HELICOPTER GROUND RESONANCE Revision B

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Introduction

A new helicopter design must undergo thorough testing to ensure the reliability of the design with respect to vibration.

A new design undergoing testing may encounter severe vibration while it is on the ground, preparing for takeoff. A similar problem may occur immediately after landing.

Many helicopters have fully-articulated rotor systems. The advancing blades flap upward and the retreating blades flap downward in order to maintain uniform lift during forward flight.

A helicopter with a fully-articulated rotor has some measure of an unbalanced rotational force, which causes an oscillating force. This force may excite one of the helicopter's natural frequencies, as the rotor accelerates to its full operating speed prior to takeoff. This condition is called resonant excitation.

Dynamic Model

A sketch of a generic helicopter is shown in Figure 1. The helicopter may be modeled as a single-degree-of-freedom system as shown in Figure 2.

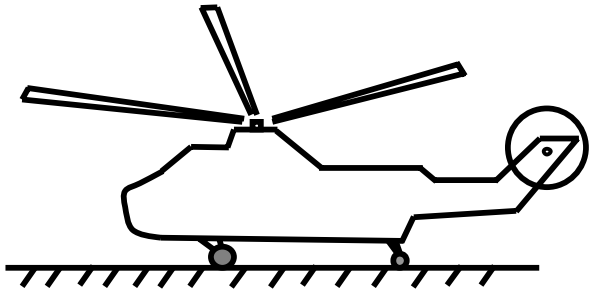
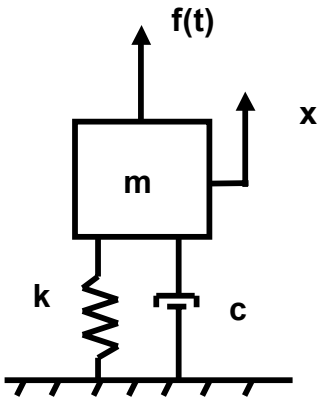


Figure 1. Helicopter Preparing for Takeoff



m is the mass
c is the viscous damping coefficient
k is the stiffness
x is the absolute displacement of the mass
f(t) is the applied force

Figure 2. Single-degree-of-freedom Model of Helicopter Preparing for Takeoff

John O. Emmerson wrote in Reference 1:

> In the mid-1950s, the emerging helicopter introduced a frightening problem called ground resonance. A perfectly sound production helicopter firmly supported on its landing gear with the rotor turning at or near flight rpm would suddenly initiate a "tramping" on the gear and then, almost immediately, completely disintegrate. The Sikorsky company, which was leading the pack in developing the helicopter, quickly gathered the most data on these ground based disasters and thus shouldered the lion's share of corrective understanding and action. The company established that the lead/lag pivots on the rotor blades, the pylon elastic stiffness, and the elastic components of the landing gear, including the tire and shock struts, all working together as a single structural entity, had an unfortunate resonant frequency near the rotor operating rpm. The engineers were able to show that a fearless pilot, entering the resonant phase, could save the day be pulling up the collective pitch control and unloading the landing gear (i.e., getting airborne). Lowering the resonant frequency and adding damping offered a permanent solution.
>
> Today, all of us in the helicopter development business, with the apprehension borne of substantial ignorance, approach initial ground whirl testing of each new helicopter with tremulous respect for the demon of ground resonances.

Solution

Modern helicopters avoid ground resonance by using dampers on the blades and on the landing gear. For example, the landing gear may have shock absorbed struts.

Case History 1

Figure 3. TH-55 Osage, Military Version of the Hughes 269A.

Figure 4. A TH-55 Destroyed by Ground Resonance

An intact TH-55 helicopter is shown in Figure 3.

A similar TH-55 helicopter was destroyed by ground resonance in March 1967, at Ft. Wolters, TX, as shown in Figure 4.

Case History 2

A Hughes 269A helicopter, similar to the one in Figure 3, encountered a ground resonance problems as described in the following summary.

> HUGHES 269A, MIA96LA209, MAINTENANCE, 08/10/96 - At approximately 1425 hours CDT, the helicopter sustained substantial damage due to ground resonance following maintenance to the main rotor system. The three main rotor blade dampeners had just been rebuilt. Conducting a maintenance test flight, the commercial pilot lifted the helicopter to a hover and immediately felt a main rotor vibration. As he landed, the helicopter went into ground resonance. The pilot sustained minor injuries, and the passenger received serious injuries. The flight was conducted under 14 CFR Part 91, and no flight plan was filed. The weather was reported as VMC with skys 2800 broken and 7 miles visibility.

Case History 3

Figure 5. Sikorsky H04S

Commander James Edgar Waldron, U. S. Naval Reserve (Ret.), encountered ground resonance while flying an HO4S helicopter in the Antarctic. He wrote the following story in "Flight of the Puckered Penguins."

> I had warned Howard about the tendency of the articulated rotor head system to go into a condition called ground resonance if one landed while moving in a direction other than straight down. It isn't a condition that one could expect to happen often, but there in the Antarctic with supercold flight controls and landing gear we had all the elements in place to get ground resonance without really trying. When the helicopter enters this condition the rotor head gets out of balance and if the aircraft remains on the ground the helicopter will disintegrate in a matter of a very few seconds. The only way out of this situation is for the pilot to immediately takeoff and the torsional vibrations will dampen out in the air. On one of our lifts from the Ice edge Howard had the flight controls and I had my hands inside my flight jacket warming them. Howard made a normal approach to a hover, but when he landed the helicopter he put it on the ice left wheel down. This sudden off balance landing put the helicopter into ground resonance and the aircraft started shaking itself in a fierce manner. I recognized what was happening immediately and I reached down to the Collective Pitch Control and yanked us into the air. Howard hadn't realized what was happening and if I hadn't taken effective action we would have come apart there with five or six men standing under the rotor blades.

Case History 4

Figure 6. Typical Seasprite

Seasprite Court Of Inquiry: Summary Of Findings

Questions and Answers for Media Release dated 6 December 04

Press Release: New Zealand Defence Force (Excerpt)

What is Ground Resonance?

Ground resonance is a phenomenon that occurs in helicopters like the Seasprite with a fully articulated rotor-head, a dampened undercarriage and, usually, on helicopters with inflatable tyres. Ground resonance occurs when the precise centre of gravity of the turning rotor disc is displaced from the precise centre of rotation. A common analogy is a child's spinning top – at low rpm the centre of gravity and centre of rotation are not aligned and the top develops a "wobble".

Helicopters are designed to provide mutual dampening between the main rotor and the undercarriage.

What happened during the accident?

On 22 May 2004, HMNZS Te Mana was conducting routine patrol operations in the Gulf of Oman. A flying operation was scheduled for that morning in support of the operation, with a maintenance ground run required before launch.

The ground run was required to check an oil cooler pipeline that had been replaced earlier. The check required running the number one engine and engaging the rotors. The aircraft was fully lashed to the deck using chain lashings, two of which were attached to the high points immediately beneath both engine nacelles.

During rotor engagement the pilot noticed slightly rougher than usual airframe oscillations. The airframe oscillation quickly developed into ground resonance and became more severe. As soon as the pilot had identified the ground resonance condition he shut the aircraft down.

Damage involved the starboard high point lashing had parted causing damage to the starboard window and door, and damage to the undercarriage on both sides with associated creasing in the skin.

What is the cost of the repair?

The estimated cost to repair the Seasprite is between NZ$1.5 and 3.0 million. It is estimated that the repairs will be completed by the end of January 2005.

What action has been taken to prevent similar occurrences in the future?

The recommendations of the Court of Inquiry are currently being implemented by the responsible agencies within the Navy and Air Force. A number of recommendations were made to improve technical and aircrew publications to better highlight the correct chain lashing procedures, and the dangers of ground resonance. Training syllabi have also been

reviewed to ensure adequate instruction on the causes and consequences of ground resonance is provided to all aircrew, maintenance crew, and flight deck officers.

Federal Aviation Regulations

Federal Aviation Regulation, Sec. 29.241 - Ground resonance, states:

> The rotorcraft may have no dangerous tendency to oscillate on the ground with the rotor turning.

Reference

1. John O. Emmerson, "On Shaky Ground," Letters, Smithsonian Air & Space, May 2001.