **Adequate program**
- **Adequate operations costs**

54

54


4.1a Program Life Cycle Integrated Master Plan (IMP)
Program Life Cycle
08/09/19
11/09/19
02/1/20
03/15/20
04/14/20
08/22/23
07/31/25
10/03/26
12/02/30
MCR
ACR/RFP Issue
SRR
SDR/CoDR
PDR
AIAA submit
CDR
FRR/PRR
ORR
DR
Mission Analysis Definition
Define Mission Requirements
Concept Definition
Concept Development
Preliminary Definition
Detailed Definition
First Article
Production
Operations & Support
ARO 4711-21, 4811-21, 4911-21
ARO 4721, 4821, 4921
PMP
ARO 4200
PROGRAM EVENTS /MAJOR MILESTONES
MCR Mission Concept Review
ACR/RFP Alternative Concept Review/RFP Issued
SRR System Requirements Review
SDR System Design Review
PDR Preliminary Design Review
AIAA Submit Design to AIAA or other customer
CDR Critical Design Review
FRR Flight Readiness Review
PRR Production Readiness Review
ORR Operational Readiness Review
DR Decommissioning Review
The Program will be Mission Ready by mid-2025 and support will continue until the end of 2030.
55

55


4.1b Life Cycle IMP + Integrated Master Schedule
Year 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15+
MCR
ACR/RFP Issue
SRR
SDR/CoDR
PDR
AIAA submit
CDR
FRR/PRR
ORR
DR
Mission Analysis Definition
Define Mission Requirements
Concept Definition
Concept Development
Preliminary Definition
Detailed Definition
First Article
Production
Operations & Support
Program Announcement
Payload Delivery Capability
Architecture Definitions
Wind Tunnel
Propulsion Ground Test
Tech Demos Proposal
Tech Demos
Concept Proposal
Concept Development
Model Verification
Preliminary Design
PDR
Detail Design
CDR
PRR
Flight Test
System Development
Flight Test Vehicle
ORR
First Flight
System Operations
System Disposal
The Program will be Mission Ready by mid-2025 and support will continue until the end 2030.
56

56

4.2a Conceptual Design Schedule

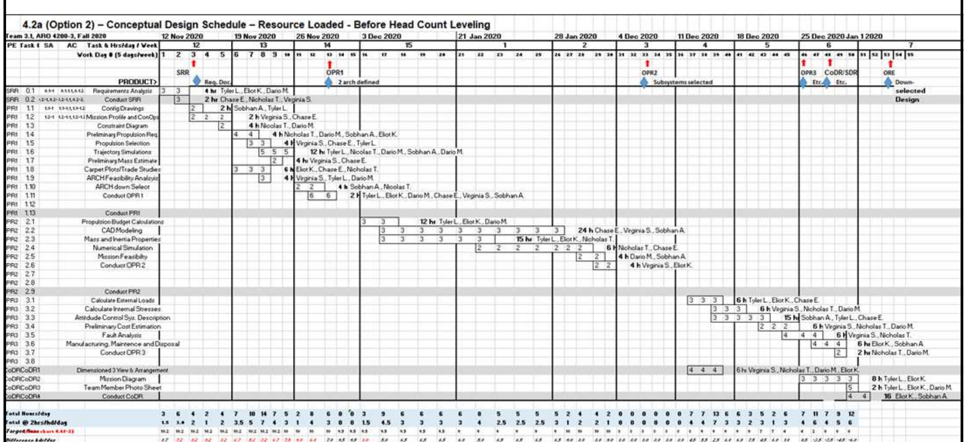
Week	12	13	14	15	1	2	3	4	5	6	7
IMP	SRR	OPR1		OPR2		OPR3		OPR4		CoDR	Proposal
Tasks	SLDR		Arch Specs								
1.1 Mission Profile 1.2 Preliminary prop system reqs 1.3 Trajectory simulations 1.4 Preliminary simulations 1.5 Specification of two design configurations 2.1 Propellant budget calc 2.2 CAD drawing for structure 2.3 Mass and inertia calcs 2.4 Simulation of launch 3.1 Estimation of shear and bending moments 3.2 Calc of internal loads 3.3 Attitude control 3.4 Fault analysis 3.5 Preliminary 3.6 Manufacturing and maintenance											

Conceptual design plan up to proposal for VCLS.

57

57

4.2b-1 Updated Budget Loaded Conceptual Design

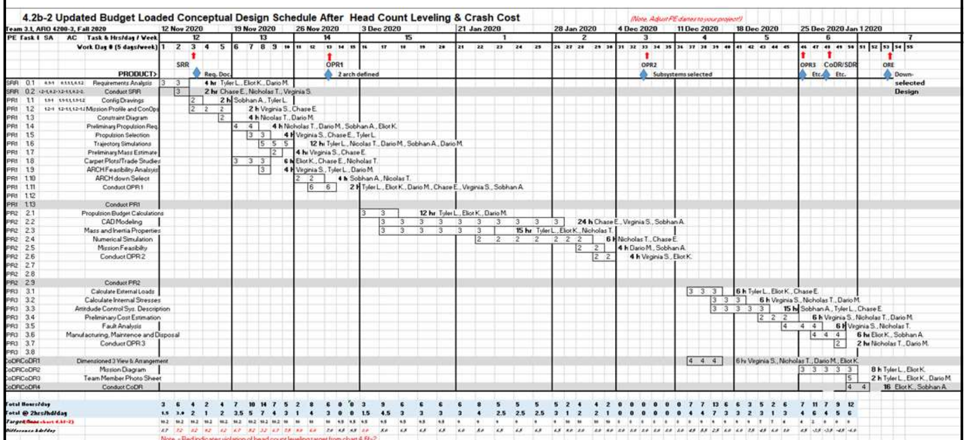


Tasks were created and organized with the amount of workers assigned to each task and how long they will be working on it

58

58

4.2b-2 Updated Conceptual Design Schedule with Allocated Heads & Hours

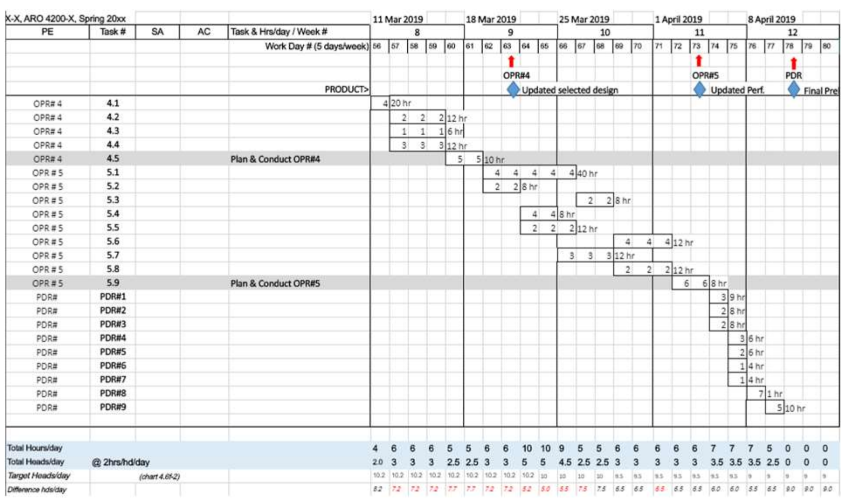


Tasks were shifted and reorganized after crash cost levelling to minimize the time the critical path takes

59

59

4.3 Budget Loaded Preliminary Design Schedule with Head Count Leveling (no crash cost)



Tasks were created and organized with the amount of workers assigned to each task and how long they will be working on it for Preliminary Design.

60

60

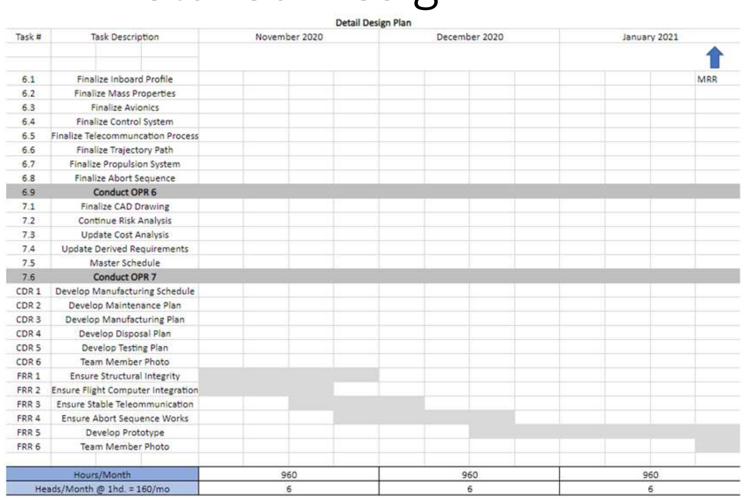
4.4-1 Detailed Design

The schedule above outlines the critical tasks that must be completed in order to ensure a successful FRR.

61

61

4.4-2 Detailed Design



The schedule above outlines the critical tasks that must be completed in order to ensure a successful FRR.

62

62

4.5 Manufacturing Schedules

The Manufacturing schedule has the Manufacturing Revision Request and the delivery dates for first delivery, block 1, and block 2 and should follow the schedule seen above.

63

63

4.6a-1 CPM Plan for VCLS

Task # From chart 2.1a	Task	Days Duration	Heads & Hours	Logic and Sequence
0.1	Write system level requirements	2	3 Head 4 Hour	First task. Must complete SRR
1.1	Configuration drawings	1	2 Head 2 Hour	Follows task 0.1
1.2	Con-Ops/Mission profile	3	2 Head 2 Hour	Follows task 0.1 and simultaneous with 1.1
1.3	Constraint diagrams	1	2 Head 4 Hour	Follows task 1.2
1.4	Preliminary propulsion requirements	1	4 Head 4 Hour	Follows task 1.3
1.5	Propulsion selection	2	3 Head 4 Hour	Follows task 1.4
1.6	Trajectory simulations	3	5 Head 12 Hour	Follows task 1.5 and 1.8
1.7	Preliminary Mass Estimate	1	2 Head 4 Hour	Follows task 1.5 and 1.8
1.8	Carpet Plots/Trade Studies	3	3 Head 6 Hour	Follows task 1.1 and is simultaneous with task 1.4 and 1.5
1.9	ARCH feasibility Analysis	3	2 Head 4 Hour	Follows task 1.5 and 1.8 and is simultaneous with 1.6

64

64

4.6a-2 CPM Plan for VCLS

Task # From chart 2.1a	Task	Days Duration	Heads & Hours	Logic and Sequence
1.10	ARCH down select	1	2 Head 4 Hour	Follows task 1.9
1.11	Conduct OPR 1	1	6 Head 2 Hour	Follows task 1.10
2.1	Propulsion budget calculations	3	3 Head 12 Hour	Follows task 1.11 since OPR 1 must be completed
2.2	CAD modelling	11	3 Head 24 Hour	Follows task 2.1 and is simultaneous to task 1.3
2.3	Mass and inertia properties	5	3 Head 15 Hour	Follows task 2.1 and is simultaneous with 2.2
2.4	Numerical simulation	6	2 Head 6 Hour	Follows task 2.3 and is simultaneous with 2.2
2.5	Mission feasibility	2	2 Head 4 Hour	Follows task 2.4
2.6	Conduct OPR 2	2	2 Head 4 Hour	Follows task 2.5 and 2.2
3.1	Calculate external loads	3	3 Head 6 Hour	Follows task 2.6 since OPR 2 must be completed
3.2	Calculate internal stresses	3	3 Head 6 Hour	Follows task 3.1 and is simultaneous with 3.3

65

65

4.6a-3 CPM Plan for VCLS

Task # From chart 2.1a	Task	Days Duration	Heads & Hours	Logic and Sequence
3.3	Attitude control system description	5	3 Head 15 Hour	Follows task 3.1 and is simultaneous with 3.2
3.4	Preliminary cost estimation	3	2 Head 6 Hour	Follows task 3.2 and is simultaneous with 3.5
3.5	Fault Analysis	3	4 Head 6 Hour	Follows task 3.3 and is simultaneous with 3.4
3.6	Manufacturing, maintenance and disposal	3	4 Head 6 Hour	Follows task 3.5 and is simultaneous with CoDR 2
3.7	Conduct OPR 3	1	2 Head 2 Hour	Follows task 3.6 and is simultaneous with CoDR 3
CoDR 1	Dimensioned 3 View & Arrangement	3	4 Head 6 Hour	Follows task 2.6 and is simultaneous with 3.1
CoDR 2	Mission Diagram	4	3 Head 8 Hour	Follows task 3.4 and is simultaneous with 3.6
CoDR 3	Team Member Photo Sheet	1	5 Head 2 Hour	Follows CoDR 2 and is simultaneous with 3.7
CoDR 4	CoDR	2	4 Head 16 Hour	Follows task 3.7 and CoDR 3

The CPM Plan clearly shows the dependencies and logic for all tasking through the process, starting from SRR to CoDR.

66

66

4.6b-1 CPM Plan for VCLS

Task#	Event	Duration	ES	EF	LS	LF	TF	FF	IF
0.1*	1-2	2	0	2	0	2	0	0	0
1.1	2-3	1	2	3	5	6	3	3	0
1.2*	2-4	3	2	5	2	5	0	0	0
1.3*	4-5	1	5	6	5	6	0	0	0
1.4*	5-6	1	6	7	6	7	0	0	0
1.5*	6-7	2	7	9	7	9	0	0	0
1.6*	7-9	3	9	12	9	12	0	0	0
1.7	7-8	1	6	7	9	10	3	3	0
1.8	5-7	3	3	6	6	9	3	3	0
1.9	7-9	1	9	10	9	12	3	3	0
1.10*	9-10	1	10	11	10	11	0	0	0
1.11*	10-11	1	11	12	11	12	0	0	0
2.1*	12-13	3	12	15	12	15	0	0	0
2.2	13-14	11	15	26	17	18	2	2	0
2.3*	13-15	5	15	20	15	20	0	0	0
2.4*	15-16	6	20	26	20	26	0	0	0

67

67

4.6b-2 CPM Plan for VCLS

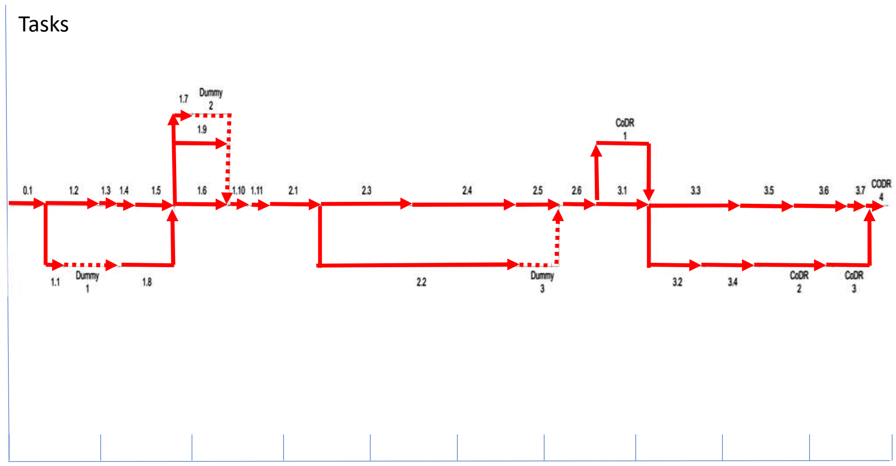
Task#	Event	Duration	ES	EF	LS	LF	TF	FF	IF
2.5*	16-17	2	26	28	26	28	0	0	0
2.6*	17-18	2	28	30	28	30	0	0	0
3.1*	20-21	3	30	33	30	33	0	0	0
3.2	21-22	3	33	36	36	39	3	3	0
3.3*	21-23	5	33	38	33	38	0	0	0
3.4	22-24	3	36	39	39	42	3	3	0
3.5*	23-25	3	38	41	38	41	0	0	0
3.6*	25-26	3	41	44	41	44	0	0	0
3.7*	26-27	1	44	45	44	45	0	0	0
CoDR 1*	20-21	3	30	33	30	33	0	0	0
CoDR 2	24-28	4	39	43	42	46	3	3	0
CoDR 3	28-27	1	43	44	46	47	3	3	0
CoDR 4*	27-29	2	45	47	45	47	0	0	0

The Task Network Table demonstrates that all time is used efficiently with very small amounts of float time in between tasks.

68

68

4.6c CPM Plan for Conceptual Design Time Grid – *Before Head Count Leveling*



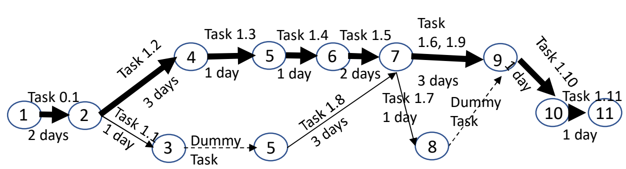
The Critical Path, visualized by the series of arrows in the center, shows that all tasking will optimistically take at least 11 weeks to complete.

69

69

4.6d-1 CPM Plan for Conceptual Design

The CPM Plan visualizes the interdependencies of the tasks and demonstrates how much of the workload will occur in series rather than in parallel.



Tasks Paths

Path	Days
1-2-4-5-6-7-9-10-11	14 days
1-2-3-5-7-8-9-10-11	9 days
1-2-3-5-7-9-10-11	11 days
1-2-4-5-6-7-8-9-10-11	12 days

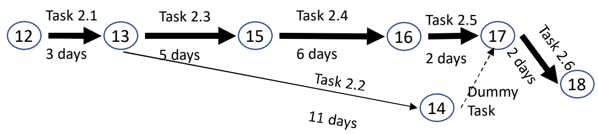
Critical Path

The CPM Plan for progress review #1 has a critical path of 14 days

70

70

4.6d-2 CPM Plan for Conceptual Design



Tasks Paths
Path Days
12-13-15-16-17-18 18 days
12-13-14-17-18 16 days

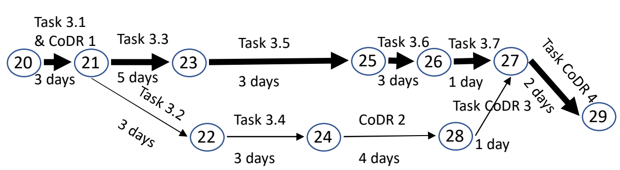
Critical Path

The CPM Plan for progress review #1 has a critical path of 18 days.

71

71

4.6d-3 CPM Plan for Conceptual Design



Tasks Paths
Path Days
20-21-23-25-26-27-29 17
days
20-21-22-24-28-27-29 16
days

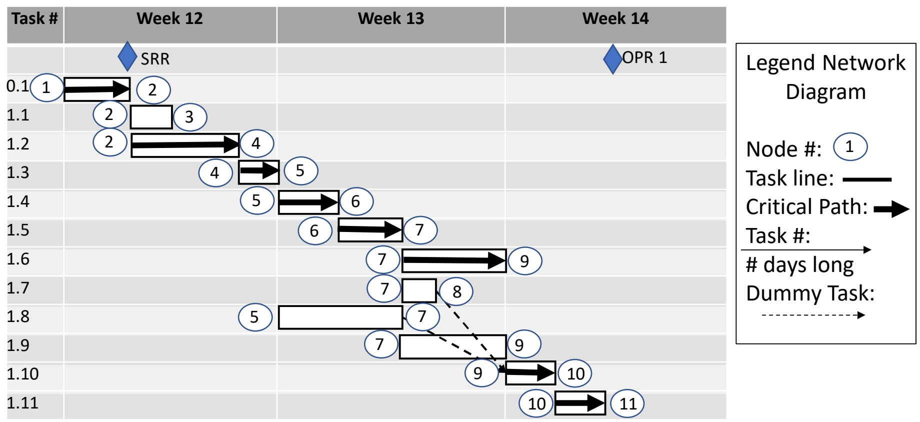
Critical Path

The CPM Plan for progress review #3 has a critical path of 17 days.

72

72

4.6e-1 CPM Plan for Conceptual Design

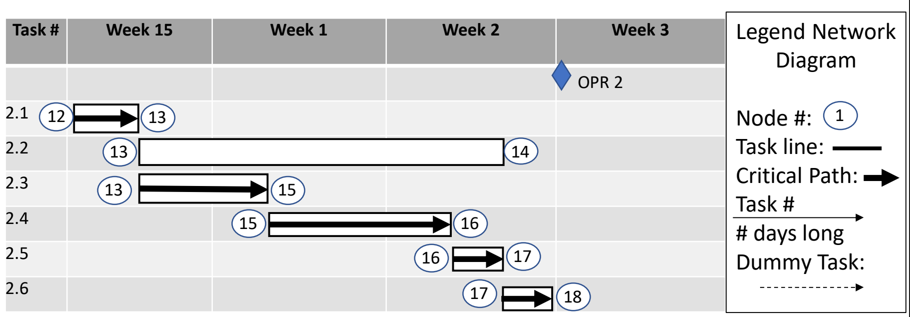


Of the tasks leading up to progress review #1, Tasks 1.7-1.9 (mass estimates, carpet plots, and architecture feasibility/selection) are the most flexible.

73

73

4.6e-2 CPM Plan for Conceptual Design

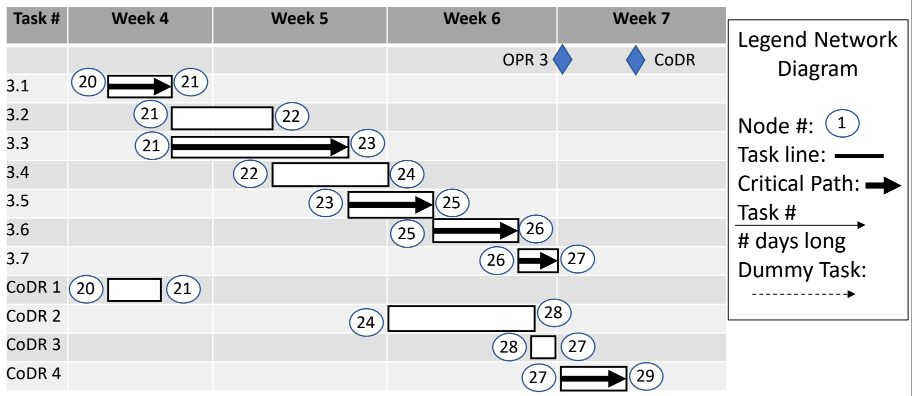


Of the tasks leading up to progress review #2, Tasks 2.2, Cad Modeling, is the most flexible with the longest float time.

74

74

4.6e-3 CPM Plan for Conceptual Design

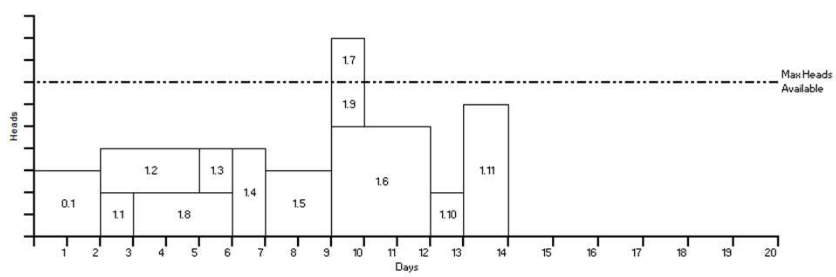


To minimize the critical path, every task leading up to progress review #3 and the Conceptual Design Review is in parallel with one other task.

75

75

4.6f-1-1 Initial CPM Plan for Conceptual Design: Before Head Leveling

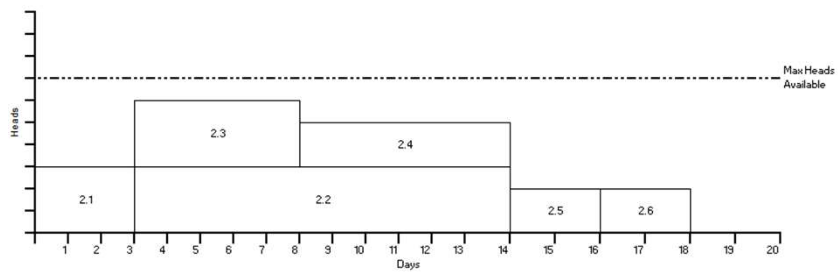


The CPM Plan before head-count leveling for progress review #1 has a shortage of workforce during week 2 of Conceptual Design.

76

76

4.6f-1-2 Initial CPM Plan for Conceptual Design: Before Head Leveling

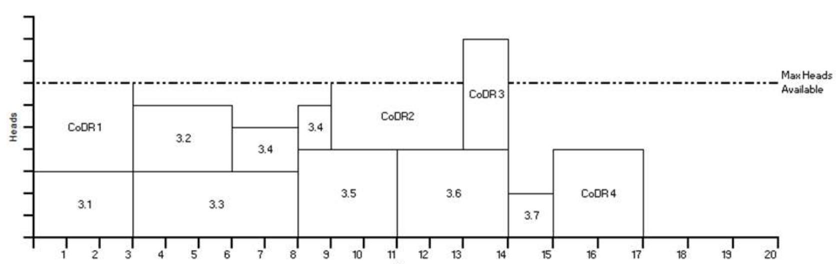


The CPM Plan before head-count leveling for progress review #2 fails to effectively utilize company resources to shorten the critical path.

77

77

4.6f-1-3 Initial CPM Plan for Conceptual Design: Before Head Leveling

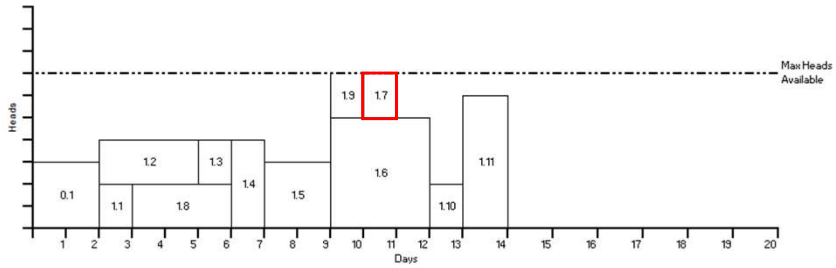


The CPM Plan before head-count leveling for progress review #3 effectively utilizes company resources, but there is a workforce shortage nearing the end of Week 6 of Conceptual Design.

78

78

4.6f-2-1 Initial CPM Plan for Conceptual Design: After Head Leveling

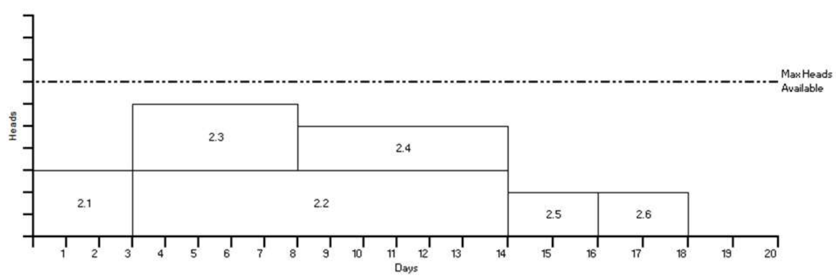


After head count leveling, the CPM Plan corrects the workforce shortage by moving Task 1.7 ahead of 1.9 instead of in parallel.

79

79

4.6f-2-2 Initial CPM Plan for Conceptual Design: After Head Leveling

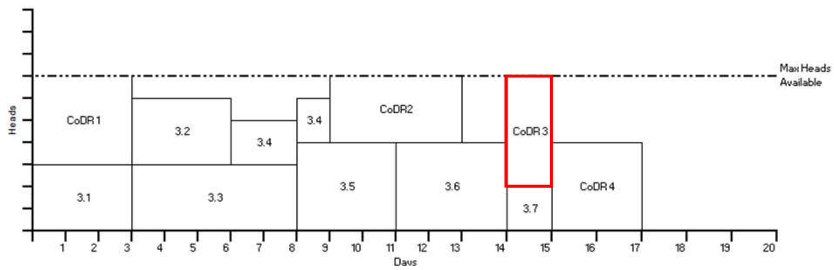


Despite not fully utilizing company resources, the CPM plan of tasks for progress review #2 remain the same, giving a great window for opportunity management.

80

80

4.6f-2-3 Initial CPM Plan for Conceptual Design: After Head Leveling

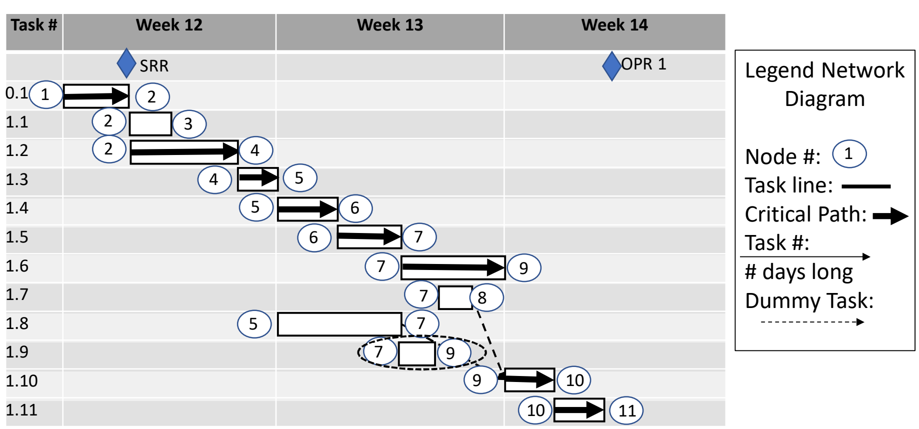


After head count leveling, the CPM Plan for progress review #3 and CoDR corrects the workforce shortage by moving Task CoDR 3 ahead of Task 3.6 instead of in parallel.

81

81

4.6f-3-1 Initial CPM Plan for Conceptual Design: Gantt Chart After Head Leveling

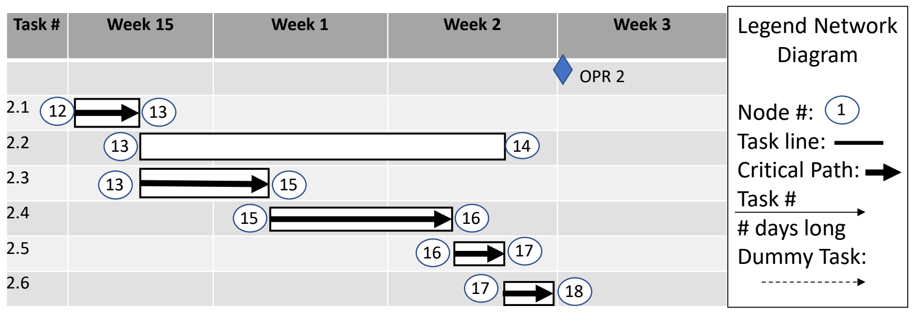


Without altering the critical path, Task 1.9 was shortened to be completed by the middle as opposed to the end of Week 13.

82

82

4.6f-3-2 Initial CPM Plan for Conceptual Design: Gantt Chart After Head Leveling

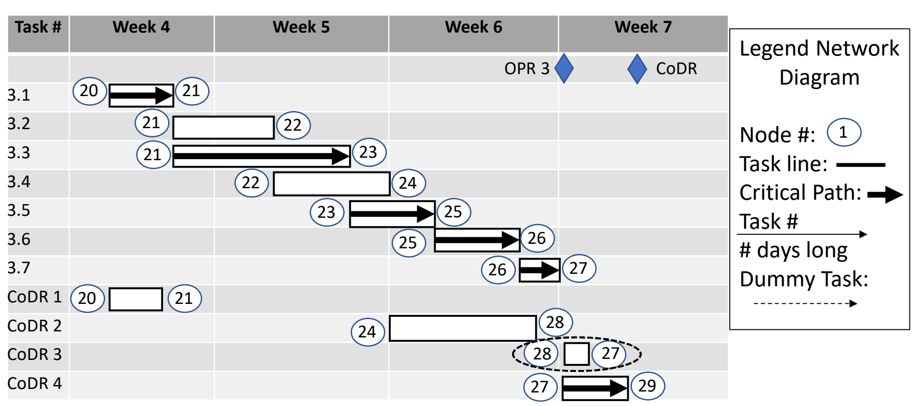


No tasks leading up to progress review #2 have been altered after head-count leveling.

83

83

4.6f-3-3 Initial CPM Plan for Conceptual Design: Gantt Chart After Head Leveling



Task CoDR3 has been moved in front of Task 3.6 after head-count leveling.

84

84

4.6g-1 CPM Plan for VCLS – Preliminary Design

Task # From chart 2.1a	Task	Days Duration	Heads & Hours	Logic and Sequence
4.1	Con-ops/trajectories	1	4 Heads 20 Hours	Comes first
4.2	Propulsion selection	3	2 Heads 12 Hours	Follows task 4.1
4.3	Detailed mass breakdown	3	1 Heads 6 Hours	Follows task 4.1
4.4	LV selection	3	3 Heads 12 Hours	Follows task 4.1
4.5	OPR4	2	5 Heads 10 Hours	Follows task 4.3
5.1	Internal layout CAD	5	4 Heads 40 Hours	Follows task 4.5
5.2	Payload bus layout and FOV	2	2 Heads 8 Hours	Follows task 4.5
5.3	Mass and inertia calculations	2	2 Heads 8 Hours	Follows task 5.1

The CAD models of the internal layout, Task 5.1, is the longest task with a total of 40 hours and a duration of 5 days.

85

85

4.6g-2 CPM Plan for VCLS – Preliminary Design

Task # From chart 2.1a	Task	Days Duration	Heads & Hours	Logic and Sequence
5.4	Environmental Disturbances	2	4 Heads 8 Hours	Follows task 5.2
5.5	Thermal analysis	3	2 Heads 12 Hours	Follows task 5.2
5.6	Quasi-static loads analysis	3	4 Heads 12 Hours	Follows task 5.3
5.7	Refined attitude control	3	3 Heads 12 Hours	Follows task 5.5
5.8	Telecommunications	3	2 Heads 12 Hours	Follows task 5.7
5.9	OPR 5	2	6 Heads 8 Hours	Follows task 5.8
PDR 1	Dimensional 3-view and CAD	1	3 Heads 9 Hours	Follows task 5.9
PDR 2	Structural analysis	1	2 Heads 8 Hours	Follows task 5.9
PDR 3	Command subsystems	1	2 Heads 8 Hours	Follows task 5.9

Each task from 5.4 through PDR 3 have a fast, steady pace of 8-12 head hours throughout OPR 5 and the beginning of PDR.

86

86

4.6g-3 CPM Plan for VCLS – Preliminary Design

Task # From chart 2.1a	Task	Days Duration	Heads & Hours	Logic and Sequence
PDR 4	Bending moment, shear, and axial forces	1	3 Heads 6 Hours	Follows task PDR 2
PDR 5	Cost analysis	1	2 Heads 6 Hours	Follows task PDR 2
PDR 6	Acoustic and environmental emission	1	1 Heads 4 Hours	Follows task PDR 3
PDR 7	Manufacturing and maintenance facilities	1	1 Heads 4 Hours	Follows task PDR 3
PDR 8	Team member photo sheet	1	7 Heads 1 Hours	Follows task PDR 4
PDR 9	PDR	1	5 Heads 10 Hours	Follows task PDR 8

There is an increase in the pace for completing tasks from PDR 4 through PDR 9, with a 1-day duration for each task.

87

87

4.6h-1 CPM Plan for VCLS – Preliminary Design

Task#	Event	Duration	ES	EF	LS	LF	TF	FF	IF
4.1	1-2	1	0	1	0	1	0	0	0
4.2	2-3	3	1	4	1	4	0	0	0
4.3	2-3	3	1	4	1	4	0	0	0
4.4	2-3	3	1	4	1	4	0	0	0
4.5	3-4	2	4	6	4	6	0	0	0
5.1	4-7	5	6	11	6	11	0	0	0
5.2	4-5	2	6	8	6	8	0	0	0
5.3	7-8	2	11	13	11	13	0	0	0
5.4	5-6	2	8	10	9	11	1	1	0
5.5	5-7	3	8	11	8	11	0	0	0
5.6	8-10	3	13	16	14	17	1	1	0
5.7	7-9	3	11	14	12	15	0	0	0
5.8	9-11	3	14	17	14	17	0	0	0
5.9	11-12	2	17	19	17	19	0	0	0

Tasks 4.1 through 5.9 have a rigid path, with float days only available for Task 5.4 and 5.6.

88

88

4.6h-2 CPM Plan for VCLS – Preliminary Design

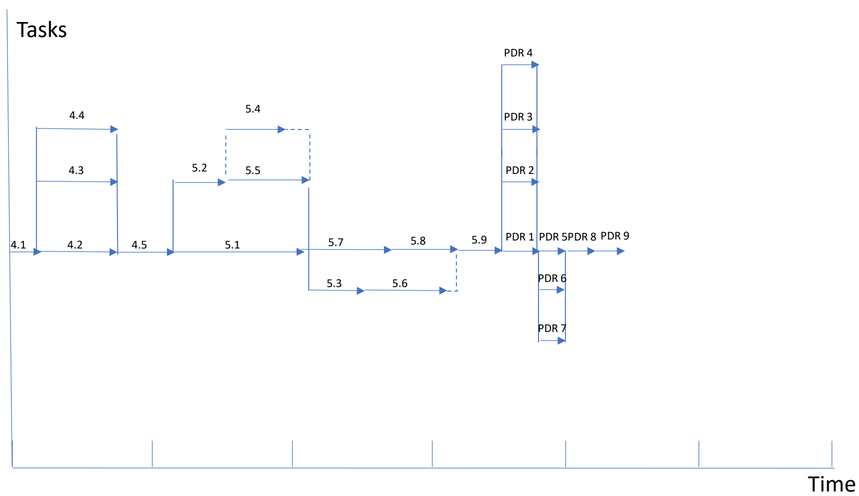
Task#	Event	Duration	ES	EF	LS	LF	TF	FF	IF
PDR 1	12-13	1	19	20	19	20	0	0	0
PDR 2	12-13	1	19	20	19	20	0	0	0
PDR 3	12-13	1	19	20	19	20	0	0	0
PDR 4	13-14	1	20	21	20	21	0	0	0
PDR 5	13-14	1	20	21	20	21	0	0	0
PDR 6	13-14	1	21	22	21	22	0	0	0
PDR 7	13-14	1	21	22	21	22	0	0	0
PDR 8	14-15	1	22	23	22	23	0	0	0
PDR 9	15-16	1	23	24	23	24	0	0	0

The tasks are laid out in a time-efficient, sequential manner, but The Task Network Table demonstrates that this may cost us flexibility in scheduling, which will be addressed in our Crash Cost Optimization.

89

89

4.6i CPM Plan for Conceptual Design Time Grid – *Before Head Count Leveling* – Preliminary Design

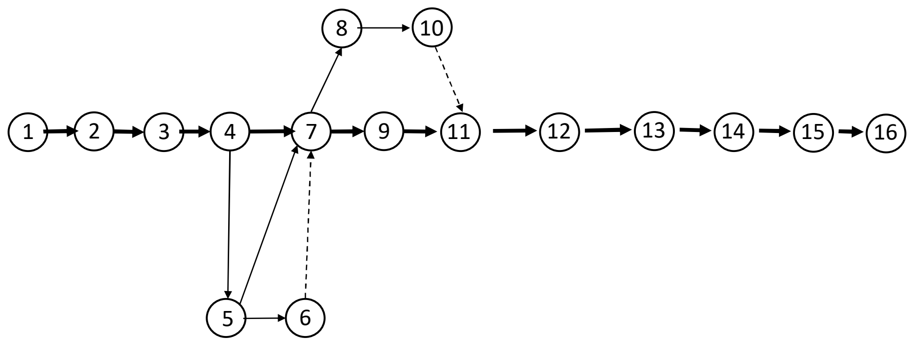


The Critical Path, visualized above by the series of arrows in the middle, shows that all tasking will take at least 24 days to complete.

90

90

4.6j CPM Plan – Preliminary Design Network Diagram

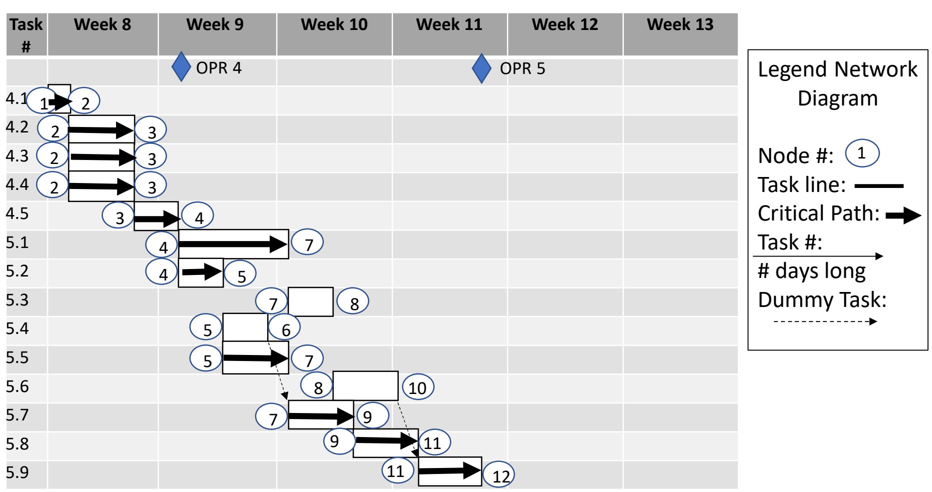


The CPM Plan Network Diagram visualizes the interdependencies of the tasks and demonstrates how much of the workload will occur in series rather than in parallel.

91

91

4.6k-1 CPM Plan – **Preliminary Design**

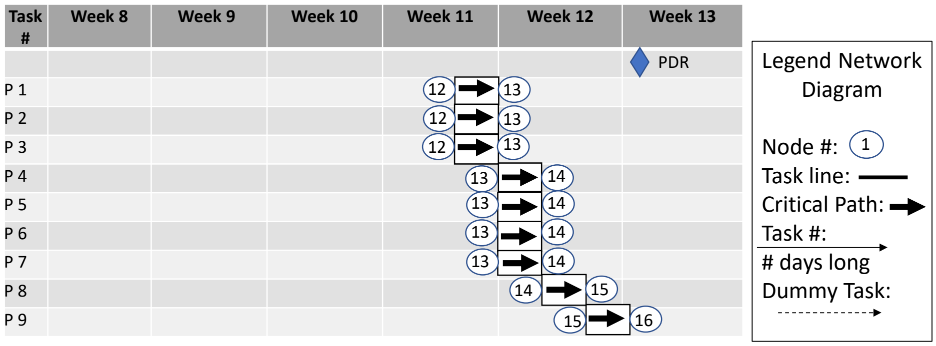


Node Paths	# days / # weeks
1) 1 – 2 – 3 – 4 – 5 – 6 – 7 – 9 – 11 – 12 – 13 – 14 – 15 – 16	22 days / 4.4 weeks
2) 1 – 2 – 3 – 4 – 5 – 7 – 9 – 11 – 12 – 13 – 15 – 16	23 days / 4.6 weeks
3) 1 – 2 – 3 – 4 – 7 – 9 – 11 – 12 – 13 – 14 – 15 – 16	23 days / 4.6 weeks
4) 1 – 2 – 3 – 4 – 7 – 8 – 10 – 11 – 12 – 13 – 14 – 15 – 16	22 days / 4.4 weeks

92

92

4.6k-2 CPM Plan – **Preliminary Design**



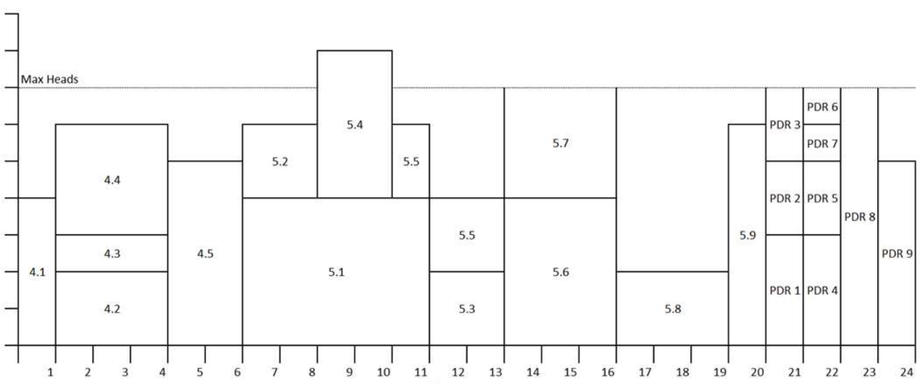
Node Paths	# days / # weeks
1) 1 – 2 – 3 – 4 – 5 – 6 – 7 – 9 – 11 – 12 – 13 – 14 – 15 – 16	22 days / 4.4 weeks
2) 1 – 2 – 3 – 4 – 5 – 7 – 9 – 11 – 12 – 13 – 15 – 16	23 days / 4.6 weeks
3) 1 – 2 – 3 – 4 – 7 – 9 – 11 – 12 – 13 – 14 – 15 – 16	23 days / 4.6 weeks
4) 1 – 2 – 3 – 4 – 7 – 8 – 10 – 11 – 12 – 13 – 14 – 15 – 16	22 days / 4.4 weeks

Most PDR tasks can be done in parallel resulting in a final critical path, denoted by Node Path 2 or 3, of 23 days or 4.6 weeks.

93

93

4.6l-1 Initial CPM Plan – Preliminary Design : Before Head Leveling

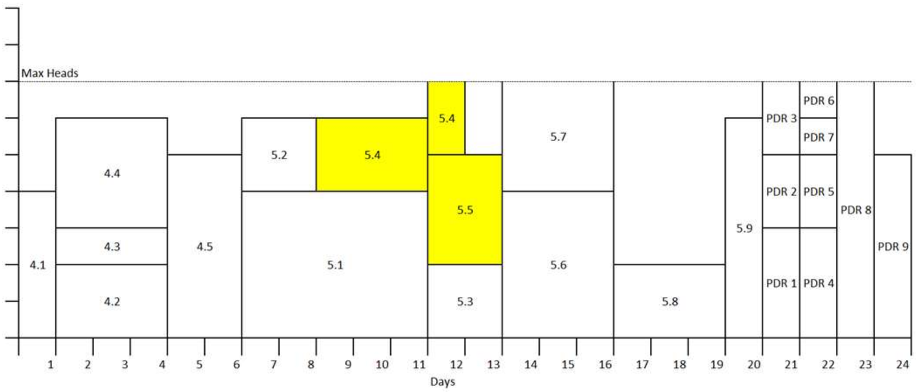


The CPM Plan originally created overestimated the amount of people available for Task 5.4 during days 8-10.

94

94

4.6l-2 Initial CPM Plan – Preliminary Design : After Head Leveling

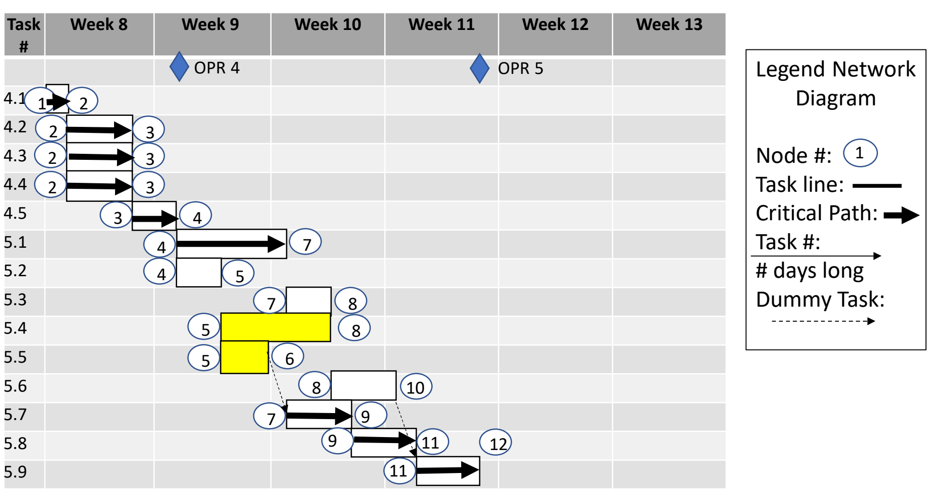


The corrected version of the CPM now accounts for the total number of heads at any given time by reorganizing tasks based on their dependencies (Tasks 5.4 and 5.5).

95

95

4.6l-3-1 CPM Plan – **Preliminary Design**



Node Paths

1) 1 – 2 – 3 – 4 – 5 – 6 – 7 – 9 – 11 – 12 – 13 – 14 – 15 – 16
2) 1 – 2 – 3 – 4 – 5 – 8 – 10 – 11 – 12 – 13 – 15 – 16
3) 1 – 2 – 3 – 4 – 7 – 9 – 11 – 12 – 13 – 14 – 15 – 16
4) 1 – 2 – 3 – 4 – 7 – 8 – 10 – 11 – 12 – 13 – 14 – 15 – 16

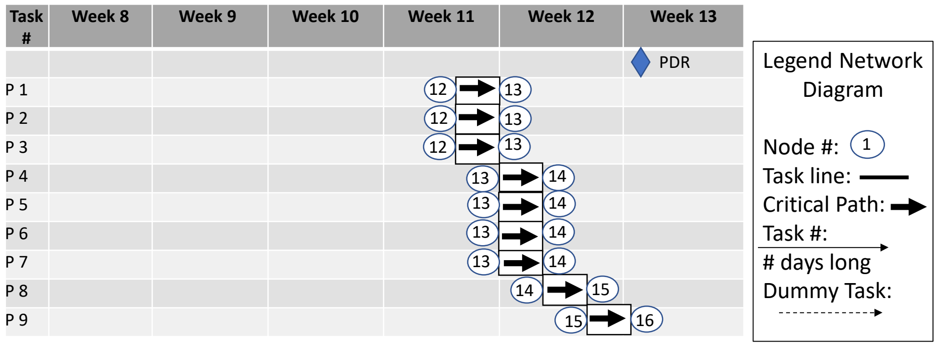
days / # weeks

22 days / 4.4 weeks
22 days / 4.4 weeks
23 days / 4.6 weeks
22 days / 4.4 weeks

96

96

4.6l-3-2 CPM Plan – **Preliminary Design**



Node Paths	# days / # weeks
1) 1 – 2 – 3 – 4 – 5 – 6 – 7 – 9 – 11 – 12 – 13 – 14 – 15 – 16	22 days / 4.4 weeks
2) 1 – 2 – 3 – 4 – 5 – 8 – 10 – 11 – 12 – 13 – 15 – 16	22 days / 4.4 weeks
3) 1 – 2 – 3 – 4 – 7 – 9 – 11 – 12 – 13 – 14 – 15 – 16	23 days / 4.6 weeks
4) 1 – 2 – 3 – 4 – 7 – 8 – 10 – 11 – 12 – 13 – 14 – 15 – 16	22 days / 4.4 weeks

Task 5.4's duration was lengthened with fewer working heads, and Task 5.5's duration was shortened but assigned more working heads. Critical Path remains Node Path 3 at 23 days.

97

97

4.7a-1 Project Crash Cost Optimization

Original							Reduced Days							Potential Savings						
Task	Cost $/day	Orig days	Orig heads /days	Orig equip cost	Orig cost w/o ind	Orig cost with ind	Days reduced	New total time	Add heads /day	Add Labor cost	Add equip cost	New heads /days	Total cost w/o ind	Total Crash/ days reduc	Ind Cost/ day	Net ind cost save	New total task cost	Total cost save	Orig head-days	New head-days
0.1	50	2	3	5	305	2305	1	1	1	50	2.5	4	52.5	-253	1000	947.5	1207.5	**1097.5**	6	4
1.1	50	1	2	10	110	1110	0	1	0	0	5	2	5	N/A	1000	-5	1115	**-5**	2	2
1.2	50	3	2	5	305	3305	1	2	1	100	2.5	3	102.5	-203	1000	897.5	2307.5	**997.5**	6	6
1.3	50	1	2	20	120	1120	0	1	0	0	10	2	10	N/A	1000	-10	1130	**-10**	2	2
1.4	50	1	4	5	205	1205	0	1	0	0	2.5	4	2.5	N/A	1000	-2.5	1207.5	**-2.5**	4	4
1.5	50	2	3	5	305	2305	0	2	0	0	2.5	3	2.5	N/A	1000	-2.5	2307.5	**-2.5**	6	6
1.6	50	3	5	50	800	3800	1	2	1	100	25	6	125	-698	1000	-125	2675	**1125**	15	12
1.7	50	1	2	5	105	1105	0	1	0	0	2.5	2	2.5	N/A	1000	-2.5	1107.5	**-2.5**	2	2
1.8	50	3	3	5	500	3500	1	2	1	100	2.5	4	102.5	-353	1000	-102.5	2407.5	**1047.5**	9	8
1.9	50	3	2	5	305	3305	1	2	1	100	2.5	3	102.5	-203	1000	-102.5	2307.5	**997.5**	6	6
1.10	50	1	2	5	105	1105	0	1	0	0	2.5	2	2.5	N/A	1000	-2.5	1107.5	**-2.5**	2	2
1.11	50	1	6	5	305	1305	0	1	0	0	2.5	6	2.5	N/A	1000	-2.5	1307.5	**-2.5**	6	6
2.1	50	3	3	5	500	3500	1	2	1	100	2.5	4	102.5	-353	1000	-102.5	2407.5	**1047.5**	9	8
2.2	50	11	3	100	1750	12750	5	6	3	900	50	6	950	-160	1000	-950	7950	**4800**	33	36
2.3	50	5	3	10	500	5500	2	3	2	300	5	5	305	-228	1000	-305	3765	**1995**	15	15
2.4	50	6	2	15	615	6615	3	3	2	300	7.5	4	307.5	-103	1000	-307.5	3622.5	**2992.5**	12	12
2.5	50	2	2	5	205	2205	0	2	0	0	2.5	2	2.5	N/A	1000	-2.5	2207.5	**-2.5**	4	4
2.6	50	2	2	5	205	2205	0	2	0	0	2.5	2	2.5	N/A	1000	-2.5	2207.5	**-2.5**	4	4

Crash optimization for the above tasks reveals that the most beneficial tasks to crash are 1.6 and 2.1.

98

98

4.7a-2 Project Crash Cost Optimization

Original							Reduced Days							Potential Savings						
Task	Cost $/day	Orig days	Orig heads /days	Orig equip cost	Orig cost w/o ind	Orig cost with ind	Days reduc ed	New total time	Add heads /day	Add Labor cost	Add equip cost	New heads /days	Total cost w/o ind	Total Crash /days reduc	Ind Cost/ day	Net ind cost save	New total task cost	Total cost save	Orig head-days	New head-days
3.1	50	3	3	20	470	3470	1	2	1	100	10	4	110	-360	1000	890	2430	**1040**	9	8
3.2	50	3	3	20	470	3470	1	2	1	100	10	4	110	-360	1000	890	2430	**1040**	9	8
3.3	50	5	3	15	765	5765	1	4	1	200	10	4	210	-555	1000	790	4825	**940**	15	16
3.4	50	3	2	5	305	3305	0	3	0	0	0	2	0	N/A	1000	0	3305	**0**	6	6
3.5	50	3	4	5	605	3605	1	2	1	100	2.5	5	102.5	-503	1000	897.5	2507.5	**1097.5**	12	10
3.6	50	3	4	5	605	3605	1	2	1	100	2.5	5	102.5	-503	1000	897.5	2507.5	**1097.5**	12	10
3.7	50	1	2	5	105	1105	0	1	0	0	2.5	2	2.5	N/A	1000	-2.5	1107.5	**-2.5**	2	2
co 1	50	3	4	5	605	3605	1	2	1	100	2.5	5	102.5	-503	1000	897.5	2507.5	**1097.5**	12	10
co 2	50	4	3	5	605	4605	1	3	1	150	2.5	4	152.5	-453	1000	847.5	3607.5	**997.5**	12	12
co3	50	1	5	5	255	1255	0	1	10	500	0	15	500	N/A	1000	-500	1755	**-500**	5	15
co 4	50	2	4	5	405	2405	0	2	11	1100	0	15	1100	N/A	1000	-1100	3505	**-1100**	8	30

Crash optimization for the above tasks reveals that the most beneficial tasks to crash are 3.3, 3.5, 3.6, and Co 2

99

99

4.7b-1 Time - Crash Cost Optimization for Conceptual Design Case 1

Original							Reduced Days							Potential Savings						
Task	Cost $/day	Orig days	Orig heads/days	Orig equip cost	Orig cost w/o ind	Orig cost with ind	Days reduced	New total time	Add heads/day	Add Labor cost	Add equip cost	New heads/days	Total cost w/o ind	Total Crash /days reduc	Ind Cost /day	Net ind cost save	New total task cost	Total cost save	Orig head-days	New head-days
1.2	50	3	2	5	305	3305	2	2	1	100	2.5	3	-347.5	-203	1000	347.5	-1042.5	1347.5	6	-21
1.6	50	3	5	50	800	3800	1	2	1	100	25	6	125	-698	1000	-125	675	125	15	12
1.9	50	3	2	5	305	3305	1	2	1	100	2.5	3	102.5	-203	1000	-102.5	307.5	-2.5	6	6
						Totals	3											1470		

Case 1 involves shortening the critical path by 3 days by changing tasks 1.2, 1.6, and 1.9.

100

100

4.7b-2 Time - Crash Cost Optimization for Conceptual Design Case 2

Original							Reduced Days							Potential Savings						
Task	Cost $/day	Orig days	Orig heads /days	Orig equip cost	Orig cost w/o ind	Orig cost with ind	Days redu ced	New total time	Add heads /day	Add Labor cost	Add equip cost	New heads /days	Total cost w/o ind	Total Crash/ days reduc	Ind Cost/ day	Net ind cost save	New total task cost	Total cost save	Orig head-days	New head-days
2.1	50	3	3	5	455	3455	1	2	1	100	2.5	4	102.5	-353	1000	4050	7950	4800	33	36
2.3	50	5	3	10	760	5760	2	3	2	300	5	5	305	-228	1000	1695	3765	1995	15	15
						Totals	3											6795		

Case 2 involves shortening the critical path by 3 days by changing 2.1 and 2.3.

101

101

4.7b-3 Time - Crash Cost Optimization for Conceptual Design Case 3

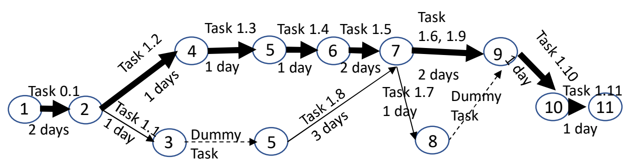
Original							Reduced Days							Potential Savings						
Task	Cost $/day	Orig days	Orig heads /days	Orig equip cost	Orig cost w/o ind	Orig cost with ind	Days redu ced	New total time	Add head s/day	Add Labor cost	Add equip cost	New head s/day s	Total cost w/o ind	Total Crash/ days reduc	Ind Cost /day	Net ind cost save	New total task cost	Total cost save	Orig head-days	New head -days
3.3	50	5	3	15	765	5765	1	4	1	50	10	4	110	-555	100 0	790	4825	940	15	16
3.5	50	3	4	5	605	3605	1	2	1	50	2.5	5	102.5	-503	100 0	897.5	2508	1098	23	20
3.6	50	3	4	5	605	3605	1	2	1	50	2.5	5	102.5	-503	100 0	897.5	2508	1098	23	20
3.2	50	3	3	20	320	3320	1	2	1	50	10	4	110	-360	100 0	890	2430	1040	9	8
Co 2	50	4	3	5	605	4605	1	3	1	50	2.5	4	152.5	-453	100 0	847.5	3608	998	12	12
						Totals	3											5174		

Case 3 involves shortening the critical path by 3 days by changing tasks 3.3, 3.5, 3.6, 3.2, and CoDR 2

102

102

4.7c-1 – Optimized CPM Plan With Crash Cost for Conceptual Design



Tasks Paths	Path Days
1-2-4-5-6-7-9-10-11	11 days
1-2-3-5-7-8-9-10-11	9 days
1-2-3-5-7-9-10-11	10 days
1-2-4-5-6-7-8-9-10-11	10 days

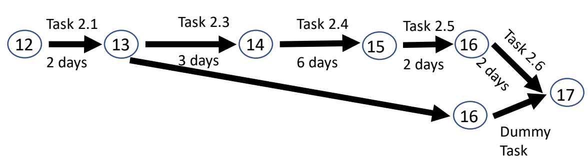
Critical Path

Reducing Task 1.2 by 2 days, and Tasks 1.6 and 1.9 by one day does not change the critical task path, but changes the path duration from 14 days to 11 days.

103

103

4.7c-2 – Optimized CPM Plan With Crash Cost for Conceptual Design



Tasks Paths	Path Days
12-13-15-16-17-18	15 days
12-13-14-17-18	15 days

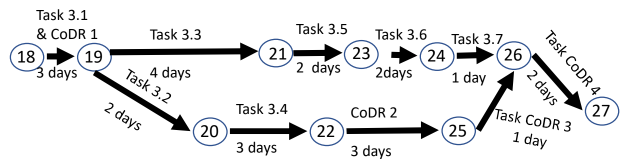
Critical Path

Reducing Task 2.1 by 1 day, and Tasks 2.3 2 days changes the path duration from 18 to 15 days.

104

104

4.7c-3 – Optimized CPM Plan With Crash Cost for Conceptual Design



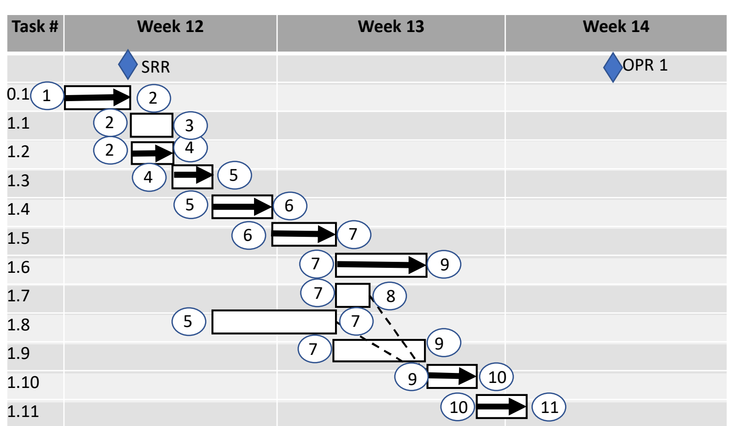
Tasks Paths
Path Days
20-21-23-25-26-27-29 14 days
20-21-22-24-28-27-29 14 days
Critical Path

The network diagram for the crash cost case 3 show that all the tasks between task 3.1 to task CoDR 4 are on the critical path after reducing the critical path.

105

105

4.7d-1 – Optimized CPM Plan Gantt Chart "Schedule" with Crash cost



Legend Network Diagram

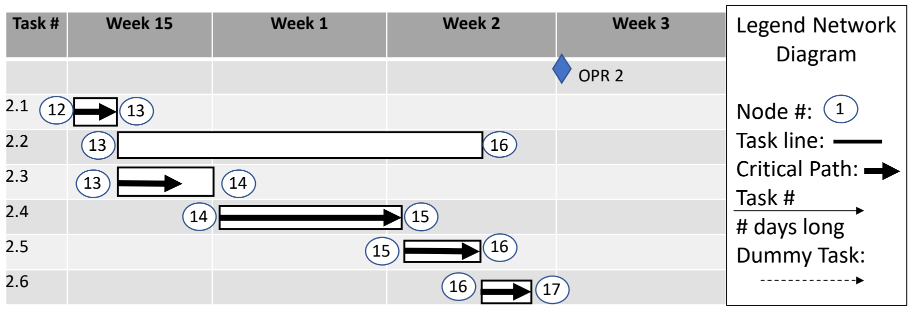
Node #: 1
Task line:
Critical Path:
Task #:
days long
Dummy Task:

As a result of crash cost optimization, the new critical path for tasks 0.1 to 1.11 ends at the end of Week 13 instead of mid Week 14.

106

106

4.7d-2 – Optimized CPM Plan Gantt Chart "Schedule" with Crash cost

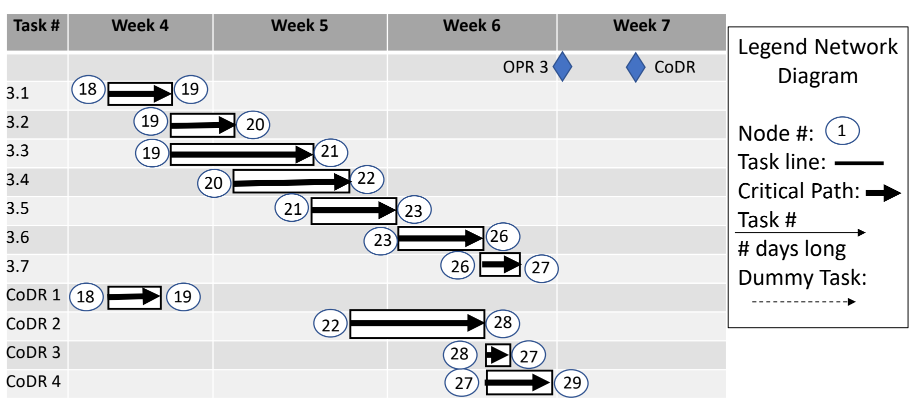


As a result of crash cost optimization, the new critical path for tasks 2.1 to 2.6 ends at the end of Week 2 instead of mid Week 3.

107

107

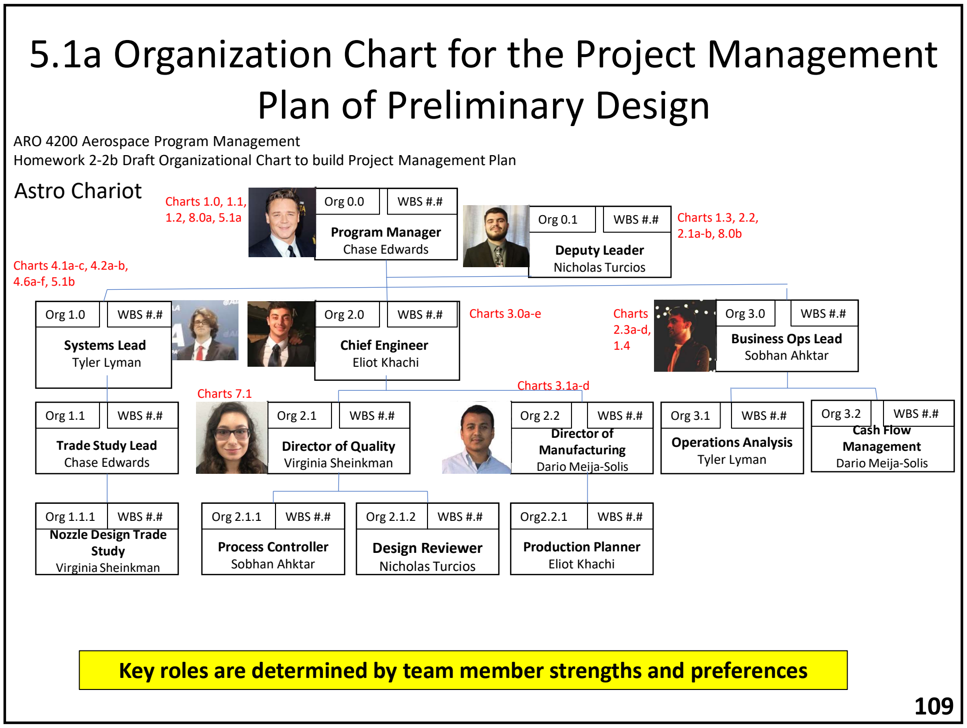
4.7d-3 – Optimized CPM Plan Gantt Chart "Schedule" with Crash cost



The Gantt Chart for crash cost case 3 shows that all these tasks have become part of the critical path.

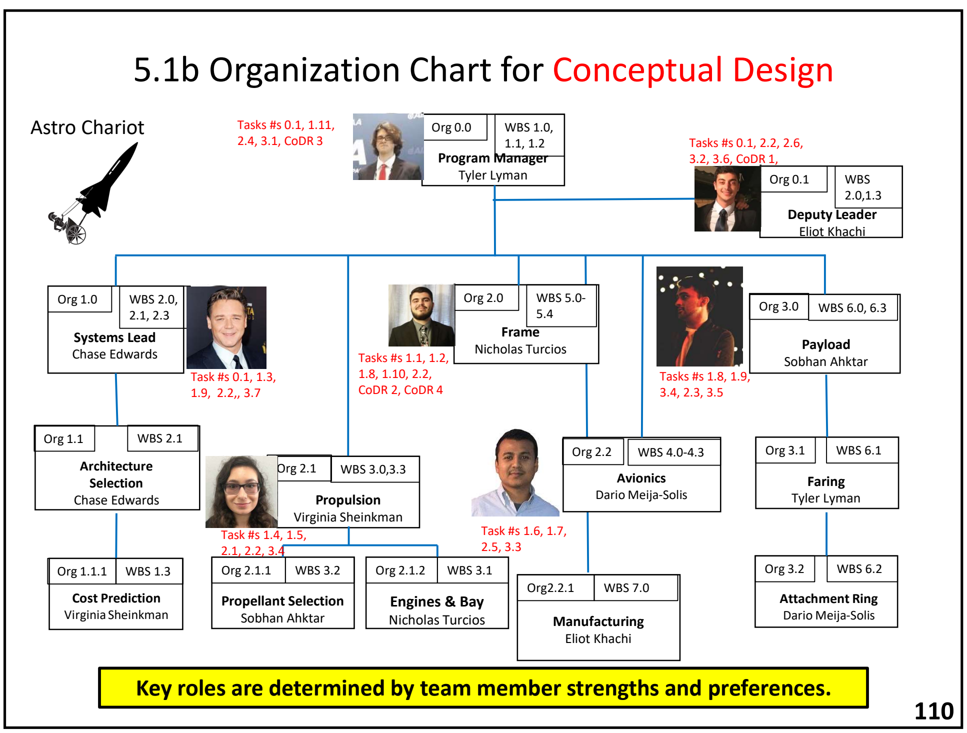
108

108



5.1a Organization Chart for the Project Management Plan of Preliminary Design
ARO 4200 Aerospace Program Management
Homework 2-2b Draft Organizational Chart to build Project Management Plan
Astro Chariot
Charts 1.0, 1.1, 1.2, 8.0a, 5.1a
Org 0.0 WBS #.# Program Manager Chase Edwards
Org 0.1 WBS #.# Deputy Leader Nicholas Turcios
Charts 1.3, 2.2, 2.1a-b, 8.0b
Charts 4.1a-c, 4.2a-b, 4.6a-f, 5.1b
Org 1.0 WBS #.# Systems Lead Tyler Lyman
Org 2.0 WBS #.# Chief Engineer Eliot Khachi
Charts 3.0a-e
Charts 2.3a-d, 1.4
Org 3.0 WBS #.# Business Ops Lead Sobhan Ahktar
Charts 7.1
Charts 3.1a-d
Org 1.1 WBS #.# Trade Study Lead Chase Edwards
Org 2.1 WBS #.# Director of Quality Virginia Sheinkman
Org 2.2 WBS #.# Director of Manufacturing Dario Meija-Solis
Org 3.1 WBS #.# Operations Analysis Tyler Lyman
Org 3.2 WBS #.# Cash Flow Management Dario Meija-Solis
Org 1.1.1 WBS #.# Nozzle Design Trade Study Virginia Sheinkman
Org 2.1.1 WBS #.# Process Controller Sobhan Ahktar
Org 2.1.2 WBS #.# Design Reviewer Nicholas Turcios
Org2.2.1 WBS #.# Production Planner Eliot Khachi
Key roles are determined by team member strengths and preferences
109

109



5.1b Organization Chart for Conceptual Design
Astro Chariot
Tasks #s 0.1, 1.11, 2.4, 3.1, CoDR 3
Org 0.0 WBS 1.0, 1.1, 1.2 Program Manager Tyler Lyman
Tasks #s 0.1, 2.2, 2.6, 3.2, 3.6, CoDR 1,
Org 0.1 WBS 2.0,1.3 Deputy Leader Eliot Khachi
Org 1.0 WBS 2.0, 2.1, 2.3 Systems Lead Chase Edwards
Task #s 0.1, 1.3, 1.9, 2.2,, 3.7
Org 2.0 WBS 5.0-5.4 Frame Nicholas Turcios
Tasks #s 1.1, 1.2, 1.8, 1.10, 2.2, CoDR 2, CoDR 4
Org 3.0 WBS 6.0, 6.3 Payload Sobhan Ahktar
Tasks #s 1.8, 1.9, 3.4, 2.3, 3.5
Org 1.1 WBS 2.1 Architecture Selection Chase Edwards
Org 2.1 WBS 3.0,3.3 Propulsion Virginia Sheinkman
Task #s 1.4, 1.5, 2.1, 2.2, 3.4
Org 2.2 WBS 4.0-4.3 Avionics Dario Meija-Solis
Task #s 1.6, 1.7, 2.5, 3.3
Org 3.1 WBS 6.1 Faring Tyler Lyman
Org 1.1.1 WBS 1.3 Cost Prediction Virginia Sheinkman
Org 2.1.1 WBS 3.2 Propellant Selection Sobhan Ahktar
Org 2.1.2 WBS 3.1 Engines & Bay Nicholas Turcios
Org2.2.1 WBS 7.0 Manufacturing Eliot Khachi
Org 3.2 WBS 6.2 Attachment Ring Dario Meija-Solis
Key roles are determined by team member strengths and preferences.
110

110

5.2a-1 Skill Requirements, Methods, and Labor Costs

Task #	Skill: Design Drawing ($22/hr)			Meth	Skill: Analysis ($24/hr)			Meth	Skill: Simulation ($20/hr)			Meth	Skill: Microsoft Office ($5/hr)			Meth	Totals	
	Head	Hr	$		Head	Hr	$		Head	Hr	$		Head	Hr	$		Total Hour	Total $
0.1													3	4	60	Word	4 Hr	$60
1.1	2	2	88	Sketch													2 Hr	$88
1.2	1	1	22	Mission Design	1	1	24	Mission Analysis									2 Hr	$46
1.3					1	2	48	Selection Analysis					1	2	10	PPT Excel	4 Hr	$58
1.4													4	4	80	Word	4 Hr	$80
1.5					2	2	96	Thrust Analysis	1	2	40	Propulsion Simulation					4 Hr	$136
1.6					2	5	240	Mission Analysis	2	5	200	Trajectory Simulation	1	2	10	Excel	12 Hr	$450
1.7					1	2	48	Mass Estimate					1	2	10	Excel	4 Hr	$58
1.8					2	4	192	Selection Analysis					1	2	10	Excel	6 Hr	$202
1.9					1	2	48	Feasibility Analysis	1	2	20	Mission Simulation					4 Hr	$68
1.10	1	2		Rough 3d Design	1	2	48	ARCH Selection									4 Hr	$48
1.11													6	2	60	PPT Word	2 Hr	$60

111

111

5.2a-2 Skill Requirements, Methods, and Labor Costs

Task #	Skill: Design Drawing ($22/hr)			Meth	Skill: Analysis ($24/hr)			Meth	Skill: Simulations ($20/hr)			Meth	Skill: Microsoft Office($5/hr)			Meth	Totals	
	Head	Hr	$		Head	Hr	$		Head	Hr	$		Head	Hr	$		Total Hr	Total$
2.1					1	4	96	Delta V Calc	1	4	80	Trajectory Sim	1	4	20	Word	8 Hr	$196
2.2	3	24	1584	CAD Modeling													24 Hr	$1584
2.3					2	10	480	Mass and Inertia	1	5	100	Trajectory Simulation					15 Hr	$580
2.4									2	6	240	Mission Simulation					6 Hr	$240
2.5					1	2	48	Feasibility Analysis	1	2	40	Mission SImulation					4 Hr	$88
2.6													3	6	90	PPT Word	6 Hr	$90
3.1								Stress Analysis	2	4	160	External Load Sim					4 Hr	$160
3.2					1	2	48	Stress Analysis	2	4	160	Internal Load Sim					4 Hr	$208
3.3					2	10	480	Controls Analysis	1	5	100	Launch Simulation					15 Hr	$580
3.4					1	3	72	Cost Analysis					1	3	15	Word	6 Hr	$87
3.5					2	3	144	Fault/Risk Analysis					2	3	30	PPT	6 Hr	$174
3.6					4	6	576	Manufacturing Analysis								Word	6 Hr	$576

112

112

5.2a-3 Skill Requirements, Methods, and Labor Costs

Task #	Skill: Design Drawing ($22/hr)			Meth	Skill: Analysis ($24/hr)			Meth	Skill: Simulation ($20/hr)			Meth	Skill: Microsoft Office($5/hr)			Meth	Totals	
	Head	Hr	$		Head	Hr	$		Head	Hr	$		Head	Hr	$		Total Hr	Total $
3.7													2	2	20	PPT Word	2 Hr	$20
CoD R 1	4	6	528	Drawing CAD													6 Hr	$5
CoD R 2													3	8	120	PPT Word	8 Hr	$120
CoD R 3													5	2	50	PPT	3 Hr	$50
CoD R 4													4	16	320	PPT	16 Hr	$320
Total																	185	6432

The hours and heads for each task are separated for each skill required for their respective task

113

113

5.2b - 1 Skill Requirements & Labor Cost- Preliminary Design

Task #	Skill: Analysis ($28/hr)			Meth	Skill: Design Drawings ($20/hr)			Meth	Skill: Simulations ($20/hr)			Meth	Skill: Technical Report Writing ($10/hr)			Meth	Totals	
	Head	Hr	$		Head	Hr	$		Head	Hr	$		Head	Hr	$		Total Hour	Total $
4.1	2	10	280	Trajectory Analysis					2	10	200	Trajectory Simulation					20	480
4.2	1	6	168	Propulsion Analysis	1	6	120	Engine Sketch									12	288
4.3	1	6	168	Mass Analysis													6	168
4.4	2	8	224	Req. Analysis					1	4	80	Trajectory Simulation					12	304
4.5													5	10	100	OPR 4 Technical Report	10	100
5.1					4	40	800	Internal 3D CAD Modelling									40	800
5.2					1	4	80	Payload Modelling	1	4	80	FOV Simulation					8	160
5.3	1	4	112	Mass Analysis	1	4	80	Inertia Simulation									8	192
5.4	2	4	112	Disturb. Analysis					2	4	80	Enviro. Simulation					8	192
5.5	2	12	336	Thermal Analysis													12	336
5.6	4	12	336	Loads Analysis													12	336
5.7	1	4	112	Attitude Analysis					2	8	160	Controls Simulation					12	272

114

114

5.2b -2 Skill Requirements & Labor Cost- Preliminary Design

Task #	Skill: Analysis ($28/hr)			Meth	Skill: Design Drawings ($20/hr)			Meth	Skill: Simulations ($20/hr)			Meth	Skill: Technical Report Writing ($10/hr)			Meth	Totals	
	Head	Hr	$		Head	Hr	$		Head	Hr	$		Head	Hr	$		Total Hour	Total$
5.8	1	6	168	Telecom. Analysis					1	6	120	Telecom. Simulation					12	288
5.9													6	8	80	OPR 5 Technical Report	8	80
PDR 1					3	9	180	3-Part view of Model									9	180
PDR 2	2	8	224	Structural Analysis													8	224
PDR 3									2	8	160	Command Subsystem Simulation					8	160
PDR 4	3	6	168	Loads Analysis													6	168
PDR 5	2	6	168	Cost Analysis													6	168
PDR 6									1	4	80	Emissions Simulation					4	80
PDR 7	1	4	112	Manufact. Analysis													4	112
PDR 8													7	1	10	Photo Operation	1	10
PDR 9													5	10	100	PDR Technical Report	10	100

The Preliminary Design skill requirements include the main skills required for all tasks and the cost of having individuals with those skills on the team.

115

115

5.4a-1 Resource Loaded Conceptual Design Schedule with EVMS

	12	13	14	15	1	2	3	4	5	6	7
BCWS	$ 252	$ 1,246	$ 1,354	$ 2,570	$ 3,693	$ 4,132	$ 4,132	$ 4,668	$ 5,216	$ 6,192	$ 6,432
BCWP	$ 223	$ 855	$ 1,332	$ 2,256	$ 3,541	$ 4,090	$ 4,132	$ 4,589	$ 5,189	$ 6,173	$ 6,432
ACWP	$250	$875	$1,400	$3,100	$3,790	$3,300	$3,200	$4,150	$4,500	$5,200	$5,500
CPI	0.890	0.977	0.951	0.728	0.934	1.239	1.291	1.106	1.153	1.187	1.169
SPI	0.883	0.686	0.983	0.878	0.959	0.990	1.000	0.983	0.995	0.997	1.000
ECAC ($)	$ 283.15	$ 1,274.70	$ 1,423.66	$ 3,530.68	$ 3,952.08	$ 3,333.72	$ 3,200.00	$ 4,221.20	$ 4,522.63	$ 5,216.34	$ 5,500.00
ETAC (wk)	18.121	23.309	16.270	18.223	16.684	16.164	16.000	16.275	16.080	16.050	16.000

0.1	Planned %	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
	Actual %	95%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
	Budget $	$ 60	$ 60	$ 60	$ 60	$ 60	$ 60	$ 60	$ 60	$ 60	$ 60	$ 60
	BCWP	$ 57	$ 60	$ 60	$ 60	$ 60	$ 60	$ 60	$ 60	$ 60	$ 60	$ 60
0.2	Planned %	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
	Actual %	95%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
	Budget $	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
	BCWP	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
1.1	Planned %	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
	Actual %	85%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
	Budget $	$ 88	$ 88	$ 88	$ 88	$ 88	$ 88	$ 88	$ 88	$ 88	$ 88	$ 88
	BCWP	$ 75	$ 88	$ 88	$ 88	$ 88	$ 88	$ 88	$ 88	$ 88	$ 88	$ 88
1.2	Planned %	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
	Actual %	90%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
	Budget $	$ 46	$ 46	$ 46	$ 46	$ 46	$ 46	$ 46	$ 46	$ 46	$ 46	$ 46
	BCWP	$ 41	$ 46	$ 46	$ 46	$ 46	$ 46	$ 46	$ 46	$ 46	$ 46	$ 46
1.3	Planned %	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
	Actual %	85%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
	Budget $	$ 58	$ 58	$ 58	$ 58	$ 58	$ 58	$ 58	$ 58	$ 58	$ 58	$ 58
	BCWP	$ 49	$ 58	$ 58	$ 58	$ 58	$ 58	$ 58	$ 58	$ 58	$ 58	$ 58
1.4	Planned %	0%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
	Actual %	0%	90%	100%	100%	100%	100%	100%	100%	100%	100%	100%
	Budget $	$ -	$ 80	$ 80	$ 80	$ 80	$ 80	$ 80	$ 80	$ 80	$ 80	$ 80
	BCWP	$ -	$ 72	$ 80	$ 80	$ 80	$ 80	$ 80	$ 80	$ 80	$ 80	$ 80

The Total Budget Cost for Work Scheduled by the end of Conceptual Design is $6,432 with an Estimated Cost At Completion of $5,500.

116

116

5.4a-2 Resource Loaded Conceptual Design Schedule with EVMS

1.5	Planned %	0%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
	Actual %	0%	80%	100%	100%	100%	100%	100%	100%	100%	100%	100%
	Budget $	$ -	$ 136	$ 136	$ 136	$ 136	$ 136	$ 136	$ 136	$ 136	$ 136	$ 136
	BCWP	$ -	$ 109	$ 136	$ 136	$ 136	$ 136	$ 136	$ 136	$ 136	$ 136	$ 136
1.6	Planned %	0%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
	Actual %	0%	50%	95%	100%	100%	100%	100%	100%	100%	100%	100%
	Budget $	$ -	$ 450	$ 450	$ 450	$ 450	$ 450	$ 450	$ 450	$ 450	$ 450	$ 450
	BCWP	$ -	$ 225	$ 428	$ 450	$ 450	$ 450	$ 450	$ 450	$ 450	$ 450	$ 450
1.7	Planned %	0%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
	Actual %	0%	50%	100%	100%	100%	100%	100%	100%	100%	100%	100%
	Budget $	$ -	$ 58	$ 58	$ 58	$ 58	$ 58	$ 58	$ 58	$ 58	$ 58	$ 58
	BCWP	$ -	$ 29	$ 58	$ 58	$ 58	$ 58	$ 58	$ 58	$ 58	$ 58	$ 58
1.8	Planned %	0%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
	Actual %	0%	75%	100%	100%	100%	100%	100%	100%	100%	100%	100%
	Budget $	$ -	$ 202	$ 202	$ 202	$ 202	$ 202	$ 202	$ 202	$ 202	$ 202	$ 202
	BCWP	$ -	$ 152	$ 202	$ 202	$ 202	$ 202	$ 202	$ 202	$ 202	$ 202	$ 202
1.9	Planned %	0%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
	Actual %	0%	25%	100%	100%	100%	100%	100%	100%	100%	100%	100%
	Budget $	$ -	$ 68	$ 68	$ 68	$ 68	$ 68	$ 68	$ 68	$ 68	$ 68	$ 68
	BCWP	$ -	$ 17	$ 68	$ 68	$ 68	$ 68	$ 68	$ 68	$ 68	$ 68	$ 68
1.10	Planned %	0%	0%	100%	100%	100%	100%	100%	100%	100%	100%	100%
	Actual %	0%	0%	100%	100%	100%	100%	100%	100%	100%	100%	100%
	Budget $	$ -	$ -	$ 48	$ 48	$ 48	$ 48	$ 48	$ 48	$ 48	$ 48	$ 48
	BCWP	$ -	0	$ 48	$ 48	$ 48	$ 48	$ 48	$ 48	$ 48	$ 48	$ 48
1.11	Planned %	0%	0%	100%	100%	100%	100%	100%	100%	100%	100%	100%
	Actual %	0%	0%	100%	100%	100%	100%	100%	100%	100%	100%	100%
	Budget $	$ -	$ -	$ 60	$ 60	$ 60	$ 60	$ 60	$ 60	$ 60	$ 60	$ 60
	BCWP	$ -	$ -	$ 60	$ 60	$ 60	$ 60	$ 60	$ 60	$ 60	$ 60	$ 60
2.1	Planned %	0%	0%	0%	100%	100%	100%	100%	100%	100%	100%	100%
	Actual %	0%	0%	0%	70%	100%	100%	100%	100%	100%	100%	100%
	Budget $	$ -	$ -	$ -	$ 196	$ 196	$ 196	$ 196	$ 196	$ 196	$ 196	$ 196
	BCWP	$ -	$ -	$ -	$ 137	$ 196	$ 196	$ 196	$ 196	$ 196	$ 196	$ 196
2.2	Planned %	0%	0%	0%	40%	90%	100%	100%	100%	100%	100%	100%
	Actual %	0%	0%	0%	30%	80%	100%	100%	100%	100%	100%	100%
	Budget $	$ -	$ -	$ -	$ 634	$ 1,426	$ 1,584	$ 1,584	$ 1,584	$ 1,584	$ 1,584	$ 1,584
	BCWP	$ -	$ -	$ -	$ 475	$ 1,267	$ 1,584	$ 1,584	$ 1,584	$ 1,584	$ 1,584	$ 1,584
2.3	Planned %	0%	0%	0%	67%	100%	100%	100%	100%	100%	100%	100%
	Actual %	0%	0%	0%	50%	100%	100%	100%	100%	100%	100%	100%
	Budget $	$ -	$ -	$ -	$ 386	$ 580	$ 580	$ 580	$ 580	$ 580	$ 580	$ 580
	BCWP	$ -	$ -	$ -	$ 290	$ 580	$ 580	$ 580	$ 580	$ 580	$ 580	$ 580
2.4	Planned %	0%	0%	0%	0%	57%	100%	100%	100%	100%	100%	100%
	Actual %	0%	0%	0%	0%	60%	90%	100%	100%	100%	100%	100%
	Budget $	$ -	$ -	$ -	$ -	$ 137	$ 240	$ 240	$ 240	$ 240	$ 240	$ 240
	BCWP	$ -	$ -	$ -	$ -	$ 144	$ 216	$ 240	$ 240	$ 240	$ 240	$ 240
2.5	Planned %	0%	0%	0%	0%	0%	100%	100%	100%	100%	100%	100%
	Actual %	0%	0%	0%	0%	0%	90%	100%	100%	100%	100%	100%
	Budget $	$ -	$ -	$ -	$ -	$ -	$ 88	$ 88	$ 88	$ 88	$ 88	$ 88
	BCWP	$ -	$ -	$ -	$ -	$ -	$ 79	$ 88	$ 88	$ 88	$ 88	$ 88
2.6	Planned %	0%	0%	0%	0%	0%	100%	100%	100%	100%	100%	100%
	Actual %	0%	0%	0%	0%	0%	90%	100%	100%	100%	100%	100%
	Budget $	$ -	$ -	$ -	$ -	$ -	$ 90	$ 90	$ 90	$ 90	$ 90	$ 90
	BCWP	$ -	$ -	$ -	$ -	$ -	$ 81	$ 90	$ 90	$ 90	$ 90	$ 90

The largest Budget Cost for Work Scheduled is $1,584 and belongs to Task 2.2, CAD Modeling.

117

117

5.4a-3 Resource Loaded Conceptual Design Schedule with EVMS

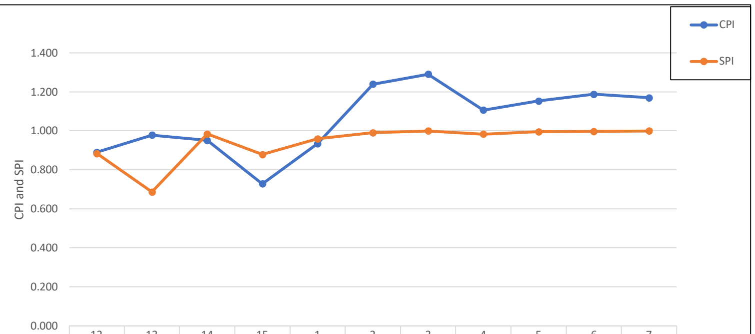
3.1	Planned %	0%	0%	0%	0%	0%	0%	0%	100%	100%	100%	100%
	Actual %	0%	0%	0%	0%	0%	0%	0%	60%	100%	100%	100%
	Budget $	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ 160	$ 160	$ 160	$ 160
	BCWP	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ 96	$ 160	$ 160	$ 160
3.2	Planned %	0%	0%	0%	0%	0%	0%	0%	67%	100%	100%	100%
	Actual %	0%	0%	0%	0%	0%	0%	0%	60%	100%	100%	100%
	Budget $	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ 139	$ 208	$ 208	$ 208
	BCWP	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ 125	$ 208	$ 208	$ 208
3.3	Planned %	0%	0%	0%	0%	0%	0%	0%	40%	100%	100%	100%
	Actual %	0%	0%	0%	0%	0%	0%	0%	40%	100%	100%	100%
	Budget $	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ 232	$ 580	$ 580	$ 580
	BCWP	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ 232	$ 580	$ 580	$ 580
3.4	Planned %	0%	0%	0%	0%	0%	0%	0%	0%	100%	100%	100%
	Actual %	0%	0%	0%	0%	0%	0%	0%	0%	80%	100%	100%
	Budget $	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ 87	$ 87	$ 87
	BCWP	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ 70	$ 87	$ 87
3.5	Planned %	0%	0%	0%	0%	0%	0%	0%	0%	25%	100%	100%
	Actual %	0%	0%	0%	0%	0%	0%	0%	0%	20%	90%	100%
	Budget $	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ 44	$ 174	$ 174
	BCWP	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ 35	$ 157	$ 174
3.6	Planned %	0%	0%	0%	0%	0%	0%	0%	0%	0%	100%	100%
	Actual %	0%	0%	0%	0%	0%	0%	0%	0%	0%	100%	100%
	Budget $	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ 576	$ 576
	BCWP	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ 576	$ 576
3.7	Planned %	0%	0%	0%	0%	0%	0%	0%	0%	0%	100%	100%
	Actual %	0%	0%	0%	0%	0%	0%	0%	0%	0%	90%	100%
	Budget $	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ 20	$ 20
	BCWP	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ 18	$ 20
CoDR 1	Planned %	0%	0%	0%	0%	0%	0%	0%	100%	100%	100%	100%
	Actual %	0%	0%	0%	0%	0%	0%	0%	80%	100%	100%	100%
	Budget $	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ 5	$ 5	$ 5	$ 5
	BCWP	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ 4	$ 5	$ 5	$ 5
CoDR 2	Planned %	0%	0%	0%	0%	0%	0%	0%	0%	0%	100%	100%
	Actual %	0%	0%	0%	0%	0%	0%	0%	0%	0%	100%	100%
	Budget $	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ 120	$ 120
	BCWP	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ 120	$ 120
CoDR 3	Planned %	0%	0%	0%	0%	0%	0%	0%	0%	0%	100%	100%
	Actual %	0%	0%	0%	0%	0%	0%	0%	0%	0%	100%	100%
	Budget $	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ 50	$ 50
	BCWP	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ 50	$ 50
CoDR 4	Planned %	0%	0%	0%	0%	0%	0%	0%	0%	0%	25%	100%
	Actual %	0%	0%	0%	0%	0%	0%	0%	0%	0%	25%	100%
	Budget $	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ 80	$ 320
	BCWP	0	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ 80	$ 320
Total	BCWP	$ 223	$ 855	$ 1,332	$ 2,256	$ 3,541	$ 4,090	$ 4,132	$ 4,589	$ 5,189	$ 6,173	$ 6,432
	Budget $	$ 252	$ 1,246	$ 1,354	$ 2,570	$ 3,693	$ 4,132	$ 4,132	$ 4,668	$ 5,216	$ 6,192	$ 6,432

The largest Budget Cost for Work Scheduled is $576 and belongs to Task 3.6, Manufacturing, Maintenance, and Disposal.

118

118

5.4b-1 EVMS Tracking for Conceptual Design



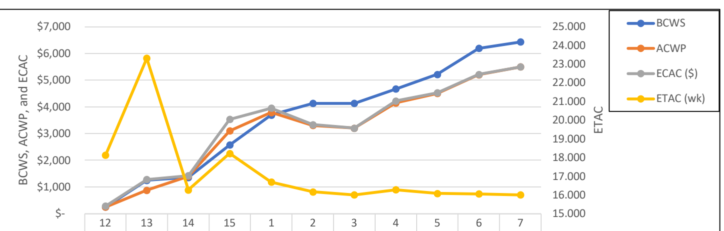
	12	13	14	15	1	2	3	4	5	6	7
CPI	0.890	0.977	0.951	0.728	0.934	1.239	1.291	1.106	1.153	1.187	1.169
SPI	0.883	0.686	0.983	0.878	0.959	0.990	1.000	0.983	0.995	0.997	1.000

Cost and schedule performance dip below planned early in Conceptual Design. By the end, the cost performance exceeds planned and schedule performance meets planned.

119

119

5.4b-2 EVMS Tracking for Conceptual Design



	12	13	14	15	1	2	3	4	5	6	7
BCWS	$252	$1,24	$1,35	$2,57	$3,69	$4,13	$4,13	$4,66	$5,21	$6,19	$6,43
ACWP	$250	$875	$1,400	$3,100	$3,790	$3,300	$3,200	$4,150	$4,500	$5,200	$5,500
ECAC ($)	$283.	$1,27	$1,42	$3,53	$3,95	$3,33	$3,20	$4,22	$4,52	$5,21	$5,50
ETAC (wk)	18.121	23.309	16.270	18.223	16.684	16.164	16.000	16.275	16.080	16.050	16.000

Actual cost for work performed (ACWP) exceeds the scheduled budget costs (BSWS) early in the program, but cost savings are expected in the weeks that follow.

120

120

5.4c-1 Resource Loaded Preliminary Design Schedule with EVMS

	8	9	10	11	12
BCWS	$ 1,290	$ 2,616	$ 3,020	$ 4,257	$ 5,198
BCWP	$ 1,250	$ 2,637	$ 3,020	$ 4,227	$ 5,198
ACWP	$ 1,265.00	$ 2,630.00	$ 2,990.00	$ 4,100.00	$ 5,250.00
CPI	0.988	1.003	1.010	1.031	0.990
SPI	0.969	1.008	1.000	0.993	1.000
ECAC ($)	$ 1,305.90	$ 2,608.49	$ 2,990.00	$ 4,128.93	$ 5,250.00
ETAC (wk)	16.517	15.869	16.000	16.113	16.000
Schedule % complete:					
4.1 Planned %	100%	100%	100%	100%	100%
Actual %	100%	100%	100%	100%	100%
Budget $	$ 480.00	$ 480.00	$ 480.00	$ 480.00	$ 480.00
BCWP	$ 480	$ 480	$ 480	$ 480	$ 480
4.2 Planned %	100%	100%	100%	100%	100%
Actual %	100%	100%	100%	100%	100%
Budget $	$ 288.00	$ 288.00	$ 288.00	$ 288.00	$ 288.00
BCWP	$ 288	$ 288	$ 288	$ 288	$ 288
4.3 Planned %	100%	100%	100%	100%	100%
Actual %	100%	100%	100%	100%	100%
Budget $	$ 168.00	$ 168.00	$ 168.00	$ 168.00	$ 168.00
BCWP	$ 168	$ 168	$ 168	$ 168	$ 168
4.4 Planned %	100%	100%	100%	100%	100%
Actual %	90%	100%	100%	100%	100%
Budget $	$ 304.00	$ 304.00	$ 304.00	$ 304.00	$ 304.00
BCWP	$ 274	$ 304	$ 304	$ 304	$ 304

The Total Budget Cost for Work Scheduled by the end of Preliminary Design is $5,198 with an Estimated Cost At Completion of $5,250.

121

121

5.4c-2 Resource Loaded Preliminary Design Schedule with EVMS

4.5 Planned %	50%	100%	100%	100%	100%
Actual %	40%	100%	100%	100%	100%
Budget $	$ 50.00	$ 100.00	$ 100.00	$ 100.00	$ 100.00
BCWP	$ 40	$ 100	$ 100	$ 100	$ 100
5.1 Planned %	0%	80%	100%	100%	100%
Actual %	0%	85%	100%	100%	100%
Budget $	$ -	$ 700.00	$ 800.00	$ 800.00	$ 800.00
BCWP	$ -	$ 744	$ 800	$ 800	$ 800
5.2 Planned %	0%	100%	100%	100%	100%
Actual %	0%	100%	100%	100%	100%
Budget $	$ -	$ 160.00	$ 160.00	$ 160.00	$ 160.00
BCWP	$ -	$ 160	$ 160	$ 160	$ 160
5.3 Planned %	0%	0%	100%	100%	100%
Actual %	0%	0%	100%	100%	100%
Budget $	$ -	$ -	$ 192.00	$ 192.00	$ 192.00
BCWP	$ -	$ -	$ 192	$ 192	$ 192
5.4 Planned %	0%	100%	100%	100%	100%
Actual %	0%	100%	100%	100%	100%
Budget $	$ -	$ 192.00	$ 192.00	$ 192.00	$ 192.00
BCWP	$ -	$ 192	$ 192	$ 192	$ 192
5.5 Planned %	0%	67%	100%	100%	100%
Actual %	0%	60%	100%	100%	100%
Budget $	$ -	$ 223.78	$ 336.00	$ 336.00	$ 336.00
BCWP	$ -	$ 202	$ 336	$ 336	$ 336

122

122

5.4c-3 Resource Loaded Preliminary Design Schedule with EVMS

5.6	Planned %	0%	0%	0%	67%	100%
	Actual %	0%	0%	0%	70%	100%
	Budget $	$ -	$ -	$ -	$ 225.12	$ 336.00
	BCWP	$ -	$ -	$ -	$ 235	$ 336
5.7	Planned %	0%	0%	0%	100%	100%
	Actual %	0%	0%	0%	100%	100%
	Budget $	$ -	$ -	$ -	$ 272.00	$ 272.00
	BCWP	$ -	$ -	$ -	$ 272	$ 272
5.8	Planned %	0%	0%	0%	33%	100%
	Actual %	0%	0%	0%	25%	100%
	Budget $	$ -	$ -	$ -	$ 95.90	$ 288.00
	BCWP	$ -	$ -	$ -	$ 72	$ 288
5.9	Planned %	0%	0%	0%	100%	100%
	Actual %	0%	0%	0%	100%	100%
	Budget $	$ -	$ -	$ -	$ 80.00	$ 80.00
	BCWP	$ -	$ -	$ -	$ 80	$ 80
PDR 1	Planned %	0%	0%	0%	100%	100%
	Actual %	0%	0%	0%	100%	100%
	Budget $	$ -	$ -	$ -	$ 180.00	$ 180.00
	BCWP	$ -	$ -	$ -	$ 180	$ 180
PDR 2	Planned %	0%	0%	0%	100%	100%
	Actual %	0%	0%	0%	100%	100%
	Budget $	$ -	$ -	$ -	$ 224.00	$ 224.00
	BCWP	$ -	$ -	$ -	$ 224	$ 224
PDR 3	Planned %	0%	0%	0%	100%	100%
	Actual %	0%	0%	0%	90%	100%
	Budget $	$ -	$ -	$ -	$ 160.00	$ 160.00
	BCWP	$ -	$ -	$ -	$ 144	$ 160

123

123

5.4c-4 Resource Loaded Preliminary Design Schedule with EVMS

PDR 4	Planned %	0%	0%	0%	0%	100%
	Actual %	0%	0%	0%	0%	100%
	Budget $	$ -	$ -	$ -	$ -	$ 168.00
	BCWP	$ -	$ -	$ -	$ -	$ 168
PDR 5	Planned %	0%	0%	0%	0%	100%
	Actual %	0%	0%	0%	0%	100%
	Budget $	$ -	$ -	$ -	$ -	$ 168.00
	BCWP	$ -	$ -	$ -	$ -	$ 168
PDR 6	Planned %	0%	0%	0%	0%	100%
	Actual %	0%	0%	0%	0%	100%
	Budget $	$ -	$ -	$ -	$ -	$ 80.00
	BCWP	$ -	$ -	$ -	$ -	$ 80
PDR 7	Planned %	0%	0%	0%	0%	100%
	Actual %	0%	0%	0%	0%	100%
	Budget $	$ -	$ -	$ -	$ -	$ 112.00
	BCWP	$ -	$ -	$ -	$ -	$ 112
PDR 8	Planned %	0%	0%	0%	0%	100%
	Actual %	0%	0%	0%	0%	100%
	Budget $	$ -	$ -	$ -	$ -	$ 10.00
	BCWP	$ -	$ -	$ -	$ -	$ 10
PDR 9	Planned %	0%	0%	0%	0%	100%
	Actual %	0%	0%	0%	0%	100%
	Budget $	$ -	$ -	$ -	$ -	$ 100.00
	BCWP	$ -	$ -	$ -	$ -	$ 100

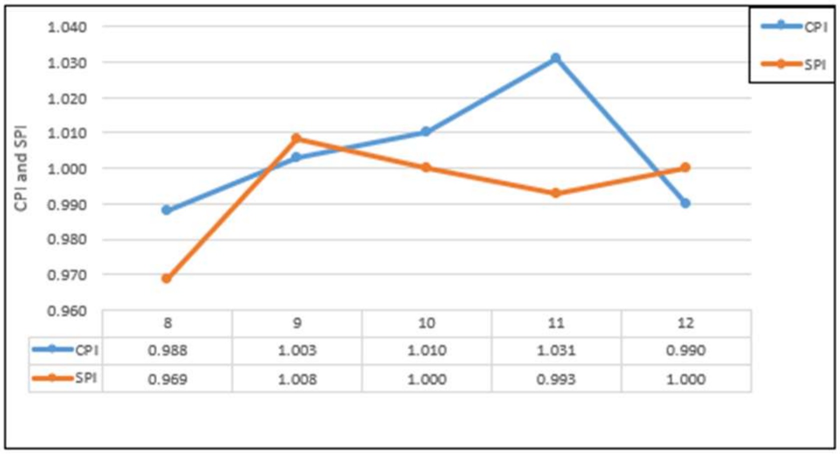
Total	BCWP	$ 1,250	$ 2,637	$ 3,020	$ 4,227	$ 5,198
	Budget $	$ 1,290	$ 2,616	$ 3,020	$ 4,257	$ 5,198

The Preliminary Design schedule will end on time and with a budget of 5,198$.

124

124

5.4d-1 Resource Loaded Preliminary Design Schedule with EVMS



	8	9	10	11	12
CPI	0.988	1.003	1.010	1.031	0.990
SPI	0.969	1.008	1.000	0.993	1.000

CPI and SPI vary across the duration of Preliminary Design and end around 1.

125

125

5.4d-2 Resource Loaded Preliminary Design Schedule with EVMS

	8	9	10	11	12
BCWS	$1,290	$2,616	$3,020	$4,257	$5,198
ACWP	$1,265.00	$2,630.00	$2,990.00	$4,100.00	$5,250.00
ECAC ($)	$1,305.90	$2,608.49	$2,990.00	$4,128.93	$5,250.00
ETAC (wk)	16.517	15.869	16.000	16.113	16.000

The ACWP ends up slightly higher than the BCWS going slightly over-budget but still ends on time.

126

126

5.6a-1 Program Planning Document Requirements

NPR 7120.5D Program Plan – Control Plans	Formulation		Implementation			
	KDP 0	KDP I	KDP II	KDP III	KDP IV	KDP n
1. Technical, Schedule and Cost Control Plan	Preliminary	Baseline	Update	Update	Update	Update
2. Safety and Mission Assurance Plan	Preliminary	Baseline	Update	Update	Update	Update
3. Risk Management Plan	Preliminary	Baseline	Update	Update	Update	Update
4. Acquisition Data	Preliminary	Baseline	Update	Update	Update	Update
5. Technology Development Plan	Preliminary	Baseline	Update	Update	Update	Update
6. Systems Engineering Management Plan	Preliminary	Baseline	Update	Update	Update	Update
7. Review Plan	Preliminary	Baseline	Update	Update	Update	Update
8. Mission Operations Plan	Preliminary	Baseline	Update	Update	Update	Update
9. Environmental Management Plan	Preliminary	Baseline	Update	Update	Update	Update
10. Logistics Plan	Preliminary	Baseline	Update	Update	Update	Update
11. Science Data Management Plan	Preliminary	Baseline	Update	Update	Update	Update
12. Information and Configuration Management Plan	Preliminary	Baseline	Update	Update	Update	Update
13. Security Plan	Preliminary	Baseline	Update	Update	Update	Update
14. Export Control Plan	Preliminary	Baseline	Update	Update	Update	Update
15. Education and Public Outreach Plan	Preliminary	Baseline	Update	Update	Update	Update

Preliminary plans are formed at the first Key Design Point, followed by modifications to meet baseline requirements, and updates throughout program implementation.

127

127

5.6a-2 Typical Contract Reports

Products	Pre-Phase A	Phase A	Phase B	Phase C	Phase D	Phase E
	KDP A	KDP B	KDP C	KDP D	KDP E	KDP F
Headquarters and Program Products						
1. FAD	Approved					
2. Program Requirements on the Project	Draft	Baseline	Update			
3. ASM minutes		Baseline				
4. NEPA compliance documents			Env Assess			
5. Interagency and International Agreements			Baseline			
Project Technical Products						
1. Mission Concept Report	Preliminary	Baseline				
2. System Level Requirements		Preliminary	Baseline			
3. Preliminary Design Reports			Baseline			
4. Missions Operations Concept		Preliminary	Baseline			
5. Technology Readiness Assessment			Baseline			
6. Missile System Pre-Launch Safety Package			Preliminary	Baseline		
7. Detailed Design Package				Baseline		
8. As-built Hardware and Software Documentation					Baseline	
9. Verification and Validation Report					Baseline	
10. Operations Handbook				Preliminary	Baseline	
11 Orbital Debris Assessment		Initial	Preliminary	Baseline		
12. Mission Report						

Headquarters and Program Products meet their baseline by Phase B and Project Technical Products are produced in the 5 phases.

128

128

5.6a-3 Typical Contract Reports

Products	Pre-Phase A	Phase A	Phase B	Phase C	Phase D	Phase E
	KDP A	KDP B	KDP C	KDP D	KDP E	KDP F
Project Planning, Cost and Schedule Products						
1. Work Agreements for next phase	Baseline	Baseline	Baseline	Baseline	Baseline	Baseline
2. Integrated Baseline	Draft	Preliminary	Baseline			
3. Project Plan		Preliminary	Baseline			
4. CADRe		Preliminary	Baseline	Update		
5. Planetary Protection Plan		Planet Protect	Baseline			
6. Business Case Analysis for Infrastructure		Preliminary	Baseline			
7. Range Safety Risk Management Plan			Preliminary	Baseline		
8. Systems Decommissioning Disposal Plan				Preliminary		
KDP Readiness Products						
1. Standing Review Board Report	Final	Final	Final	Final	Final	Final
2. Project Manager Readiness Report	Final	Final	Final	Final	Final	Final
3. CMC Readiness Report	Final	Final	Final	Final	Final	Final
4. Program Manager Readiness Report	Final	Final	Final	Final	Final	Final
5. MD-PMC Readiness Report	Final	Final	Final	Final	Final	Final
6. Governing PMC Readiness Report	Final	Final	Final	Final	Final	Final

Project Planning, Cost and Schedule Products meet most baseline requirements by Phase B, and KDP Readiness Products are produced in each phase of the program.

129

129

5.6a-3b-1 Reports –Map to WBS

Report	Title	WBS	SRR	1st Prog Rev.	2nd Prog Rev.	3rd Prog Rev.	SDR/ CoDR	PDR and ORE	4th Prog Rev.	5th Prog Rev.	6th Prog Rev.	PDR	Submit
SRR.1-ReqD PDRR.2-ReqD	System Level Requirements	1.1	Baseline										
1.1-MisP 4.1-MisP	Mission Profile	1.1	Prelim	1.1 – Baseline					4.1- Update				
1.2-PMPE 4.2- PMPE	Preliminary Mass and Power Estimates	1.2		1.2- Baseline					4.2- Update				
1.3-LVA 4.3-LVA	Launch Vehicle Analysis	1.2		1.3- Baseline					4.3- Update				
1.4	Trajectory Analysis	4.4		Baseline					1.4- Update				
1.5	Propulsion System	4.1		Baseline					1.5- Update				
1.6	Trade Studies	1.2		Baseline					1.6- Update				
4.7 ADS	Architecture Down Select	1.2											
2.1-CAD 5.1-CAD	CAD drawings of stowed and mission config	4.2			2.1- Baseline				5.1- Update				
2.2-ENV 5.2-ENV	Environmental disturbances	4.2			2.2- Baseline				5.2- Update				

Tasks shown must be completed before the 1st Progress Review and updated before the 4th Progress review.

130

130

5.6a-3b-2 Reports –Map to WBS

Report	Title	WBS	SRR	1^{st} Prog Rev.	2^{nd} Prog Rev.	3^{rd} Prog Rev.	SDR/ CoDR	PDR and ORE	4^{th} Prog Rev.	5^{th} Prog Rev.	6^{th} Prog Rev.	PDR	Submit
2.3	Heating and Thermal	4.2			2.3-Baseline								
2.4	Detailed Mass and Inertia	4.2			2.4-Baseline								
2.5	Attitude Control System	4.1			2.5-Baseline								
2.6	Payload and Bus layout	4.2			2.6-Baseline								
3.1-CDS 6.1-CDS	Command and data subsystem	4.3				3.1-Baseline					6.1-Update		
3.2	Telecommunications	4.3				Baseline					Update		
3.3	Quasi-static launch loads	4.2				Baseline					Update		
3.4	Fault analysis	1.0				Baseline					Update		
3.5	Lifetime assessment	3.1				Baseline					Update		
3.6	CAD drawings of internals	4.2				Baseline					Update		
3.7	Cost analysis	1.3				Baseline					Update		

Tasks must be completed for the second and third progress review and updated before the 6^{th} and final progress review.

131

131

5.6a-3b-3 Reports –Map to WBS

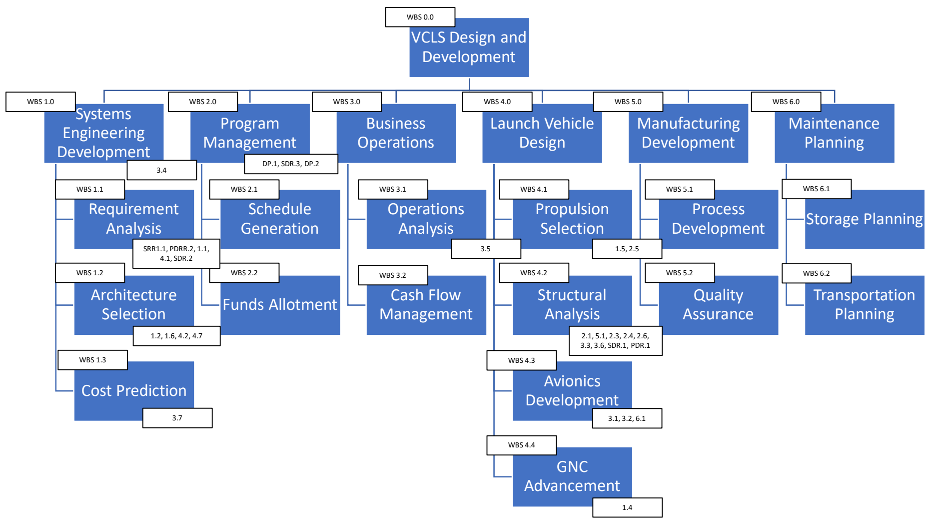
Report	Title	WBS	SRR	1^{st} Prog Rev.	2^{nd} Prog Rev.	3^{rd} Prog Rev.	SDR/ CoDR	PDR and ORE	4^{th} Prog Rev.	5^{th} Prog Rev.	6^{th} Prog Rev.	PDR	Submit
DP.1	Draft of design proposal	2.0				Draft							Final
SDR.1.-3V PDR.1,-3V	Dimensional 3 view	4.2									SDR.1-3V Baseline	PDR.1-3V Baseline	
SDR.2	Mission Diagram	1.1									Baseline		
SDR.3	Team member photo sheet	2.0									Baseline	Update	
DP.2 Final	Final Design Proposal	2.0				Draft							Final

The design proposal must be submitted to AIAA by the submittal date and all previous tasks must be updated and finalized.

132

132

Chart 5.6a-4 Documentation Responsibility Mapped to WBS



The VCLS System will be planned and executed according to the plan developed in WBS 1.0 Systems Engineering Development.

133

133

5.6 b-1 - Baseline Definition for Configuration Management

Configuration Data	Functional Baseline (end of Conceptual Design)	Allocated Baseline (end of Preliminary Design)	Product Baseline (end of Detail Design)
Architecture Design	• Level 1 Arch. Perf. Reqmts. • Architecture elements WBS • Architecture Selection and Feasibility Analysis		
Hardware Design		• Structural materials definition • Structural bones layouts drawings • Loads and stress analysis • Detail environmental disturbances	• Detail structures design drawings • Finalize stress, loads, and aerodynamics diagrams
Software Design	• Level 1 Software reqmnt's • Software subsystem allocation and architecture flow charts	• Telecommunications hardware description • Refine attitude control system • Trajectory simulations	• GNC systems finalization • Finalize trajectory simulations • Finalize avionics programs

Final products for hardware design and software design include the detailed design drawings and refined GNC/trajectory simulations, respectively.

134

134

5.6 b-2 - Baseline Definition for Configuration Management

Configuration Data	Functional Baseline (end of Conceptual Design)	Allocated Baseline (end of Preliminary Design)	Product Baseline (end of Detail Design)
Operations Design	• Level 1 Ops Reqmt's • Mission concept functional flow • Ground support architecture definition	• Ground station type and scheduling defined • Command/data subsystems • Launch and abort sequence flow charts	• Detailed operations scheduling and cost
Maintenance Design	• Level 1 Maintenance Rqmnt's • Maintenance functional flowcharts	• Test and refurbishment facilities • Storage and transportation type defined	• Detailed maintenance & disposal scheduling and cost
Manufacturing Design	• Level 1 Manufacturing Rqmnt's • Hardware subsystem allocation	• Manufacturing facilities and production plants defined • Hardware specifications defined for inspection	• Detailed manufacturing scheduling and cost

Operations, Maintenance, and Manufacturing Design scheduling and cost baselines will be finished prior to the end of Detail Design.

135

135

6.1 CER Independent Variables for the WBS Product Tree

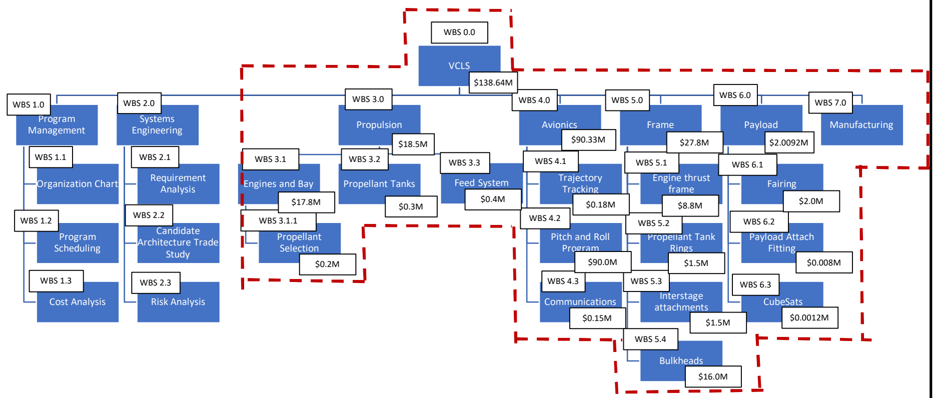
WBS#	Acquisition cost/unit	Function of	Equation	$Cost/unit	Total Cost
3.1	Engines	Thrust	$100/Newton	$8.8M	$17.6M
3.1.1	Propellant	Mass of propellant	$20/kg	$0.2M	$0.2M
3.2	Propellant Tanks	Volume of propellant	$10/m^3	$0.3M	$0.3M
3.3	Feed System	Mass of hardware	$400/kg	$0.4M	$0.4M
4.1	Trajectory tracking	Range	$300/km	$0.18M	$0.18M
4.2	Gyroscope program	Lines of code	$30/line of code	$30M	$90.0M
4.3	Communication system	Range	$250/km	$0.15M	$0.15M
5.1	Thrust structure	Thrust	$50/Newton	$4.4M	$8.8M
5.2	Propellant tank ring	Stress	$40/kPa	$1.5M	$1.5M
5.3	Interstage attachments	Stress	$40/kPa	$1.5M	$1.5M
5.4	Bulkheads	Stress	$40/kPa	$2M	$16.0M
6.1	PLF	Stress	$40/kPa	$2M	$2.0M
6.2	PAF	Mass	$200/kg	$8000	$0.008
6.3	Cubesat	Quantity	$60/Cubesat	$1200	$0.0012M

Summing the cost of each component in WBS 3.0-6.0 results in a total cost of $138.64 million.

136

136

6.2 Vehicle Acquisition $ Cost Allocation to Product Tree Portion of WBS



The cost of each component adds up through the product WBS to a total of $138,640,000.

137

137

7.1.1 Risk Statements

Programmatic Risk

- P1.0 If the company that would provide the components is late for delivery due to a slow economy during the viral outbreak then the assembly, and thus the launch, will be delayed pass the end date.
- P2.0 If a supplier contractor has an exclusive technology that is required for program completion due to a utility design patent or monopolization in the market then we lose leverage over bargaining for price.
- P3.0 If the technology development of a candidate architecture is delayed due to unfamiliarity of problems faced then the delivery date to the customer will be late.

Technical Risk

- 1.0 If the launch vehicle cannot reach the desired orbit due to sloshing causing ΔV losses, then the payload will not be injected into the desired orbit.
- 2.0 If the launch vehicle's autopilot fails due to malfunctions in various sensors, then the vehicle will be forced to abort the mission.
- 3.0 If the launch vehicle cannot be constructed out of readily available materials due to a lack in said materials, then a new material is required, or the materials must be bought from a different provider.

There are 3 programmatic risks and 3 technical risks that are to be considered important to analyze and mitigate.

138

138

7.1.2 Risk Cube

Severity					
5			T1.0 T8.0		
4				T9.0	P1.0
3			P2.0	P3.0	
2					
1					
	1	2	3	4	5

Likelihood

Programmatic Risks

Risk #	Req #	Risk Description
P1.0	P1.0	The company that would provide the components is late for delivery
P2.0	P2.0	A supplier contractor has an exclusive technology that is required for program completion
P3.0	P3.0	The technology development of a candidate architecture is delayed

Technical Risks

Risk #	Req #	Risk Description
T1.0	1.0	Sloshing instability causing loss of ΔV
T2.0	8.0	Faulty/damaged sensors can disable autopilot and cause LV to lose control
T3.0	9.0	Lack of desired materials will lead to redesigns for more readily available materials

The risk cube can help mitigate and visually interpret high to low risk requirements.

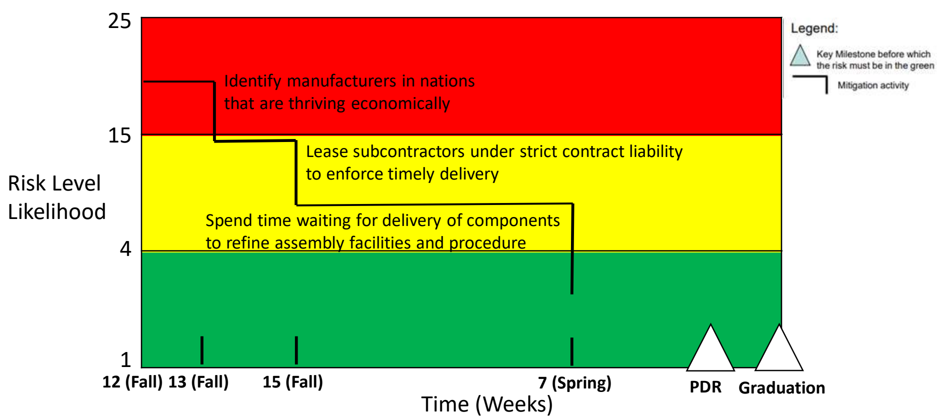
139

139

7.1.3-1 Mitigation Waterfall – Programmatic Risk

REQ P1.0: The program will finish no later than the date of graduation

Risk P1.0: If the company that would provide the components is late for delivery due to a slow economy during the viral outbreak then the assembly, and thus the launch, will be delayed pass the end date.



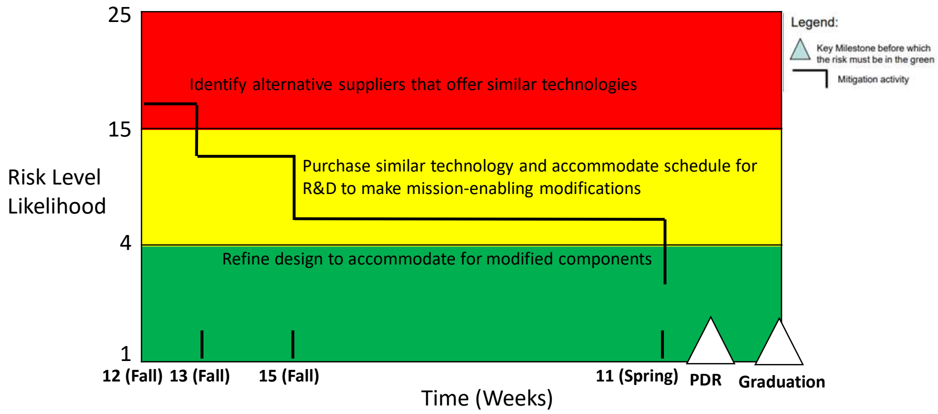
Risk P1.0 is mitigated by identifying and leasing reliable subcontractors.

140

140

7.1.3-2 Mitigation Waterfall – Programmatic Risk

REQ P2.0: The project will not exceed cost negotiated with vendor
Risk P2.0: <u>If</u> a supplier contractor has an exclusive technology that is required for program completion <u>due to</u> a utility design patent or monopolization in the market <u>then</u> we lose leverage over bargaining for price.



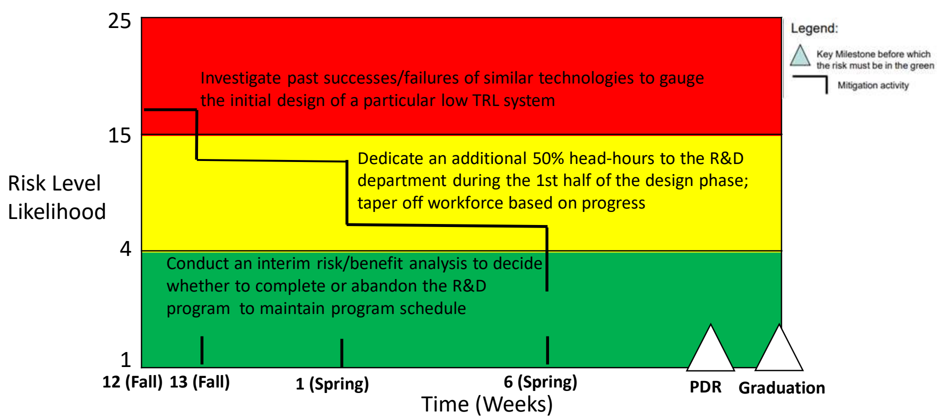
Risk P2.0 is mitigated by finding alternative technologies, modifying components, or R&D solutions to avoid monopolized technology.

141

141

7.1.3-3 Mitigation Waterfall – Programmatic Risk

REQ P3.0: The product will be ready to be delivered no more than one month after finishing PDR.
Risk P3.0: <u>If</u> the technology development of a candidate architecture is delayed <u>due to</u> unfamiliarity of problems faced <u>then</u> the delivery date to the customer will be late.



Risk P3.0 is mitigated by increasing the work force during the initial design phase and conducting an interim progress report to assess program feasibility.

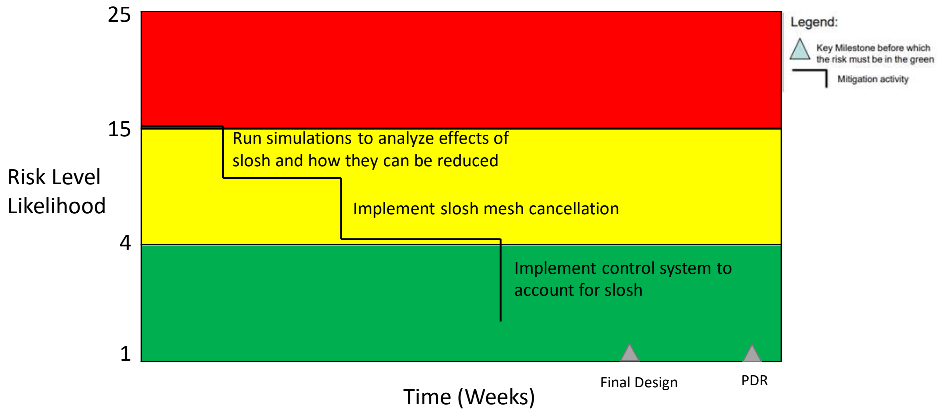
142

142

7.1.3-4 Mitigation Waterfall – Technical Risk

REQ T1.0: The system must be able to complete both Mission 1 and Mission 2 in the VCLS RFP

- Risk T1.0: If the launch vehicle cannot reach the desired orbit due to sloshing causing ΔV losses, then the payload will not be injected into the desired orbit



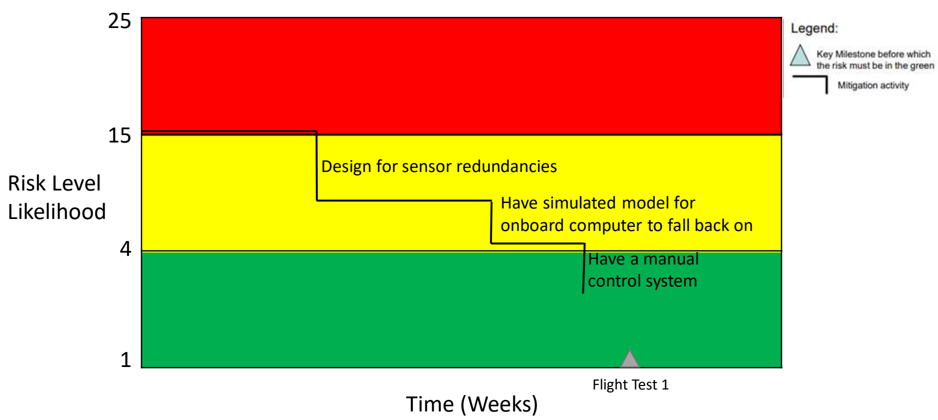
Risk T1.0 is mitigated in 3 steps by running further analysis, implementing slosh mesh cancellation techniques and implementing control systems to compensate for it.

143

143

7.1.3-5 Mitigation Waterfall – Technical Risk

REQ T6.0: The system must be controlled entirely remotely
Risk T2.0: If the launch vehicle's autopilot fails due to malfunctions in various sensors, then the vehicle will be forced to abort the mission



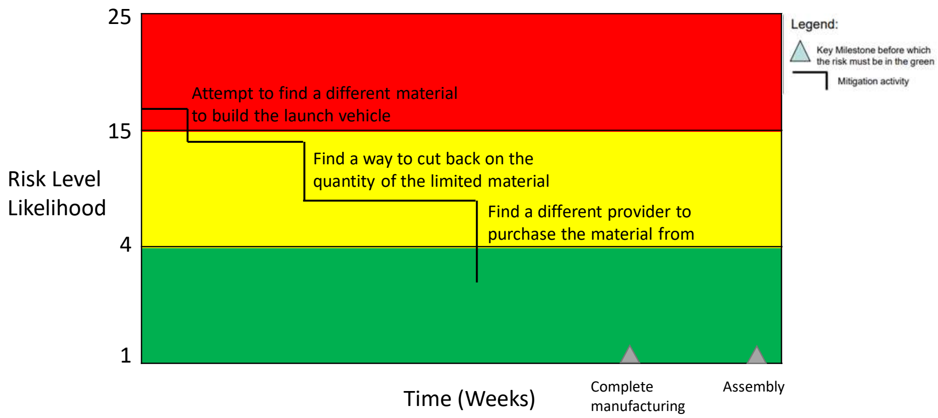
Risk T2.0 is mitigated with sensor redundancies and a method for manual control.

144

144

7.1.3-6 Mitigation Waterfall – Technical Risk

REQ T9.0: The launch vehicle must be constructed from a readily available material
Risk T3.0: If the launch vehicle cannot be constructed out of readily available materials due to high material requirements, then a new material is required, or the materials must be bought from a different provider



Risk T3.0 is mitigated by searching for alternative materials, finding ways to cut back on materials, and finding a different provider lined up.

145

145

7.2.1 Opportunity Statements

Program Opportunity
- 1.0 If price reduction on avionics hardware is acquired due to improved business relationship with specific suppliers, then the potential benefit to the mission will be a reduction of hardware cost.
- 2.0 If technological improvements in 3-dimensional printing are implemented due to technological development reducing in additive manufacturing cost, then the program cost will be reduced.
- 3.0 If manufacturing operates near the launch facility due to a third-party manufacturing facility opening for purchase at the launch site, then transportation costs would be reduced.

Technical Opportunity
- 1.0 If technological development of improved composite materials are implemented due to advances in material sciences, then the potential benefit to the system is a reduction in structural mass and a stronger overall structure.
- 2.0 If technological development of aerospike engines are implemented due to proven reliability of aerospike engines and increased production of aerospike engines, then less propellant mass and cost is needed.
- 3.0 If new suitable launch locations for Sun-Synchronous Orbits are developed due to new international agreements, then a better location may be used so that less fuel mass and cost is needed.

There are 3 programmatic opportunities and 3 technical opportunities that are to be considered important to analyze and capitalize on.

146

146

7.2.2 Opportunity Management Cube

Likelihood					
5					
4					
3		P1.0	P3.0		
2			T1.0 P2.0	T3.0	
1					T2.0
	1	2	3	4	5

Benefit

Program Opportunities		
Opp. #	Req #	Opportunity Description
P1.0	C2.0	Reduced cost of materials
P2.0	C2.0	3D Printing cost reduction
P3.0	C2.0	Reduced Transportation

Technical Opportunities		
Opp #	Req #	Opportunity Description
T1.0	T2.0	Reduction in mass
T2.0	T2.6	Aerospike engine improvement
T3.0	T3.0-1	New launch site

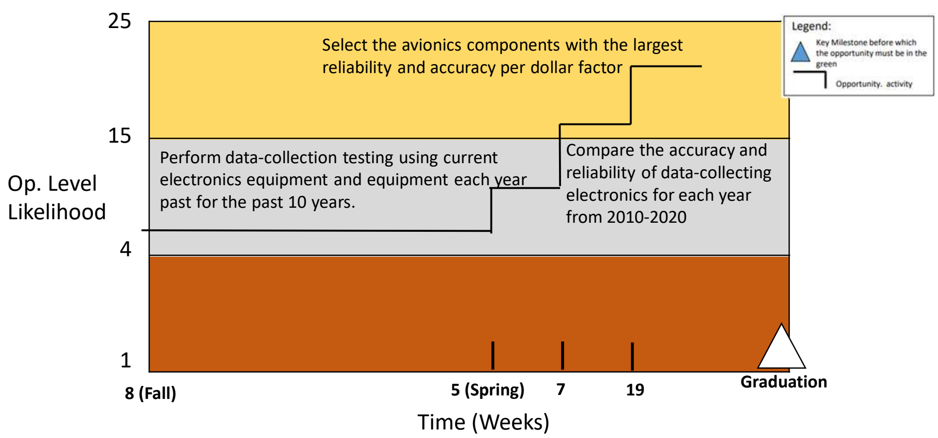
The opportunity cube provides a visual interpretation of high to low opportunity requirements.

147

147

7.2.3-1 Opportunity "Fish Ladder" – Program Opportunity

REQ C1.0:
Opportunity P1.0: If the costs of outdated electronics hardware is reduced due to the continuing trend of increased computational power, then the potential benefit for using outdated yet, mission-enabling avionics is a reduction in total hardware costs.



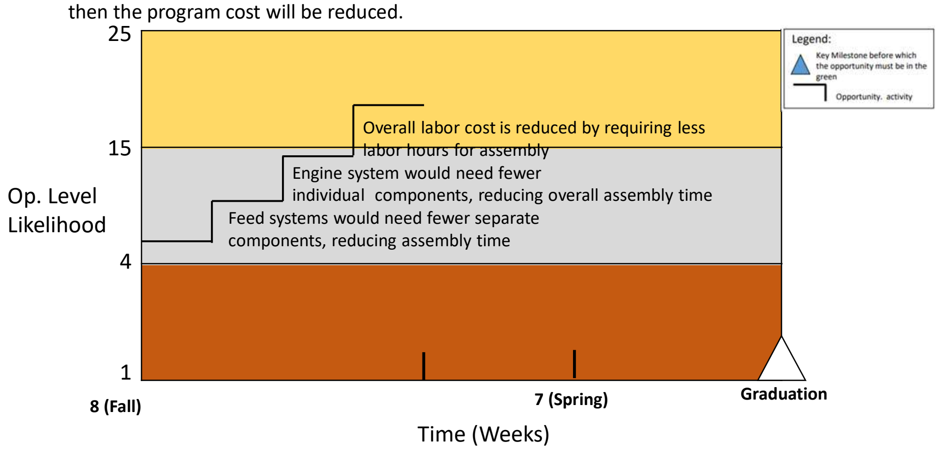
Opportunity P1.0 is capitalized on by testing, comparing, and selecting avionics hardware based on reliability, accuracy, and costs.

148

148

7.2.3-2 Opportunity "Fish Ladder" – Program Opportunity

REQ C2.0: Total program development cost must not exceed $2 billion
Opportunity P2.0: If technological improvements in 3-dimensional printing are implemented due to technological development reducing in additive manufacturing cost, then the program cost will be reduced.



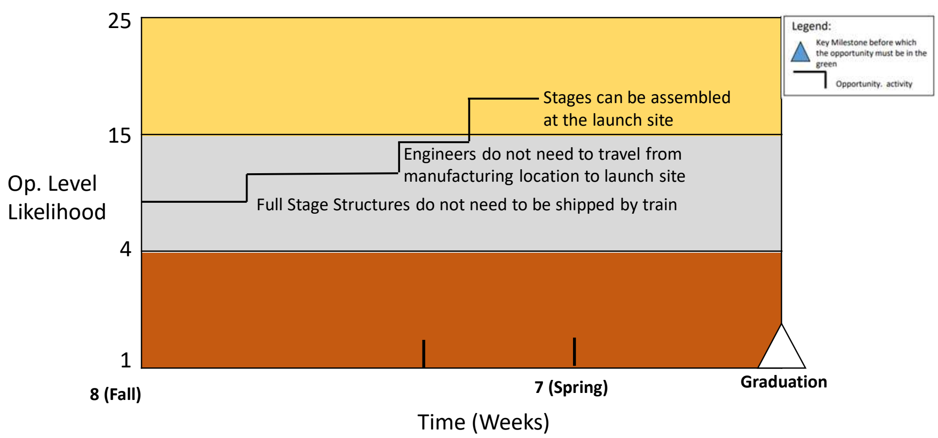
Opportunity P2.0 is capitalized on by utilizing improved 3-D printing technologies which reduces overall manufacturing costs.

149

149

7.2.3-3 Opportunity "Fish Ladder" – Program Opportunity

REQ C1.0:
Opportunity P3.0: If manufacturing occurred closer to the launch pad due to building a manufacturing facility at the launch site, then transportation would not be needed, and cost would be reduced.



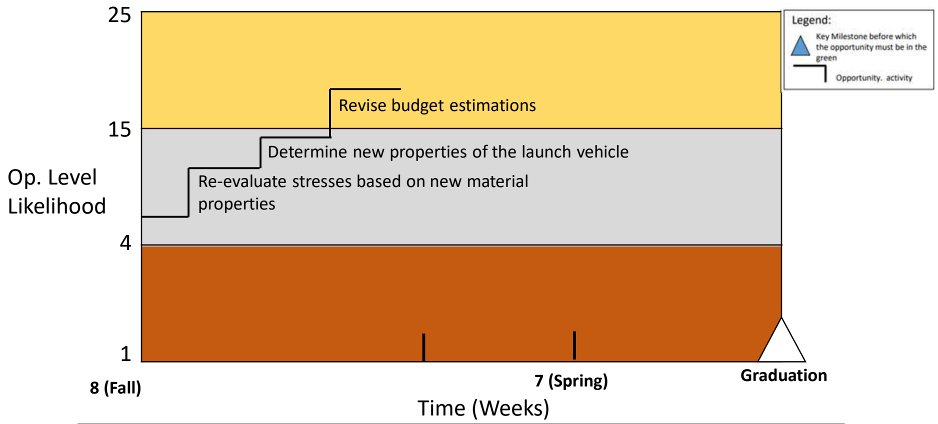
Opportunity P3.0 is capitalized on by reducing major transportation costs by purchasing manufacturing facilities near the launch facility.

150

150

7.2.3-4 Opportunity "Fish Ladder" – Technical Opportunity

REQ T2.0-1: The system must have the payload capacity for a 30 kg payload for Mission 1
Opportunity T1.0: If technological development of improved composite materials are implemented due to advances in material sciences, then the potential benefit to the system is a reduction in structural mass and a stronger overall structure.



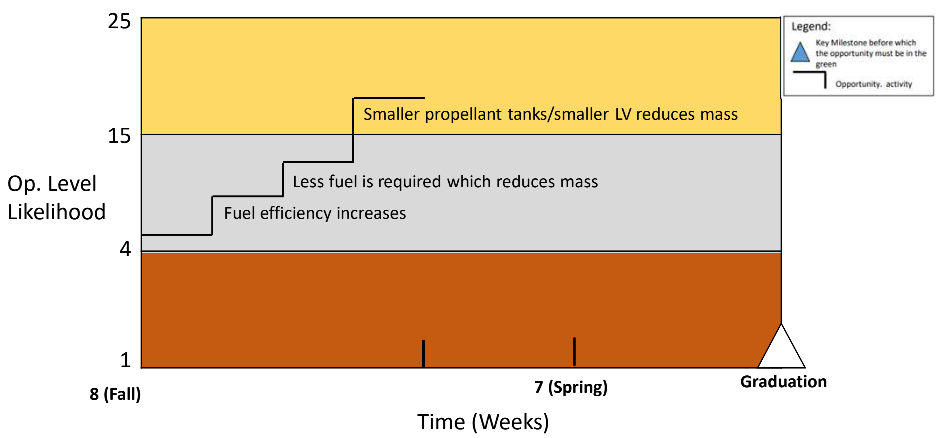
Opportunity T1.0 is capitalized on by creating a smaller and potentially stronger launch vehicle at a reduced price by incorporating composite materials.

151

151

7.2.3-5 Opportunity "Fish Ladder" – Technical Opportunity

REQ T2.6: The system must provide a Δv of approximately 11.3 km/s for Mission 2
Opportunity T2.0: If technological development of aerospike engines are implemented due to proven reliability of aerospike engines and increased production of aerospike engines, then less propellant mass and cost is needed.



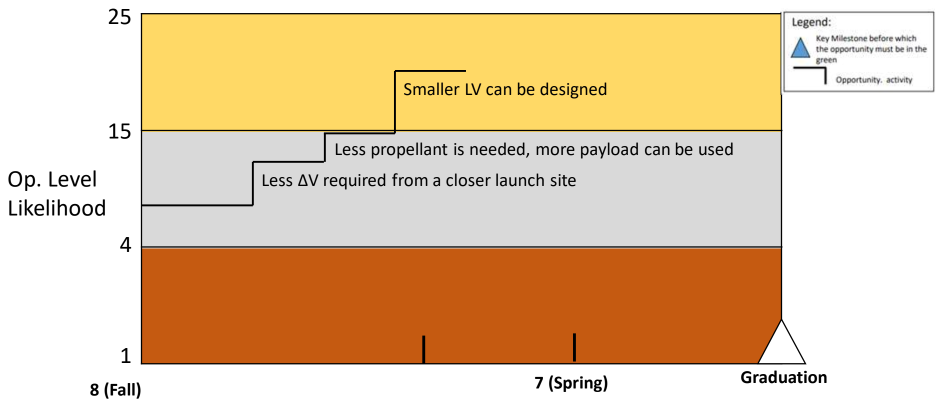
Opportunity T2.0 is capitalized on by reducing the mass of the vehicle by reducing the amount of propellant needed.

152

152

7.2.3-6 Opportunity “Fish Ladder” – Technical Opportunity

REQ T3.0-1: The system must launch from Vandenberg and Kennedy Space Station
Opportunity T3.0: If new suitable launch locations for Sun-Synchronous Orbits are developed due to new international agreements, then a better location may be used so that less fuel mass and cost is needed.



Opportunity T3.0 is capitalized on by using the new launch site to design a smaller vehicle that uses less mass and propellant.

153

153

8.0a Summary & Implementation for Conceptual Design

Summary:

- The system for the VCLS will be able to affordably deliver CubeSats payloads to 500 km orbit at 40° to 60° inclination and a 550 km SSO with an 10° inclination change.
- Requirements were burst from the RFP and their subsequent derived requirements will be what guides system architecture design and down selection.
- Rough draft of schedule was designed, and head-leveling techniques have begun.
- Risk mitigation techniques have begun so that we can guarantee the project's success beyond the design phase.

Key PMP Charts that we will use in design:

- Chart 1.4 Customer Requirements: Will be used to derive design drivers so that we may guide the design process to satisfy the customer.
- Chart 2.3 WBS: Will be used to ensure all elements are included in the design that are important so that we can stay organize and not miss any important elements.
- Charts 3.0 Technical Approach and Processes Concepts: Will be used to define program concepts for multiple aspects of system design so that the elements can be connected.
- Chart 4.2 Conceptual Design Schedule: Will be used to determine if the team is on track

Summary of PMP: The VCLS system will utilize system engineering and program management techniques to ensure its success.

154

154

8.0b Summary and Implementation Of the Program Management Plan

- A comprehensive requirements compliance system has been set along with optimized schedule to maximize LV efficiency
- Detailed schedules have been developed alongside the cost analysis to ensure all deadlines are met and the mission is performed on budget
  - Alongside the detailed schedule and cost analyses, an opportunity management plan has been implemented to capitalize on potential technical and program opportunities
- All team members have been assigned positions that best match their personality styles, skills, and interests to allow for exemplary and detailed technical development
- Key PMP Charts:
  - Chart 4.3 Preliminary Design Schedule: Will determine if the team is on schedule
  - Chart 5.4 EVMS: Will determine if the chart is on schedule with the correct and allocated budget

Summary of PMP: The VCLS system will utilize system engineering and program management techniques to ensure its success.

155

155