SSC19-I-05

Flexible, high-speed, small satellite production

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ABSTRACT

Planet's first mission is to image the entire land mass of the Earth every day in an effort to make global change visible, accessible, and actionable. To do this, Planet designs and builds highly capable Earth-imaging satellites and today operates the largest Earth-imaging fleet in history. To support this mission, Planet had to develop an adaptable concurrent product development cycle associated with a unique assembly and manufacturing line to support the quick production and delivery of satellites. This paper introduces how Planet achieved that objective by building multiple spacecraft design iterations concurrently and how Planet orchestrates a production line for speed, flexibility, and high throughput of satellite delivery in just over a few weeks.

PLANET

Planet's mission: *Image the whole world every day and make global change visible, accessible, and actionable.*

Planet's vision of establishing a Queryable Earth means indexing what is on the Earth and making it queryable. To do this, Planet provides the platform with the best geo-data and foundational analytics, enabling users to make informed and timely decisions.

To support Planet's mission and product vision, we have built over 400 satellites, iterating more than a dozen times in a process called"agile aerospace," which mean releasing satellites early and often. In order to guarantee build success, Planet has developed an agile and adaptable concurrent product development cycle in sync with a flexible and high throughput manufacturing line to ensure Planet's capability to iterate and deliver quickly.

ADAPTABLE CONCURRENT PRODUCT DEVELOPMENT CYCLE

Over eight years, Planet went from a startup building its first satellite in a garage to a widely recognized company which operates well over 100 medium resolution satellites and 15 high resolution satellites. During that growth Planet reviewed the principles built around traditional aerospace to come up with its own approach to adapt to the new demand for large constellations of satellites. The boom of the semi-electronic conductor industry has made available smaller, lighter, cheaper and more performant technology. The launch industry has flourished to make space more accessible. Planet's approach orchestrates all those key verticals to create an adaptable concurrent product development cycle.

Thiscycle is organized around managing different spacecraft builds and spacecraft build iterations in parallel. One spacecraft build is defined by a set of spacecraft build specifications which will be achieved through a set of three build iterations, which are aimed at demonstrating, maturing, and productionizing. For a

given build, the maturity of the spacecraft is achieved by leveraging on-orbit feedback, analysis, a ground-test campaign conducted in parallel, and all the dfx and dfm lessons learned through the early build assembly and manufacturing.

Phase one: The first build iteration is always associated with a technology demonstration platform that is launched very early. The platform has not achieved full design maturity but is used as a means of on-orbit validation to accelerate the spacecraft maturity. That platform is very crucial since it exercises the manufacturing line very early on and also validates, on-orbit, some subsystems which are very difficult to test on the ground.

Phase two: The second build iteration captures small design changes driven by the early on-orbit feedback from the units launched during phase one, as well as the changes revealed by the qualification ground test campaign and the production line.

Phase three: There are typically very little design changes between phase two and three except as required to increase first pass yield, reduce BOM cost and tact time, or increase quality. The build iteration has achieved full maturity and is considered stable from a design and manufacturability point of view achieving all requirements.

Another generation of spacecraft will come with its own new set of specifications and iterations. However, those two different spacecraft build cycles will run in parallel and as such, a given delivery for launches will typically be composed of a mix of stable spacecraft builds focused on mission continuity and the technology demonstration platform to test new technology candidates early from the next spacecraft build. The adaptable concurrent product development cycle is driven by four key pillars: Capability driven, access to space, lean process and vertical integration.

Capability driven

Sub-systems maintain autonomous independent roadmaps that allow concurrent product development and innovation. When new subsystems have shown incremental improvement and passed ground qualifications, they are integrated into tech demos. New components or hardware can be tested and brought to maturity in parallel of the current build cycle, leveraging the available and existing platform. In this respect, much like an agile software development, features slip—not releases. This is in addition to our primary product development, which incorporates product requirements, feedback from customers, business needs, etc. Together they form a solid and robust platform for both incremental improvement to the system and substantial improvements to our platform.

Access to Space

Having an active and diversified launch manifest spreads risk and opportunity across multiple launches per year. A constellation of Dove spacecraft is referred to as a flock. Typically, we aim to manifest launches quarterly to coincide with our product development milestones. This provides replenishment to our currently deployed constellations and assures ample opportunities for iterative improvement to our spacecraft, both for internal system efficiency and our customers. Additionally, quick access to space enables quicker on-orbit validation that feeds into the next spacecraft build cycle. This allows Planet to evaluate the performance of commercial off-the-shelf (COTS) parts in the most realistic environmental conditions possible.

This is about enhancing innovation through access to space, which accelerates design maturity and drives innovation. Also, by leveraging small percentages of launches we can mitigate risk.

Lean process

Concurrent engineering and production permits the building, testing, and operating of spacecraft in house, which boosts the speed of design cycles and feedback loops. The documentations and processes are as minimal and simple as they need to be, but no simpler: when writing documentation, we ask ourselves: “What do we need as a minimum to understand, handle, and operate the hardware?” We also consider the best way to architect those procedures to be streamlined and to be accessible and understandable by the entire team, with the important information available first. Those processes are built on basic first principles, like collaboration, proactively asking for help, giving and accepting feedback, and making time to teach each other without condescension. All documentation generated is paperless and lives in our proprietary software systems that have been developed in house. Processes, build guides, and documentation can be authored directly on tablets. The notion of agility is at the center of our focus and everything Planet doee. Wwe iterate, build, test, and demonstrate rather than exhaustively simulating.

Vertical integration

Design for manufacturability and operations of the product takes all essential components into consideration, including assembly and on-orbit operations. Simplified interactions are streamlined between different departments and enhanced by peer-to-peer communication. Planet Space Systems is organized around this notion of one culture, one team. The system is driven by agile planning which provides the team more stability and control over timeframe. In addition, flexible automation accelerates build cycles and operational flexibility makes design and software changes easier to fold in. This is all for the end goal of enabling and supporting multiple spacecraft builds on the same production line or operated in the same mission control interface.

HIGH THROUGHPUT MANUFACTURING LINE

The concept of a high throughput manufacturing line is centered around concurrent product development cycles paced by on-orbit and ground design validation and frequent access to space. It requires several key entities to work together in harmony for maximum results. Although Planet could easily produce thousands of spacecraft a year, the goal of over-building capacity is actually to allow more time for design iterations.

Supply chain and quality management

The supply chain is one of the most tentacular groups inside of Planet's Space System: from the design teams, the production and test teams, to all the external suppliers. Early on during manufacturing, the supply chain team acts as a conductor, controlling and directing relevant milestones for the program.

The supply chain leverages state of the art cloud based management software coupled with proprietary software designed in house for rapid prototyping. It interfaces with the suppliers and also drives state of the art quality management to resolve non-conformance issues and perform workmanship root-cause analysis in the most effective way.

Dynamic testing: bringing factory future concept to reality

Planet uses line balancing to create multiple workstations in assembly line to reach throughput of one spacecraft per day. Visual factory is used to convey data and information effectively in the lean manufacturing environment. The floor layout is designed for optimization with objectives of minimizing transportation of light hardware and eliminating non-value added operation. Modular, portable, and automated test stations have been created to make tests easy and convenient to run, such that a functional test line can be brought up in a day.

Running tests is streamlined with our manufacturing software, which is developed internally to support lights out operations. Results and data are sorted and displayed in easy-to-view dashboards to facilitate quick review and data interpretations. Adaptive testing helps facilitate great communication with development teams to ensure all needed data points are captured and constant iteration makes tests more comprehensive and sustainable. In addition to real time results, immediate feedback is incorporated in the instruction and execution during the build process, which can be fed directly into the current build in addition to the next design and test cycle.

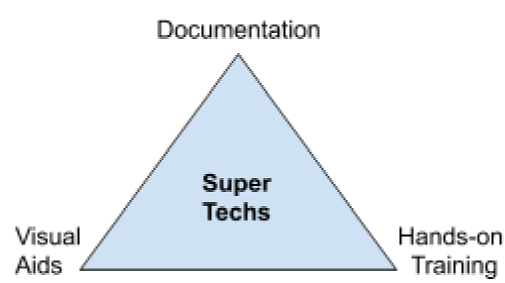
Design for manufacturability is key. Our satellites feature common mechanical and electrical attributes that facilitate handling and ground operations including assembly on the production line, transportation, and spacecraft integration. Everything happens in house, meaning all in-lab activities are controlled and safer.

Planning

Holistic thinking allows our schedule to be adjusted on a day-to-day basis to account for launch delays. Our streamlined, in-house production activities help us optimize a resource-loaded schedule within multiple cross-functional teams to allow agility in the organization and high manufacturing throughput.

Triangle training

Dynamic testing requires dynamic training. Planet uses three concepts of documentation, visual aids and hands-on training to develop "super technicians" that are capable of wearing many different hats. They are trained with real hardware which accelerates their readiness.



Electronic process sheets are created by the manufacturing engineers to guide through the build process. These guides are easily adapted to ensure all changes and best practices are captured.

CULTURE

Culture is one of the most important verticals since it defines and drives how effective the system is going to be. These five rules define what culture means for a manufacturing floor at Planet:

- Team diversity through professional backgrounds, demographics, genders and ethnicities are drivers of creativity and inventiveness.
- Trust and empowerment of people to make good decisions speeds execution.
- Openness and transparency in the decision-making process helps engineering teams to understand why we are going in that direction.
- A forward leaning and curious mindset allows the team to focus on translating difficult ideas into exceptional hardware.
- We don't solve problems by creating walls, interfaces, or processes, but by developing a culture that values a cooperative approach to solving problems.

CONCLUSION

Since its early age, Planet has never ceased to progress, revisit and redefine its development cycle, factoring all the lessons learned from challenges through the design cycle as well as challenges faced on the manufacturing floor. That motivation of continuous improvement is driven by a culture based on embracing technical challenges and empowering people to do things not because they are easy but because they are hard. The outcome results in avery unique and innovative cycle which combines parallel concurrent spacecraft builds and iterations to accelerate product maturity. The flexibility and automation of the manufacturing line allows new assembly lines to be brought up to speed within days for a new build cycle, with the capability of handling different spacecraft iterations involving different hardware and software revisions. Streamlined and optimized planning allows activities to be adjusted quickly within hours for maximum resource and activities throughput. The outcome is a flexible and high speed production line that has manufactured the largest number of Earth-imaging satellites to date and holds the record of the largest fleet of satellites deployed from a single rocket[1].

REFERENCE

1. Rob Zimmerman, Deanna Doan, Lawrence Leung, James Mason, Nate Parsons, Kam Shahid, Planet Labs, Inc "Commissioning the World's Largest Satellite Constellation" Proceedings of the 31st Annual AIAA/USU Conference on Small Satellite, SSC17-X-03.