WHITE PAPER

Ansys

# Hybrid & Electric Propulsion Systems for Sustainable Aviation

The commercial aviation industry is at the threshold of a decades-long transformation to dramatically improve its environmental sustainability. The success of this quest will largely depend on the development of new, more efficient propulsion systems. Unfortunately, current propulsion technologies are insufficiently advanced to enable a singular, comprehensive leap to solve the problem. Instead, commercial aviation companies must segment their approach, simultaneously developing multiple propulsion systems on separate timelines. This strategy will enable manufacturers to improve sustainability in the short term — through the development of hybrid-electric systems that use a combination of batteries and traditional combustion — while working toward hydrogen-powered and all-electric systems.

The development of each of these system types presents engineers with numerous technical challenges, such as designing and optimizing system architectures, managing interactions among system physics, and improving energy storage capacity in batteries. Companies that can efficiently succeed at these challenges and meet the industry's stringent performance and safety requirements will gain a crucial competitive advantage over their rivals.

To accomplish these goals, manufacturers must adopt digital engineering solutions that enable their engineers to quickly optimize and test their designs. Ansys' simulation solutions have the design, analysis, and verification capabilities to help them meet their transformation goals. This report contains three sections:

- **Drivers of New Propulsion System Development:** This section explores the commercial aviation industry's push to improve aircraft sustainability; details the multitrack, multitimeline development strategy that the industry is pursuing; and summarizes the propulsion system types under development.
- **Technical Challenges:** This section explains the technical challenges of developing hybrid-electric, hydrogen, and all-electric propulsion systems for commercial aircraft.
- **Advantages of Ansys Solutions:** This section details the ways in which Ansys digital solutions can help manufacturers overcome the technical challenges of developing new, more sustainable propulsion systems.

## / DRIVERS OF NEW PROPULSION SYSTEM DEVELOPMENT

This section of the report will explore:

- The factors driving aviation manufacturers to make commercial flights more sustainable.
- The industry's segmented approach to propulsion system development.
- The characteristics and development timelines of the three new propulsion systems.

### A Focus on Sustainability

If there is one word that will define the commercial aviation industry over the next decade, it is "sustainability." Sustainability guidelines, regulations, and incentives are already an important consideration for manufacturers, but as the number of global travelers increases, so too will pressure to reduce emissions and mitigate the industry's impact on the environment. The International Air Transport Association estimates that the number of air travelers will increase from 4 billion to nearly 8 billion by 2040, driven heavily by growing air travel markets in China and India.

Commercial aviation dumps more than a billion tons of CO2 into the atmosphere per year. And because of the high altitude at which most of these emissions occur, they have an even greater environmental impact than other types of emissions. It is unlikely that efforts to decarbonize existing fuel sources will have enough of an effect to blunt that impact. In fact, the aviation industry is widely recognized as one of the most carbon-intensive forms of transport and one of the most difficult to decarbonize. Armed with this knowledge, companies are developing new propulsion systems that would significantly improve aircraft sustainability.

A similar story has played out in the automotive industry for the last several years, as hybrid and all-electric vehicles (EVs) have become more commonplace. However, developing propulsion systems that are light and powerful enough to work onboard a commercial aircraft — and meet safety requirements — makes the aviation industry's task even more difficult.

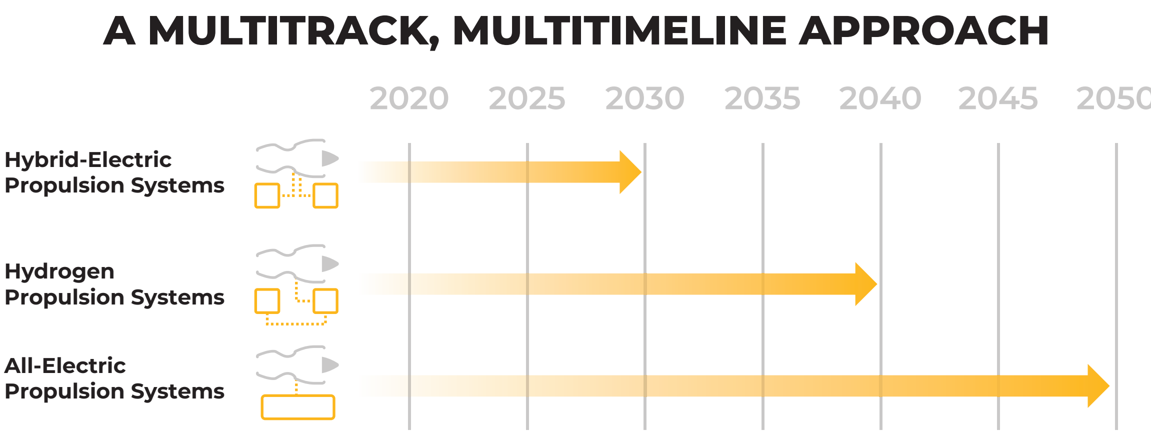
**A Multi-Track, Multi-Timeline Approach**

Commercial aviation companies initially examined the feasibility of moving directly from traditional combustion engines to all-electric propulsion systems. They quickly realized that doing so in the near-term was impossible given the current limitations of battery technology. Instead, manufacturers decided to take a segmented approach that will enable them to pursue meaningful breakthroughs in sustainability for combustions engines while maintaining a longer-term focus on developing even more efficient hybrid-electric, all-electric, or hydrogen-based systems.

Developing three distinct propulsion systems on distinct timelines offers another important advantage for the industry. As aviation companies develop these advanced propulsion systems for commercial aircraft, they can also apply their findings to other applications and markets, such as the civil aviation sector.

As aviation companies contend with the technical challenges of sustainable propulsion systems, they must also establish the business case for each, and navigate the industry's extensive certification process. Regulators are establishing recommendations that will guide manufacturers as they develop the new systems.

The details and development timelines of each of the propulsion systems are discussed in the subsections below.




*Commercial aviation companies will develop hybrid-electric, hydrogen, and all-electric propulsion systems on discrete timelines in the coming decades.*

**Hybrid-Electric Propulsion System**

The most technologically mature of the propulsion system types discussed in this report is a hybrid propulsion system that uses a combination of batteries and traditional internal combustion technology. Advancements in propulsion architecture, including battery systems, control systems, and electrical components, have improved the efficiency of these hybrid systems significantly, which makes them an important stopgap between today's combustion engines and the all-electric systems of the future.

Hybrid-electric propulsion systems will likely be ready for use in a commercial airliner sometime in the 2030s.

### All-Electric Propulsion System

All-electric propulsion systems are powered entirely by batteries. Producing these systems is a significant long-term goal for the commercial aviation industry, though it will likely be decades before it is achieved. Critical to aviation is the need to increase the energy density of the batteries' watt-hours per kilogram (Wh/kg).

In the near term, these systems will power small aircraft on short-range flights. One such emerging application is for electric vertical take-off and landing (eVTOL) vehicles, a component of the advanced air mobility (AAM) industry. These aircraft transport people and goods across distances of up to 150 nautical miles (nmi). As autonomous systems are developed, we will see a rapid increase in the type and application of these aircraft.

One advantage for large manufacturers is that they will be able to pursue AAM and autonomous business opportunities for all-electric propulsion as they work toward their longer-term, commercial aviation goals. However, the feasibility of current electric propulsion technology may give small companies an opportunity to disrupt this secondary market.
In 15 to 20 years, all-electric systems may be viable for medium (600 to 2,000 nautical miles (nmi)) and long-haul (2,000-plus nmi) flights. By 2050, such a system could work aboard large commercial airliners.

### Hydrogen Propulsion System

Hydrogen propulsion systems are another promising option in the commercial aviation industry's quest to improve sustainability. These systems use fuel cells to convert cryogenically stored liquid hydrogen into electricity, which then complements a gas turbine. Alternatively, hydrogen can be burned directly in a gas turbine. The result is a highly efficient propulsion system that promises zero emissions — water is the only byproduct.

In addition, liquid hydrogen contains three times more energy per unit of mass than jet fuel, and costs about the same, making it an especially appealing energy source. Aviation manufacturers are developing hydrogen propulsion systems with a targeted completion date of 2035, meaning that these systems will likely follow hybrid-electric and precede all-electric propulsion systems.

## / TECHNICAL CHALLENGES

Developing new propulsion systems presents numerous technical challenges for commercial aviation companies. Many of these challenges apply to all the systems identified in the previous section, though each system also presents some unique development issues. This section of the report will detail:

- The technical challenges of developing hybrid-electric, all-electric, and hydrogen propulsion systems.
- The effects of failing to address these challenges.

### Electric Drivetrain and Systems Integration

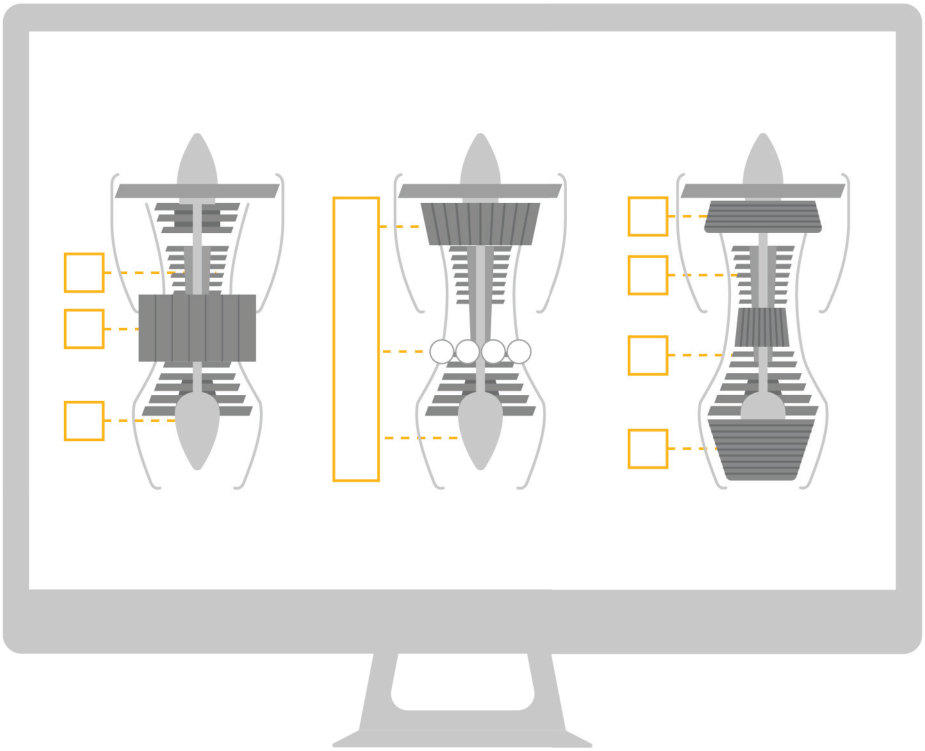
Aviation manufacturers face multiple closely related technical challenges when developing new propulsion systems. Not only must they identify the optimal architecture for a given need, they must also develop integrated embedded-control systems and satisfy extensive requirements for safety-critical systems, power management, and thermal management. This is particularly true for hybrid-electric systems.

The competing requirements of some of these systems can cause development issues and require frequent trade-offs. For example, designing a system that requires more power means adding weight and possibly impacting thermal management. And as engineers add electrical components to the system, electromagnetic interference (EMI) can increase, raising electromagnetic compatibility issues.

The complexity of these propulsion architectures requires a holistic, multidisciplinary development approach. Engineers must undertake a safety analysis, use multiphysics simulation and embedded software design to validate the architecture, and then automate safe controls. This toolchain is necessary to efficiently design a product that will meet performance goals and product and passenger safety goals, and provide supporting evidence for certification.

Establishing optimal architectures requires real-time insight into the system's performance to guide engineers toward the best option. Doing so necessitates using high-fidelity models to evaluate the behavior of the system being tested.

# ELECTRIC DRIVETRAIN AND SYSTEMS INTEGRATION

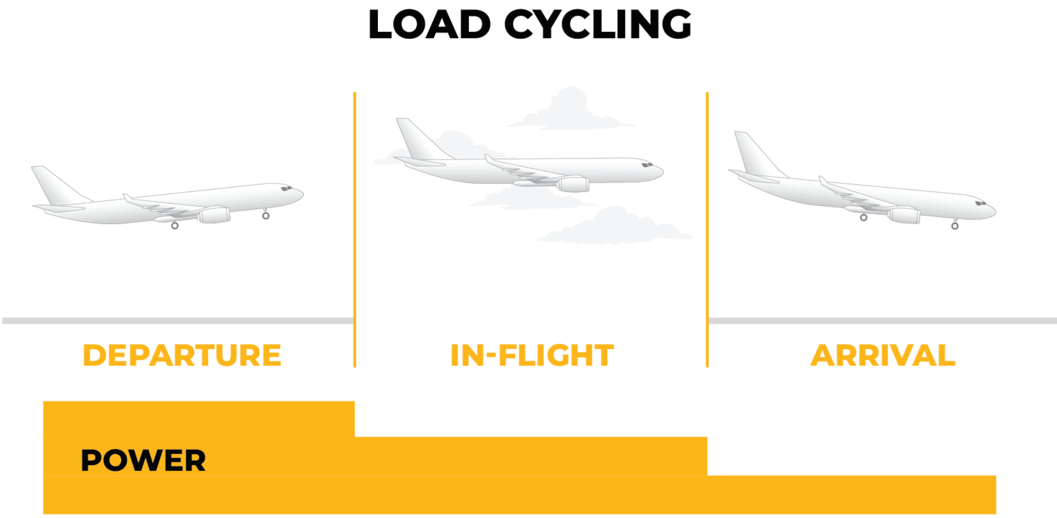


*Developing requirements for safety-critical systems and identifying optimal system architectures are among the notable technical challenges facing engineers as they develop more sustainable propulsion systems.*

**Electric Machine Design**

Designing a sound architecture for an electric motor presents a difficult multiphysics problem. The systems' thermal management, electromagnetic performance, and capacity to handle noise and vibration must meet the industry's high standards. But adjustments to any one of these system aspects affects the others. A design with strong electromagnetic performance might cool poorly, which means the design cannot be used as long in a high-power configuration. Engineers must carefully analyze these trade-offs as they develop new iterations in pursuit of an optimized design.

Once a design is established, the system's reliability and durability must also be tested. Engineers must determine how the system will behave during the different duty cycles required for flight. It must be able to repeatedly cycle between multiple power configurations while in different environments to ensure that it can handle the stress of takeoff, flight, and landing in variable conditions.



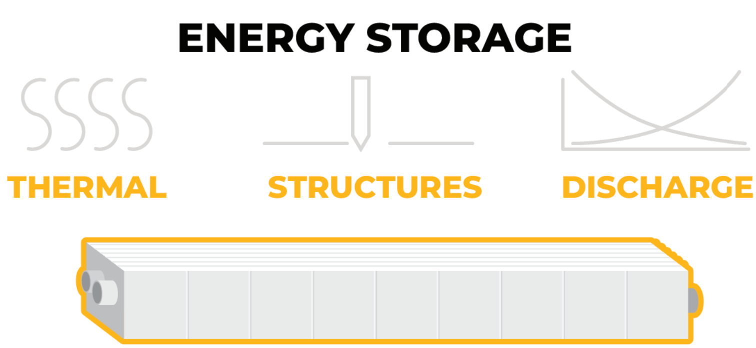

*Electric propulsion systems must be designed to withstand the stress of repeatedly cycling between the multiple power configurations required by an aircraft's flight cycles.*

**Energy Storage**

The goal of any battery is to store the highest possible amount of energy while providing an effective way to extract that energy. But, the fastest extraction method is not necessarily the best. If a battery discharges too quickly, it may affect system performance through thermal impact or EMI and EMC issues. This means that engineers must devise a strategy for how a battery will be discharged that accounts for the power management controls that must be applied to the system. Cooling, fault, and safety control management built into the battery management system, for example, could prevent overheating and thermal runaway.

A battery's structural reliability is another significant concern. Systems that are compact enough to fit into an aircraft's tight spaces will be subjected to intense vibration, which they must be able to endure without issue.

Finally, the material management of energy storage presents additional difficulties. Engineers must consider the multiphysics issues related to determining the best materials for their batteries. Not only must the components within the batteries interact safely, but the batteries must also interact safely with the rest of the propulsion system, avoiding thermal management, EMI, and EMC issues.



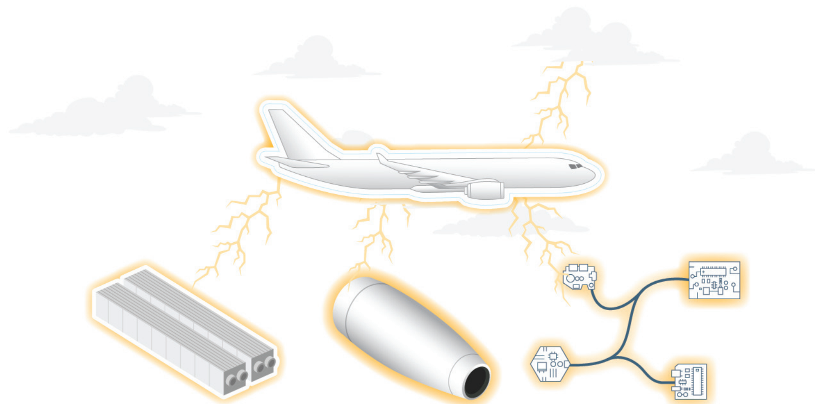

*The batteries that power all-electric propulsion systems must store and discharge energy without creating thermal management, EMI, or EMC issues, and their structures must be durable enough to withstand the rigors of flight.*

**Power Electronics and Controls Design**
Control systems must be able to effectively manage the power electronics that they contain. The goal is to make sure that the system's safety is preserved in any conditions, but the high voltages involved, and the switching required, make this especially difficult to achieve.

Engineers must design the propulsion system in such a way that the amount of energy required by its critical components does not interfere with other onboard components detrimentally, thermally, or electromagnetically. They must also make sure that the system is protected against environmental events, such as lightning strikes.

Because of the high voltage levels that aircraft propulsion systems require, cable and cable system design is also difficult to manage. Cables themselves must be optimized to handle these high voltages while also meeting thermal management requirements. But, such cables will necessarily be thicker and heavier, adding weight to the system. And with the amount of cabling the system requires, that weight adds up quickly. Once integrated, the cable system can also easily create EMI and EMC issues that engineers must account for as part of the design. Because many avionic systems are integral to the aircraft's safety, proper EMI and EMC compliance is critical.

## POWER ELECTRONICS AND CONTROL DESIGN



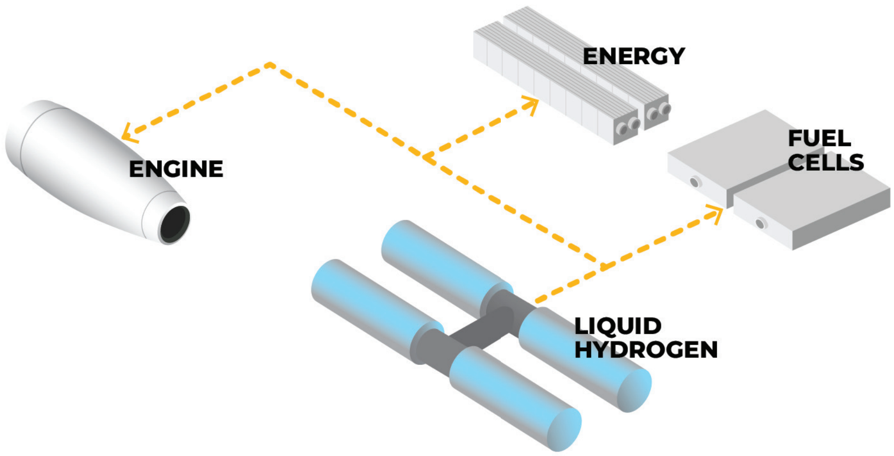

*In addition to safely managing the system's power electronics, designs must also be able to protect against severe environmental conditions.*

**Cryogenic Storage and Distribution Requirements**
Because the liquid hydrogen that fuels a hydrogen system must be stored cryogenically, the entire system must be durable enough to prevent leaks and operate safely at temperatures below -250°C. This makes identifying the optimal materials for the system's tanks, piping, valves, pumps, and other components critical to its operation.

Liquid hydrogen presents numerous flow and distribution challenges. Unless its flow and thermal state is carefully controlled, the hydrogen can change from liquid to gas. Keeping the hydrogen contained and flushing any that escapes is another issue. Other materials can absorb hydrogen, changing their properties and making them more brittle. Rapid decompression can lead to material breakout. Additionally, hydrogen combustion works differently than jet fuel combustion and creates conditions under which safety-critical problems such as flashback can occur. This means that hydrogen-based propulsion systems must undergo a different safety analysis than their hybrid-electric counterparts.

Hydrogen fuel cells, which convert liquid hydrogen into electricity, also present efficiency challenges. Because hydrogen has a low fuel density, the volume required to power an aircraft would be so large that it would significantly reduce the number of passengers or amount of cargo that could be carried. Engineers must improve the efficiency of these cells significantly for hydrogen to become a viable energy source in the aviation industry. This makes performing chemistry and thermal analyses of the fuel cells essential to determining the viability of hydrogen propulsion architectures.

# CRYOGENIC STORAGE AND DISTRIBUTION




*Hybrid-hydrogen propulsion systems use liquid hydrogen stored at temperatures below -250°C, which means the system must be optimized to distribute it safely and protect against leaks.*

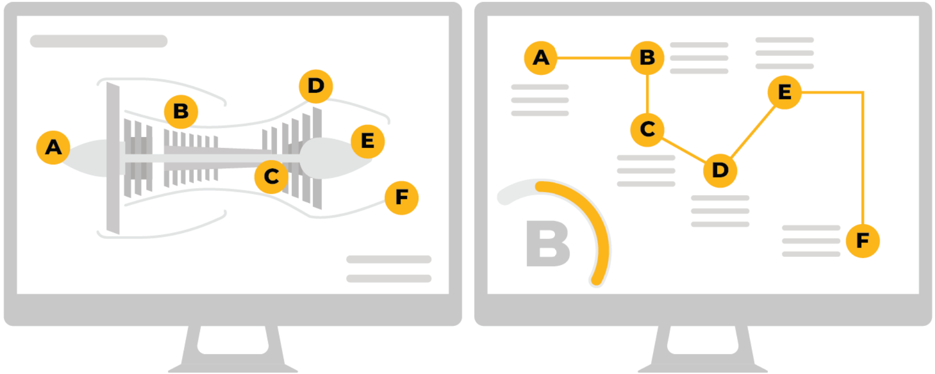
## / ADVANTAGES OF ANSYS SOLUTIONS

As the commercial aviation manufacturers develop the propulsion systems discussed in this report, they will need development and engineering solutions to aid those efforts. This section of the report will:

- Detail the ways in which Ansys solutions enable commercial aviation companies to more effectively develop new propulsion systems.

**Electric Drivetrain and Systems Integration**
Ansys solutions give engineers visibility into the system's performance. Our requirements management tools enable engineers to correctly identify functional and safety requirements early in the development process, meaning that they can mitigate potential issues through design or control software and more efficiently ensure that the systems meet the industry's extensive safety requirements.

# ELECTRIC DRIVETRAIN AND SYSTEMS INTEGRATION




*Ansys solutions allow engineers to model a design and simulate its performance so they can refine system architectures and satisfy the system's competing requirements.*

**Electric Machine Design**
Ansys offers solutions that provide templates featuring a wide range of electronic machine technologies. Our solutions also provide multiphysics analysis capabilities from the earliest stages of the design process, which provide clear insights into interaction between the system's electromagnetic, thermal, and mechanical components.

Using these tools, engineers can further improve a design's durability and reliability by simulating its noise, vibration, and harshness (NVH). Data from NVH simulation guides design changes that can reduce fatigue on the system, elevate its performance, and increase safety.

Ansys' simulation capabilities also enable engineers to accurately assess and optimize a design's performance for each of its required operational configurations.

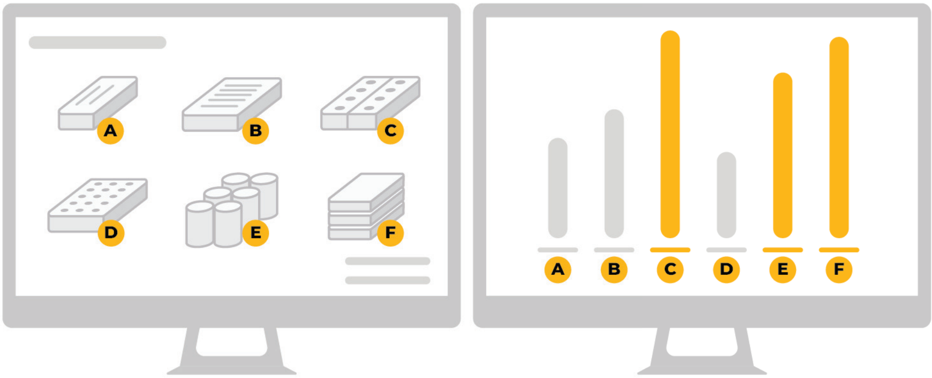
**Energy Storage**
Ansys solutions provide multiphysics simulation capabilities to quickly and accurately assess material needs and battery system performance. With Ansys solutions, design teams can analyze a battery design's performance under flight conditions to optimize its structural integrity. They can also model a battery's flow and heat transfer to improve thermal management, which, in turn, enhances the system's efficiency.

These analyses enable engineers to identify the optimal materials for the system and improve their understanding of how flight and charging cycles will affect a battery's life. Using Ansys solutions, engineers can create digital twins that record the battery's experience, then use what they learn to extend the battery's life and inform the economics of when it should be replaced. Ansys materials selection tools also provide opportunities to create more innovative designs and support sustainable design choices.

In addition to simulating electrochemical reactions and materials performance, Ansys solutions can also help predict EMI emissions and susceptibility early in the design process and analyze a battery system to find the root cause of existing EMI issues. This capability improves EMI filter design and lowers the cost of compatibility testing.

In addition, Ansys' integrated battery management system design software enables engineers to develop, test, and verify systems quickly and efficiently.

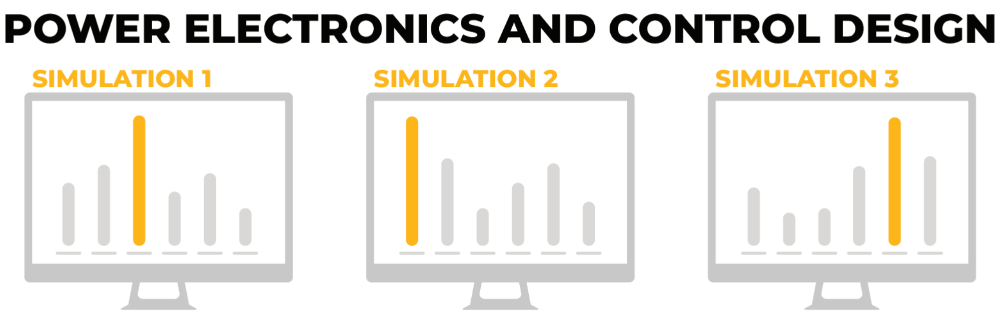
## BATTERY OPTIONS




*Design teams can use Ansys solutions to optimize a battery's multiphysics performance to determine an optimal structure and maximize its efficiency and lifespan.*

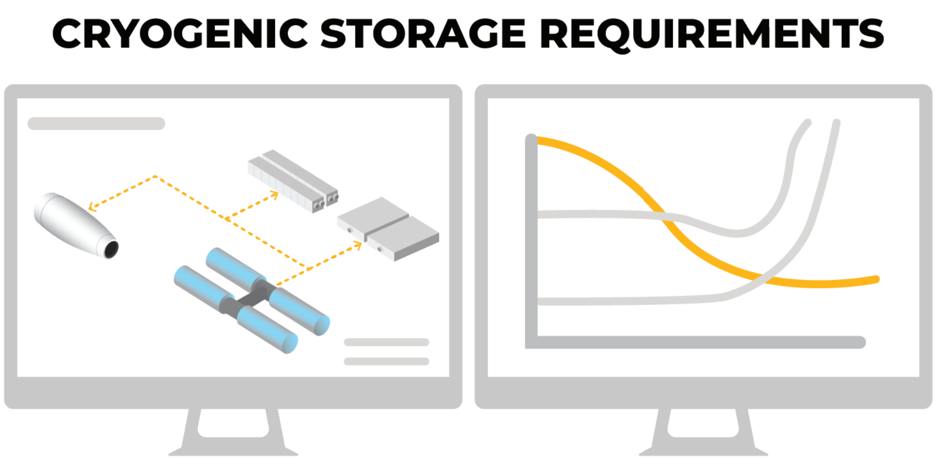
**Power Electronics and Control Design**
Ansys offers several solutions to support the design and optimization of power electronics. Engineers can use Ansys software to simulate the effects of a propulsion system's power cycles on its other components. This enables them to quickly identify and address any failures that may occur during these cycles.

Engineers can also use Ansys software to simulate a system's thermal behavior as its electronic components switch from one state to another, to ensure that any impact to the system is minimized or eliminated. These solutions also enable engineers to simulate the electronics' electromagnetic effects when switching, to ensure EMI and EMC issues do not unduly affect the system's safety or performance.




*Ansys tools' simulation capabilities allow engineers to analyze a propulsion system's performance during various power cycles to ensure its thermal and electromagnetic effects do not cause safety issues.*

**Cryogenic Storage and Distribution Requirements**
With Ansys solutions, engineers can conduct thermal analyses of the system's fluid and other components to ensure that safety-critical requirements are met throughout the combustion process. Using the multiphysics simulation capabilities in Ansys solutions, aviation manufacturers can optimize the system architecture to function effectively under extreme conditions and assess the durability and reliability of the materials used to build the system. This enables engineers to manage liquid hydrogen's flow and distribution issues and optimize the system's design to mitigate their effects.




*Analyzing the flow and distribution of the liquid hydrogen in a hybrid-hydrogen system allows stakeholders to select materials ideally suited to the frigid temperatures—and other volatile conditions—the system must endure.*

## / SUMMARY AND RECOMMENDATIONS

Driven by government and market pressures to improve sustainability — and the corresponding need to develop new, more efficient propulsion systems — the commercial aviation industry is entering a time of change and innovation. It will be crucial for these organizations to use simulation to accelerate development and optimize the performance of these systems.

- Several factors, including the limitations of today's battery technology, have required the industry to adopt a multi-track, multi-timeline approach to developing these propulsion systems. Each is being developed simultaneously with the expectation that hybrid-electric systems will be feasible first, followed by hydrogen and all-electric systems.
- This segmented approach will yield opportunities for companies to pursue other markets and applications, such as eVTOL vehicles with all-electric propulsion systems. But, the near-feasibility of the technology needed for small vehicles and short flights will also create opportunities for small companies to disrupt these markets.
- Optimizing system architectures is one of the key technical challenges engineers face when developing hybrid-electric propulsion systems. Tracking the requirements, design decisions, analysis data, verification, and validation required by these systems is crucial to effective optimization.
- The primary technical challenge of developing all-electric propulsion systems is managing energy storage and distribution. To optimize safety and performance, engineers must identify the most effective materials for the system's construction, determine the best way to store and extract energy, and minimize the batteries' effects on other system components.
- The storage, flow, distribution, and combustion of liquid hydrogen presents several technical challenges when developing hydrogen-based propulsion systems. The system's design and materials must be optimized to endure extremely low temperatures and temperature fluctuations, while protecting it against leaks and other safety-critical issues.
- Ansys' physics-based simulation solutions offer design, modeling, simulation, and testing capabilities that enable engineers to efficiently address these technical challenges and create propulsion systems that meet the industry's performance and safety requirements.

**ANSYS, Inc.**
Southpointe
2600 Ansys Drive
Canonsburg, PA 15317
U.S.A.
724.746.3304
ansysinfo@ansys.com