Conceptual Design Review of the B-2 Spirit Bomber

ARO 2011L　Section 3　Team 4

Prof. Dobbs

Date Submitted: 6 March 2019
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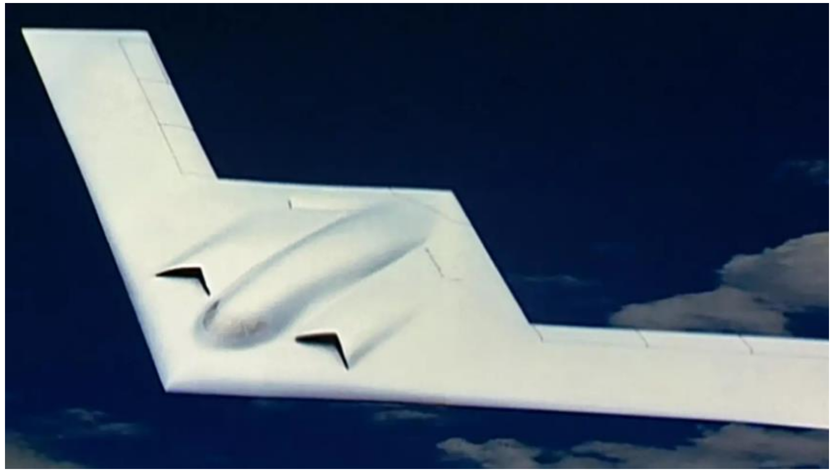


Team Spirit
Cal Poly Pomona Aerospace Engineering Department

1.1 Needs Analysis – *The Spirit Project*

NEED: *"The current arsenal of US bombers is susceptible to Soviet missiles* <u>*due to*</u> *lack of anti-radar implementation. The Air Force* <u>*needs*</u> an *aircraft capable of infiltrating the Soviet air-defense network and attacking key targets for continued dominance in the Cold War."*

The key <u>*external*</u> stakeholders and their needs:

– The US Air Force will use this stealth bomber to immobilize key targets during the Cold War, while also avoiding detection.

– The military, an important part of the public sector, has the need for an upgraded bomber that can evade detection.

– The Pentagon will be deciding the program worthiness and procurement.

– In addition to the above stakeholders and their needs, Congress will be voting to give the Pentagon money for procurement, the city of Pico River will see an increase in employed workers, and the FAA will need to give permission to the aircraft to fly in US airspace.

The key <u>*internal*</u> stakeholders and their needs:

– Our companies' reason for designing a bomber is that we have a stake in a potential USAF contract.

– Employees need to participate in creating this system to increase their knowledge about stealth technology.

– Other external stakeholders include the employees near Pico Rivera who will be given jobs and sworn to secrecy, managers that may be promoted once the bid is won and successfully completed, and the R&D team's interest in studying stealth tech

1.2 Program Goals

- Primary Customer Goals of the Program:
  - Design, develop, test, and manufacture a highly advanced long- range stealth bomber capable of a mission radius of 6,000 nmi, carry 40,000 lbs of payload (conventional, guided, and nuclear), and have a radar cross section (RCS) small enough to where it would be safe from contemporary weapons.

- Company Goals:
  - Win Advanced Technology Bomber competition in 1981.
  - Maintain and upgrade fleet of B-2 bombers for future use.

The key program goal is creating a bomber program with long range, large payload, and stealth.

1.3 Program Objectives

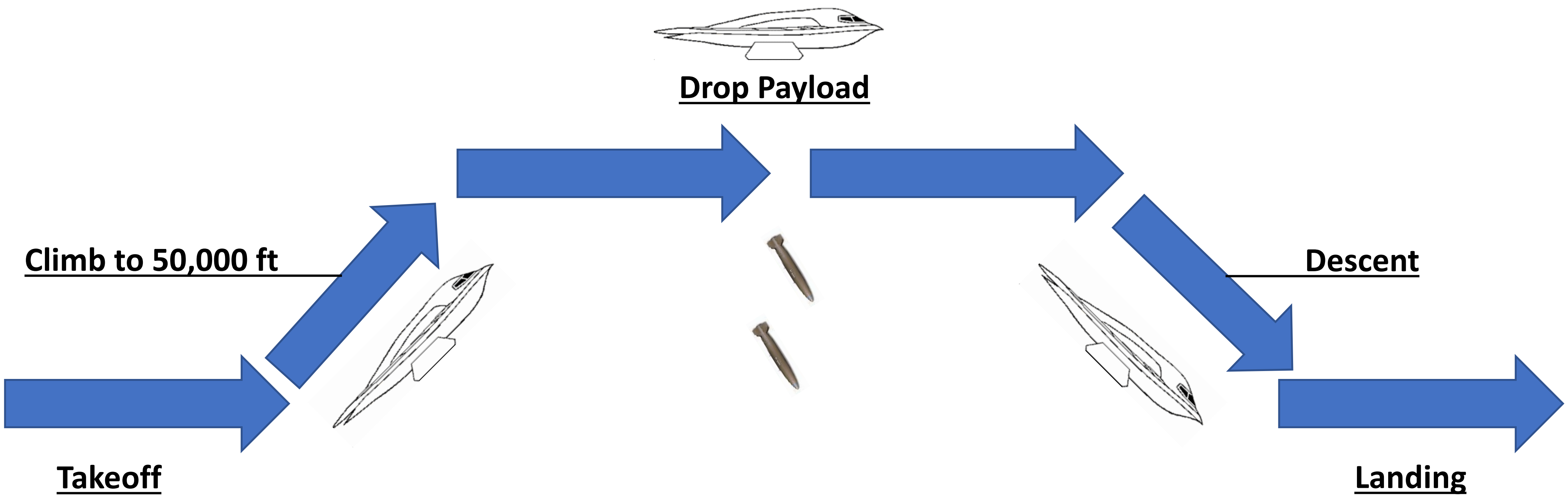
Customer Objectives	Our Company's Objectives
1. Gain researched and studied information regarding large aircraft radar cross-sections that would be most effective at being relatively invisible to radars.	1. Accomplish development regarding the creation and implementation of various stealth technology and state of the art research methods to create an aircraft capable of being invisible to radars while having a large radar cross section.
2. Conduct a contract competition where various companies are to design, develop, test, and manufacture a new aircraft capable of stealth and payload delivery.	2. Participate in the program competition with gradual success over other companies to win further study contracts in order to progress our work for the improvements and refinements for a superior program design to reach stealth bomber program capability.
3. Select a company from the competition with the most viable or effective design and approach to that design for implementation into the new stealth bomber program.	3. Win the competition and gain a contract for the aircraft program. Make final refinements and tests to the design or architecture of the project and begin initial production for our customers. This win would allow us to pursue the stealth bomber market and start off as a lead in that industry, while also making an 8-10% profit from the success of the program.

Use of state-of-the-art methods and technology will be used to bring about the viability of a stealth bomber program where we can effectively design and develop an aircraft that suits customer requirements.

Ethan Dominic Victoriano

1.4-1 Design Reference Missions

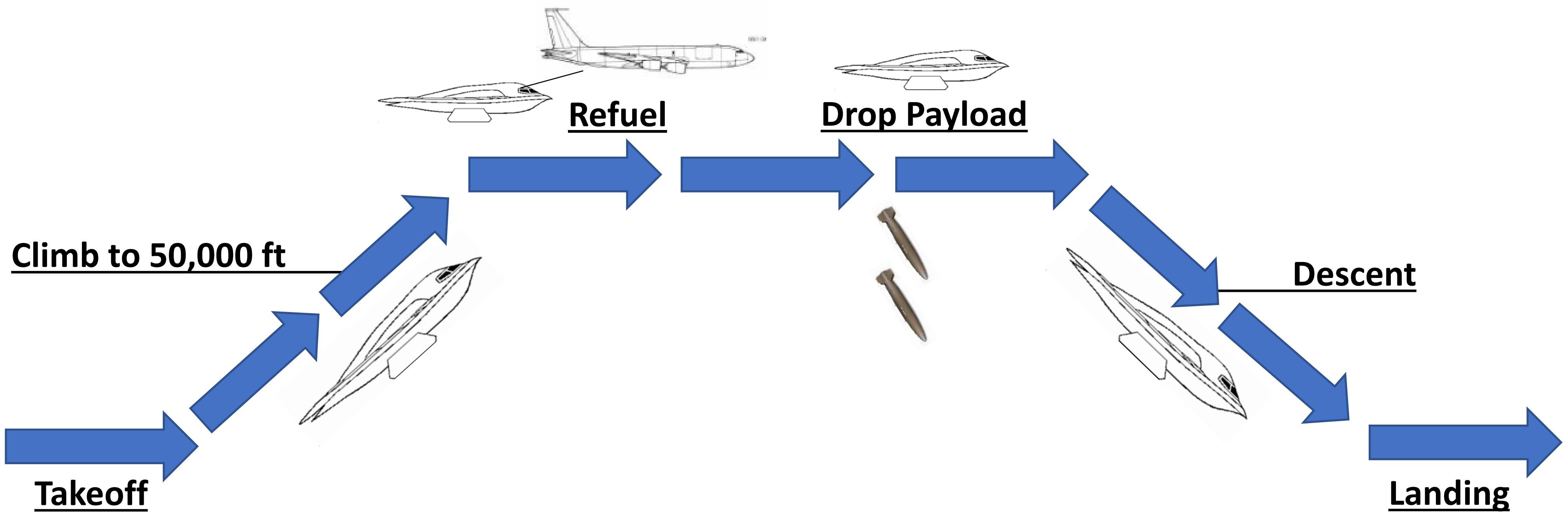
- Mission #1: Stealth Bombing Mission
- Mission Diagram:



Payload drop and return up to 6,000 nautical miles with minimal to no detection.

1.4-2 Design Reference Missions

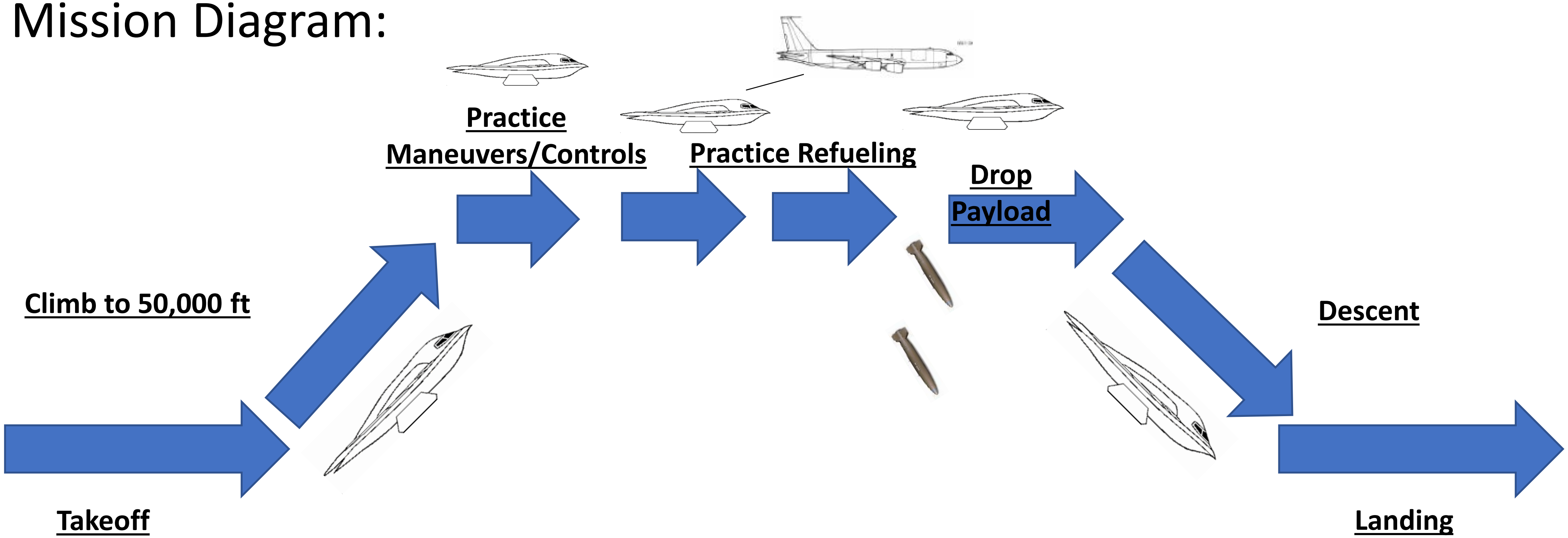
- Mission #2: Long Distance Mission with Midair Refueling
- Mission Diagram:



Enables the B-2 to complete missions with a round trip up to 10,000 nautical miles.

1.4-3 Design Reference Missions

- Mission #3: Training
- Mission Diagram:



Maneuverability, weapons deployment, and real-life scenario training for pilots.

1.5a System Level Requirements

Type & Req. Ref #	WBS #	Requirement Statement	Validation Method	Req Met at CoDR
TR0.0-1	0.0	The bomber should be able to evade Russian radar. The radar cross-section of the bomber needs to be less than 0.4 m^2.	Computer Simulations	Yes
TR0.0-2	0.0	The bomber should be able to carry out oversees missions with a range of 6,000-10,000 nmi at an altitude of 50,000 feet.	Numerical Calculations	Yes
TR0.0-3	0.0	Shall have Terrain Following (TF) capabilities at 400 ft above terrain at 0.7 Mach.		Yes
TR0.0-4	0.0	Capable of operations at low altitude (less than 8000 ft)	Analysis	Yes
TR0.0-5	0.0	Be able to deliver 40,000 lbs of guided/unguided bombs, air to ground missiles, nuclear weapons, etc.	Analysis	Yes
TR0.0-6	0.0	In order to quickly complete the mission, stealth bomber must travel at speeds of 0.95 Mach at its height ceiling.	Wind Tunnel Tests	Yes
PR0.0-1	0.0	Create a fully capable bomber with a budget limit of $45 billion.	Analysis	Yes
PR0.0-2	0.0	First flight approval by December 1981.	Observation	Yes

The B-2 Spirit Bomber's essential system level requirements are its minimal radar cross-section, long range, high subsonic speed, and its ability to deliver heavy nuclear weapons.

Eliot Khachi

1.5b Key System Level Requirements FOM's & Resulting Attributes

Design Mission = Integrate state of the art technology and design to create a menacing stealth bomber.

- **FOM 1** = Be 1st stealthiest and most advanced aircraft in production.
  - Attribute: Funding for research and development.
  - Attribute: Accurate deployment of payload.
- **FOM 2** = Range is 6,000 nmi, 10,000 nmi with an aerial refueling.
  - Attribute: Midair refuel requires mechanism to fuel midflight.
  - Attribute: Efficient engines to fly 6,000 nmi.
- **FOM 3** = Achieve a speed of 0.95 Mach at its height ceiling.
  - Attribute: Powerful engines to propel aircraft.
- **FOM 4** = Max payload mass is 40,000 lb.
  - Attribute: Be able to drop different types of payload.
  - Attribute: Safely store thousands of pounds of explosive weaponry.
- **FOM 5** = The cost of procurement is $2.1 billion.
  - Attribute: Maximize design by using research and development.
- **FOM 6** = Max altitude of 50,000 feet.
  - Attribute: Avoid enemy detection by staying at high altitudes.
- **FOM 7** = Program Cost is no more than $23 billion.
  - Attribute: Testing, transportation, prototyping, and transportation of vehicle.

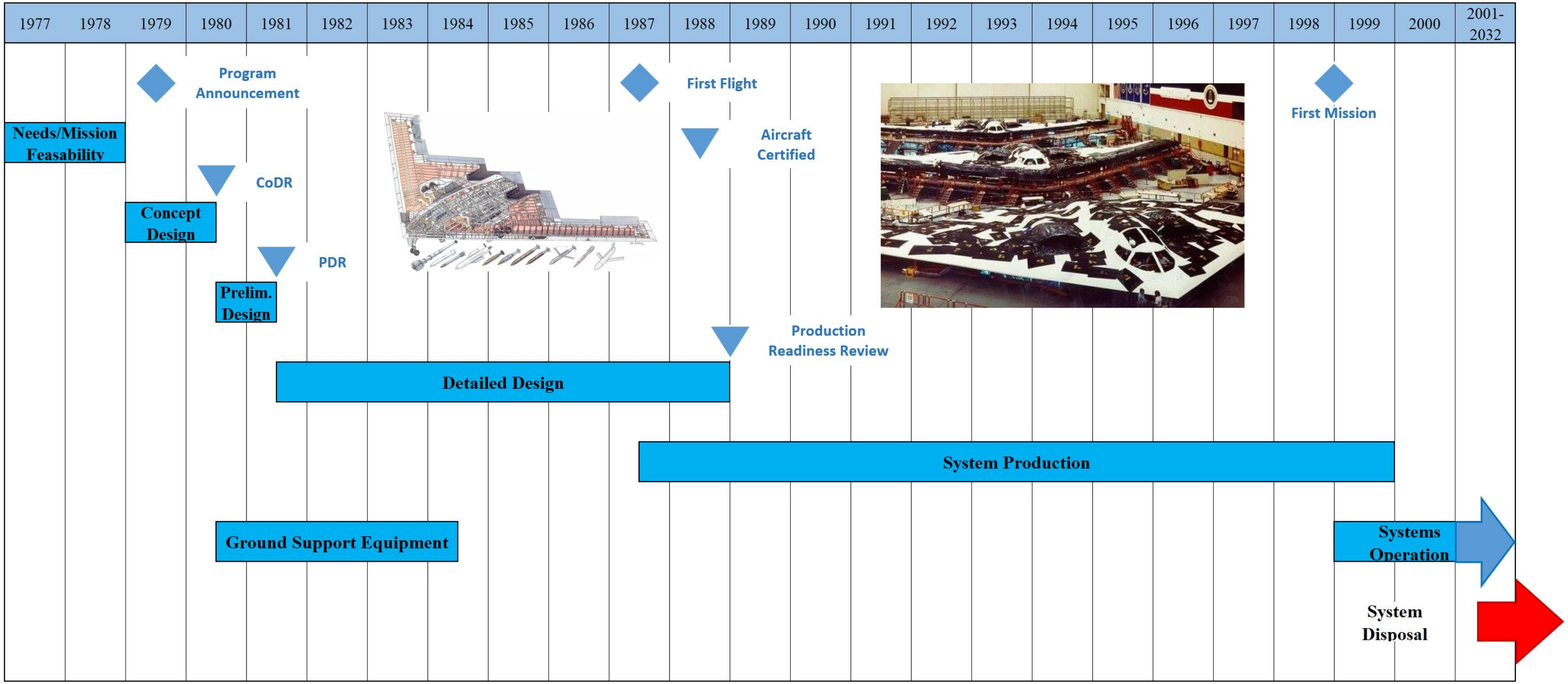
The key system level FOM requirements are that this bomber is the stealthiest bomber in production and that it has a range of 10,000 nmi with an aerial refueling.

1.5c Derived Requirements

Req. #	WBS #	Req. Statement	Valid. Method	Req met @ CoDR?
TR1.1-1	1.1 (Vehicle)	The structure of the aircraft must have a radar cross-section of 0.2 m^2.	Radar reflection testing	Yes
TR1.1-3	1.1 (Vehicle)	Must be able to fly for at least 6,000-10,000 nautical miles by refueling in midair.	Test flight range with midair refueling	Yes
TR2.1-1	2.1 (Ops)	Shall be able to evade enemy surface-to-air missiles.	Test speed & maneuverability	Yes
PR3.2-2	3.2 (Maintenance)	Total program costs shall be less than $23 billion by decreasing cost of maintenance and ease of manufacturing.	Cost analysis	Yes
PR2.2-1	2.2 (Ops)	Prototype shall have maiden flight by July 1989.		Yes
PR2.3-3	2.3 (Ops)	Must be able to carry 80 500-lb JDAM GPS-guided bombs by the making outer structure from strong, light material.	Test carrying capacity	Yes
PR7.3-2	7.3 (Manufacturing)	Manufacturing assembly line shall be ready for initial production of aircraft by January 1993.		Yes

We will achieve a radar cross-section of 0.2m^2, fly for 10,000 nautical miles with one refueling, and have a low program cost through ease of manufacturing & a decrease in need for maintenance.

1.6 Life Cycle B-2 Spirit



By 1988, the B-2 Spirit Bomber will be a long-term successor to the B-52, lasting until 2032.

Ashton Teimoori

2.0 Organization Chart: Conceptual Design

0.0 Team Lead
Charts 2, 9, 10, 11
Ashton Teimoori
Deputy: Dominic Victoriano

1.0 Chief Systems Engineer
Chart 1
Eliot Khachi
Deputy: Anton Beloslutsev

3.0 Chief Architect
Chart 3
Dominic Victoriano
Deputy: Harut Hajibekyan

4.0 Work Breakdown Structure
Chart 4
Alexander Kwon
Deputy: Eliot Khachi

5.0 Operations Analysis
Chart 5
Harut Hajibekyan
Deputy: Ashton Teimoori

6.0 Maintenance & Support
Charts 6, 8
Anton Belosludtsev
Deputy: Alexander Kwon

Our team has successfully developed and tested new stealth technologies capable of being implemented into a stealth bomber program.

2.1 Organization Chart Responsibilities

- 0.0 Team Lead - Responsible for organization of team, seeing that each sub-lead's task comes to fruition and all components of the system integrate with each other.
- 0.1 Team Deputy - Responsible for enforcing and looking over overall team work progress and adding in supplementary ways of communication between team members. Also responsible to be active team lead should main team lead be unable to do so.
- 1.0 Chief Systems Engineer - Responsible for managing and overseeing all aspects of a system, including construction, installation, testing, maintenance.
- 3.0 Chief Systems Architect - Responsible for designing the systems and procedures to each possible design candidate, as well as partaking in architecture trade studies and the down selection of the candidates.
- 4.0 Work Breakdown Structure - Responsible for breaking down the project into key components and organizing them into a manageable order to execute.
- 5.0 Operations Analysis – Responsible for figuring out how the aircraft will be run in day-to-day operations, including where it will take off from and the missions it will perform..
- 6.0 Maintenance & Support - Responsible for ensuring system operations will run smoothly until the end of its life cycle through preventative maintenance, structural repairs, overhauls, upgrades, disposals, etc.

Although all members work on each chart, each member is responsible for one of the above roles.

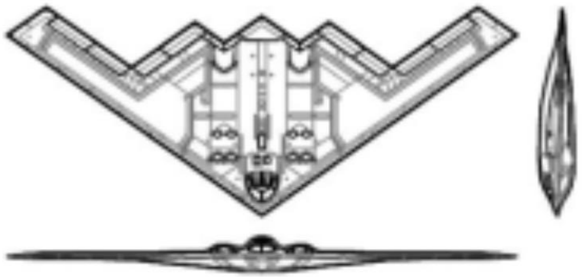
Ashton Teimoori

3.1 System Candidate Architecture Concepts

Need For System: Safe long-range heavy stealth bomber

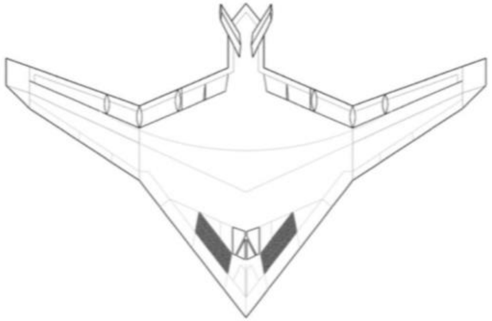
System Architecture 1
"Northrop Grumman B-2 (Senior Ice)"

Attributes:
1. Procurement Cost: $2.1 billion
2. Speed: 0.95 Mach
3. Radar cross-section: ~0.2 m^2
4. Payload: 40,000 lbs
5. Combat Range: 6,000 nmi



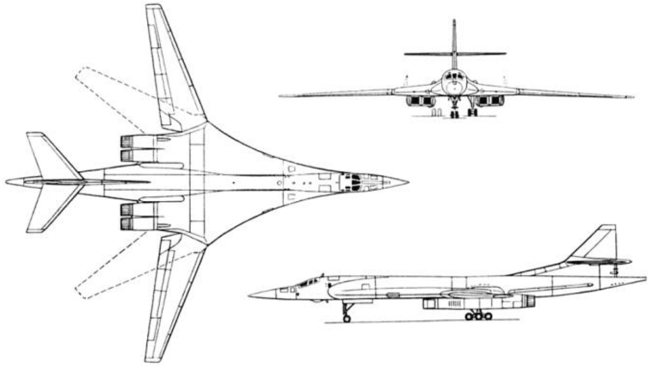
System Architecture 2
"Lockheed Martin B-2 (Senior Peg)"

Attributes:
1. Procurement Cost: $2 billion
2. Speed: 0.95 Mach
3. Radar cross-section: ~0.4 m^2
4. Payload: 30,000 lbs
5. Combat Range: 4,800 nmi



System Architecture 3
"Tupolev Tu-160 (White Swan)"

Attributes:
1. Procurement Cost: $215 million
2. Speed: 2.05 Mach
3. Radar cross-section: 1-2.5 m^2
4. Payload: 100,000 lbs
5. Combat Range: 4,000 nmi



Proposing a wide variety of viable system architectures is crucial to covering all grounds in design-approach to develop a safe, long-range, heavy stealth bomber that ensures customer's needs are met.

3.2 System Level Figures of Merit

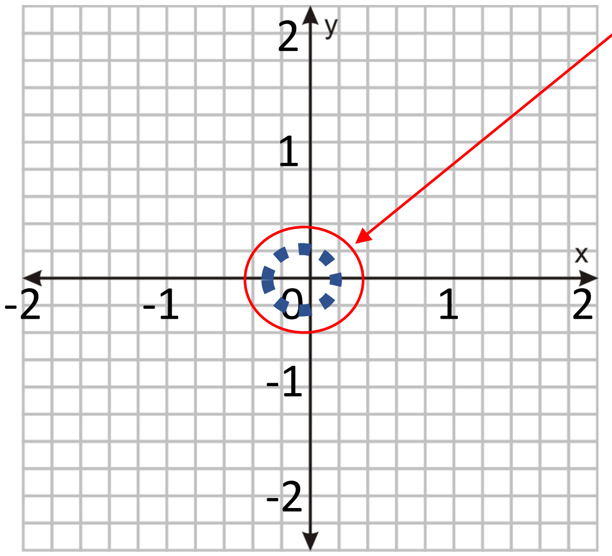
#	Description	Target Value/ Characteristic	Rank	Weight Factor = W
1	Cost of program procurement	$2.1 billion	2	1
2	Maximum payload capacity	40,000 lbs	4	2
3	Maximum aircraft range without refueling	5,000 nmi duration	5	3
4	Maximum aircraft altitude	50,000 ft	7	1
5	Maximum aircraft speed	0.95 Mach at height ceiling	6	1
6	Maximum aircraft radar cross-section	0.40 m^2	3	3
7	Program cost	$23 billion	1	1

Cost of the program and key attributes envisioned for the stealth aircraft are identified as figures of merit, becoming key components that drive the main design of the system.

3.3 Feasibility Analysis: Step 4: Screen Alternatives Using Key Evaluation Criteria

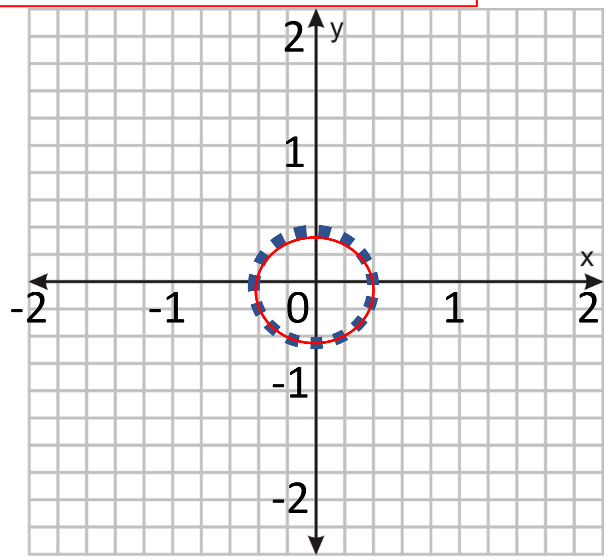
Key FOM 1: Radar Cross Section (m^2)

Radar Cross Section Goal (0.40 m^2)



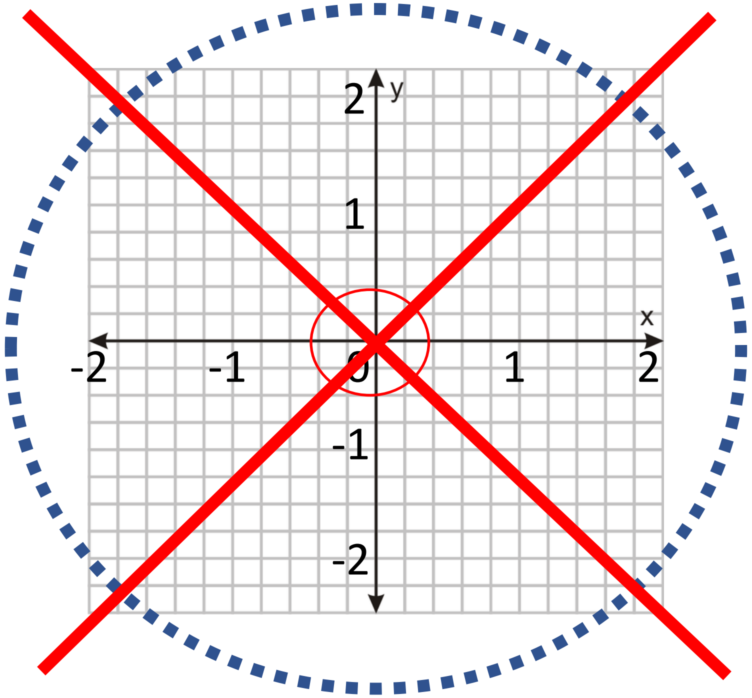
Config 1: 0.2 m^2

Config 1: Northrop Grumman Senior Ice
Radar Cross Section = 0.2 m^2
Combat Radius = 6,000 nmi
Payload= 40,000 lbs
Techn. Readiness Level: 3-6 years, OK



Config 2: 0.4 m^2

Config 2: Lockheed Martin Senior Peg
Radar Cross Section = 0.4 m^2
Combat Radius = 4,800 nmi
Payload = 30,000 lbs
Techn. Readiness Level: 3-6 years, OK



Config 3: 2.5 m^2

Config 3: Tupolev Tu-160
Radar Cross Section = 2.5 m^2 -Reject
Combat Radius = 4,000 nmi
Payload = 100,000 lbs
Techn. Readiness Level: Current; OK

Though the first two configurations are not in current technology readiness level, they fulfill the product's first FOM requirement, whereas the third configuration went beyond the required limit and is subsequently eliminated from further consideration.

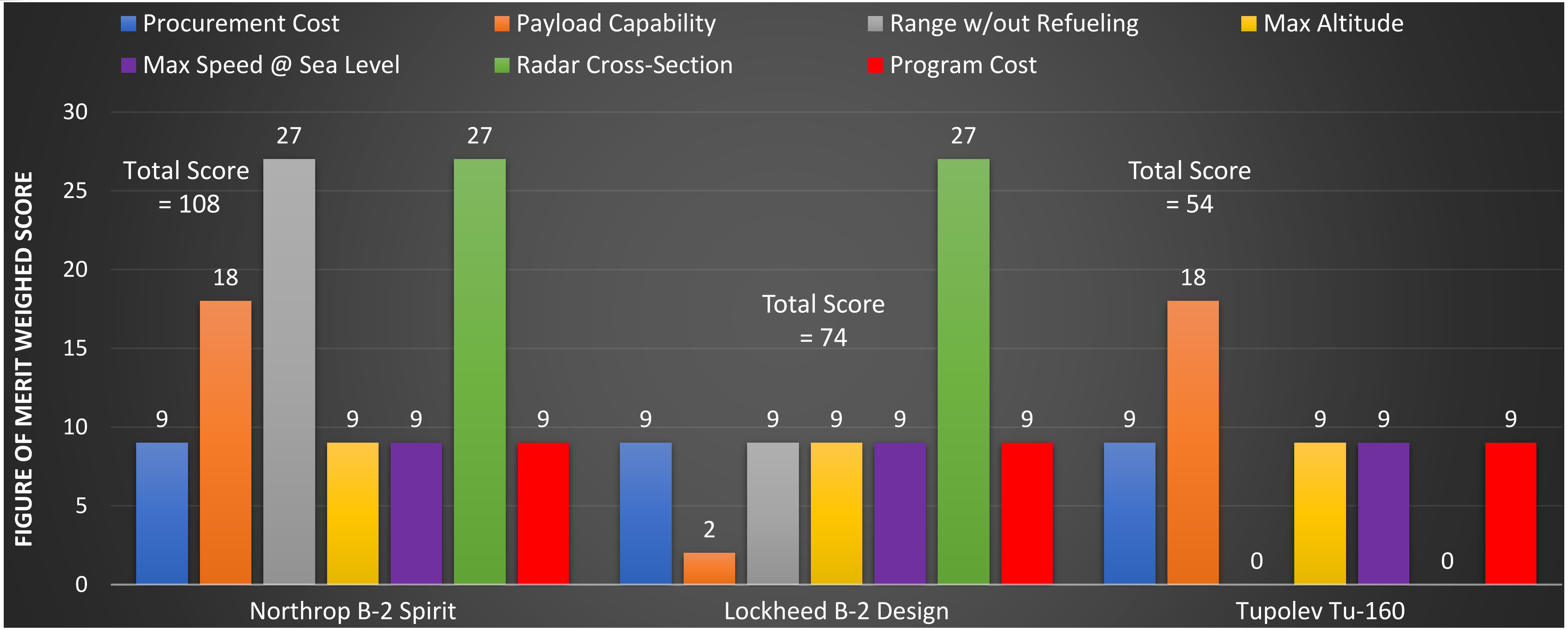
Ethan Dominic Victoriano

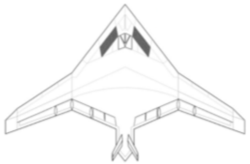
3.4-1 Trade Matrix

FOMs / Alternative Architectures	Procurement Cost ($2.1B) Wt. 1		Payload Capacity (40,000 lbs) Wt. 2		Range With no Refueling (5,000 nmi) Wt. 3		Max Altitude (50,000 ft) Wt. 1		Max Speed @ Sea Level (Mach 0.90) Wt. 1		Radar Cross-Section (0.4 m^2) Wt. 3		Program Cost ($45B) Wt. 1		Weighted Total = Sum (U x Wt)
	U	W	U	W	U	W	U	W	U	W	U	W	U	W	
Northrop Grumman B-2	9	9	9	18	9	27	9	9	9	9	9	27	9	9	108
Lockheed Martin B-2	9	9	1	2	3	9	9	9	9	9	9	27	9	9	74
Tupolev Tu-160	9	9	9	18	0	0	9	9	9	9	0	0	9	9	54

Northrop Grumman's B-2 bomber will be able to outperform on its missions because of its smaller radar cross-section and higher combat range.

3.4-2 Quantify & Down-Selected Alternatives and Order Relative to FOM Scores from Trade Matrix

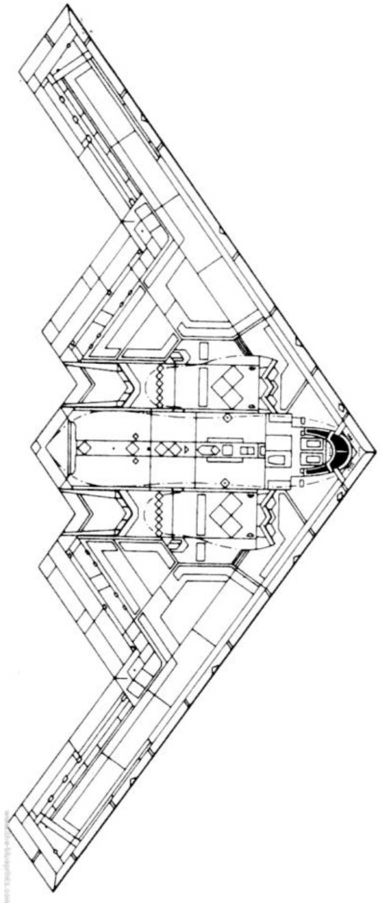




Compared to the alternative architectures, B-2 Spirit bomber outperforms on both cross-sectional area and single-tank range, and is on par with procurement cost and max speed.

Harut Hajibekyan

3.5 Selection of Best Architecture



Vision Vehicle: B-2 Spirit Bomber

Radar cross-section: 0.2 m^2

- **Procurement Cost: $2.1B/ea**
- **Operations Cost: $130k/flight-hour**
- **Wt gross: 376 kips**
- **Wt empty: 158 kips**
- **Wt pyld: 40 kips**
- **Radar cross-section: 0.2 m^2**
- **Range w/o aerial refueling: 6,000nmi**
- **Fus Length: 69 ft**
- **Span: 172 ft**
- **Max Speed: 628mph (0.95 Mach)**
- **T/W: 0.205**

Concept art

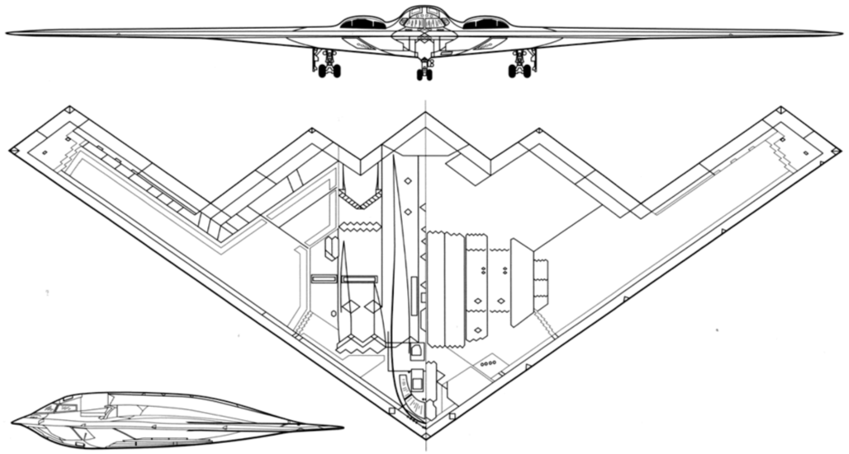
Among the highest in acquisition and operations costs, the B-2 Bomber delivers in optimization of every key FOM.

3.5 Selection of Best Architecture (cont.)

Project Title: Northrop Grumman B-2 Spirit Bomber

The candidate selected for Best Architecture is the B-2 Spirit Bomber, a long-range stealth bomber capable of delivering nuclear weapons.

Key Rationale for selection: Maximal combat range, innovative stealth technology, and optimized payload capacity.



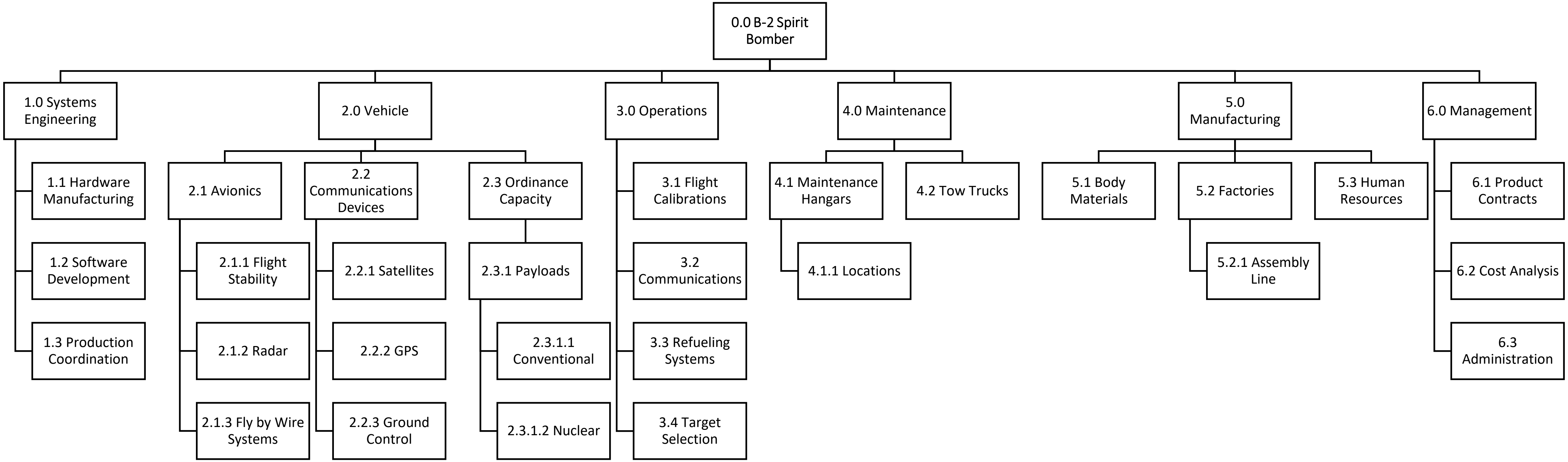
Northrop Grumman's system architecture meets the primary FOMS as requested by the customer and exceeds expectations with regards to development and implementation of stealth technology.

4.0a Work Break Down Structure (Functional)

- 0.0 B-2 Spirit Bomber
  - 1.0 Systems Engineering
    - 1.1 Requirements Analysis
    - 1.2 Architecture Candidates Definition
    - 1.3 Architecture Trade Process & System Design Process Identification
    - 1.4 Risk Analysis
  - 2.0 Mission Design
    - 2.1 Needs Analysis
    - 2.2 Constraint Review
  - 3.0 Subsystem Design
    - 3.1 Process Layout
  - 4.0 Technology Development Risk Reduction
    - 4.1 Radar Reduction Tests
    - 4.2 Avionics Testing
    - 4.3 Flight Software Development
  - 5.0 Program Management
    - 5.1 Cost Analysis
    - 5.2 Life Cycle Development
    - 5.3 Development Scheduling
  - 6.0 Mission Operations
    - 6.1 Flight Planning
    - 6.2 Communications
  - 7.0 Maintenance Concept Design
    - Maintenance Depot Development
    - Maintenance Scheduling
  - 8.0 Manufacturing Concept Development
    - 8.1 Onsite Manufacturing

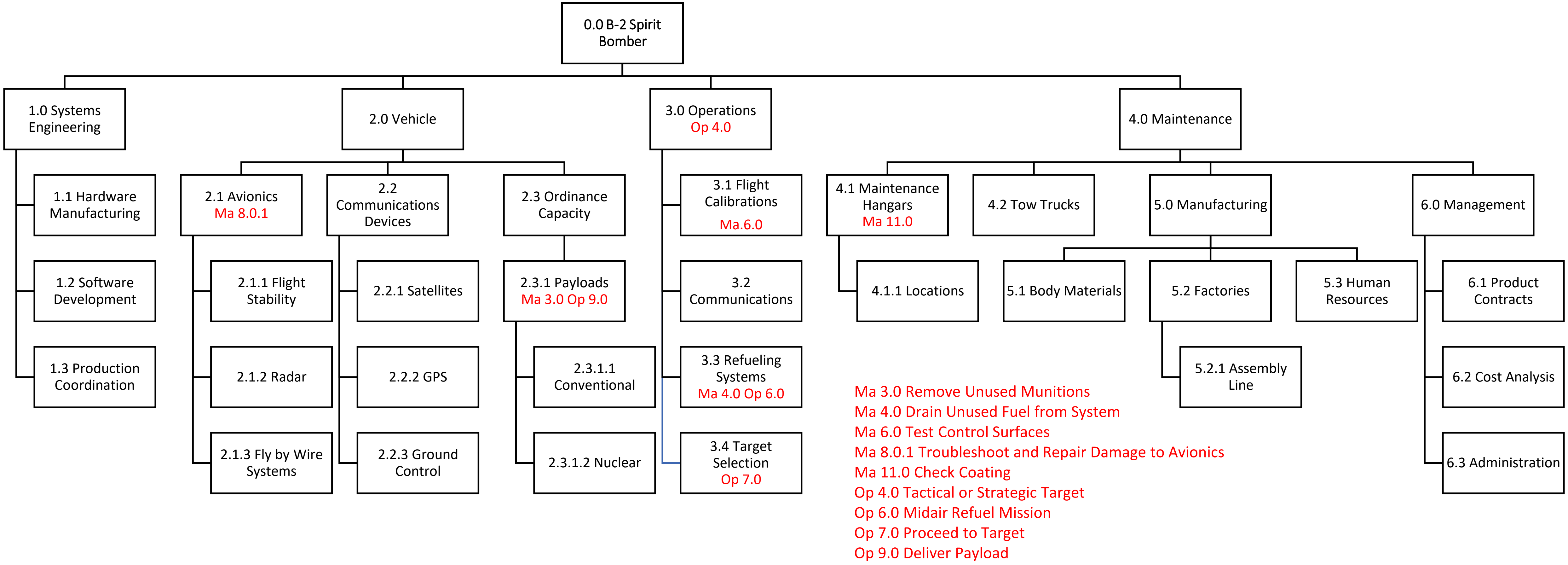
Analysis of subsystems for proper project management and process organization to ensure everything from mission design to maintenance is optimized for the system development.

4.0b Work Break Down Structure (Product)



Integration of all components that are required for the proper operation and maintenance of the B-2.

4.0c Functional Allocation on the Product Work Break Down Structure



Many of the functional allocations are reliant on the payloads and refueling systems because these are one of the most important features of the bomber.

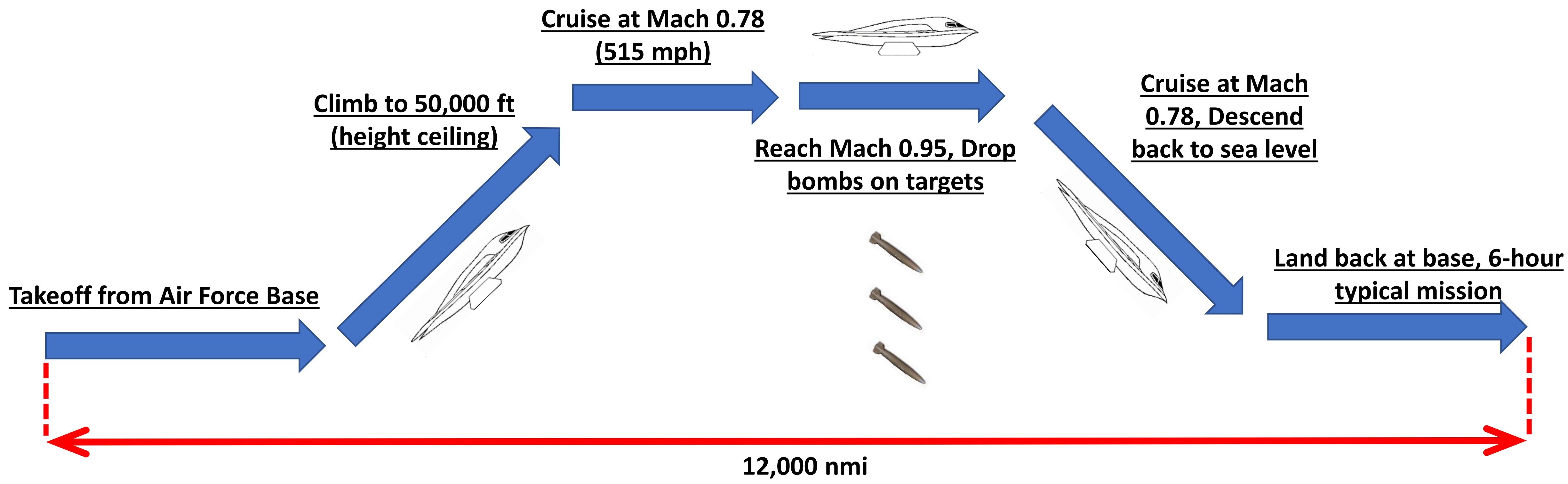
Alexander Kwon

5.1-1a Design Reference Mission #1

- What is the system to accomplish? Drop bombs on strategic enemy locations and return to base without being detected.
- How will the system accomplish its objectives? Aircraft will use either JDAM GPS-guided bombs or unguided thermonuclear bombs flying at around Mach 1 at or slightly below 50,000 feet to evade detection by radar.
- The mission may be defined through one or a set of scenarios or operational profiles:
    - Scenario 1: Conflict in foreign enemy nations near Europe
    - Scenario 2: Enforcing UN Security Council resolutions
- Identify the dynamics of the system operating characteristics – Rapid climb, flight, and descent to eliminate the target within a 6,000 nmi radius away from a 50,000-foot ceiling while sustaining a max of 2 Gs.

The Northrop B-2 will be able to disable key enemy locations at a radius of 6,000 nmi with a single tank of fuel and return to base without detection.

5.1-1b Mission #1 Definition (sketch)



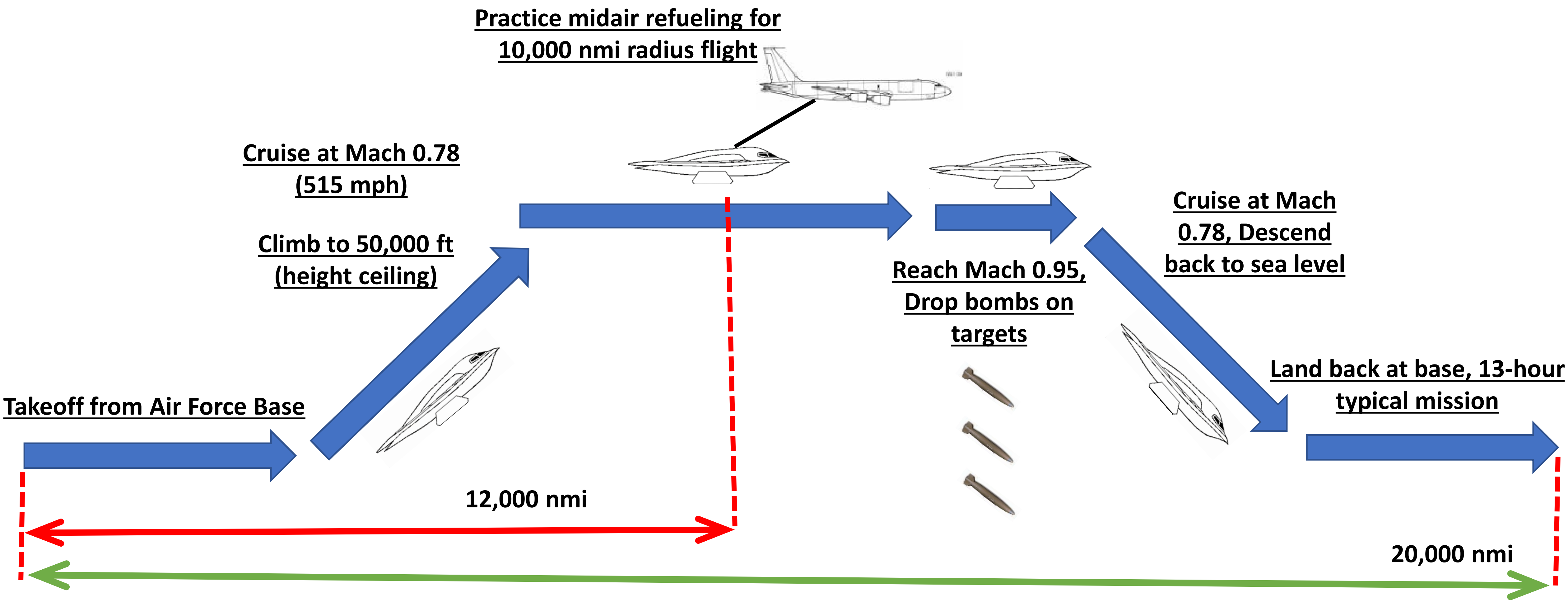
Taking off from Whiteman Air Force Base, the Northrop B-2 will be back to base in 6 hours or less after completing a mission with a maximum radius of 6,000 nmi.

5.1-2a Design Reference Mission #2

- What is the system to accomplish? Use midair refueling to accomplish bomb deployment during intercontinental missions that require a maximum radius of 10,000 nmi while also evading detection.
- How will the system accomplish its objectives? The aircraft will use midair refueling to drop bombs at strategic locations around the globe and fly at or slightly below 50,000 feet to avoid detection.
- The mission may be defined through one or a set of scenarios or operational profiles
  - Scenario 1: Possible wars in the Middle East
  - Scenario 2: NATO war effort support
- Identify the dynamics of the system operating characteristics – Rapid climb, flight, and descent to eliminate the target within a 10,000 nmi radius from a 50,000-foot ceiling while sustaining a max of 2 Gs.

Completion of multiple missions across the globe within a 24 hour period will be possible with the use of midair refueling, with each one adding an extra 4,000 nmi radius in which it can operate.

5.1-2b Mission #2 Definition (sketch)



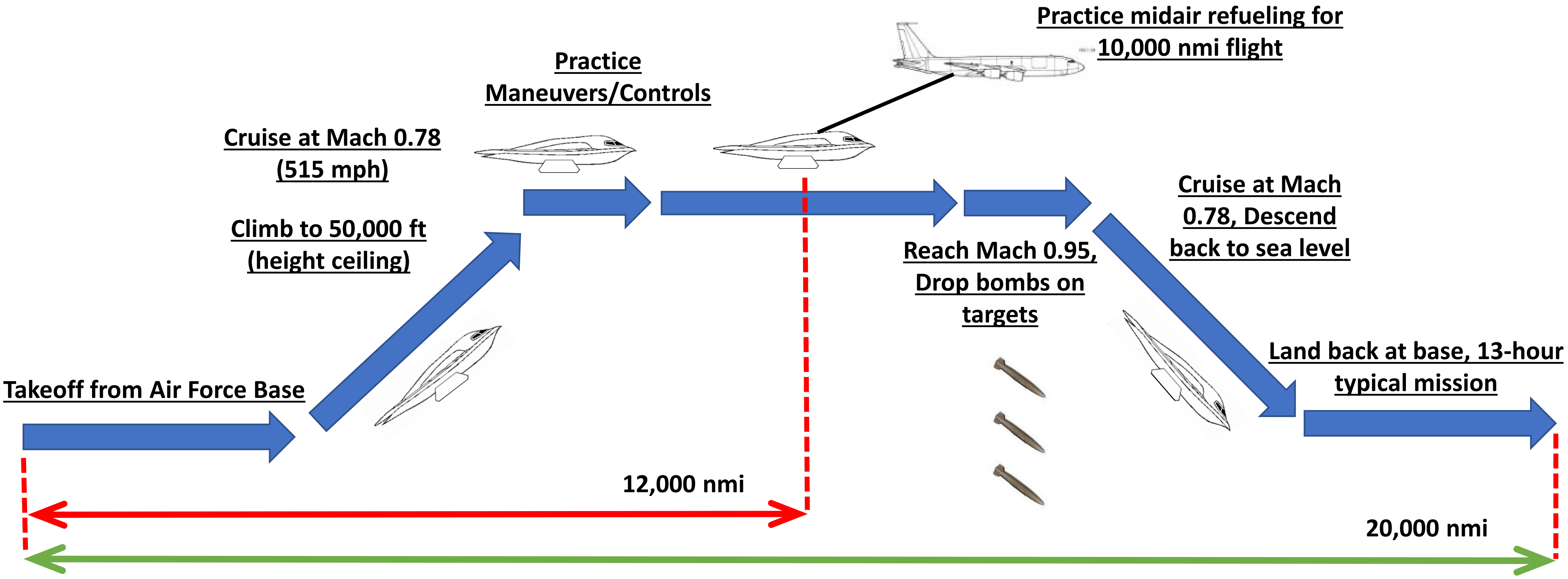
With the addition of midair refueling, the Northrop B-2 will now be able to complete missions that require a maximum radius of 10,000 nmi and a minimum completion time of 13 hours.

5.1-3a Design Reference Mission #3

- What is the system to accomplish? Train pilots to maneuver and deliver payload without detection
- How will the system accomplish its objectives? Aircraft pilots will push aircraft to limit, practice live-fire runs & maneuvers to give them familiarity with aircraft
- The mission may be defined through one or a set of scenarios or operational profiles:
  - Scenario 1: Train in conjunction with other fighter aircraft
  - Scenario 2: Fly intercontinental practice missions
- Identify the dynamics of the system operating characteristics – Rapid climb, flight, and descent to eliminate the target within a 6,000 nmi radius from a 50,000-foot ceiling while sustaining a max of 2 Gs and rehearsal of flight maneuvers and aerial refuel.

Pilots shall learn to react to real-life scenarios through handling of aircraft controls, payload deployment, and drill maneuvers.

5.1-3b Mission #3 Definition (sketch)



By practicing maneuvers and controls at 50,000 feet, refueling for a maximum 10,000 nmi radius mission, and reaching Mach 0.95, pilots will become accustomed to the aircraft & 13-hour mission time.

5.2 Performance and Physical Parameters

1) Has a radar cross section of 0.2 m^2

2) Enemy airspace penetration: Mach number = 0.95 at 50,000 ft AGL for a 6,000 nmi unrefueled radius

3) Minimum flight duration of 6 hours without refueling & 13 hours with

4) Capable of carrying 80 500-lb Mark 82 JDAM GPS-guided bombs or 16 2,400-lb B3 nuclear bombs

- #s 1, 3 and 4 are all required for survival and weapon delivery for Scenario #1: Stealth Bombing
- #s 1-4 allow for intercontinental missions and long training exercises for Scenario #2: Long Distance Mission with Midair Refueling & Scenario #3: Training.

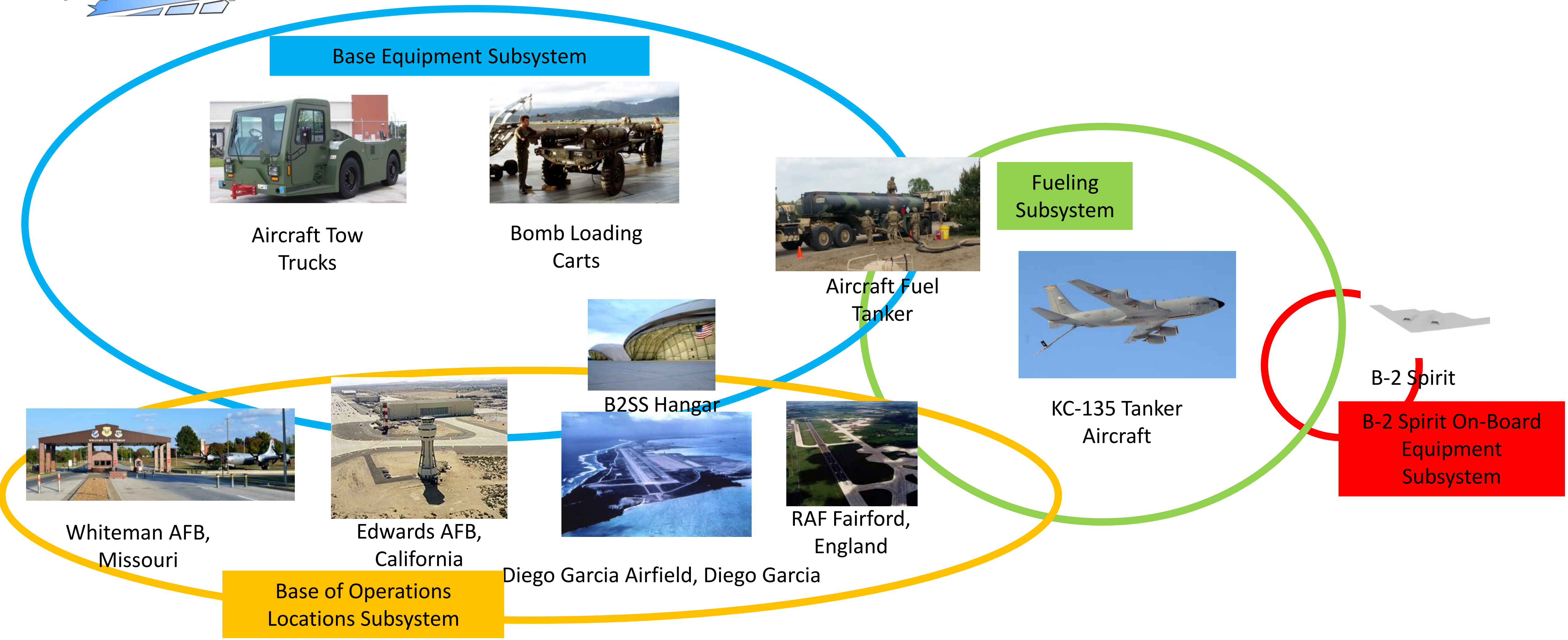
Key FOMs of the aircraft will allow for quick payload deployment, long-range intercontinental missions, and pilot readiness.

5.3a Operational Deployment or Distribution

- How much equipment and associated software is distributed, and where is it to be located?
  - Total of 20 aircraft to be distributed between two USAF bases (19 in Whiteman Air Force Base, and 1 in Edwards AFB)
  - At least five B2SS environmentally controlled hangar shelter systems, with first two distributed to Naval Support Facility Diego Garcia and RAF Fairford.
  - 1 aircraft tow truck at each base
  - 1 AN/APQ-181 multi-mode radar and 1 NAS-26 astro-inertial navigation system per aircraft.
  - 13 EMP-resistant MIL-STD-1750A computers and 26 MIL-STD-1553B-busses interconnected and installed on-board per aircraft.
  - 1 Link-16 network and 1 high-frequency satellite per aircraft.
  - 5 bomb loading carts at each air base.
  - 2 fuel tankers at each base.
  - 1 KC-135 aircraft for aerial refuel per base.
- When does the system become fully operational?
  - Aircrafts AV-7 through AV-11 ready by end of 1994, AV-12 through AV-14 by 1995, AV-15 through AV-19 by end of 1996, AV-2, AV-3, and AV-21 operational by 1997, and AV-1 operational by 2000.

All aircraft are released by sets and their supplementary base support systems ensure that each aircraft can be maintained effectively for them to carry out various missions and sorties at various locations.

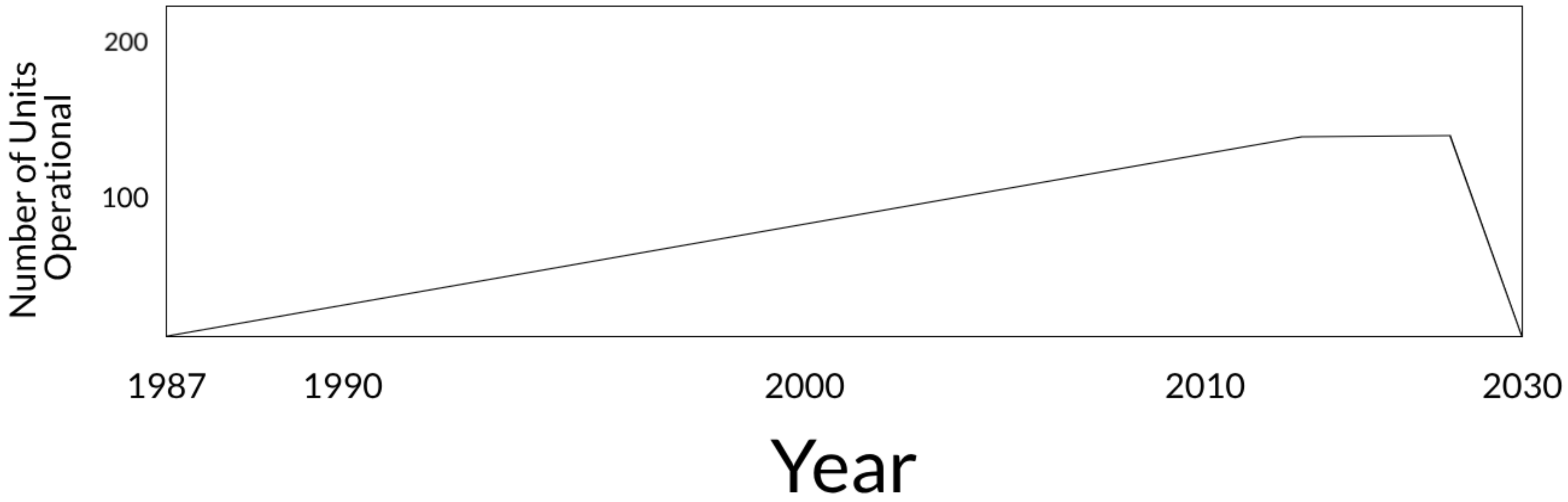
5.3b Operational Deployment Locations



Integration of logistical services allows for deployment and maintenance of aircraft in various locations that also incorporates aerial refueling.

5.4 Operational Life Cycle

Anticipated time that the system will be in use: 1987-2030



- USAF usage for entirety of system duration, 132 planned for initial procurement

The system is expected to be used from 1987 to its phase-out nearing 2030.

5.5 Utilization Requirements

Anticipated usage of the system and its elements:

- During All Mission Scenarios: Have at least 50% of the B-2's operational at any given time.
- During Mission Scenario #1: Be able to fly 6,000 nautical miles to drop payload.
- During Mission Scenario #2: Be able to fly 10,000 nautical miles with aerial refueling and still be able to drop payload.
- During Training Missions Scenarios: Be capable of dropping payload to target in a real life scenario.

How is the system to be used by the customer or operator in the field?

- During All Mission Scenarios: The capability to safely and efficiently eliminate staged target and return home.
- During Training Mission Scenarios: The capability of replicating real life situations.

The B-2 has multiple purposes and is very effective at long-range missions.

5.6 Effectiveness Factors

System requirements specified as figures-of-merit (FOM’s) such as cost or system effectiveness, operational availability, readiness rate, dependability, logistics support effectiveness, mean time between maintenance, failure rate, maintenance down time, facility utilization, operator skill levels and task accomplishment requirements, and personal efficiency:

- Cost of procurement shall be no more than $2.1 billion.
- Total program cost shall be no more than $45 billion
- Shall have a minimum speed of 0.95 Mach @ height ceiling.
- Range shall be 6,000 nmi on a single tank.
- Shall be able to carry at least 40,000 lbs of payload (i.e. conventional and thermonuclear weapons)
- Radar cross-section shall be at around, or smaller than, $0.3m^2$.
- Aircraft shall have a minimum height ceiling of 50,000 feet.

Given that the system will perform, how effective or efficient is it?

- The B-2 bomber is very efficient (about 95%) because of its advance targeting systems and flight computer.

How are these factors related to the mission scenarios?

- If the bombers aren’t available, then the mission cannot be executed.

The B-2 is capable of extremely high levels of accuracy (95%) because of its advancements in technology.

5.7 Environment

Definition of the environment in which the system is expected to operate. This should include a range of values as applicable and should cover all transportation, handling, and storage modes:

- Be able to operate in temperatures at a low of -20 degrees Celsius
- Be able to operate in temperatures at a high of 40 degrees Celsius.
- Be able to handle stresses associated when traveling at transonic speed.
- Be able to be stored in specialized hangars to deal with humidity.

How will the system be handled in transit?

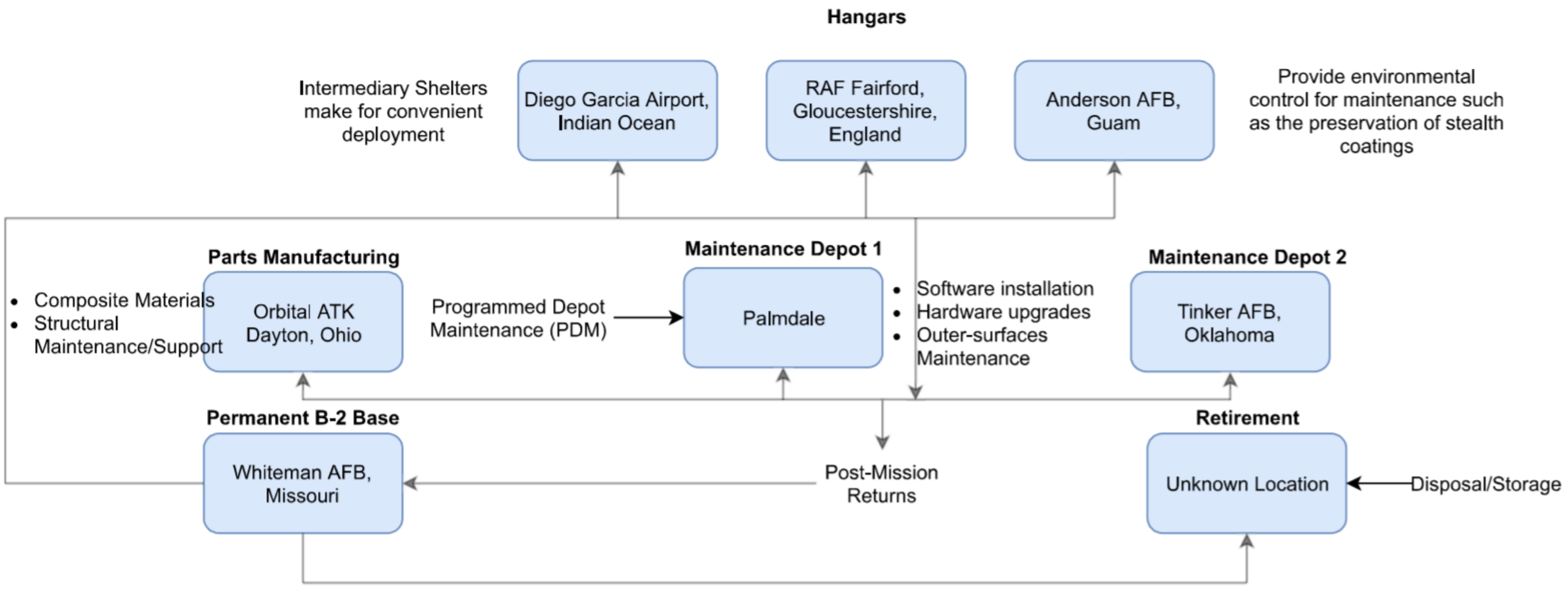
- Manufactured and assembled domestically, maintained at forward operating bases.

What will the system be subjected to during operational use, and for how long?

- Expected to be operated at all altitudes up to 50,000 ft for a maximum of 50 hrs.
- Be able to withstand weather conditions expected in combat areas (such as Russia and the Middle East).

The B-2 is capable of withstanding the cold winters of Russia and the arid summer of the Middle East.

6.0 Maintenance & Support Concept Diagram



Strategically placed hangars allow the B-2 to respond within HOURS to any global threat. The convenience of multiple Maintenance Depots and AFBs allow the B-2's to be stationed for further maintenance BETWEEN missions.

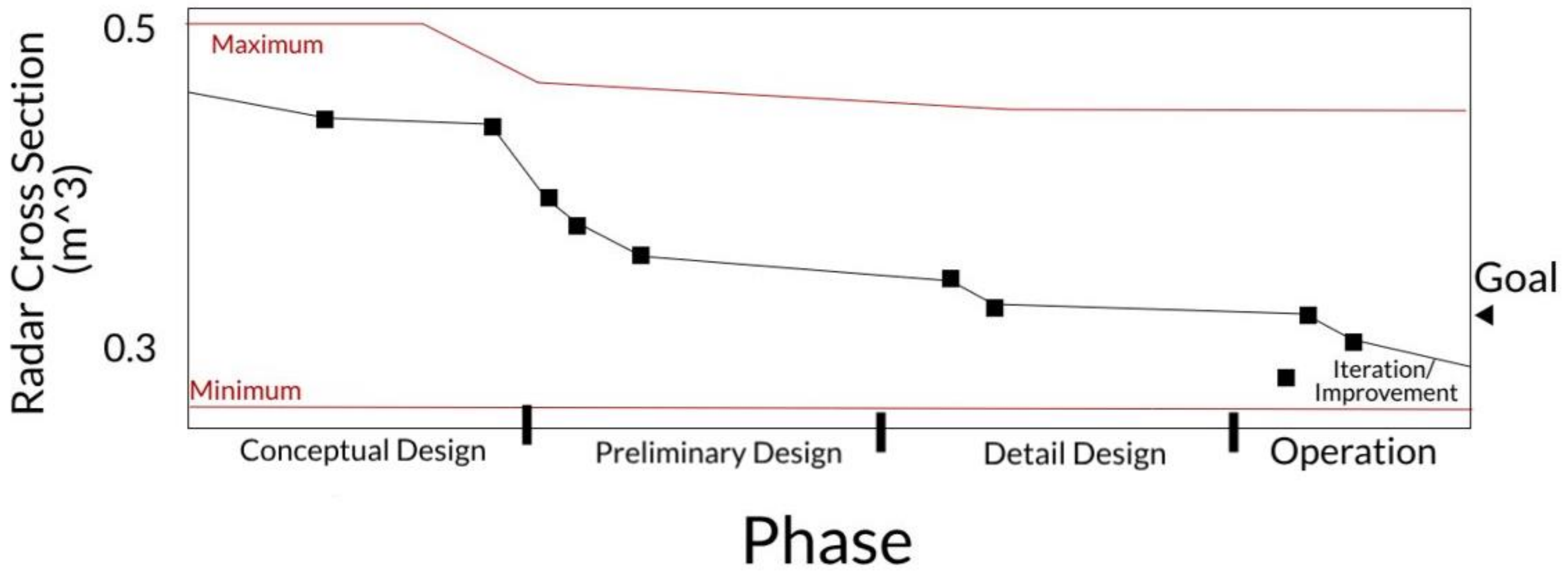
Eliot Khachi

7.0a Prioritization of TPM

Technical Performance Measure	Quantitative Requirement	Current Benchmark	Relative Importance
Top Speed (Mach)	0.95	0.95	9
Radar Cross Section (m^3)	0.3	0.5	29
Payload (lb)	40,000	30,000	16
Range (nmi)	6,000	4,800	27
Cost (USD)	$550 Million	$520 Million	7
Operational Availability	90%	90%	12
			100

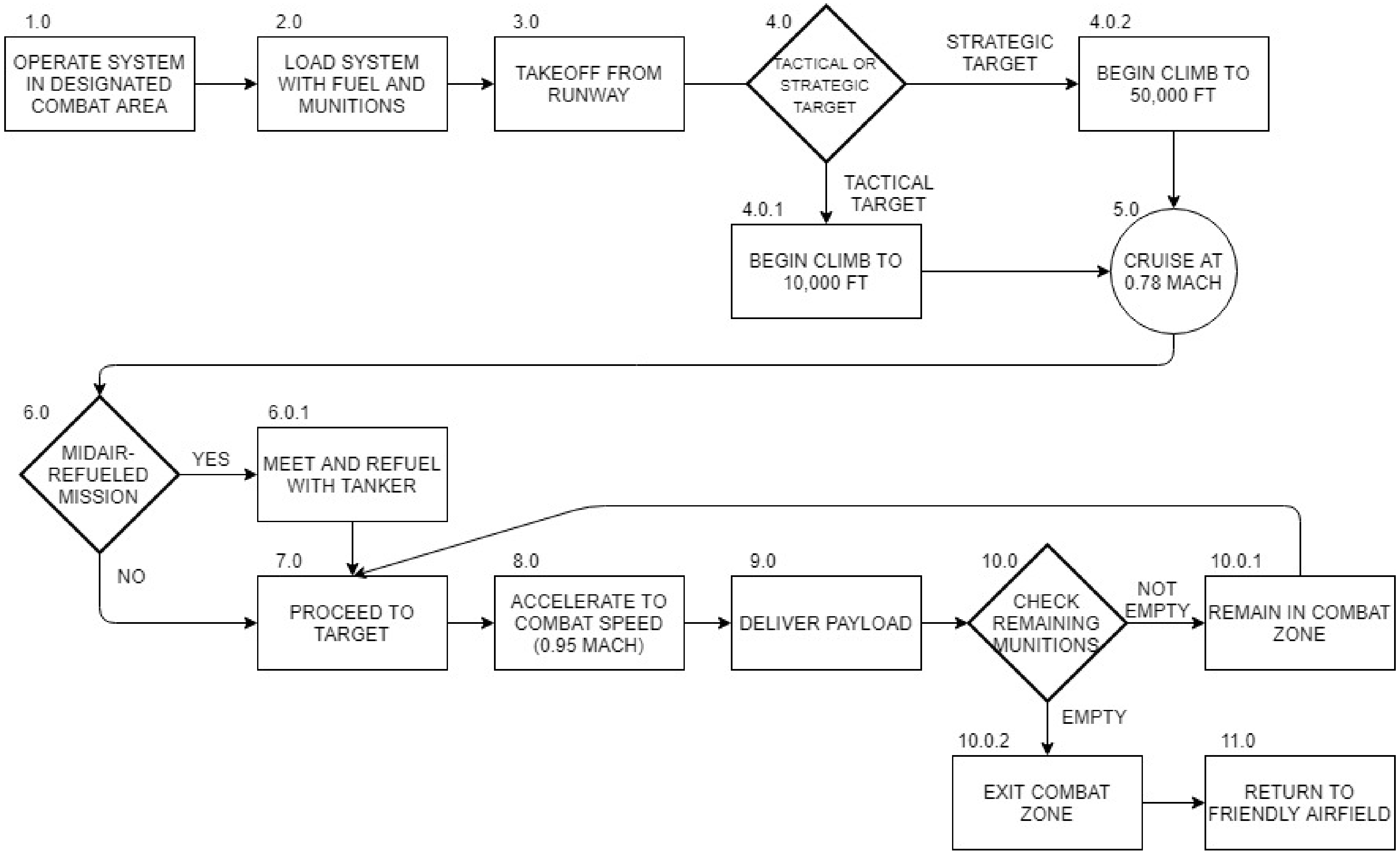
Due to the importance of Radar Cross Section, the system chosen is superior when considering the goals of the project.

7.0b Typical TPM Report



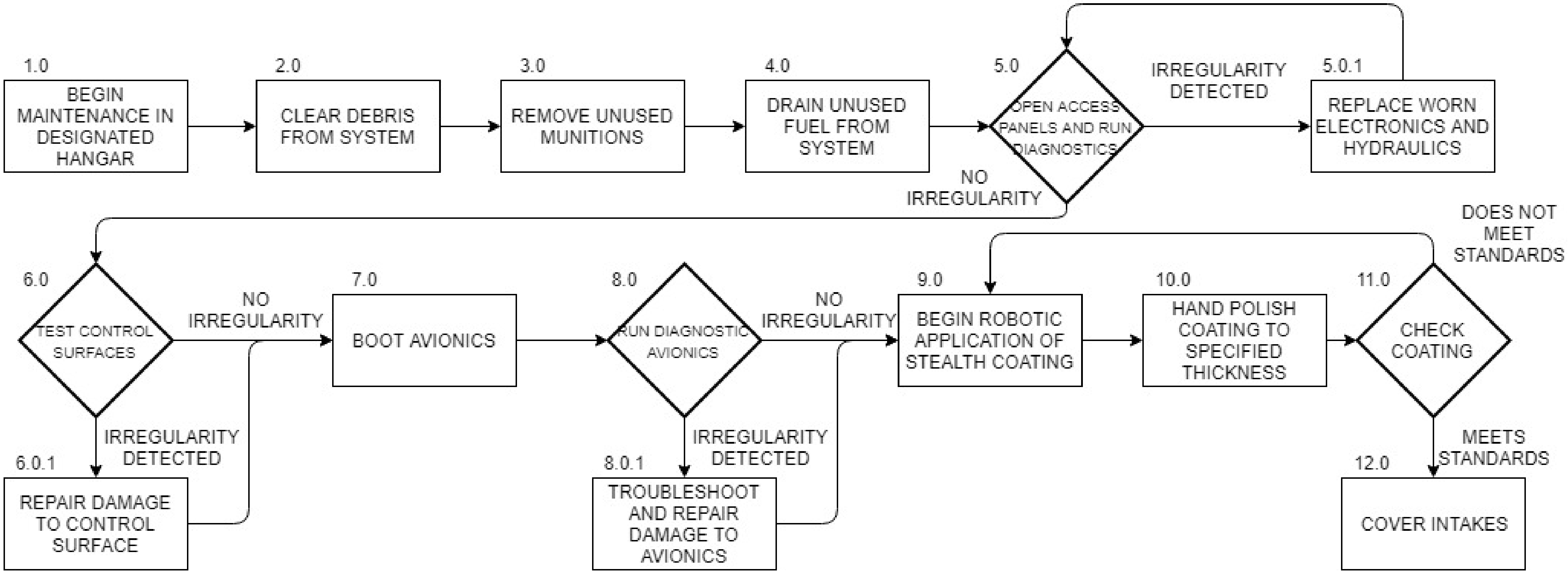
The B-2 Spirit decreases its radar cross section the longer it remains in development, increasing its effectiveness.

8.0a System Operations Functional Flow Breakdown



The B-2 is designed around all altitude bomber missions and is flexible with strategic and tactical bombing capabilities.

8.0b System Maintenance Functional Flow Breakdown



Because of the B-2's complex computer systems and stealth coating, additional steps are required to maximize the effectiveness of the system.

9.0 System Spec – *B-2 Spirit*

1.0 Design Reference Missions:

1.1 - Stealth Bombing Mission: Climb to 50,000 ft, drop payload, descend, and land.

1.2 - Long Distance Mission: Climb to 50,000 ft, mid-air refuel after 6,000nmi, drop payload after an additional 4,000nmi, and descend and land.

1.3 - Training Mission – Climb to 50,000 ft, practice maneuvers and control, drop payload, and land.

2.0 System Level Requirements

2.1 - Radar cross-section - < 0.3m^2

2.3 - Max Payload – 40,000 lbs

2.4 - Acquisition Cost - $2.1 billion

3.0 Environmental Requirements

3.1 - Withstand temperatures ranging from -20° to 40° Celsius.

3.2 - Withstand stresses at transonic speeds.

4.0 Mission and Performance Requirements

4.1 - Max Speed – 0.95 Mach

4.2 - Range – 6,000nmi-10,000nmi

4.3 - Operates at altitudes up to 50,000 ft and under 8,000 ft.

4.4 - Capable of aerial refueling.

5.0 Utilization and Operational Requirements

5.1 - Based in Whiteman AFB, Missouri.

5.2 - 50% of B-2 fleet must be operational at any given time.5

6.0 Maintenance and Support Requirements

6.1 - Programmed Depot Maintenance (PDM) takes place at Northrop Grumman, Palmdale.

6.2 - Environmentally conditioned hangars positioned globally.

6.3 - Retirement/Disposal begins as the B-21 Raiders are introduced (mid-2020s).

The B-2 ultimately met the needs of the customer and also was able to perform its reference missions.

10.0 Conceptual Design Compliance Matrix

Document Section	Compliance	Initials	Page #
0. Title Page	Yes	A.T.	1
1.1 Needs analysis, 1.2 Goals, 1.3 Objectives, 1.4 DRM's, 1.5a System Level Requirements, 1.5b System FOM Attributes, 1.5c Derived Requirements, 1.6 System Life Cycle	Yes	E.G.K.	2
2. Organization Chart – Conceptual Design	Yes	A.T.	12
3. Trade Study: 3.1 Candidate Architectures, 3.2 Sys. Level FOMs, 3.3 Feasib. Ana., 3.4a Trade Matrix, 3,4b Quantif. & Down Select (Bar Chart), 3.5 Select Best Arch. & Rational. statm.	Yes	E.D.V	14
4a, b, c Work Breakdown Structure – (Conceptual Level with Key Functional Allocations)	Yes	A.S.K.	22
5. Operationalrequirements: 5.1 DRMs, 5.2 Perf & Phy Param, 5.3a Ops Deployment, 5.3b Ops Depl Diagram, 5.4 Oper. Life Sycle, 5.5 Utilt. Reqmts, 5.6 Effect. Facts., 5.7 Envirn.	Yes	H.H.	25
6. Maintenance & Support concept diagram	Yes	A.B.	35
7. Five Tech Performance Measures	Yes	A.B.	36
8. Functional block diagrams, 8a Operations, 8b Maintenance & Support	Yes	A.B.	38
9. System spec.	Yes	A.T.	40
10. Compliance Matrix.	Yes	A.T.	41
11. Summary	Yes	A.T.	42

Each member of this team was compliant throughout the execution of this project and contributed to the final product.

Ashton Teimoori

11.0 Summary

- **Key Benefits of our Design concept**
  - The Northrop Grumman (NG) B-2 bomber's radar cross section is 50% smaller than the closest design.
    - NG's lacks a vertical tail, which minimizes radar cross section.
  - The NG's bomber can travel 25% further than the closest competing design without aerial refueling.
  - The material and engine placement of NG's bomber minimizes the detection from enemies.

  - **Our Company's Capability to do the job right**
  - Our team of engineers exhausted all possible designs.
  - Development of computer software to help select wing design to minimize radar detection.
  - Successfully delivered 10+ projects with 9+ years of engineering experience between us.

- **What do you think?**

Northrop's B-2 design is more efficient and exceeds the FOM's more than our other architectures.

References

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- https://www.globalsecurity.org/wmd/systems/b-2-specs.htm
- http://www.deagel.com/Combat-Aircraft/Tu-160M2_a000332003.aspx
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- Maintenance and Support 6.0
  - https://news.northropgrumman.com/news/releases/northrop-grumman-completes-b-2-bomber-maintenance-in-record-time
  - https://www.airforce-technology.com/projects/b2/
  - https://www.airforce-technology.com/projects/raf-fairford/
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  - https://www.upi.com/Orbital-ATK-to-produce-components-for-B-2-stealth-bomber/4751496166461/
- 3.5 Best Configuration, SDR
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Team Spirit does not wish to have this information come off as their own, and gives credit to the individuals who gave the information.

References (contd.)

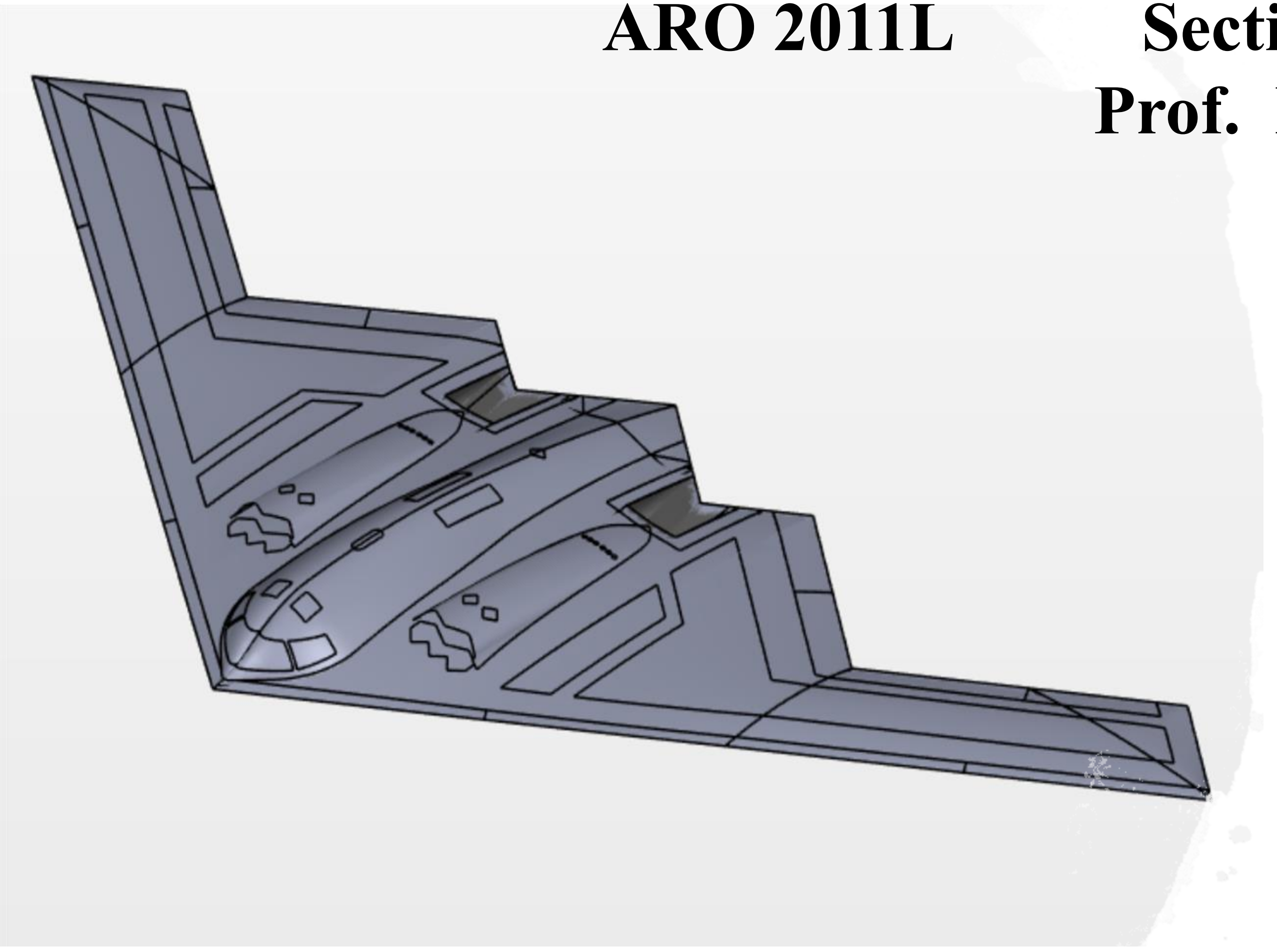
- https://medium.com/war-is-boring/america-has-20-stealth-bombers-guess-how-many-can-fly-right-now-9f0575cd52ff
- 5.1 Design Reference Mission
  - http://www.aerospaceweb.org/aircraft/bomber/b2/
- https://www.cleveland.com/nation/index.ssf/2010/06/b-2_stealth_bombers_require_60.html

Team Spirit does not wish to have this information come off as their own, and gives credit to the individuals who gave the information.

Preliminary Design of the B-2 Spirit Bomber

ARO 2011L Section 3 Team 4

Prof. Dobbs



Date Submitted: 13 March 2019

Team Lead : Harut Hajibekyan

Team Deputy : Alexander Kwon

Members: Ashton Teimoori

Ethan Dominic Victoriano

Anton Belosludtsev

Eliot Khachi

Team Spirit

Cal Poly Pomona Aerospace Engineering Department

1.0 Team Organization Chart

0.0 Program Manager
Harut Hajibekyan
Deputy: Alexander Kwon
WBS 6.0

Chief Systems Engineer
Alexander Kwon
Deputy: Dominic Victoriano
WBS 1.0

1.0 Chief Maintenance Engineer
Dominic Victoriano
Deputy: Anton Belosludtsev
WBS 4.0

2.0 Chief Vehicle Engineer
Ashton Teimoori
Deputy: Harut Hajibekyan
WBS 2.0

3.0 Chief Manufacturing Engineer
Eliot Khachi
Deputy: Ashton Teimoori
WBS 5.0, 1.3

4.0 Chief Operations Engineer
Anton Belosludtsev
Deputy: Alexander Kwon
WBS 3.0

Our team has successfully tested & proven new stealth technologies capable of being implemented into a stealth bomber program.

1.1 Org Chart Responsibility Charters

- Program Manager – Oversees the entire project from organization and execution, to production and disposal. Responsible for Charts # 1.0, 1.1, 3.0
- Chief Systems Engineer – Monitors all project progress & ensures fluid subsystem integration throughout lifecycle of program. Responsible for Charts # 4.0b-1, 4.0.b-2, 4.0b-3
- Chief Maintenance Engineer – Devises long- and short-term plans for maintaining the aircrafts ability to fly & perform all necessary missions. Responsible for Chart # 4.0a
- Chief Vehicle Engineer – Works on overall design and fluid integration, of current and future changes, of all vehicle sections throughout program lifecycle. Responsible for Charts # 5.0a-1, 5.0b
- Chief Manufacturing Engineer – Builds and assembles all aircraft parts within specifications while also studying cheaper and easier ways to perform those tasks. Responsible for Chart # 5.0c
- Chief Operations Engineer – Clearly defines & tests how the design will be used and operated to fulfill all its requirements. Responsible for Chart # 2.0

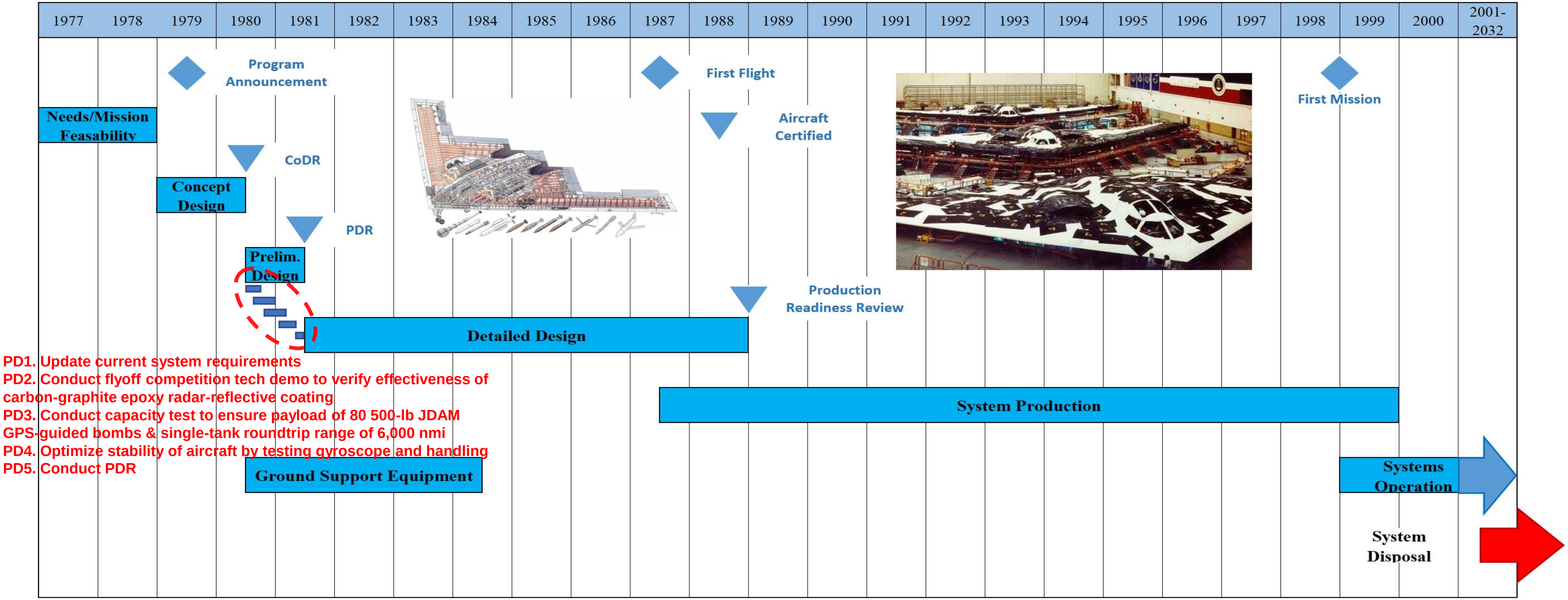
Each member of our team was responsible for a section of aircraft design listed above.

2.0 Program Objectives for Preliminary Design Phase

Customer Objectives	Our Company's Objectives
1. Create a technology demonstrator.	1. Build a physical model that fits the derived requirements, looking and functioning similarly to the production variant.
2. Improve flight characteristics.	2. Design and redesign wing, cockpit, and engine shape to best fit the derived requirements.
3. Research more effective methods of reducing radar cross section.	3. Simulate and test radar cross section reducing technologies and methods, further developing capabilities of the system without compromising in other areas.
4. Develop flight software for B-2's computer systems.	4. Develop software to analyze and correct aerodynamic effects and create test scenarios to ensure that software does not fail.

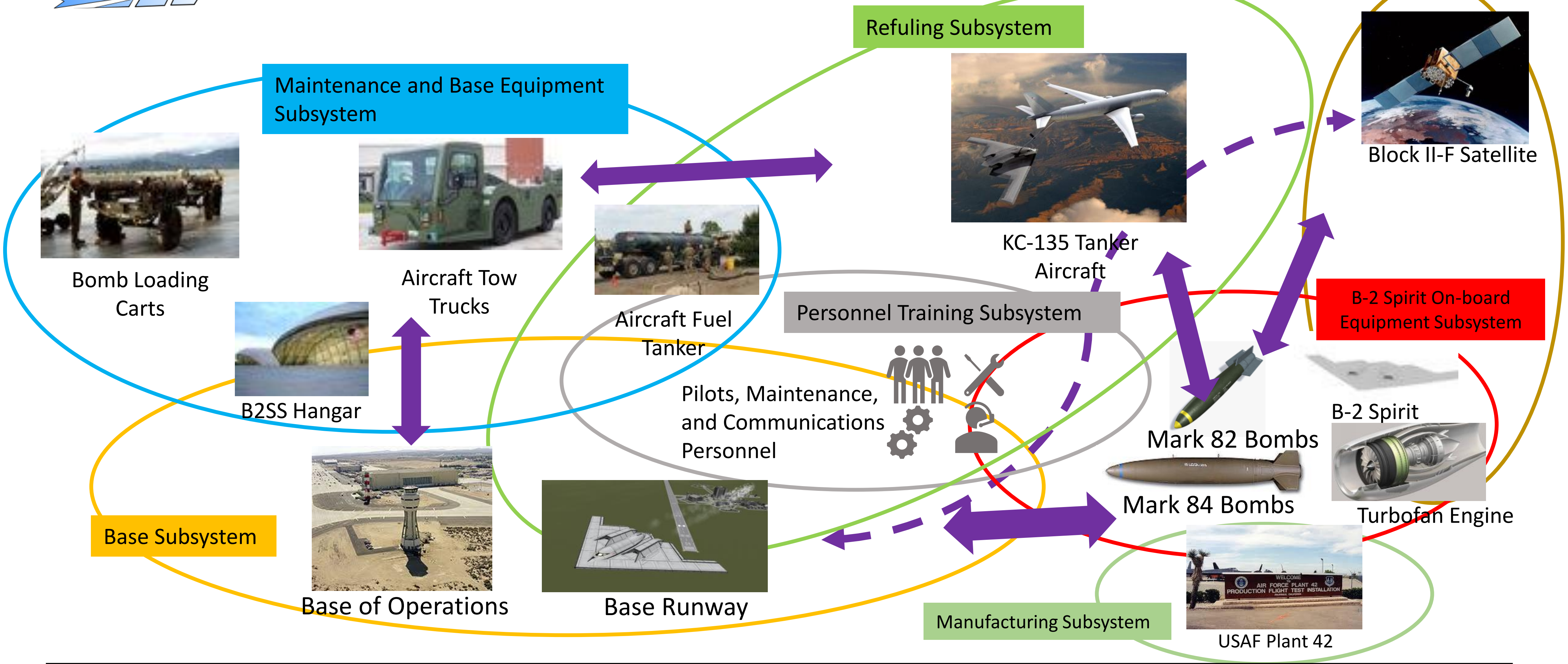
The objectives of the PD phase are to ensure performance improvements to the key attributes of the B-2.

3.0 Life Cycle for B-2 Spirit Bomber



Preliminary design processes allow for review and refinement of current design and technology implementation.

4.0a Chosen System Elements

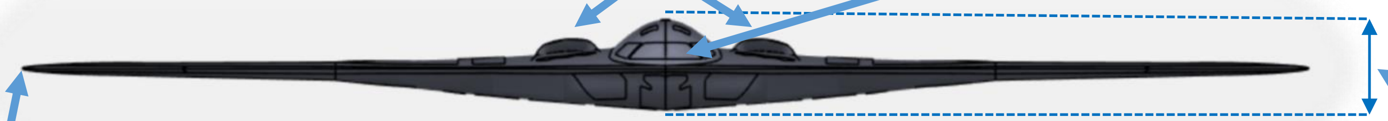


B-2 Aircraft has subsystems specifically tailored to maintain and operate the main system while also being designed to be compatible with existing military assets and hardware.

4.0b-1 Design Concept Graphics – Key Subsystem: Vehicle

Propulsion:
- Four Turbofan engines places near fuselage to minimize infrared signatures.

Characteristics:
- Empty weight of about 15,000 lbs.
- Wing loading: 67.3 lb/ft^3



Flight controls:
- Ailerons for pitch and yaw.
- Split rudder was the secret for yaw stability.

Profile:
- Height: 17ft
- Wingspan: 172ft
- Length: 69ft
- Flying wing design, minimizes radar cross section to $0.2m^2$.

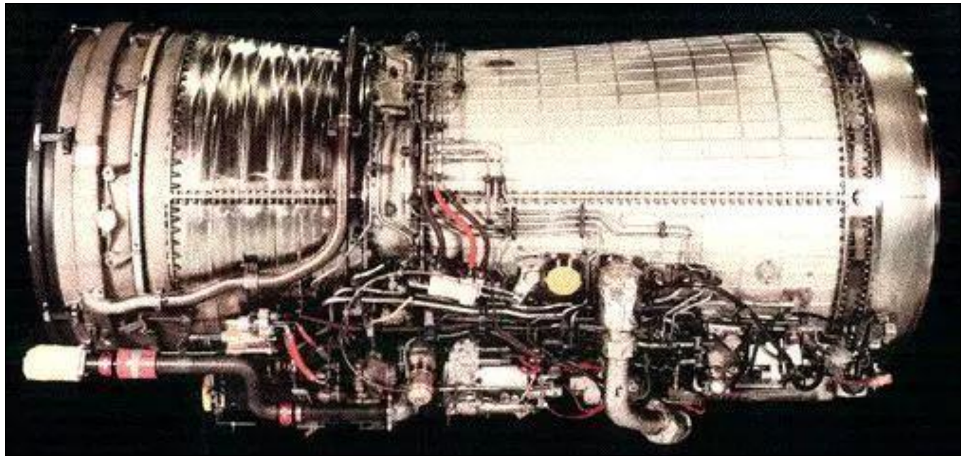
Crew/Accessories:
- Two pilots.
- One bed, toilet, and a place to prepare hot meal.

Features:
- Mid-air refueling.
- Specific wing angles that reflect radar waves.

Armament:
- Capable of carrying a maximum of 40,000 lb of payload.
- Can store multiple different types of payload, including nuclear.

The split rudder gave the B-2 bomber yaw stability. When the split rudder opens up on one side, the plane yaws to that side.

4.0b-2a Engine Trade Study

General Electric F118:	Rolls Royce Olympus 593:
	
• Max Thrust: 19,000 lbf • Dry Weight: 3,200 lb • Pressure Ratio: 35:1 • Thrust-to-weight ratio: 5.9:1 • Size: 101 in diameter, 46.5 in long	• Max Thrust: 38,500 lbf • Dry Weight: 7,000 lb • Pressure Ratio: 15.5:1 • Thrust-to-weight ratio: 5.4:1 • Size: 47.75 in diameter, 159 in long

The General Electric F118 engine has a pressure ratio more than double that of the Rolls Royce Olympus 593, increasing range.

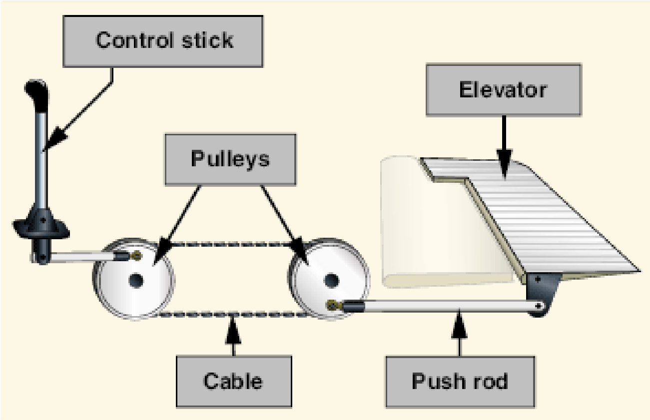
4.0b-2b Engine Trade Matrix

FOMs / Alternative Architectures	Size (100d in x 75l in) Wt. 1		Thrust (18,000 lb) Wt. 2		Thrust to Weight (30:1) Wt. 3		Pressure Ratio (20.0) Wt. 3		Weighted Total = Sum (U x Wt)
	U	W	U	W	U	W	U	W	
General Electric F118	3	3	3	6	9	27	9	27	63
Rolls Royce Olympus 593	1	1	9	18	0	0	0	0	19

The General Electric F118 fits many more categories than the Rolls Royce Olympus 593, making it the preferred engine.

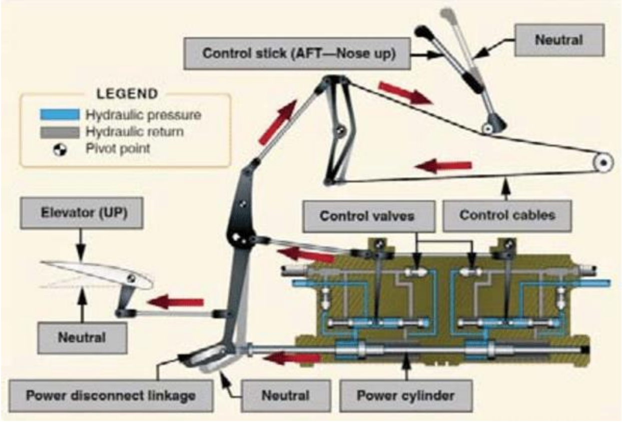
4.0b-3 Aircraft Flight Control System Trade Study

Mechanical:



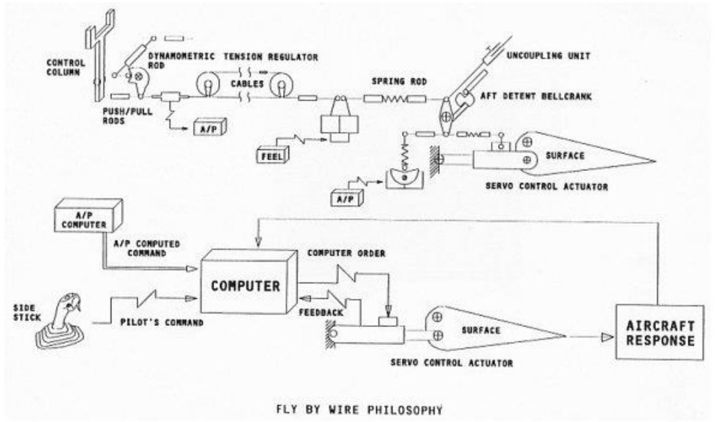
- Acquisition Cost: $500,000
- Reliability: 1/400 flights
- Reaction Time: 0.25 sec
- Weight: 1,000 lbs

Hydro-mechanical:



- Acquisition Cost: $800,000
- Reliability: 1/500 flights
- Reaction Time: 0.25 sec
- Weight: 3,000 lbs

Fly-by-wire:



- Acquisition Cost: $1 Million
- Reliability: 1/2000 flights
- Reaction Time: 0.01 sec
- Weight: 300 lbs

The fly-by-wire system has the fastest reaction speeds while also having the most reliable design.

4.0b-2b Aircraft Flight Control System Trade Matrix

FOMs / Alternative Architectures	Reaction Time (0.25 sec) Wt. 1		Acquisition Cost ($700,000) Wt. 2		Reliability (1/500) Wt. 3		Weight (2000 lbs) Wt. 3		Weighted Total = Sum (U x Wt)
	U	W	U	W	U	W	U	W	
Mechanical	3	3	9	18	1	3	3	9	33
Hydro-mechanical	3	3	1	2	3	9	3	9	23
Fly-by-wire	9	9	0	0	9	27	9	27	63

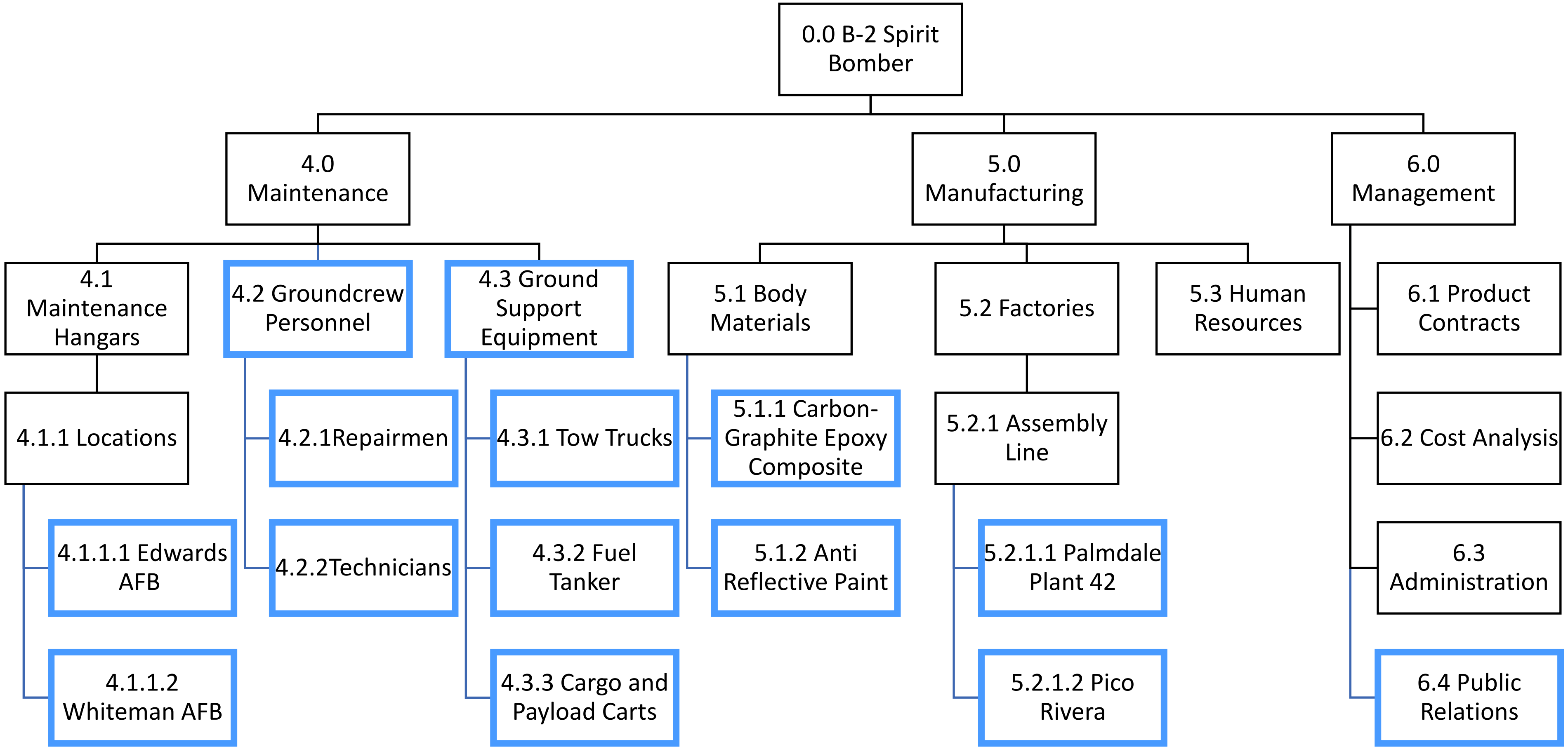
After evaluating the trade matrix, the fly-by-wire architecture surpasses both traditional methods and is the most reliable.

5.0a WBS for Preliminary Design

- 0.0 B-2 Spirit Bomber
  - 1.0 Systems Engineering
    - 1.1 Hardware Manufacturing
    - 1.2 Software Development
    - 1.3 Production Coordination
  - 2.0 Vehicle
    - 2.1 Avionics
      - 2.1.1 Defense Management Systems
        - 2.1.1.1 Radar
          - 2.1.1.1.1 Terrain Following Radar
      - 2.1.2 Flight Control Systems
        - 2.1.2.1 Flight Stability
          - 2.1.2.1.1 Gyroscope
      - 2.1.3 Fly by Wire System
        - 2.1.3.1 Instrument Panel
          - 2.1.3.1.1 Pitot-Static Sensing Plates
        - 2.1.3.2 Control Surfaces
    - 2.2 Communications Devices
      - 2.2.1 Satellites
        - 2.2.1.1 Block II F
      - 2.2.2 GPS
      - 2.2.3 Ground Control
        - 2.2.3.1 Whiteman
    - 2.3 Ordinance Capacity
      - 2.3.1 Payloads
        - 2.3.1.1 Conventional
        - 2.3.1.2 Nuclear
  - 3.0 Operations
    - 3.1 Flight Calibrations
    - 3.2 Communications
    - 3.3 Refueling Systems
    - 3.4 Target Selection

Total system design further refined and reorganized to qualify initial preliminary product design phase.

5.0a (Cont.) WBS for Preliminary Design



Total system design further refined and reorganized to qualify initial preliminary product design phase.

5.0b WBS Dictionary Format

Project/ Program B-2 Spirit Bomber	Work Breakdown Structure Dictionary	Date 03/13/19	
Contract No. 1		Sheet 1	Of 1

WBS Level						Element Title
1	2	3	4	5	6	
	x(2.0)					Air Vehicle

Element Description

AIR VEHICLE
The complete post-procurement aircraft with its components for testing and initial flyaway. The B-2 aircraft encompasses and possesses prototype avionics, communication devices, and ordinance capacity as defined in the WBS Preliminary Design graph for fielding test flights and further system analysis.

WBS Level						Associated Lower Level Elements
1	2	3	4	5	6	Title
		(2.1) x(2.2) (2.3)				Avionics Communication Devices Ordinance Capacity

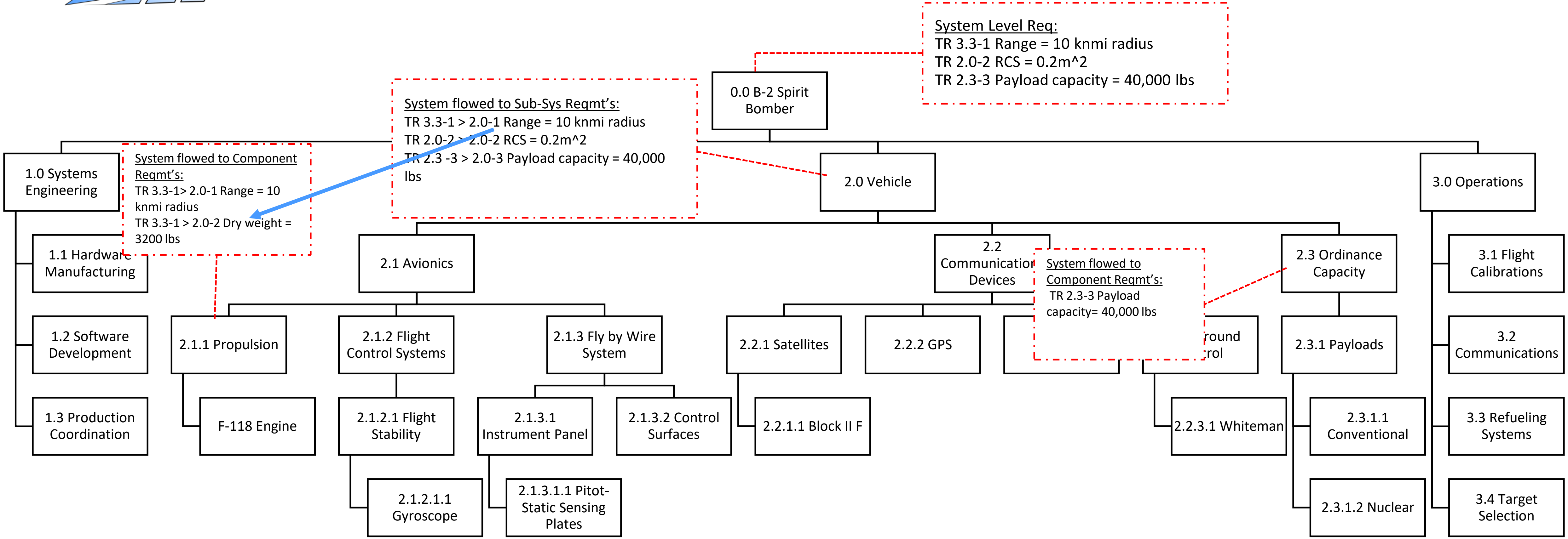
Air Vehicle subsystem is defined with its role and purpose, with its sub-components that make it up subsequently listed.

5.0c Preliminary Design Derived Requirements

Req. #	WBS #	Req. Statement	Valid. Method	Req met @ CoDR?
TR3.0	3.0 (Operations)	Aircraft must be able to reach Russian airspace in order to deliver payload to target locations.	Analysis: Compare target distance with estimated range	Yes
TR3.3	3.3 (Operations – Refueling Systems)	Must be able to complete missions that require a maximum radius of 10,000 nautical miles with a single midair refueling.	Flight Test: Tech Demonstration	Yes
PR2.1.1	2.1.1 (Vehicle – Avionics – Flight Control Systems)	Aircraft must be able to perform autopilot flight for a minimum of 6 hours and maximum of 9 hours, especially when flying 0.95 Mach at the height ceiling.	Flight Test: Tech Demonstration	Yes
PR2.1.2.1	2.1.2.1 (Vehicle – Avionics – Flight Control Systems – Flight Stability)	The aircraft will have to be in stable flight during the full duration of the mission (ie. 6 hours to 13 hours).	Ground Test: Model wind tunnel test	Yes
TR5.1	5.1 (Manufacturing – Body Materials)	The structure and composition of the aircraft will yield a radar cross-section of 0.2 m^2.	Analysis: Radar reflection testing	Yes
TR5.1.1	5.1.1 (Manufacturing – Body Materials – Carbon-Graphite Epoxy Composite)	The aircraft must be built out of a carbon-graphite epoxy composite to increase radar-absorbing capabilities.	Analysis: Measure radar signal reflection strength	Yes

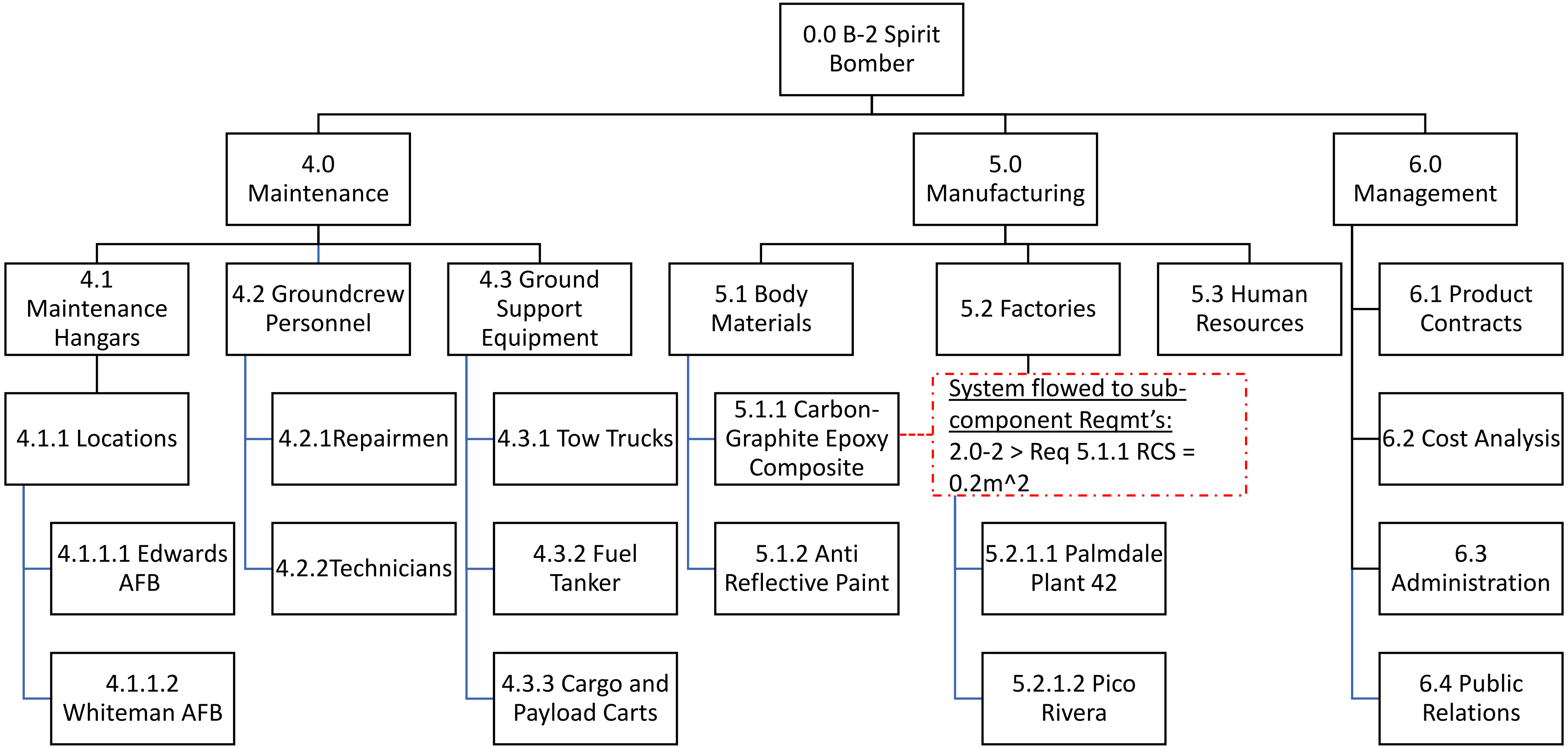
A carbon-graphite epoxy composite provides radar absorbing capabilities to yield a cross section of 0.2 m^2, while the payload capacity provides for a total of 80 500-lb JDAM GPS-guided bombs.

6.0 Requirements Allocation on WBS



Allocations are flowed down towards requirement components deemed most prominent to the program, such as the aircraft's range and carrying capacity.

6.0 (Cont.) Requirements Allocation on WBS



Carbon graphite composite layer coating utilized to fulfill system level requirement of low radar cross-section (0.2 m^2).

7.0a B-Level Sub-System Specification

- 1.0 Scope- Covers preliminary design requirements and features for the air vehicle subsystem.
- 2.0 Applicable Documents- Chart 5.0a, Chart 6.0
- 3.0 Requirements
  - 3.1.1 General Description- Long-range stealth bomber aircraft.
  - 3.1.2 Operational requirements- Aircraft capable of making 6000 nautical mile flights and having a radar cross-section, of 0.2m^2 while also carrying 40,000 lbs of conventional and nuclear payloads.
  - 3.1.3 Maintenance Concept- Aircraft fitted with a custom-made environmentally-controlled hangars; maintained with existing tow trucks, bomb carts, and specially trained personnel. -Chart 5.0a
  - 3.1.4 Functional Analysis- Development and integration of stealth technologies and fly-by-wire avionics.
  - 3.1.5 Allocation of Requirements- Requirements allocated based on system level requirements as shown in Chart 6.
  - 3.1.6 Functional Interfaces- Aircraft system and maintenance system work together to allow for efficient service and functionality of the aircraft.

The B-2 Spirit aircraft system is designed around main requirements, of which requirements are allocated based on program importance.

7.0a (Cont) B-Level Sub-System Specification

- 3.2 System Characteristics
  - 3.2.1 Performance Characteristics- Aircraft has a flight ceiling of 50,000 ft and a flight duration of 6,000 nmi without aerial refuel.
  - 3.2.2 Physical Characteristics- Aircraft is 69 feet long and 17 feet high, with a wingspan of 172 feet.
  - 3.2.3 Effectiveness Requirements- Aircraft must be able to be in service and mission-ready for the duration of more than 30 years after production.
  - 3.2.4 Reliability- Capable of traveling on virtually any point of the globe within a few hours.
  - 3.2.5 Maintainability- Aircraft has a programmed depot maintenance process averaging 400 days of the year, with an engine overhaul every 7 years.
  - 3.2.6 Usability (Human Factors)- Aircraft designed with an in-flight crew of two, with on-board controls based on a fly-by-wire system- Chart 5.0a, subsystem level 2.1.3.
  - 3.2.7 Supportability- B-2 Spirit can be accommodated with existing maintenance vehicles and fitted with conventional and nuclear payloads.
  - 3.2.8 Transportability/Mobility- Aircraft operability on high and low altitudes with a height ceiling of 50,000 feet, and extreme hot and cold climates, such as the weather of Russia.
  - 3.2.9 Flexibility- Whole aircraft and supplementary system can operate under various bases of operations.

The aircraft subsystem is specified with characteristics ensuring that the aircraft itself is designed to be durable, maintainable, and reliable under mission conditions.

7.0b B-Level System Specification

- 3.3 Design Construction – The construction of the B-2 bomber will be done on site in one facility.
  - 3.3.1 CAD/CAM Requirements – Will be used before production to validate aerodynamics and design.
  - 3.3.2 Materials, Processes, and Parts – Special carbon-graphite material will be used for the skin, making it less susceptible to detection by enemy radar.
  - 3.3.3 Mounting and Labeling – Payload will be mounted onto the bomber before the lunch.
  - 3.3.4 Altitude – The cabin will be pressurized so the pilots will be able to operate.
  - 3.3.5 Safety – The B-2 will be equipped with ejection seats in the event something is to go wrong.
  - 3.3.6 Interchangeability – Many different classes of bombs can be dropped by this bomber.
  - 3.3.7 Workmanship – The quality of the work will be checked during the completion of each subsystem.
  - 3.3.8 Testability – The engines of the B-2 will be tested in facilities, and the design of the aircraft will be tested by computer software and flight tests.
  - 3.3.9 Economic Feasibility – The total program cost of the B-2 will not exceed ***$45 billion*****.**
- 3.4 Documentation/Data – The information regarding the technical aspects of the B-2 will be well documented and classified.
- 3.5 Logistics – All missions will be carried out by the DOD and mission details will be classified.
  - 3.5.1 Maintenance Requirements – All aircraft have a special hanger where they will be maintained.
  - 3.5.2 Supply Support – The payload will be manufactured by a classified, off location supplier.
  - 3.5.3 Test and Support Equipment – Testing will be done after CDR to perfect the fly-by-wire technology.

The B-2 bomber will be manufactured, assembled, and maintained at the same facility.

7.0b (Cont.) B-Level Sub-System Specification

- 3.5.4 Personnel and Training – There is training missions so crew will become more familiar/comfortable with the maneuverability of the bomber.
- 3.5.5 Facilities and Equipment – Only one facility will house the B-2.
- 3.5.6 Packing, Handling, Storage and Transportation – All assembly of the B-2 will be done on sight, no packing or handling. Special hangers are needed for safe keeping of the bomber.
- 3.5.7 Computer Resources (Software) – There will be advancements in the avionics of the bomber. It will implement a fly-by-wire flight control system.
- 3.5.8 Technical Data/Information – Performance and technical data will remain classified to the public.
- 3.5.9 Customer Service – Northrup Grumman will keep maintenance on the bomber.

- 3.6 Producibility – There will be 132 bombers produced.
- 3.7 Disposability – The bomber will be phased out in 2032.
- 3.8 Affordability – Each bomber will cost a total of $2.1 billion to produce.
- 4.0 Test and Evaluation – There will be a series of tests conducted to validate the new technologies and design.
- 5.0 Quality Assurance Provisions – The figures that the B-2 is predicted to achieve is all validated and should hold true.
- 6.0 Distribution and Customer Service – Will be operated from globally and maintained by designated airfields.
- 7.0 Retirement and Material Recycling/Disposal – The bomber will be retired in 2032 and will be completely disposed of.

Each B-2 Bomber will cost $2.1 billion to produce.

9.0a Application Of Models

Design Problem Objective: Determine the shock strut damping coefficient to minimize the landing g's to < 2g of the vehicle body. The landing gear is subject to a hard landing at 2m/s vertical velocity.

Knowns: Sink rate = 2m/s, spring rate of gear attachment = 6397500 N/m, spring rate of tire = 85300000 N/m, spring rate of shock strut = 2559000 N/m, mass of vehicle on landing gear = 170600 kg

Method: LMS AMESim simulation software by Siemens in 17-2103

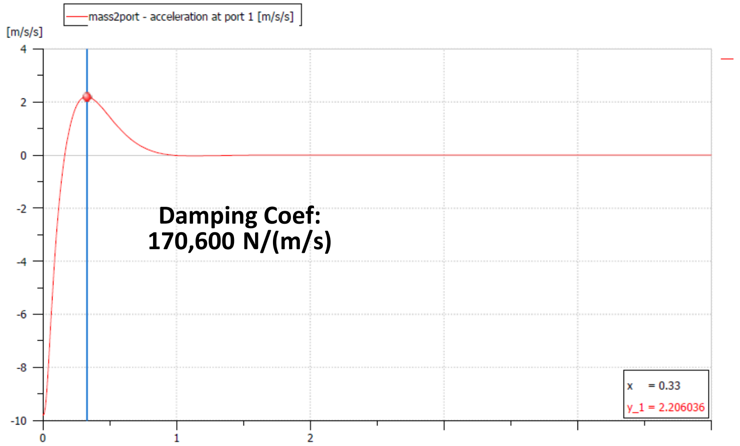
The landing gear of the B-2 is designed to withstand a 2 m/s hard landing and impart less than 2 g's to the airframe structure.

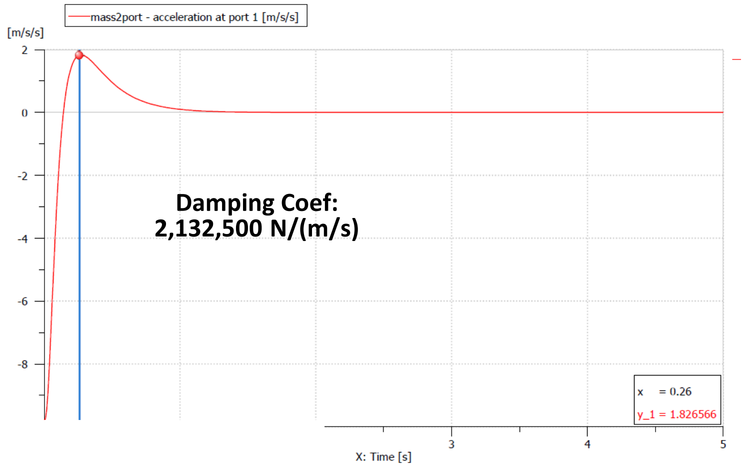
9.0b Input Data and Sim Results for AMESim Hard Landing Simulation for the B-2 Spirit Bomber That Determines the Optimum Shock Strut Absorber Damping Coefficient

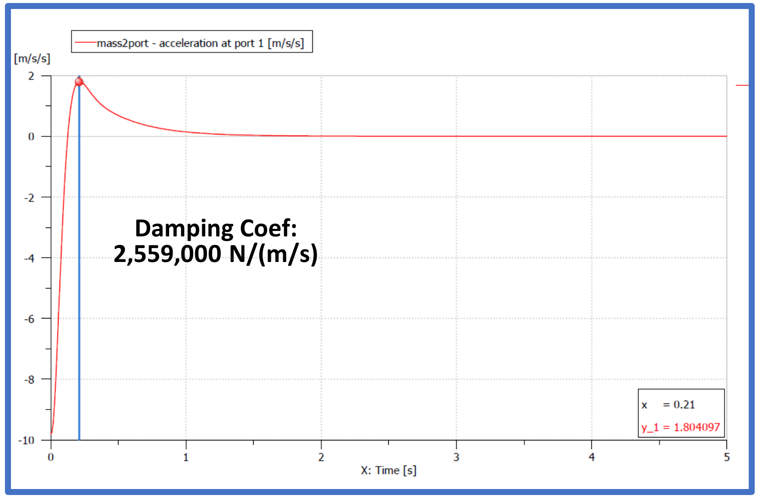
Model	Body Mass (kg)	Suspension Spring (N/m)	Susp. Shock Absorber Damp Coef (N/(m/s))	Wheel Mass (kg)	Tire Stiffness (N/m)	Max + Body Mass Acceleration (m/s^2)	Max - Body Mass Acceleration (m/s^2)	Max Accel (m/s^2)	Max Accel Allowed
Quarter Car	400	15000	500	50	200000	7.430461	-6.447762	0.7574374	
B-2 Rm = 426.5	170600	6397500	106625	21325	85300000	8.572838	-7.444588	0.874155	(+/-) 2G
	170600	6397500	213250	21325	85300000	7.531459	-5.6559	0.7679677	
	170600	6397500	426500	21325	85300000	5.952872	-3.307254	0.6070023	
	170600	6397500	853000	21325	85300000	3.97592	-1.121518	0.4054165	
	170600	6397500	1706000	21325	85300000	2.206036	NA	0.224945	
	170600	6397500	2132500	21325	85300000	1.826566	NA	0.1862512	
	170600	6397500	2559000	21325	85300000	1.804097	NA	0.1839601	
	170600	6397500	2985500	21325	85300000	2.067709	NA	0.2108401	
	170600	6397500	3412000	21325	85300000	2.445689	NA	0.249382	
	170600	6397500	4265000	21325	85300000	3.173545	-0.2462261	0.3236	

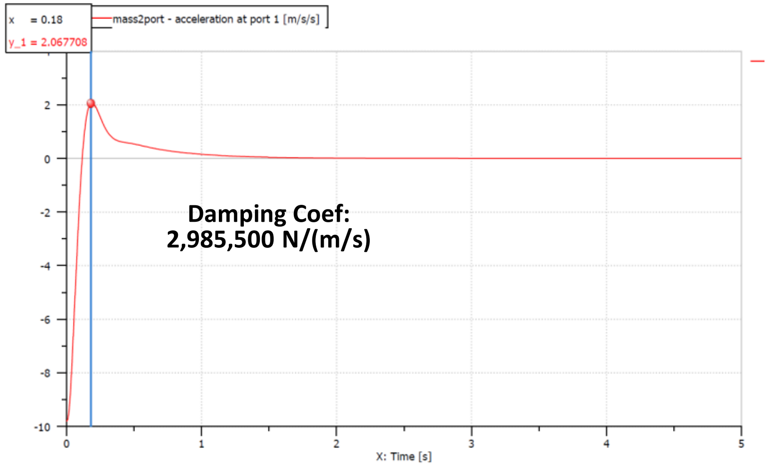
The B-2 shock absorber damping coefficient was chosen from the results of our AMESim data where we recorded the sub 2g force to the airframe body mass structure

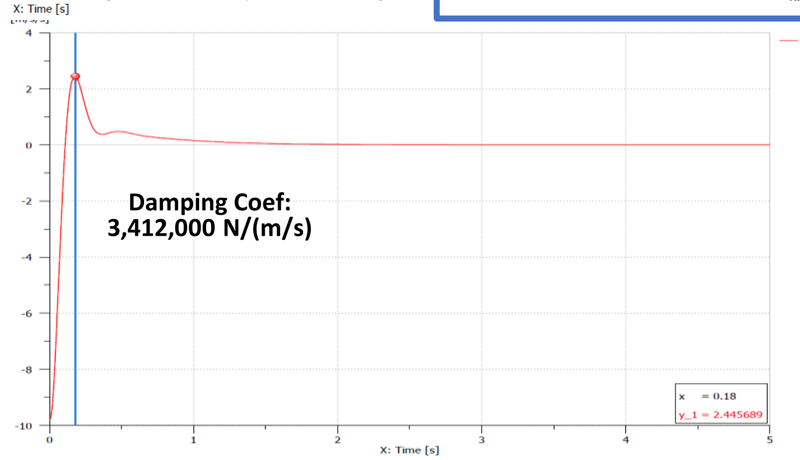
9.1 AMESim Hard Landing Time Histories at Various Damping Coefficients for B-2 Spirit Bomber





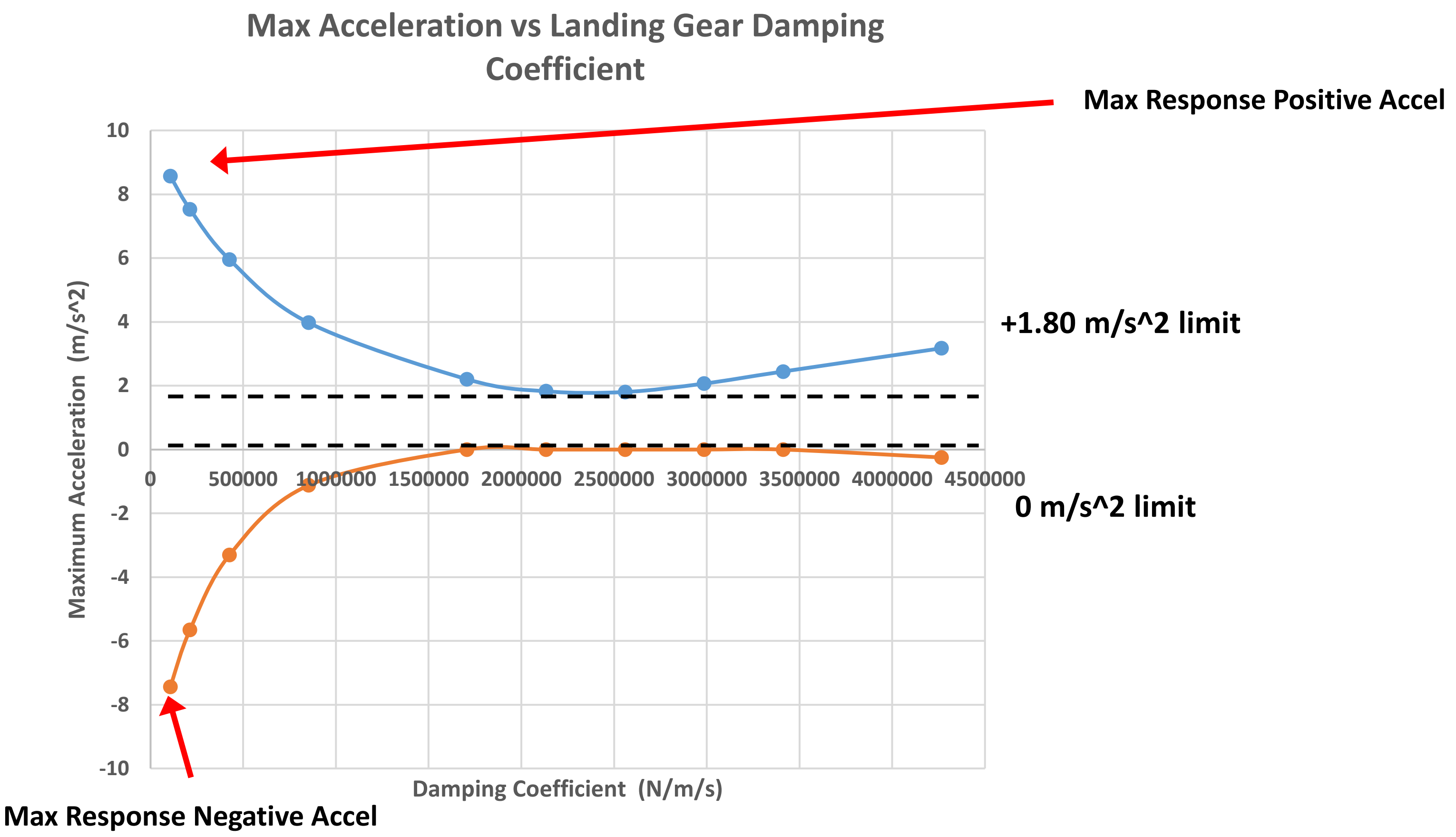


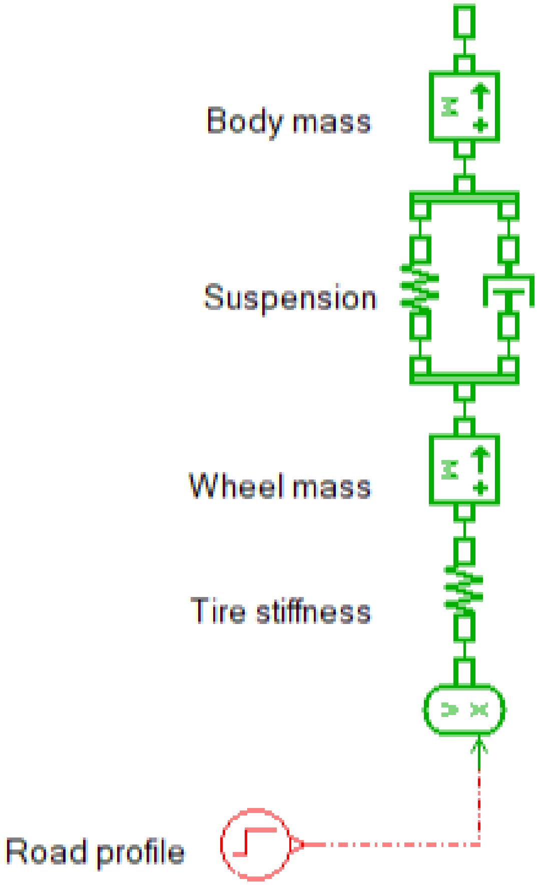




We found that the best Damping Coefficient was 2,559,000 N/(m/s).

9.2 Model Based Systems Engineering – B-2 Spirit Bomber





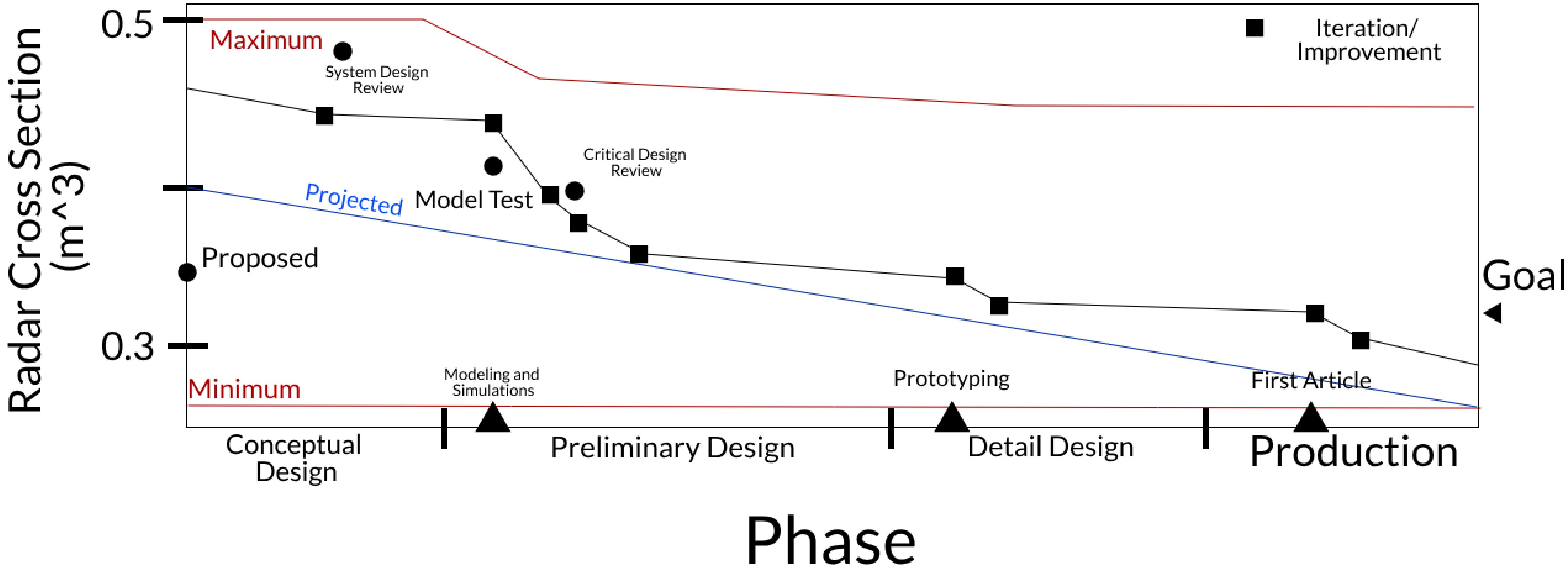
The best choice for the B-2 Bomber landing gear damping coefficient is around 2,559,000 N/(m/s).

10a. TPM Priority Change from Conceptual Design to Preliminary Design w/Rationale

TPM	Conceptual Design Priority # (Presentation #1)	Prelim Design Priority # (Presentation #2)	Rationale for Change of Priority (What change in Prelim Design from Concept Design?)
Radar Cross Section (m^3)	1	1	No change.
Payload (lb)	2	3	Simulation of aircraft models shows that marginally lower payload allows for a better aerodynamic performance.
Range (nmi)	3	2	B-2's range is made more important as DoD requires longer range vehicle.
Max Speed (Mach)	4	5	Max speed becomes less important as thrust is more important to keep the aircraft aloft.
Operational Availability	5	7	Increases in complexity increases time spent in maintenance.
Cost (USD)	6	8	Cost is always least prioritized due to nature of the project.
Maneuverability /Stability		6	Fly-by-wire control systems allow for superior.
Thrust		4	The thrust required to keep the vehicle aloft takes the place of max speed as it keeps the aircraft functioning.

The only major change to preliminary design TPMs is the switch in priority between payload and range, with the latter moving down a level.

10.b Tracking Plot for #1 Priority TPM



Most of the B-2's RCS decrease is made during the modeling and simulation part of development.

11.0 Test Strategies for B-2 Spirit Bomber

- Subsystems to Validate and Verify via testing: Vehicle
- TPMs to be addressed by this test: Mach Speed, Radar Cross-Section, Payload, and Range
- Primary test objective: To ensure a top speed of 0.95 Mach @ its height ceiling, an unrefueled range of 6,000 miles & a weapon payload capacity of 40,000 lbs for the bomber.
    - Flight test required for max velocity verification for 0.95 Mach number @ height ceiling
    - Fuel mass flow rate calculations required to verify range capability
    - Drag coefficient & aerodynamics calculations required for weapon payload capacity verification
    - Total vehicle flight weight, excluding weapon payload, required for verification of all
- Secondary test objectives: Use gathered data to predict thrust, payload capacity, range, max Mach speed, TPM values and vehicle tolerances throughout the life cycle of the project.
- What is to be tested: The vehicle and its Avionics, Communication Devices, and Ordinance Capacity.
- Stage of development hardware/software to be tested: Technology demonstrations
- Number of items to be tested: 10
- Number of times each test item will be tested: Avionics Controls will be tested dozens of times, while top speed, maximum range, and payload capacity will be measured by a few flight tests.
- Top speed, maximum range, and payload capacity will all be tested during each test flight.
- Environmental conditioning required prior to the test: For the Radar Reflection Test the stealth coating must be at its best condition.
- Facilities required to conduct tests: Electronic Facility, RCS Facility, Airport/Landing strip
- Test facility modifications required for tests: No modifications required.

The Vehicle subsystem of The Spirit Project will be thoroughly tested to ensure the TPM requirements of top speed, radar-cross-section, payload, and range are met.

12.0 Risk Statements

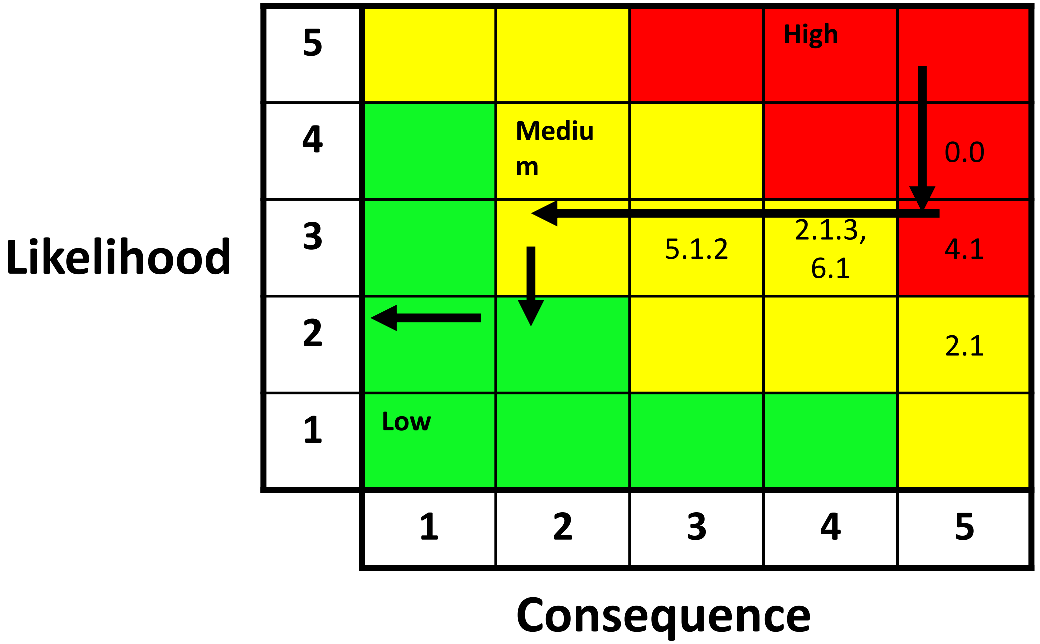
Programmatic Risk

- Requirement 0.0: The B-2 bomber must have a key purpose for production.
- P-Risk 0.0-1: If the USSR collapses due to political tensions, then the B-2 bomber program loses its primary rationale for creation.
- Reqmt 4.0: All maintenance hangers must be manufactured and ready for use before the first flight.
- P-Risk 4.0-2: If the maintenance hangers are not complete before the first flight due to manufacturing delays, then each B-2 bomber will require more frequent maintenance and early disposal.
- Reqmt 6.1: The fleet of bombers requested by Congress through a military budget must be produced.
- R-Risk 6.1-3: If Congress decides to purchase less B-2 Spirit bombers than originally planned due to Congress decreasing the military budget, then the cost associated with the project will be significantly altered.

- Technical Risk
  - Requirement 2.1.3: A fly-by-wire control system must be implemented into the aircraft.
  - T-Risk 2.1.3-1: If the development of a fly-by-wire control system does not meet milestones due to lack of technological development, then the resort to a conventional aircraft control system will increase Radar Cross-Section (RCS).
  - Reqmt 5.1.1: A carbon-graphite epoxy composite must surround the entire outer surface of the aircraft.
  - T-Risk 5.1.1-2: If the automated development and implementation of the carbon-graphite epoxy composite is delayed due to assembly line problems, then the B-2 bomber will be easily susceptible to detection by enemy radar and lead to loss of crew.
  - Reqmt 2.1: Flight control systems must be in place to increase effectiveness of maneuvering and stability.
  - T-Risk 2.1-3: If the stability and maneuvering capability is compromised due to a failure in the flight control systems, then the aircraft's integrity and flightworthiness is compromised, increasing loss of crew ratio.

Programmatic and technical risks are being assessed to ensure smooth completion of requirements and deadlines.

12a Risk Cube



Goal: reduce risk from red to green through mitigations

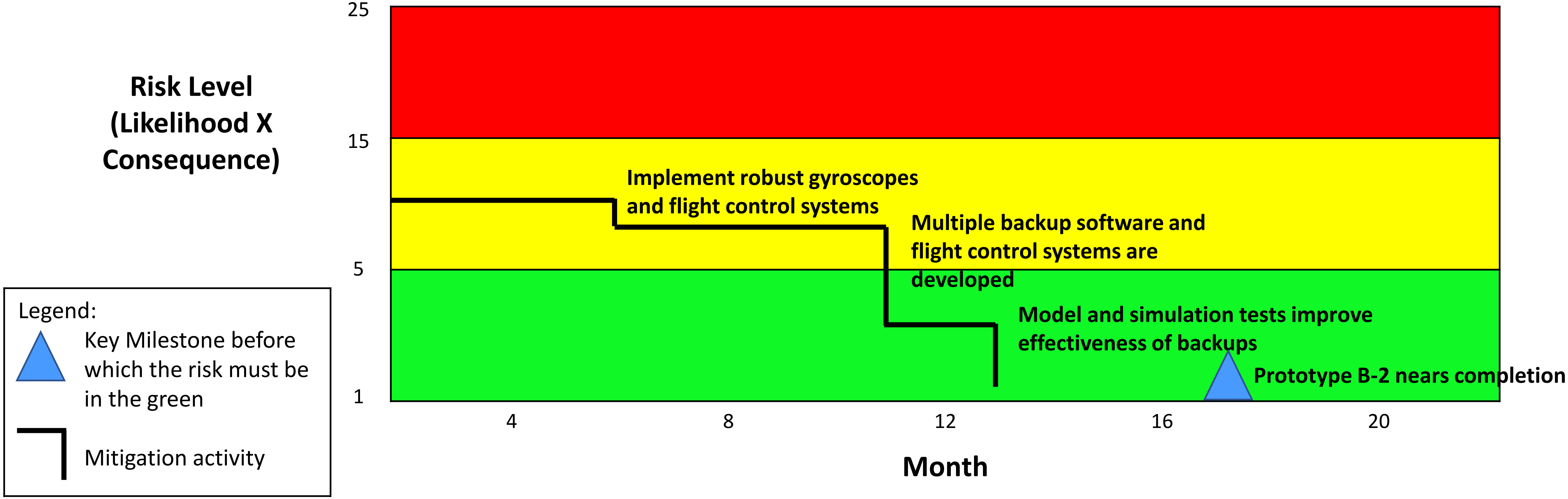
	Programmatic Risks	
Risk #	**Related Reqm't**	**Risk Description**
0.0	Bomber must have purpose for production	USSR collapse causes cancellation of program
4.1	Maintenance hangers due before first flight	Delays increase maintenance cost & deterioration of aircraft
6.1	Full number of requested aircraft must be delivered	Congressional budget cuts cause program cash flow to decrease

	Technical Risks	
Risk #	**Related Reqm't**	**Risk Description**
5.1.2	Carbon-graphite epoxy composite surrounds entire outer surface	Assembly line issues increases loss of crew ratio.
2.1.3	Fly-by-wire control system implemented	Lack of tech development increases chances of failure.
2.1	Avionics system for stability and maneuvers	Avionics fail and increase loss of crew ratio.

All foreseeable technical & programmatic risks have contingency plans in place.

12b-1 Mitigation Waterfall~ Technical Risk 2.1:

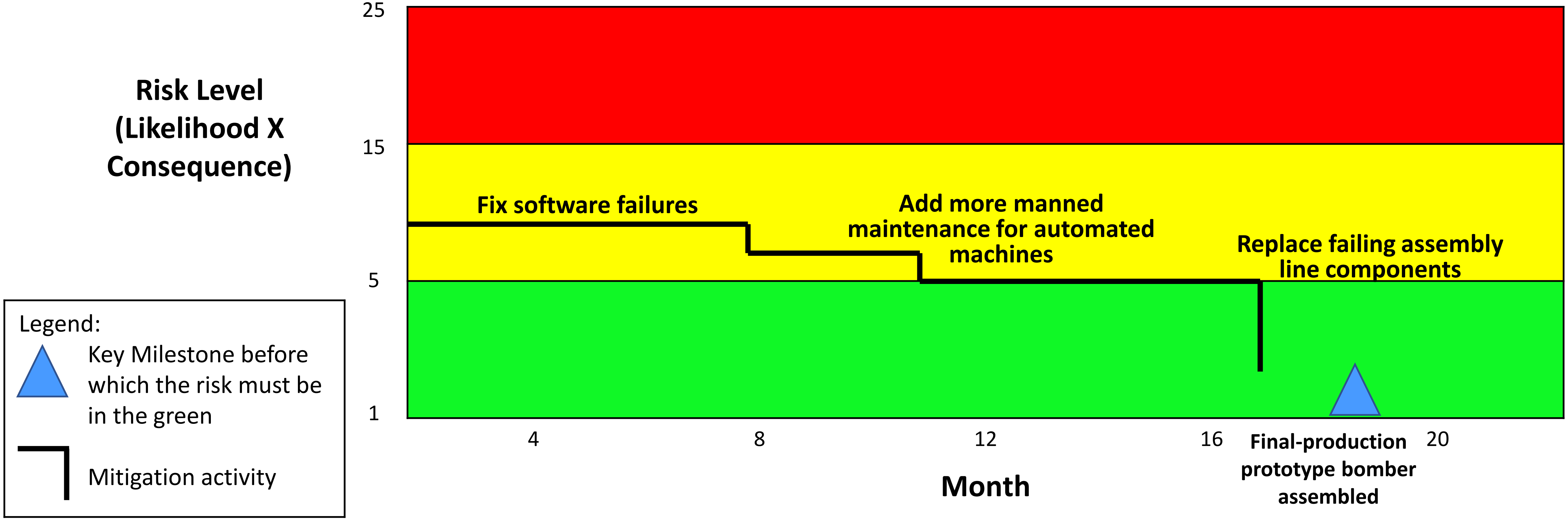
- Risk Statement: Flight computers, gyroscopes, and other avionics could fail leading to a loss in aircraft.



In slightly over a year, the B-2's flight control systems will be clear of any potential dangers.

12b-2 Mitigation Waterfall~ Technical Risk 5.1.2:

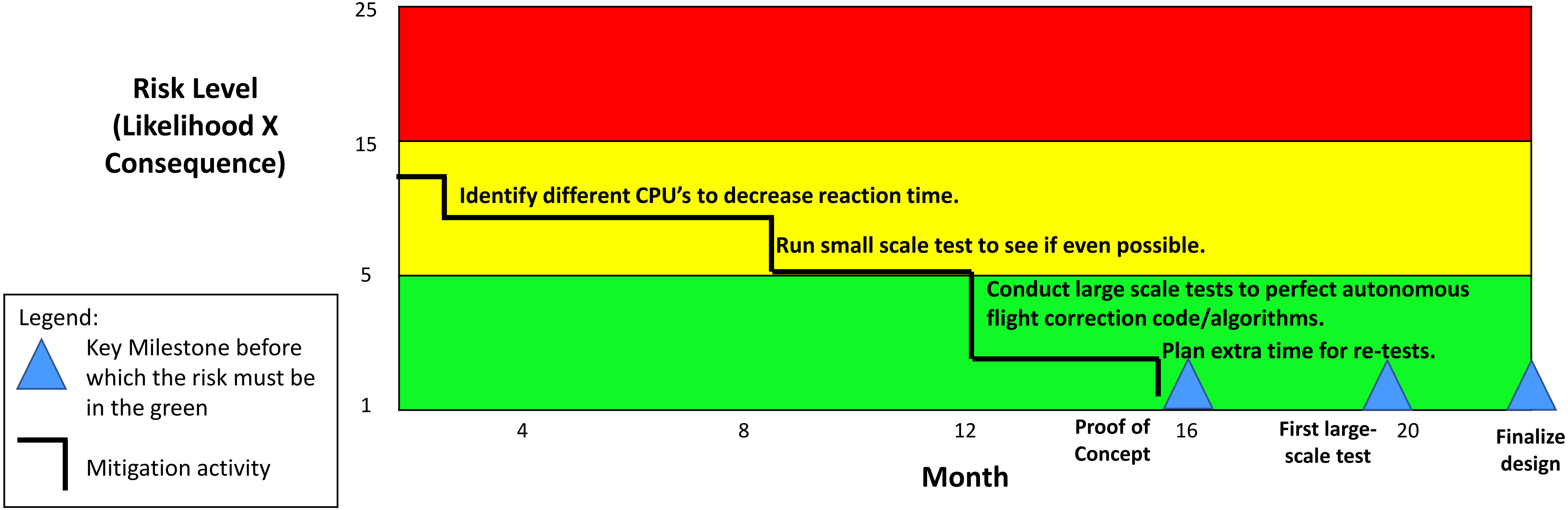
- Risk Statement: Automated assembly line problems when producing the outer-surface carbon-graphite composite increases loss of crew ratio.



Assembly line production problems will be solved before the first prototype is built.

12b-3 Mitigation Waterfall~ Technical Risk 2.1.3:

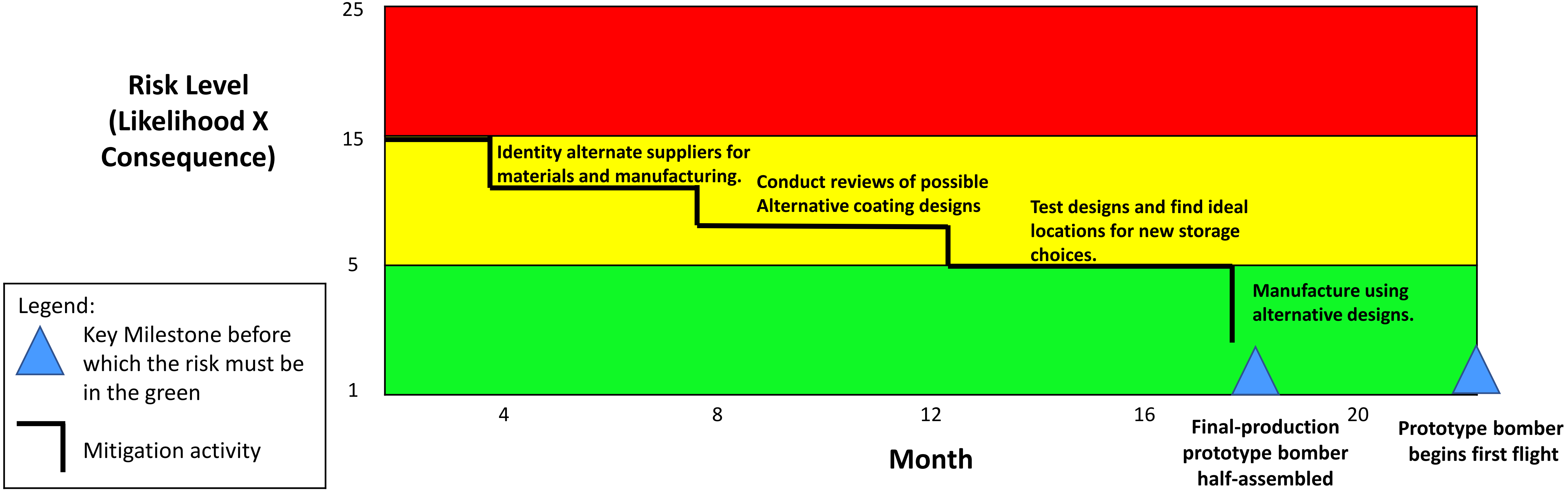
- Risk Statement: Resorting to conventional aircraft control systems to ensure stability (such as a vertical tail) will increase radar cross section.



The B-2 Bomber will have perfected fly-by-wire system within two years of testing.

12b-4 Mitigation Waterfall~ Programmatic Risk 4.1:

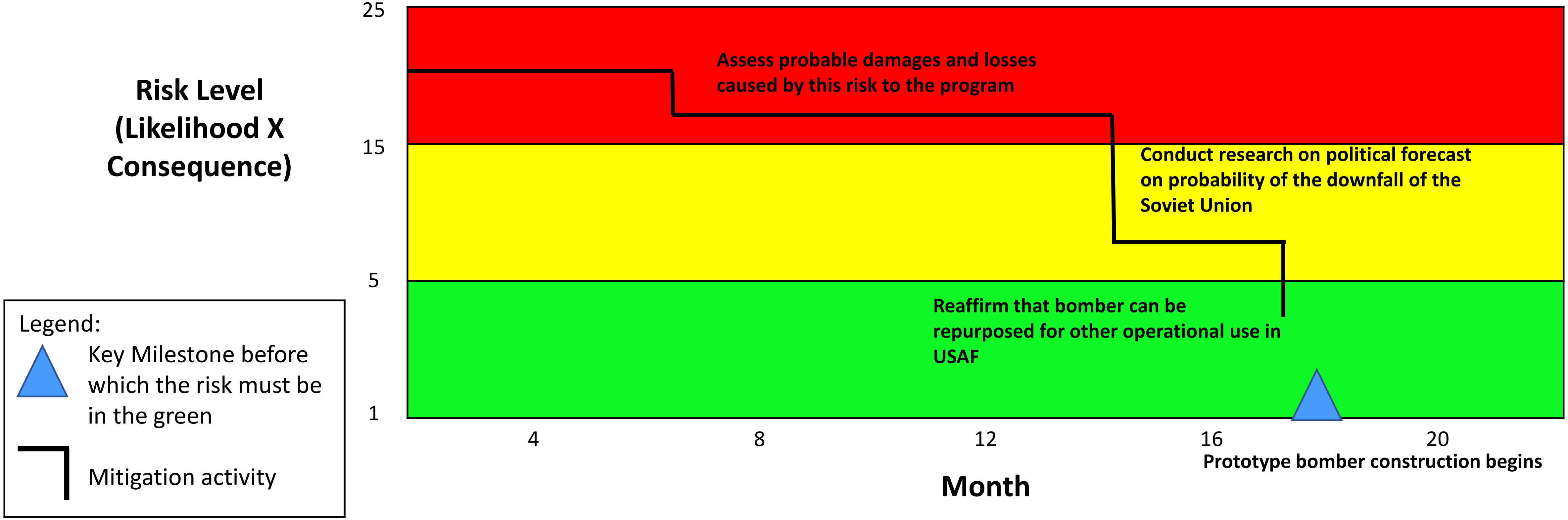
- Risk Statement: Aircraft outer-surface coating deteriorating before the first and last flight increases long-term cost & deterioration of aircraft



Alternative carbon-graphite coating designs and materials will reduce the likelihood of cost overruns and deterioration of each B-2 purchased.

12b-5 Mitigation Waterfall~ Programmatic Risk 0.0:

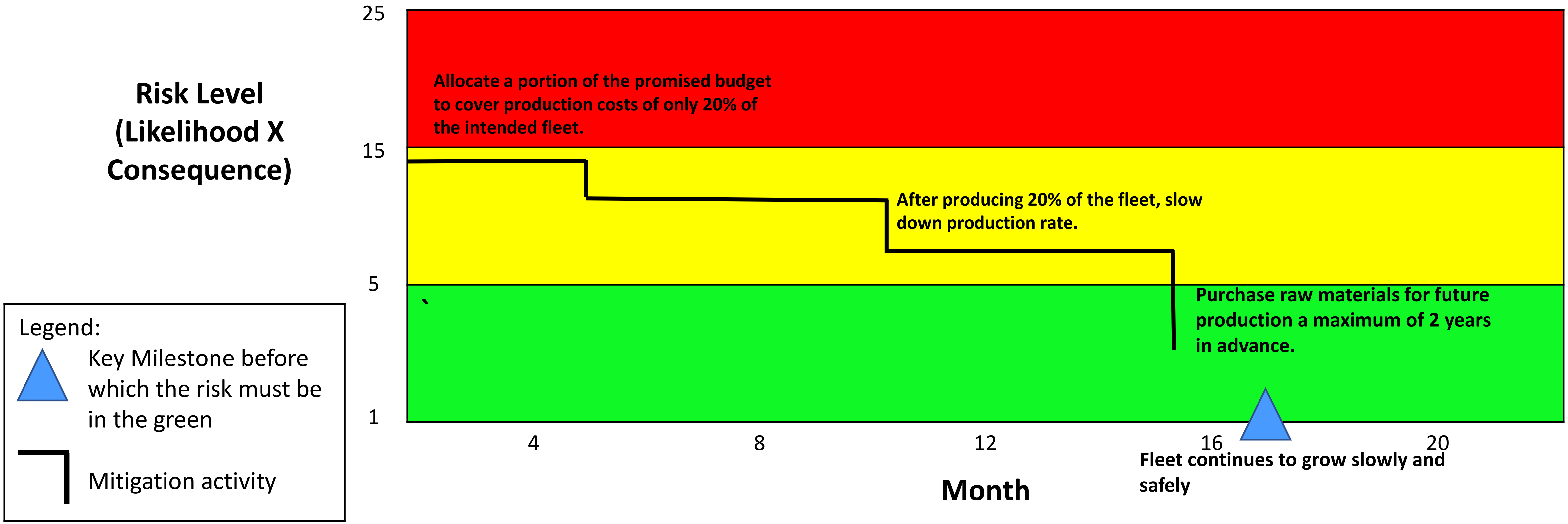
- Risk Statement: Fall of the Soviet Union dissolves primary rationale of the development of the stealth bomber program.



Though there is a chance of the bomber program being slated due to the dissolution of the main objective, it can continue instead as a program that fulfills other bombing roles as a leading edge, frontline asset for the military.

12b-6 Mitigation Waterfall~ Programmatic Risk 6.1:

- Risk Statement: Military budget cuts decrease cash flow into program



In the case of a decrease in the military budget, B-2 Bomber production will slow down after a quota is reached and large quantities of raw materials will be purchased with caution.

13 Summary PDR

- Our Preliminary Design of the B-2 Spirit will effectively deliver to buyers a bomber with the lowest radar cross section, longest range, and highest payload capacity in industry, past and present, at an acceptable risk level.
- Our company is prepared to carry the project into the detail design phase because of our successful technological advancements and level of accuracy in previous design phases.

The B-2 Spirit Bomber will lead the way in stealth bombings through its 10,000 nmi refueled range and 0.2m^2 RCS, causing it to be the envy of the world for decades to come.

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  - https://news.northropgrumman.com/news/releases/northrop-grumman-completes-b-2-bomber-maintenance-in-record-time

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