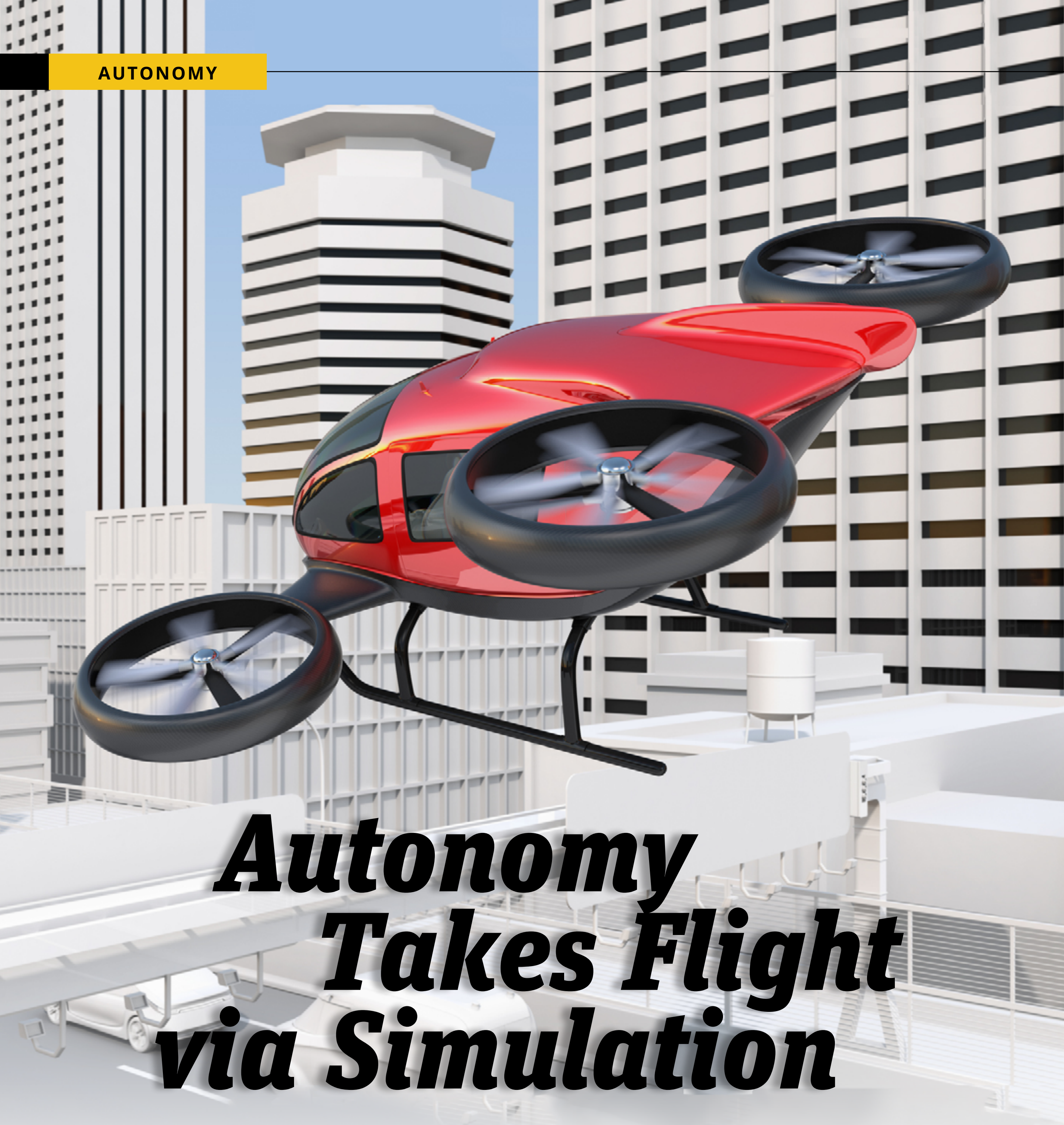

# Autonomy Takes Flight via Simulation

While self-driving cars are already a reality, the aerospace industry has been slower to develop fully autonomous systems for aircraft. There are a number of reasons, including the high cost and long time frames involved in testing and verifying the software and systems that deliver autonomy. However, closed-loop capabilities from Ansys are now helping aerospace leaders develop and verify systems for vertical takeoff and landing (VTOL) vehicles — the first step toward the launch of truly autonomous aircraft.

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The commercial drone — or unmanned aerial vehicle — market is growing at 14% annually because a remote-piloted craft is simpler, safer and less expensive — and can be smaller — than a piloted craft for many functions. In addition to the well-publicized potential of drones for military applications and package delivery, unmanned aerial vehicles (UAVs) also represent a simpler, more affordable solution for inspecting bridges, monitoring power lines, checking the conditions in agricultural fields, spraying crops and performing other industrial tasks.

In addition, the urban air mobility (UAM) market has huge potential, as crowded airspace and traffic congestion create a demand for small aircraft that can lift off and land in confined spaces.

The vertical takeoff and landing (VTOL) aircraft segment is the subject of increasing attention and investment today — and with good reason. Aerospace leaders, including Airbus, Rolls-Royce and Bell, are developing product solutions, hoping to capitalize on a market opportunity that Booz Allen estimates to exceed $500 billion. As many of these aircraft can carry two or four passengers, eliminating a pilot via autonomy increases the payload capacity by 25% to 50% — creating a significant cost advantage.

However, there are significant engineering challenges involved in making VTOL aircraft fully autonomous. They need to safely handle every possible scenario, without intervention from a human operator. They must navigate the difficult transition from vertical to horizontal flight under every conceivable weather condition. And they must accurately sense the physical environment around them, so they can reliably distinguish a harmless visual phenomenon like a light reflection from a potential

**This Ansys simulation of a drone in an urban virtual environment includes physical factors such as the effects of wind on flight dynamics, and accounts for optical phenomena such as the reflection of sunlight on glass buildings.**

hazard such as a flock of birds. Finally, in the event that any component fails, it is essential that software systems protect system integrity and functional safety as needed.

Engineering an autonomous VTOL aircraft is a complex proposition, bringing together physics, electronics, optics, embedded systems and control software. Engineers need to accomplish these tasks with a high degree of confidence:

- **Model and test millions of operating scenarios**, including the animation of both the VTOL aircraft and its surroundings
- **Develop and test sensors** that observe the vehicle's surroundings and deliver appropriate output signals
- **Define software algorithms and embedded systems** that consider inputs, make decisions and drive actuator behavior in response
- **Ensure the functional safety** of the aircraft at the system level, by identifying and addressing all potential failure modes

Given the complexity of these tasks, and the drive to commercialize autonomous VTOL vehicles quickly, simulation-driven product development is the only answer. Ansys software makes it possible to simulate VTOL aircraft at both the component and the system level, while ensuring tight control, functional safety and compliance with all relevant regulatory standards.

Ansys provides the first complete simulation environment that includes virtual world models and operating scenarios, simulation of vehicle dynamics, physically accurate sensor models, embedded software development tools and functional safety analysis. In addition, the Ansys VRXPERIENCE virtual-reality platform helps optimize the flight experience for human passengers. One of the keys to widespread adoption of autonomous vehicles is overcoming users' fears about their safety and comfort. By recreating the user experience in a virtual environment, simulation can help ensure a positive experience that makes autonomous flight an attractive proposition for consumers.

By capitalizing on these integrated capabilities, the developers of VTOL and other autonomous aircraft can dramatically reduce the time and cost involved in launching safe, reliable designs to capture this market opportunity.

### Flight Simulation: Understanding the Physics

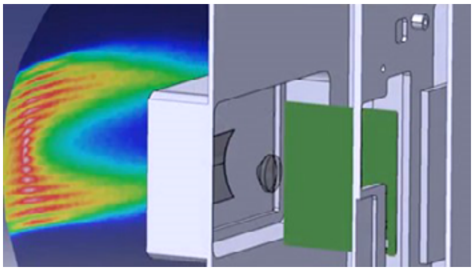
Known for its flagship physics-based modeling solutions, Ansys allows aerospace engineers to simulate VTOL aircraft during virtual test runs — including flight dynamics and wind effects. Engineers can use traditional simulation capabilities already proven in the global aerospace industry to optimize the aerodynamics involved in flight as they model VTOL designs under real-world conditions.

Because of their unique functionality, VTOL vehicles present additional engineering challenges. To accurately model the complex fluid dynamics involved in vertical takeoffs and landings, Ansys Fluent delivers custom capabilities that are unmatched in the industry.

To establish reliability across years of use and thousands of flight miles, Ansys supports very detailed simulation of specific physical environments. Via a closed-loop process that brings other Ansys software into play, engineers can consider all the interactions of the autonomous craft with its environment, including any physical forces and obstacles, across millions of operating scenarios.

Results obtained via the Ansys closed-loop flight simulation process give engineers a much deeper understanding of how to engineer the vehicle to ensure its compliance with both safety regulations and customer expectations. Based on realistic operating conditions, the Ansys simulated autonomous vehicle makes the same reliable decisions as the future real-world connected vehicle.

Vertical takeoff of a drone in an urban environment. Since vertical takeoff is driven by the output of camera sensors installed on the drone, it is crucial that these sensors are simulated and tested for reliable performance.



Ansys SPEOS enables engineers to simulate the optical images that are gathered by cameras and lidar systems mounted on the VTOL vehicle — critical in ensuring that the craft can accurately sense and respond to its physical surroundings.

### Optical Sensors: Obtaining a Clear View

In addition, specialized Ansys software enables the simulation of all the optical sensors integrated into a VTOL aircraft. Autonomous vehicles require an increasing number of optical sensors, including cameras for visible and infrared detection, as well as lidar systems for a 360-degree, three-dimensional view of the operating environment.

Ansys SPEOS optical simulation software validates the performance of the optical sensors through physics-based simulation that accurately represents their real-world performance. SPEOS enables engineers to perform a detailed physics simulation of optical cameras and lidar — taking optical lenses, imagers, mechanics, sensors, materials and light properties into account in both visible and non-visible (IR) wavelengths, as well as merging images obtained by multiple cameras.

SPEOS also simulates in-vehicle installation via reduced-order modeling (ROM) of the cameras and lidar as integrated into actual operating scenarios. These simulations accurately replicate the images that are gathered, so that sensors can be engineered to identify complex optical factors such as sun glare and reflections.

Ansys HFSS can be used in a similar manner for evaluating and verifying the performance of radar sensors, as well as other antenna systems mounted on a VTOL aircraft.

### Embedded Software: Ensuring Tight Control

After input has been gathered from sensors, the VTOL vehicle must now be programmed to take the right actions in response. This is the role of embedded software, which applies machine learning and control logic to determine a flight plan and execute it by driving the craft's actuators. This control loop is executed repeatedly, in cyclic fashion, so that the vehicle can respond to constant environmental changes.

In order to design and generate code for the control logic, Ansys has developed a comprehensive solution capable of automatically generating code from software models for autonomous vehicles. The Ansys SCADE Suite KCG code generator has been qualified to meet the most stringent aerospace standards and ensure the safe operation of VTOL aircraft under every operating condition.

Because the SCADE solution is part of the integrated Ansys development platform for VTOL vehicles, it is possible to verify by closed-loop simulation of the flight scenarios that any changes in the control software perform as expected and do not create any regression. By using SCADE to generate a control architecture and underlying code, software developers can drastically reduce the time and cost of validating and certifying their embedded systems.

### Functional Safety: Bringing It All Together

The final step in engineering a VTOL aircraft is ensuring that all components work together in a safe, reliable manner when brought together as a system. All failure modes must be identified, and appropriate responses must be defined. Functional safety analysis acts as the "cockpit" for the entire engineering process, ensuring that the system-level design is safe and meets all relevant aerospace industry standards.

Ansys medini analyze addresses functional safety, and has been proven in many automotive and aerospace applications. While there is not a specific aerospace standard developed yet for VTOL vehicles, medini analyze meets standard ARP 4761, which requires that aeronautics safety engineers evaluate and assess the safety of aircraft systems by identifying relevant hazards and failure modes for all electronic components. In addition, the emerging SOTIF standard that is currently created for autonomous cars can be used as a basis to assess the safety of such complex systems, including sensors and AI-based perception.

**The Ansys VRXPERIENCE platform enables engineers to test the impact of a specific control law — developed with the SCADE software suite — on the real-world human experience. The simulation user is fully immersed in a highly accurate virtual reality environment, and can experience a complete VTOL flight scenario long before the real aircraft exists.**

While many product developers implement functional safety analysis as a separate, manual activity, the integrated Ansys simulation platform brings this mission-critical task into the closed-loop process. By considering functional safety as part of the system architecture, reliable performance and industry certification are built into the aircraft design at an early stage.

### VTOL Autonomy: An Achievable Goal

Autonomous vertical takeoff and landing aircraft have enormous market potential, but engineering them is a practical challenge that still needs to be overcome. Bringing together physics, electronics, optics, embedded software controls and functional safety, VTOL aircraft represent one of the most complex product designs today — and, because their performance is absolutely mission-critical, there can be no shortcuts.

Simulation provides the only practical answer, replacing years of physical testing and hours of flight time with affordable, low-risk, system-level modeling. By placing their VTOL designs into a highly detailed, three-dimensional simulated environment, engineers can verify their safe performance, including sensors, software and other highly sophisticated components. They can recreate millions of real-world operating scenarios without investing in prototypes or physical tests.

By leveraging the integrated autonomous vehicle development platform from Ansys, engineering teams can quickly and economically simulate any VTOL vehicle, with any combination of sensors, with any control system, in any operating scenario. This allows them to significantly reduce the time and financial investments needed to achieve both performance and safety goals for these advanced product systems.