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Insights

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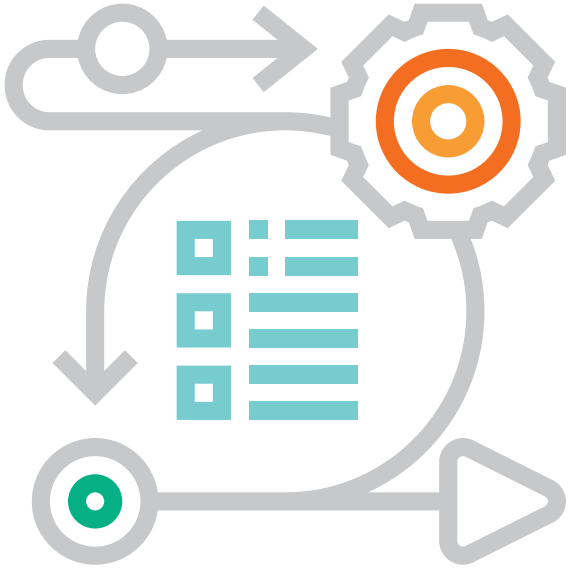
Processes originally aimed at speedy application development are giving manufacturers the tools to build the next generation of urban-flight and space vehicles.

First for software, agile is a boon to manufacturing



Key takeaways

1. When designing and prototyping complex products, catching issues and errors later in development can have an enormous cost. Iterative development shortens each cycle, gives detailed feedback sooner, and results in less-expensive and quicker product development.
2. Digital prototyping uses digital twins and real-world data from sensors to verify designs and highlight potential issues before they arise, reducing the time it takes to have working products.
3. Multidisciplinary teams tap the expertise of specialists, from engineers and programmers to applied materials and artificial intelligence systems, making it less likely issues will be overlooked.

When Zipline, the operator of the world's largest autonomous drone delivery system, began building its logistics service to deliver medicines, vaccines, and medical supplies to health facilities across rural Africa, the company needed a development and manufacturing process that could quickly incorporate design improvements. It also needed to remain flexible so it could cater to different customers and geographies.

The company concentrated on solving the most challenging problems in the early design phase with sprints as a team and then moved into smaller groups for detailed design efforts. They used fast feedback loops in simulation and testing to improve the design before going into production.

This focus on agile development and manufacturing helped Zipline take its unmanned aerial vehicle (UAV) from design to commercialized and scaled operations across Ghana and Rwanda in less than 18 months, a timeline that included six months of hardcore development, another six months of prototype testing, and a final six months in design validation and engineering verification.

"In general, the idea of focusing resources on a specific problem in sprints is something that we are taking from the software world back into the hardware world," says Devin Williams, lead mechanical engineer on the UAV production platform at Zipline. "One thing we do really well is find the minimum viable product and then go prove it out in the field."

Using an agile process allows Zipline to focus on releasing changes to the product that address customer needs quickly while maintaining high reliability. The San Francisco Bay Area company now has distribution centers in North Carolina and Arkansas, with another underway in Salt Lake City, and will soon be launching in Japan as well as in new markets across Africa.

From startups to manufacturers with decades of history, companies are turning to agile design, development, and manufacturing to create innovative products at lower costs.

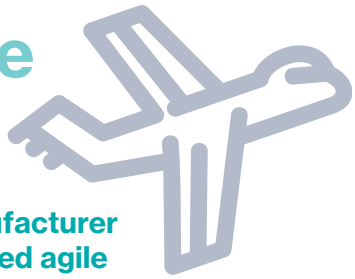
Zipline is not alone. From startups to manufacturers with decades of history, companies are turning to agile design, development, and manufacturing to create innovative products at lower costs. Airplane manufacturer Bye Aerospace cut costs by more than half in its development of an electric airplane and sped up the cadence of its prototypes. And Boeing used agile processes to win the T-X twin-pilot trainer jet project with the US Air Force.

Overall, applying agile methodologies should be a priority for every manufacturer. For aerospace and defense companies, whose complex projects have typically followed the long time horizons of waterfall development, agile design and development are needed to propel the industry into the age of urban air mobility and the future of space exploration.

The evolution of traditional product design

While agile production has its origins in the Kanban method of just-in-time auto manufacturing developed in the 1940s at Toyota, the modern agile framework for development was refined in the late 1990s by programmers looking for better ways to produce software. Rather than create a "waterfall" development pipeline that included specific stages, such as design and testing, agile development focused on creating a working product, the minimum viable product, as early in the process as possible and then iterating on the technology. In 2000, a group of 17 developers **drafted the Agile Manifesto**, focused on working software, individuals and interactions, and customer collaboration.

Agile plane making



Electric airplane manufacturer Bye Aerospace has used agile processes and tools to move from creating new designs only two to three times during the life of a program to incorporating iterative improvements on a weekly basis. Agile development not only shortens the company's development life cycle, but requires a team of 20 engineers rather than the team of 50 needed in the past.

Agile tools allow Bye Aerospace to take design changes for prototype aircraft and update all previous models. "It's an order-of-magnitude savings," says Jim Forrester, director of design engineering. "We're shrinking our product development time and doing more iterations at the same time. In the end, what that allows us to do is to get to market fast with the right plane."

Agile versus traditional

Agile product development, rooted in the Manifesto for Agile Software Development, offers a flexible approach while traditional methods favor comprehensive, linear plans.

Agile manufacturing	Traditional manufacturing
Iterative: value is delivered as fast as possible, in increments	Linear: each phase depends on the deliverables of the previous one
Responds to change	Follows a plan
Favors adaptation and flexibility	Favors anticipation
Testing happens at every iteration	Testing once a product is finished
Simultaneous work allows for continuous changes	Each stage must be completed before moving on

Sources: Manifesto for Agile Software Development/"Agile in the Enterprise," Gartner, July 2019

Over the past decade, agile software development has focused on DevOps – "development and operations" – which creates the interdisciplinary teams and culture for application development. Likewise, design companies and product manufacturers have taken the lessons of agile and reintegrated them into the manufacturing life cycle. As a result, manufacturing now consists of small teams iterating on products, feeding real-world lessons back into the supply chain, and using software tools to speed collaboration.

In the aerospace and defense industry, well known for the complexity of its products and systems, agile is delivering benefits. In working on the development of the **T-X two-seat jet trainer**, Boeing committed to developing agile design and manufacturing processes, which has resulted in half the program cost for the US Air Force, a 75% increase in the quality of the initial prototype, half the software development time, and an 80% reduction in assembly time.

"We adopted an agile mindset and a block plan approach to hardware and software integration," says Paul Niewald, Boeing's T-X program manager. "This had us releasing software every eight weeks and testing it at the system level to validate our requirements. By doing this, in such a disciplined way – at frequency – it allowed us to reduce our software effort by 50%."

In the end, the T-X went from design to the building of "production-representation jets" in three years. This is a major departure from the initial development of traditional aircraft programs, which use waterfall development in the initial design and development stages and can require a decade of development.

Framework for agile in aerospace and defense

The development of new products in aerospace and defense is notoriously complex, and engineering and design teams have used long cycles of design and testing to create or update systems. Agile development focuses on smaller chunks of the design, iterates on them, and uses smaller teams while incorporating some traditional milestones such as preliminary design review. When Dale Tutt worked in the aerospace industry, his engineering team focused on specific sections of an aircraft's design, such as the wing, improved it, and moved on to a different system or section of the craft the next week. The result was a prototype that flew

Lessons from agile software development

While agile manufacturing's genesis came from Japanese car manufacturers in the 1940s and 1950s, many of the concepts were honed in the digital domain when adopted by software development teams. In a 2010 paper, researchers at IBM estimated a flaw in a software system cost 100 times more to fix after the product was released than if the defect was caught in the design phase. Because of the generally greater cost to fix physical systems compared with their digital counterparts, the cost of fixing a design flaw in a physical product is likely higher for manufacturers than it would be for software companies, underscoring the benefit of finding design issues as quickly as possible.

But other concepts from agile software development don't translate well into manufacturing. One of the core tenets of the last decade—quickly testing a product and gauging customer response, often encapsulated in the admonition to "fail fast"—doesn't fit in the prototyping of physical products. Without extensive sensors on a physical prototype, a failure often spells the loss of a design iteration and, at best, might require weeks or months of engineering time to reconstruct the incident. Yet companies that digitize their design and prototype phases gain the ability to fail fast during digital prototyping, which highlights another benefit of manufacturers' digital transformations.

> "When I think about agile, it is about speed, about going faster, being more flexible, but what it is not about is being chaotic. Good agile is about being structured."
>
> Dale Tutt, Vice President, Aerospace and Defense Industry Strategy, Siemens Digital Industries Software

23 months after the first concept sketch, requiring half the time and half the people.

"When I think about agile, it is about speed, about going faster, being more flexible, but what it is not about is being chaotic," says Tutt, vice president for aerospace and defense industry strategy at Siemens Digital Industries Software. "Good agile is about being structured. The projects are too big, too complicated to allow them to be chaotic. You still have to follow good program management practices, but in a structured way."

By focusing on a flexible, customer-centric process, agile development and manufacturing can accommodate a variety of changes through short sprints focused on specific aspects of the product, such as adding a new feature, updating a system, or incorporating a change that a customer requested.

Agile development has benefited from advances in software and tools. With the focus on extensive simulations of materials and designs using real-world data, so-called digital-twin technology has become part of many manufacturers' digital transformations. Embracing digital for manufacturing means creating digital product designs, using real-world data to simulate those designs as a digital twin, and using sensors and actuators to monitor and improve operations in the real world. Turning product development into a simulation based on real-world conditions gives companies a way of testing designs before they run into real-world problems. In addition, managing the testing, verification, and manufacturing life cycles allows companies to make changes to their supply chains to improve the sustainability of future products. Chaos in the supply chain, for example, can quickly be taken into account and the product redesigned with materials whose availability is more consistent.

Machine learning and AI are critical

Digital transformation for manufacturers means fewer physical prototypes, which speeds testing and validation but requires agile teams to support this type of development. In addition, such development benefits a great deal from machine-learning systems and artificial intelligence (AI) technology. As demonstrated by digital twins and simulations, machine-learning-based systems can quickly test prototypes and suggest potential improvements, augmenting the expertise and experience of engineers and other members of an agile team.

The greater reliance on machine learning and AI could lead to testing basic design components using adversarial algorithms, in which different materials or designs compete to rise to the top of lists of potential candidates. In materials science, for example, machine-learning algorithms and the material genome initiative are being used to seek out new materials for solid-state batteries and composite structural components. Digital-twin technology and simulation can further test specific designs to seek out flaws that would be hard to discover in real-world testing.

Using agile design and development with a digital pipeline will reduce the time to production, and simulation can help reduce the number of vendors.

Agile development required for future products

With increasing pressure on aerospace and defense companies to innovate, agile development is not just a competitive advantage but a necessity to survive in the markets of the future. Companies are facing requirements to reduce the costs of their programs, speed their time-to-market, and develop new families of products based on electric platforms, while program collaboration and complexity continue to grow.

To usher in an innovative future of urban air mobility and space exploration, manufacturers need to pursue agile methods of design, development, and testing, as well as focus on more modular systems that can be quickly improved over time. With a variety of challenges potentially affecting future flight vehicles – from power density and electric propulsion to systems integration and automated flight – a better way of developing and testing vehicle designs is a necessity.

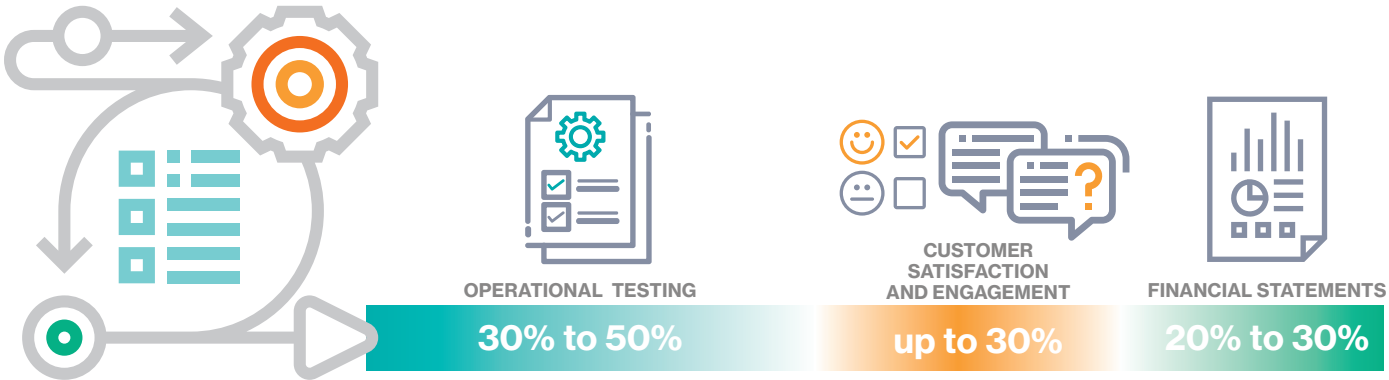
Applying agile methodology to different domains – from software to component design to the development and manufacturing pipeline – results in processes that run at different "clock speeds," where a software life cycle can be quickly iterated while a physical prototyping stage requires longer feedback loops, says Corey Glickman, vice president and head of sustainability and design at technology services giant Infosys.

"I may be able to run eight software cycles in the same time as a single business cycle," Glickman says. "So how do I sync all those different clock cycles? That is what we use agile for."

In the past, the auto manufacturing pipeline took about seven years to complete a single cycle – every seven years you get a new generation of car buyers – and incorporated a supply chain of 17,000 different vendors. Moving to electric vehicles and complete redesigns of the platforms has forced companies to shorten their release

Becoming agile, through and through

Adopting agile processes throughout an organization combines a shared purpose, self-sufficient teams, and cutting-edge technology – and can lead to improvements in multiple areas:



Source: "Enterprise agility: Buzz or business impact?" McKinsey & Company, March 20, 2020

"If we find a problem on the aircraft or on the ground systems, we respond extremely fast. We can roll out changes rapidly across hundreds of aircraft at Zipline hubs around the world."

Devin Williams, Lead Mechanical Engineer, Zipline

Zipline is an instant logistics system that uses unmanned aircraft to deliver medicines, vaccines, and medical supplies across Africa and around the world. Photo courtesy of Zipline

cycles and produce a new car model every two years, reducing the number of suppliers to 4,000.

Similarly, aerospace and defense companies focused on building the next generation of aircraft and vehicles for urban air mobility and space exploration must reduce complexity. Using agile design and development with a digital pipeline will reduce the time to production, and simulation can help reduce the number of vendors.

Finally, a fully digital pipeline allows tracking of every component, from mined resources to manufactured components to eventual waste disposal and recycling. Using this data – paired with authentication technologies such as blockchain – promises to create a more sustainable supply chain and allow companies to quickly test how different designs could affect the cost and sustainability of necessary raw materials and the inevitable recycling of a product's materials.

A future of innovative air and space travel

Hundreds of startups are working on urban-air mobility, such as air taxis, and space exploration, such as creating private space stations or sending robotic probes to Mars or other destinations. Remaining innovative and agile requires finding ways to achieve these lofty goals without the expense.

Agile design and development can deliver on that promise. Creating digital designs, testing digital prototypes using digital twins and simulation, and monitoring the real-world performance of the products post-manufacturing and into operations means that real-world data can quickly be integrated into the next agile sprint, either incorporating design improvements or fixing flaws quickly.

Drone maker Zipline sees the fast feedback loop as one of the primary benefits of a focus on agile development, giving the company the ability to quickly improve its innovative drone product.

"If we find a problem on the aircraft or on the ground systems, we respond extremely fast," says Zipline's Williams. "As soon as we have confidence in a fix, we can roll out changes rapidly across hundreds of aircraft at Zipline hubs around the world."

Aerospace and defense are entering an age of fast innovation, in which only the most agile companies will compete and succeed. With the complexity of designs continuing to rise, aerospace and defense manufacturers must use agile development practices and interdisciplinary teams to quickly develop the technologies they need to drive humans into the next generation of ubiquitous flight and space exploration.

"First for software, agile is a boon to manufacturing" is an executive briefing paper by MIT Technology Review Insights. It is based on research and interviews conducted in September and October 2021. We would like to thank all participants as well as the sponsor, Siemens Digital Industries Software. MIT Technology Review Insights has collected and reported on all findings contained in this paper independently, regardless of participation or sponsorship. Jason Sparapani, Sonia Rubeck, and Laurel Ruma were the editors of this report, and Nicola Crepaldi was the publisher.

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