Robinson's newly certified empennage will be standard on all new production, FAA-registered R66 helicopters and on foreign-registered R66s as validations by other regulators are obtained. **Robinson Helicopter Photo**

HOW ROBINSON HELICOPTER ARRIVED AT ITS NEW TAIL DESIGN

BY ELAN HEAD

When Robinson Helicopter Company unveiled a new empennage for the R66 helicopter on Sept. 6, the company described it as the product of "years of development and testing." Now, in a *Vertical* exclusive, Robinson has shared extensive details of the research and development program that led to the updated design.

As previously reported, the new empennage replaces the R66's original horizontal stabilizer — which is mounted on the right side of the tail, directly across from the tail rotor — with a different stabilizer that is forward of the tail rotor and symmetrical across both sides of the tail cone. The new stabilizer is designed to enhance roll stability during high-speed flight, a regime in which the aircraft is at increased risk for mast bumping.

Vertical examined the topic of mast bumping in 2016, following an investigation into a fatal R66 crash by New Zealand's Transport Accident Investigation Commission (TAIC). Mast bumping — in which the hub of a two-bladed, "seesawing" main rotor system contacts the rotor mast, often causing a catastrophic break-up of the helicopter in flight — was not a new phenomenon at that point. It had been studied by Bell and the U.S. Army in the 1970s in response to a number of accidents involving two-bladed Huey and Cobra helicopters, and by Robinson and the Federal Aviation Administration in the 1980s and '90s, following similar accidents involving the R22 and R44.

The Army distilled its early mast bumping research into a 1980 training video that also shaped many civilian pilots' understanding of the phenomenon. Viewers learned that mast bumping happens in low-G situations when the weight of the helicopter becomes unloaded from the main rotor disc, such as when the pilot abruptly pushes the cyclic forward after a climb. In an unloaded condition, lateral cyclic control inputs will still tilt the rotor disc left or right, but will not change the roll attitude of the fuselage in the absence of thrust.

The new empennage includes a symmetrical horizontal stabilizer and a new tail cone, both with extended TBOs of 4,000 hours. In the future, operators will have the option of retrofitting older aircraft with the full empennage or just the stabilizer. **Robinson Helicopter Photo**

Once the rotor system is unloaded, the video explained, "the thrust of the tail rotor acting above the helicopter's center of gravity starts the fuselage rolling to the right. Seeing this, the pilot wants to counter the roll — normally the right thing to do." However, abrupt left cyclic input on an unloaded rotor causes flapping to increase drastically. "The rotor hub strikes the mast violently on one side, then the other, and the mast may separate," the video described. Pilots were instructed to instead apply gentle aft cyclic to reload the rotor disc before correcting for the roll.

The message of the video, and of Robinson's subsequent training material on the topic, was that pilots could prevent mast bumping by avoiding low-G situations to begin with and by reacting appropriately should one occur. The company maintained that mast bumping could not take place without an improper cyclic input from the pilot, and this view was generally accepted by the rest of industry as mast bumping accidents continued to happen in Robinson helicopters.

However, the TAIC declined to accept the primary role of the pilot as a proven fact, noting that many of the fatal Robinson mast bump accidents in New Zealand occurred in turbulent conditions and that the behavior of the Robinson rotor system in turbulence had not been fully tested. Some people speculated that the unique "tri-hinge" design of the Robinson main rotor system could lead to a blade unexpectedly diverging from its path of rotation in response to forces beyond the control of the pilot, thereby making Robinsons inherently more susceptible to catastrophic in-flight breakups than helicopters with more traditional two-bladed rotor systems, like the Bell JetRanger and Huey.

The TAIC recommended that the FAA reinstate research into the dynamic behavior of two-bladed, teetering, underslung rotor systems that had been started by the Georgia Institute of Technology but halted due to a lack of funds in 1995. When *Vertical* visited Georgia Tech in 2016, Marilyn Smith, who is now the director of the school's Vertical Lift Research Center of Excellence, agreed that the time was ripe to revisit the topic. The continued development of aeroelastic modeling tools, she said, had given researchers the ability to model much more complex aerodynamic phenomena, including transient conditions that could lead to mast bumping, and ways in which the fuselage interacts with airflow.

BUILDING A BETTER MODEL

The FAA did not act on the TAIC's recommendation, but Robinson did. The company commissioned researchers at the University of Maryland to conduct a mast bumping simulation and mitigation analysis, results of which were presented in a public paper in 2018.


Robinson's original design, common across the R22, R44 (pictured) and R66, features an asymmetrical horizontal stabilizer on the right side of the tail, directly across from the tail rotor. **True Blue Power Photo**

The researchers developed a simulation model specifically for Robinson's tri-hinge rotor system, which includes a central teetering hinge, responsible for normal blade flapping, and two coning hinges, which accommodate the coning motion of the rotating blades due to the production of lift. In other helicopter models, this coning action is provided for through a combination of a fixed pre-cone angle and blade bending.

The model was validated against R66 flight test data, then used to explore maximum teeter angles and hub clearances in various flight conditions. According to the researchers, preliminary results were consistent with the earlier Georgia Tech study in not finding any unusual behavior under low-G conditions that would make the Robinson hub configuration more susceptible to mast bumping than other teetering rotor designs.

The study also explored how a number of potential design changes — including changes to the rotor radius, rotor speed, rotor shaft mounting angle, and vertical offset between the teeter and coning hinges — would impact teeter angles in low-G conditions. Of the many parameters studied, only changing the horizontal tail mounting angle on the airframe effectively reduced the maximum teeter angle. The researchers cautioned, however, that "increasing the horizontal tail angle will have an adverse effect on static stability, and all relevant ramifications of this design change must be taken into account, necessitating further analysis."

Although the University of Maryland study did not find evidence that Robinson's tri-hinge main rotor system is more susceptible to mast bumping than other designs, a planned second phase of research was not completed, and skeptics remained unconvinced. An R44 accident investigation report published last year by the Australian Transport Safety Bureau (ATSB) mentioned "some uncertainty regarding … whether inappropriate recovery control inputs are necessary for an accident to occur," as most of the helicopters involved in mast bumping accidents lacked cockpit video recorders that could have provided definitive proof of pilots' actions.

The ATSB noted that New Zealand's TAIC had identified turbulence as a sufficient condition for low-G mast bumping to occur and stated that certain low-G situations could lead to mast bumping and in-flight breakup before a pilot could reasonably react. The year before, an investigator in New Zealand had called for an independent body to develop an analytical model of the Robinson rotor system.

The R66 (pictured) is the first model to achieve certification with the new empennage by the FAA, but certification programs for the R44 and R22 are also under way, as is validation by the European Union Aviation Safety Agency and other regulators.
Robinson Helicopter Photo

By 2018, however, Robinson was confident that its rotor design was not uniquely unsafe and that theories to the contrary lacked a full accounting of the physics involved. For example, the company dismissed blade divergence theories on the basis that any unexpected deviation of a rotor blade from its normal plane of rotation would cause such a massive load imbalance at the rotor hub as to cause a spontaneous in-flight break-up without mast impact. Following the initial research by the University of Maryland, Robinson chose to work with a private company to develop the simulation model further, specifically assessing the contributions of tail rotor thrust, fuselage inertia and aerodynamic surfaces in the roll response of the aircraft in high-speed, low-G flight. The results "were kind of a surprise to the team here," said David Smith, an operations executive at Robinson who recently joined the company from Bell, where he held various positions including chief engineer and program director for the two-bladed Bell 505 helicopter.

The simulation showed that tail rotor thrust was not the primary contributor to the rolling behavior of the R66 in low-G conditions — in contrast to the conclusions reached by the U.S. Army for its Hueys and Cobras, which have tail rotors that are mounted much higher. Instead, the simulation identified the asymmetric horizontal stabilizer on the right side of the tail, which exerts a downforce in forward flight, as the most significant contributor to the R66's right rolling moment when the main rotor was suddenly unloaded.

"The way we teased it out was over a bunch of different simulation setups," Smith explained. When the model showed that adding a balancing aerodynamic surface on the left side of the tail would substantially decrease the rolling moment, Robinson's engineers were inspired to build a prototype. Flight testing by the company's experienced test pilots confirmed that the new, balanced stabilizer greatly reduced the tendency of the aircraft to roll to the right under conditions of low G.

CHANGE MANAGEMENT

As the University of Maryland paper cautioned, altering any aspect of a helicopter design, especially one as aerodynamically significant as a stabilizer, can create a cascade of undesired consequences. Thus, when Robinson embarked on the certification program for its new empennage, it had to spend a lot of time demonstrating that the new design doesn't make things worse.

"Even with something like this that we believe has a positive role in our company's future, it can be difficult to get through a certification program because it is so important to prove that there are no unintended side effects of change," Smith said. "We have a stable solid design that has 51 million hours of flight time on it, we want to add this change, it comes with some risks."

The new stabilizer is designed to enhance roll stability during high-speed flight, a regime in which the aircraft is at increased risk for mast bumping. **Robinson Helicopter Photo**

Over the past two years, certification authorities have imposed rigorous demands on the program. Robinson has had to demonstrate satisfactory handling qualities throughout the full flight envelope, in addition to performing a strain survey to measure flight loads on every configuration of the aircraft, comprehensive fatigue analysis and testing, and even new noise tests.

The R66 is the first model to achieve certification with the new empennage by the FAA, but certification programs for the R44 and R22 are also under way, as is validation by the European Union Aviation Safety Agency and other regulators. While retrofit kits are not yet available, the new stabilizer is designed to be easily retrofittable, even without the optional new tail cone, and will be offered to the market at a very low cost, Smith said.

Although Robinson aims to see wide adoption of the new empennage across its global fleet, the company contends that its recent studies have validated the safety of its original configuration within the approved flight envelope. Smith drew an analogy to automotive safety, in which safety enhancements are continually added to new vehicles without prompting the recall of older ones.

Increasing the roll stability of Robinson helicopters in high-speed flight won't eliminate the possibility of mast bumping or enable safe operations in low G, and Robinson will continue to prohibit both low-G maneuvers and high-speed flight in turbulence. However, the company believes that its new design will reduce the likelihood that a pilot will make an incorrect control input should a low-G situation occur.

That is especially important because there is currently no safe and legal way for pilots to train the correct response in flight, as demonstrations of the low-G condition have long been prohibited in Robinson helicopters. Smith previously served as the chief executive of TRU Simulation + Training, and is thus keenly interested in how flight simulators might be used for this task in the future. For the time being, however, Robinson has not yet endorsed any training device as accurately modeling low G and the onset of mast bumping.

Meanwhile, the company said it continues to invest in other safety enhancements, including a 4K cockpit video and voice recorder that is now standard on all new R44 and R66 helicopters, optional on new R22s, and available for retrofit on all three models. Robinson said it is also planning improvements to training through its factory safety course and has ongoing projects in advanced autopilot systems.