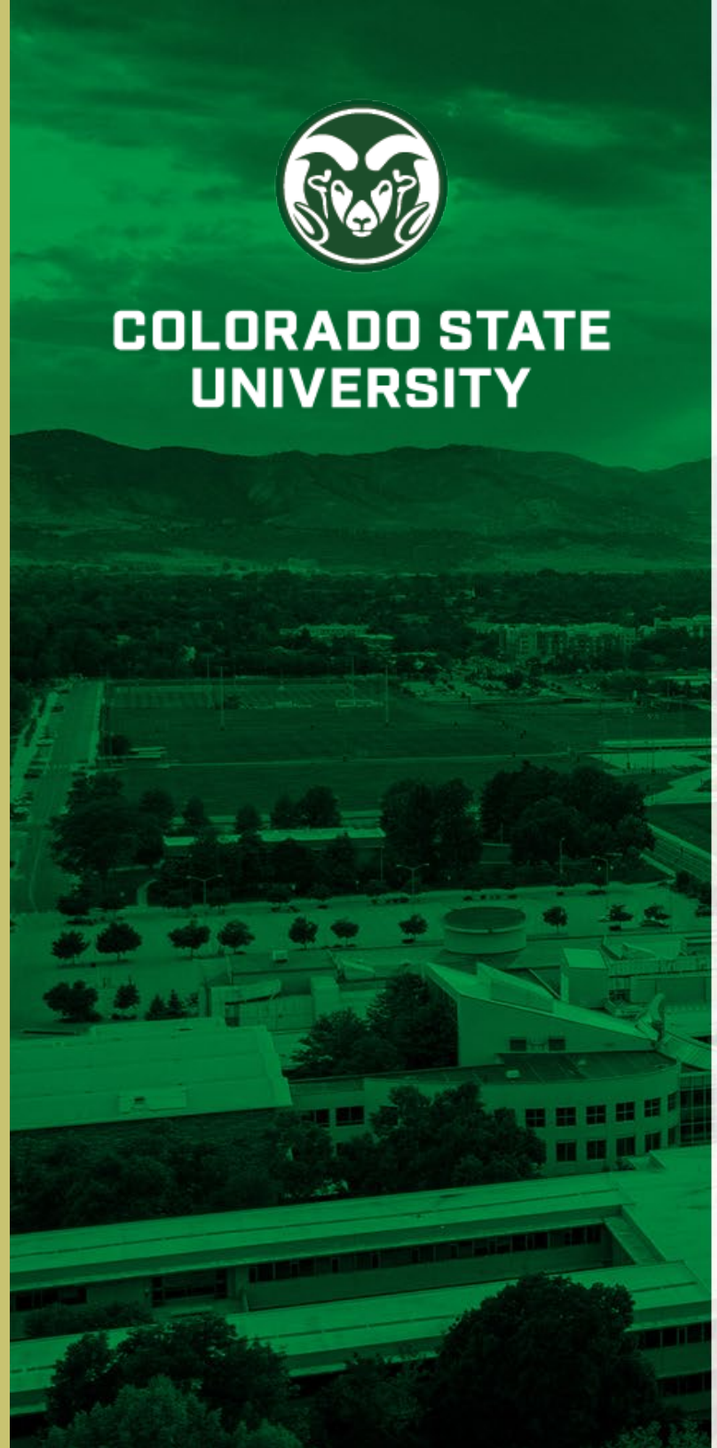


Applying Agile to Large-Scale, Safety-Critical Systems: A Comparative Analysis of Agile and Waterfall Approaches in Satellite Development

Robin Yeman PhD

Research Questions

RQ1: Can Agile methodologies improve the development speed of large-scale, safety-critical, cyber-physical systems without compromising safety and security?

RQ2: What are the key benefits and challenges of applying Agile methodologies at the system level in the development of complex systems like satellites?

RQ3: How do Agile and Waterfall methodologies compare in terms of meeting regulatory compliance, ensuring safety assurance, and managing integration complexity in the context of satellite development?

Satellite Case Study (Waterfall vs Agile)

Identified Existing Satellite and defined Specifications

Used Nebula from Terran Orbital as a starting Point

Created Mission Requirements Model (Why)

Highest level Objectives (Earth Observation)

Created Requirements Model (How)

Decomposed satellite into subsystems using MOSA Principles

Developed Assumptions

Assumed procurement was complete

Developed Waterfall Model

NASA SE Manual

NASA SP-2016-6105 Rev2

and traced activities to requirements to model

Developed Agile Model

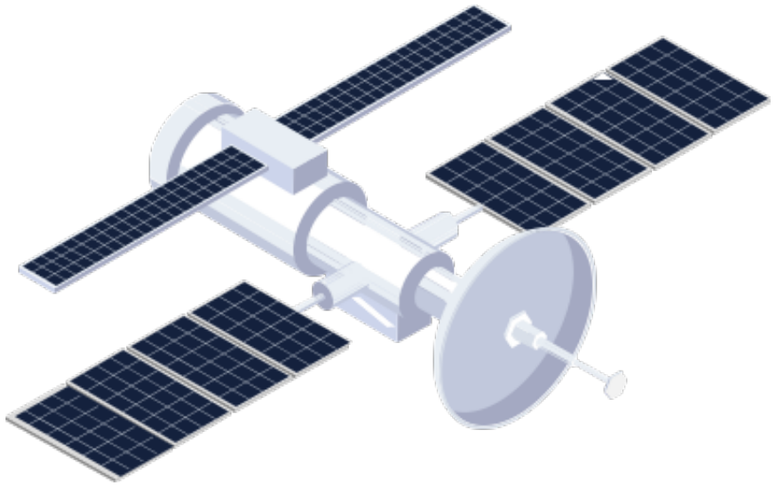
Developed a series of MVPs based on Modular Architecture and traced activities to requirements to model

Monte Carlo Analysis

Innoslate performs Monte-Carlo Simulation)

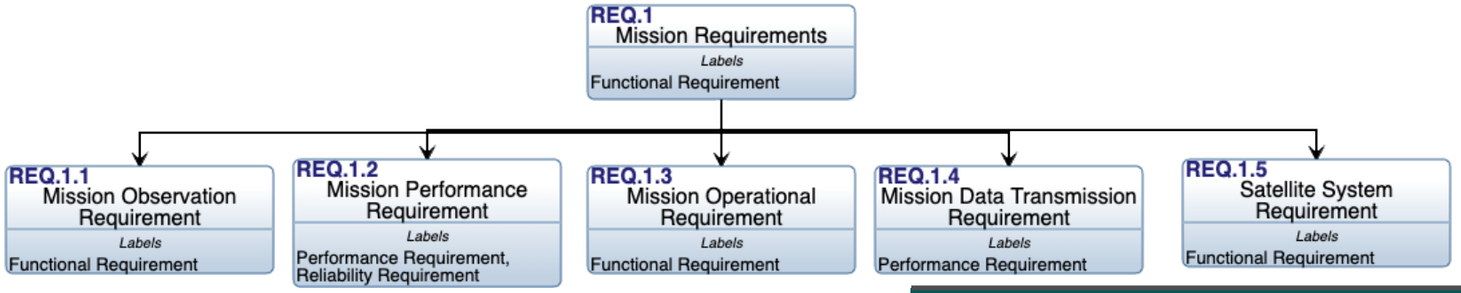
Estimates were expert judgement and comparisons of similar activities

Specification



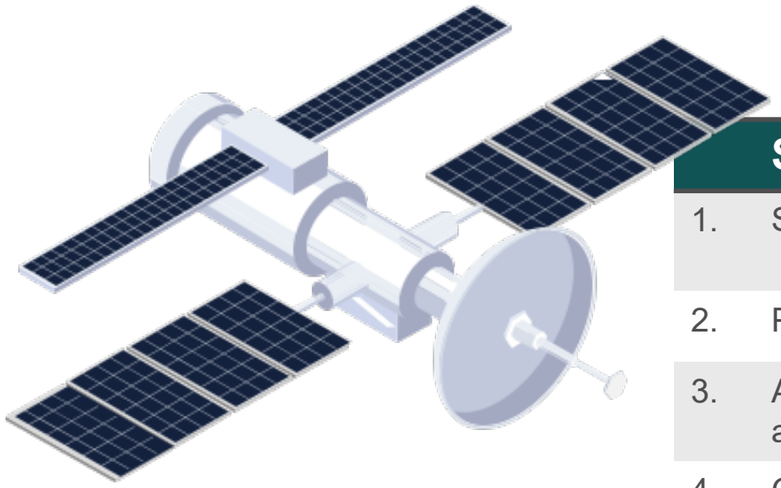
	Specification	Detail
1.	Application	LEO
2.	Native Orbit	400km-1200km
3.	Launch Mass	250kg
4.	Payload Mass	130kg
5.	Max Solar Array Power	1kW
6.	Redundancy	Dual-string
7.	Power Systems	66V system power
8.	Communication Data Rate	S-band: 125 Kbps uplink, 2 Mbps downlink X-Band: 650 Mbps downlink
9.	Propulsion	2150s hall effect standard, options available
10.	Thrust	1.1mN
11	Dimensions w/o Solar Panels	82cm x 58cm x 39cm

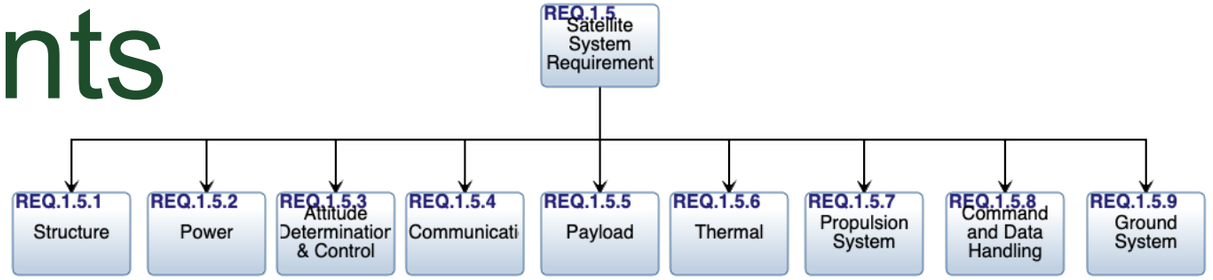
Mission Requirements



	Mission Req	Description
1.	Observation	The satellite shall provide Earth observation data with 1 meter/pixel. The satellite shall transmit data every orbit.
2.	Performance	The satellite must operate for a minimum of 5 years.
3.	Operational	The satellite must maintain a stable Low Earth Orbit (LEO).
4.	Data Transmission	The satellite shall transmit data every orbit to ground stations.
5.	System Structure	The System must be a modular architecture

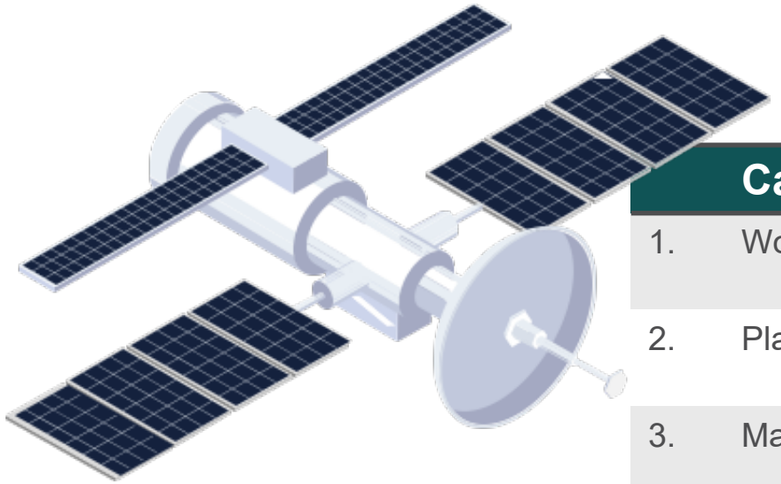
System Requirements





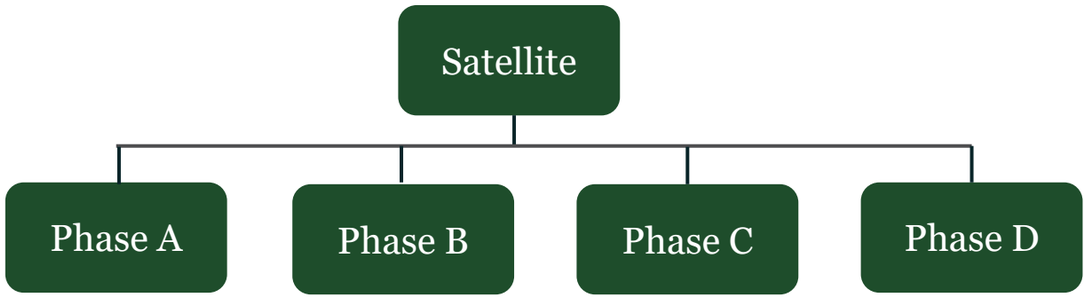
	Subsystem	Inputs	Outputs
1.	Structure	Primary & Secondary Structures	Verified structural integrity
2.	Power	Battery, Solar Arrays	Power distribution verified
3.	Attitude Determination and Control	Reaction Wheels, Star Trackers, Software	Attitude accuracy verified
4.	Communication	Transmitters, Receivers, Antennae	Reliable communication link established
5.	Payload	Scientific Instruments, Payload Specifications	Data collection and processing operational
6.	Thermal Control	Radiators, Heaters, Insulation, sensors	Thermal controls verified
7.	Propulsion	Thrusters, Fuel Thanks, Piping	Basic maneuver capability established
8.	Command and Data Handling	Onboard Computer, Software, Sensors	Command & Data handling verified

Assumptions

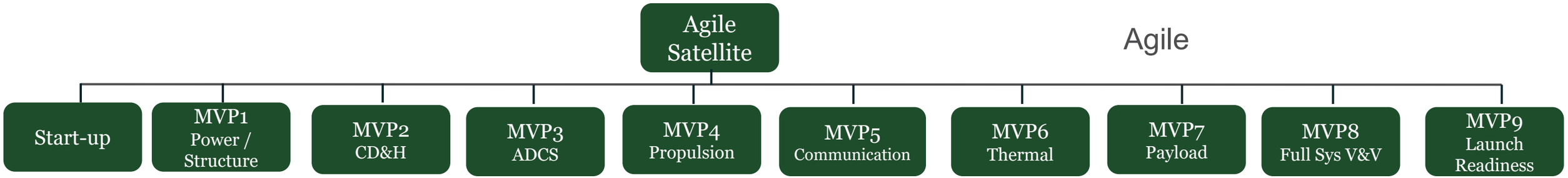


	Category	Waterfall Assumption	Agile Assumption
1.	Workflow	NASA Defined approach (NASA SP-2016-6105 Rev2)	Iterative and Incremental with Continuous Assurance Toolkit Plugin
2.	Planning	Complete Integrated Master Schedule defined before work starts.	Roadmap and Planning approach defined
3.	Materials / Components	All required resources are available from the start and cause no delays.	All required resources are available from the start and cause no delays.
4.	Labor / Skill Availability	Functionally Organized Workforce	Cross-Functional Workforce with T-Shaped skills.
5.	Integration and Test	Test equipment and Infrastructure available immediately.	Test equipment and Infrastructure available immediately.
6.	Regulatory Compliance and Safety	Validated at the Phase Gates	Automated and continuously validated at each sprint and Increment (Quarter)
7.	Material Cost	Fixed Material Cost	Fixed Material Cost
8.	Labor Cost	$120 Per Hour	$120 Per Hour

Satellite WBS

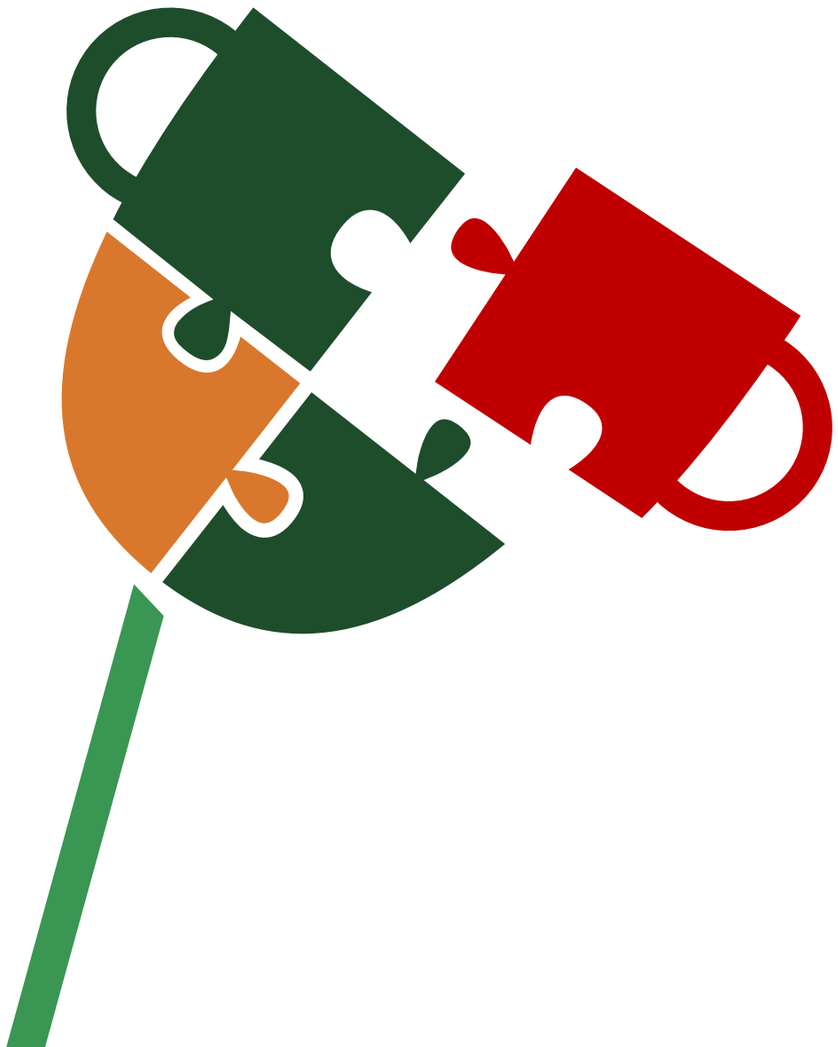


Waterfall



Agile

Continuous Assurance Plugin



People

Safety, Regulatory compliance expertise; Extreme Ownership

Process

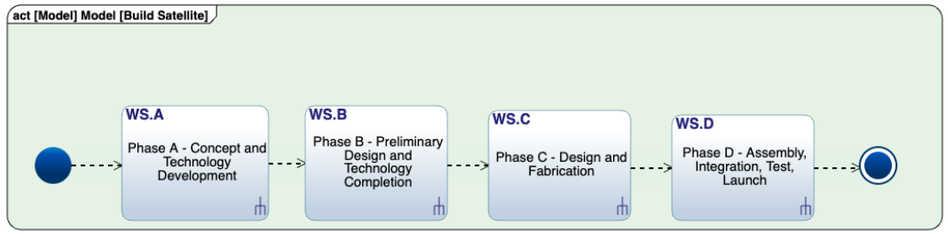
Risk Management, Hazard Analysis, Fault Injection, Intent Driven Development.

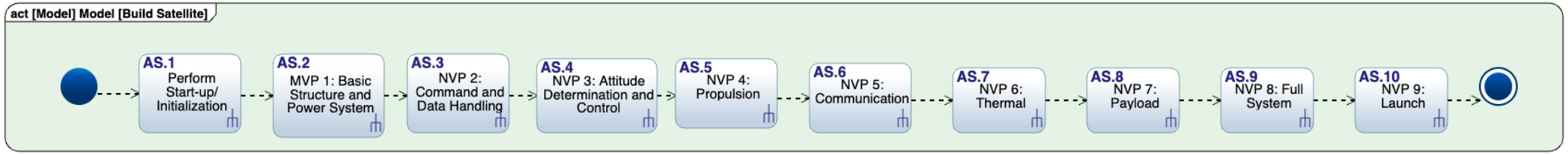
Tools

Traceability Matrix, automate safety and compliance, expand scope of CI/CD and Stories

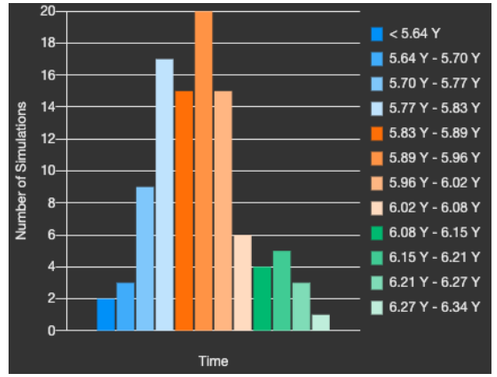
*A **plugin** is a software component that extends the functionality of an existing software system, we expand This metaphor to the Agile Scaling Frameworks*

Results

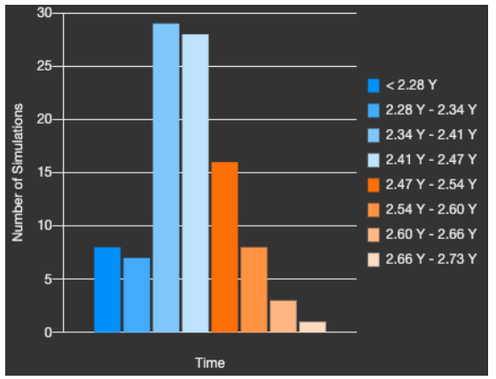




Mean: 5.92 Year / SD 1.7 M



Mean: 2.43 Year / SD 1 M



Research Question Observations

01

Observation

Simulation found that total time for development for Waterfall was 5.92 years, Agile was 2.43 years ~ 60% reduction in development time Primary reason was due to batch size and rework at the decision gates and Waterfall focused on getting plan right versus Product.

02

Observation

Simulation showed a reduced standard deviation 1.7 months to 1 month suggesting Agile not only shortens time-to-delivery but also reduces uncertainty and variation in delivery timelines, supporting higher predictability and schedule stability

03

Observation

The decomposition showed we could shrink the timeline further if we introduced concurrent engineering. For example, Power and communication modules could be built at same time.

04

Observation

The lower standard deviation in the Agile build indicates tighter control and faster feedback loops, allowing teams to detect and manage risks more efficiently compared to the Waterfall approach, where issues may not be discovered until later phases

Questions