New Zealand Helicopter Association

Safety Bulletin

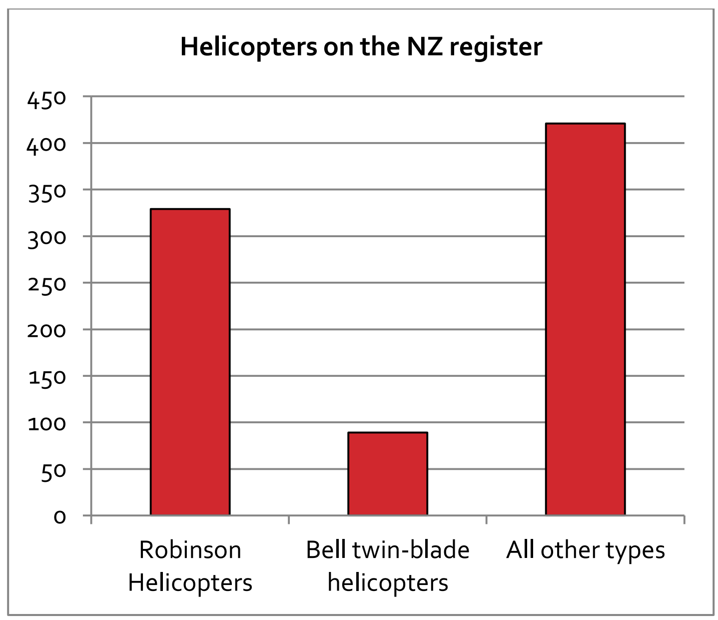
Low-G situations, mast bump, and turbulence

NZHA SAFETY BULLETINS SB 4

Late last year, shortly after a fatal R44 accident at the top of the South Island, we received the following e-mail:

"Having just returned last night from the South Island where I spent the day with the pilot's father and sister on a hill waiting for ground search teams to follow along the wreckage trail in steep heavily covered bush forest, to discover the cabin and the pilot dead I believe the following is worthy of consideration for all who fly two-bladed rotor systems.
In relation to the above accident, the prevailing conditions, terrain, and wreckage trail was very similar to that of a 2013 accident in the Central North Island. The helicopter was flying downwind in about a 20 knot wind and had crossed a high ridge. First found were pieces of paper, followed by clear plastic, a blade tie down, honeycomb, and eventually the cabin.
It is most likely going to take a while for the formal investigations to be completed but I suspect both will identify mast bumping as a result of negative G experienced in the turbulence encountered after crossing the ridge."

Mast bump and other situations where control over the main rotor is lost are **leading causes of fatal accidents** in two-bladed semi-rigid rotor helicopters. In terms of machines operating in New Zealand, this means mainly Robinsons and Jet Rangers. Combined these helicopter types make up **50% of the total register:**



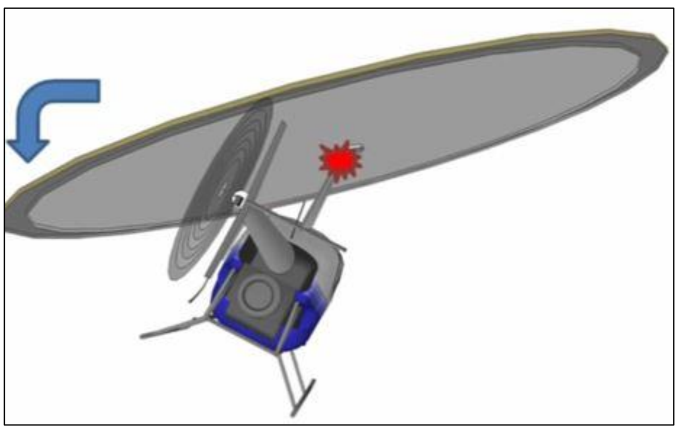
Combined with New Zealand's unique topography and weather, the high proportion of twin-blade machines means pilots here are at increased risk of mast bump accidents. This bulletin is targeted at preventing us from having any more of these accidents, which in the vast majority of cases are catastrophic. It also looks at other risks posed by turbulent conditions, particularly when operating over and within mountainous terrain.

Mast bumping explained

Twin-blade semi-rigid rotor systems are designed to allow the blades to flap. **Mast bump** is the name given to the accident situation where this flapping exceeds the structural limitations of the rotor hub's connection to the mast: the rotor head tilts so far that it contacts the mast, usually causing separation of either one blade or the entire rotor. The flapping can be such that the rotor severs the tailboom or strikes the cabin. **The vast majority of these accidents are fatal as the helicopter becomes completely uncontrollable. The causes are outlined below.**

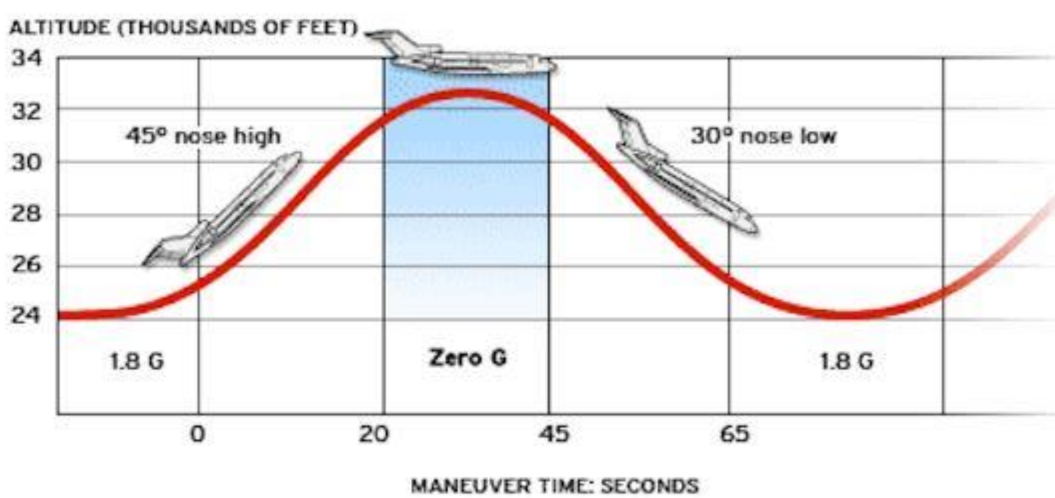
Low-G situations and mast bumping

Pilot-induced low-gravity situations are the most commonly-mentioned causes of mast bump in the operating handbooks and textbooks. In a low-G situation the weight of the fuselage is momentarily unloaded from the rotor disk. The thrust from the tail rotor then causes the fuselage to roll to the right very, very quickly: in a safety video from the early 90's Frank Robinson explains that **this roll rate can be "as fast as 100° a second".** It is the instinctive reaction of pilots finding themselves in this situation to apply left cyclic – and generally this is done abruptly considering the rapidness of the roll and the panic induced by the sudden weightless condition that has preceded it. Application of left cyclic tilts the disk but has no effect on the fuselage: the static stop limits are exceeded, the rotor head contacts the mast and either the mast separates or the blades contact the fuselage, either the tailboom or the cabin. The image to the left illustrates the process.



How control inputs can induce low-G states

Abrupt cyclic pushovers are the most frequently-mentioned cause. These can be induced in several ways. For instance they may occur when a pilot becomes focused on **following terrain**: as terrain begins to slope downhill the pilot may initiate a cyclic pushover while they concentrate on maintaining a steady height above the ground. Cyclic pushovers can also occur when pilots **attempt to level out after climbing**. This is illustrated in the picture below. Although the example is for large jet aircraft flying many thousands of feet high, the principle is exactly the same. Note that the first of these (following descending terrain) can occur in level flight. Both of these cyclic pushover causes were addressed specifically in the Robinson Safety notice SN-11, originally issued in 1982. A related safety notice is SN-29 concerning fixed wing pilots transitioning to rotary. The learned, highly ingrained reaction of fixed wing pilots to push the stick forward when attempting to descend or to avoid a collision (say with a bird) can be fatal. Please be aware of the special risk that this presents.



An example of just such a low-G accident in New

Zealand occurred in Taupo in early 2004:

The R22 was found crashed inverted, with a debris trail of cabin contents and shattered perspex leading to the accident site. Both the pilot and passenger were fatally injured. The weather on the day was perfectly clear, calm and still. The accident site was near several high voltage power lines. It was determined that at some point in the flight, possibly after climbing rapidly to avoid the power lines, the pilot had initiated an abrupt pushover leading to a low-G situation. The low G and roll to the right were so violent that the pilot's windshield, which survived the accident intact, bore marks from where his boots left the pedals and were forced against it (shown below):

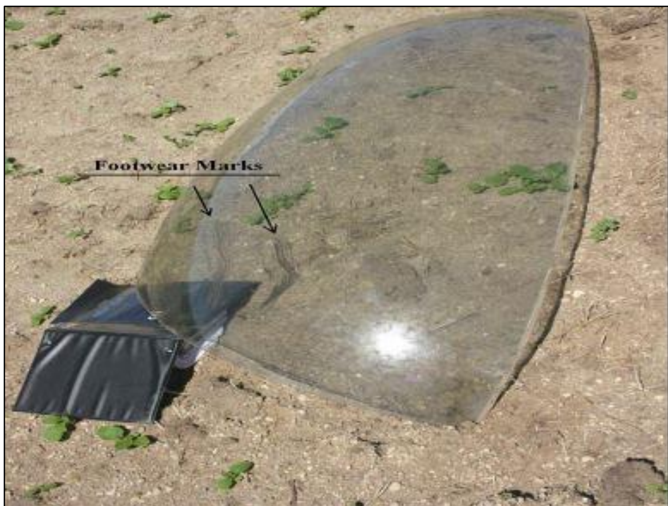


Figure 3: Pilot's windscreen with footwear marks. Note abrupt change in direction.

As the fuselage continued into the right roll the main rotor blades sliced through the cabin 3 times; first severing the roof of the canopy, then the control panel, and then the cabin floor through the center. The accident wreckage revealed that the cyclic pushover must have been so abrupt that once the low-G situation was reached it would have been impossible to recover from.

This accident vividly and horrifically demonstrates how critical this safety warning (in several Robinson safety notices and in operating handbooks) is:

"Never abruptly push the stick forward".

Turbulence can induce a low-G state

Windshear and other meteorological conditions play a huge role in NZ aviation accidents, due in large part to the fact that the weather conditions here are uniquely challenging. **In New Zealand this is especially true of turbulence.** The Robinson Safety Notice SN-32 warns pilots of the increased risk of mast bumping and excessive blade flapping when operating in turbulent conditions.

In a severe downdraft the loading on the main rotor disk can become low or negative, exactly like the pushover-induced low-g situation mentioned above. Once again the main rotor becomes unstable; the tail rotor begins to roll the fuselage over and the risk of mast bump and/or the rotor cutting through the fuselage increases rapidly. If the turbulence is severe enough then recovery can become next to impossible, as in the accident below:

R22 near Mt. Aspiring. Both the instructor and the student were killed when the helicopter broke up in flight. The investigation revealed that the rotor hub teeter stops were crushed, indicating that mast bump had occurred, however before the blades separated from the mast they flapped to the extent that they severed the tail boom and the helicopter fell to the ground. At the time the helicopter was flying above 5000 ft in mountain country, crossing the Waipara Saddle. The turbulence was described as 'severe to extreme' by subsequent rescue pilots operating near the area. The wind speed in the area was around 30 kts. The severe turbulence was cited as the main cause of the accident.

Certain factors can increase the risk that an encounter with turbulence will be catastrophic for you and your machine. One of these factors is your airspeed. The effects of turbulence on blade flapping are increased as airspeed increases and if you are going too fast for the conditions you simply will not have the time to react and save the situation. Another factor is the control inputs used in response to turbulence encounters. Turbulence can encourage sudden, abrupt control inputs including overpitching that can lead to excessive blade flapping and mast bumping.

Consider these words from Robinson Safety Notice SN-32: ***"Do not overcontrol. Allow aircraft to go with the turbulence, then restore level flight with smooth, gentle control inputs."***

Both turbulence and airspeed were considered likely factors in the accident below:

> **R22 over Lake Wanaka: the helicopter crashed over Lake Wanaka and was recovered by a Navy Dive Squad from a depth of 80m. The wreckage and injuries to the pilot showed that a catastrophic mast bump event had occurred. Almost immediately following the mast bump one of the main rotor blades cut through the cabin, killing the pilot and sending the helicopter nose-down into the lake. While the exact causes of the mast bump could not be determined the TAIC investigation determined it was likely brought about by an encounter with turbulence while the helicopter was travelling with a high forward airspeed. A further contributing factor was the pilot's use of his cellphone during the onset of the accident sequence.**

Below is an image of the damaged rotor hub and mast from the R22 in the accident:

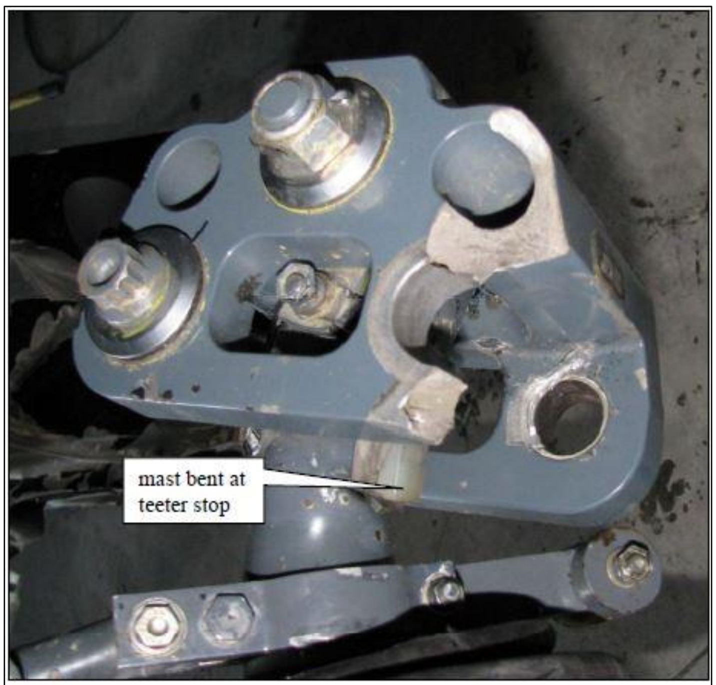


Figure 7
Rotor hub and evidence of mast bump

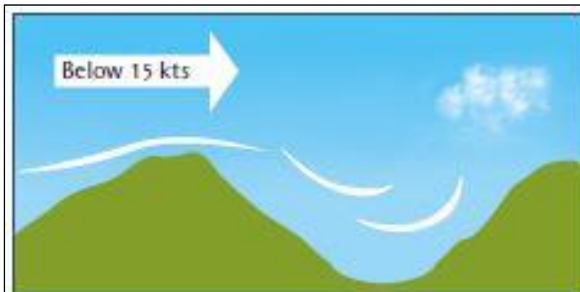
Resilience against the risk

As so many other safety notices and bulletins state, the most important strategy to reducing the risk of being involved in a mast bump accident is avoiding the conditions where it might occur in the first place. As the Rotorcraft Flying Handbook says: ***"this means avoiding turbulence as much as possible."*** But of course that's easier said than done in New Zealand, where over half of the terrain is mountainous and we lie as we do in the Roaring 40's. **It is important therefore that those who operate twin-bladed machines are fully up-to-speed on where and when turbulence will occur and what to do to:**

a) Avoid it; or

b) Manage it correctly

As the diagram below shows, whenever the wind speed gets up over around 15 kts and there are obstacles in front of that wind, turbulence is likely to occur:



Below 15 knots the wind flow is generally predictable.

Above 15 knots the patterns alter and become more difficult to predict.

Understanding how air flows in the mountains can be really hard but there is an easy way to learn about it. Get students to go to the river and watch how the water goes around the rocks (hills/mountains). Place different rocks in the river in various places (where the current is slow and fast, creating valleys and seeing the venturi affect) and use milk or cream dripped into the water upstream. This shows the turbulent areas and where the wind changes speed and even goes backwards. As air is just a fluid the water behaves the same as wind in the mountains. Before you scoff at how simple this sounds, bear in mind that this type of accident has claimed two experienced pilots in the last two years. Understanding air movements and how turbulence occurs is key to ensuring the list of accidents in this category stops where it is now. There are some great resources online that are worth a look. Although it's focused on fixed-wing, Mountain Flying offers a lot of good information on weather in the mountains and is an extremely good resource for operators of all machines and all levels of experience: http://www.mountainflying.com/Menu/mtn_fly_menu/mtn_fly_menu.html

The CAA's GAP booklet on Mountain Flying is another good resource:

http://www.caa.govt.nz/safety_info/GAPs/Mountain_Flying.pdf

Flight techniques: keeping the disc loaded and recovering from a low-G roll

The secret to avoiding mast bumping situations is to keep the disc loaded. Think of the helicopter fuselage as a pendulum suspended by the rotor disc. When the pendulum effect is removed by low G then the tail rotor will roll the fuselage – if it is providing sufficient thrust. The lower the collective, the less will be the T/R thrust so any uncommanded roll will be slower and give you more time to react. The reality is that the less cyclic inputs you make in turbulence, the safer the flight condition. So think about this:

- Lower the collective and reduce speed BEFORE turbulence is encountered. To be able to do this you need to understand wind over terrain.
- Where possible stay on the windward side of any ridge and if you must cross over try and follow a ridge that heads in the general downwind direction – then stay on the windward side of that.
- Keep the disc loaded by gently applying aft cyclic
- Use minimal cyclic inputs
- Restore the helicopter to normal flight once you are through the turbulence
- **Accept that there are conditions in NZ which will generate turbulence beyond the helicopter's ability to withstand. So wait for better conditions to prevail.**

When planning a flight that may involve significant turbulence consider the weight of the helicopter. A lightly loaded machine is more likely to suffer mast bumping than when it is heavily loaded. The forgoing is really all about prevention rather than cure.

A word on recovery

Pilots have been taught that the correct response to a low G roll is to apply aft cyclic to load the disc. And this will work but the challenge for any pilot is not to apply cyclic in the opposite direction of the roll – **because that is instinctive.**

So the ability of pilots to cure a low G situation is heavily compromised by their instinctive reaction to a roll and that is why NZHA promotes prevention rather than cure. Please see the Appendix on the next few pages (pp. 6-9) for a paper on mast bump accidents and Robinson helicopters compiled by the CAA's Andy Mackay.

Appendix:
Flight into Turbulence

(Andy McKay March 2015)

Robinson Safety Notice SN-32

Issued: March 1998
Revised: May 2013

HIGH WINDS OR TURBULENCE

A pilot's improper application of control inputs in response to high
Winds or turbulence can increase the likelihood of a mast bumping
Accident. The following procedures are recommended:

1.
If turbulence is expected, reduce power and use a slower than normal cruise speed. Mast bumping is less likely at lower airspeeds.

2.
If significant turbulence is encountered, reduce airspeed to 60 - 70 knots.

3.
Tighten seat belt and firmly rest right forearm on right leg to prevent unintentional control inputs.

4.
Do not overcontrol. Allow aircraft to go with the turbulence, then restore level flight with smooth, gentle control inputs.
Momentary airspeed, heading, altitude, and RPM excursions are to be expected.

5.
Avoid flying on the downwind side of hills, ridges, or tall buildings where the turbulence will likely be most severe.
The helicopter is more susceptible to turbulence at light weight. Use caution when flying solo or lightly loaded.

Correct Recovery from a low "G" Roll

First -Gentle aft cyclic (to recover from low G condition)

Second -Apply lateral cyclic (to recover from right roll)

Third –Land immediately

So why does Robinson ask us to slow down in Turbulence?

- Simply put, to avoid a low G induced right roll that could lead to "Mast Bumping."
- To a lesser degree, to reduce aerodynamic shock loading that can lead to damage

The actual mechanics of the "Mast Bump" itself is explained in another briefing.

The effects of shock loading damage can be unique to the type of Helicopter and Rotorhead. E.g. Hughes 500 heads have a tendancy to break strap packs in bad turbulence.

In this briefing I want to get the relationship sorted between Speed, Low G and a Low G Roll on a two bladed helicopter, specifically the Robinson.

Low G is any G loading below 1g (1g is what we feel normally). Below 1g we start to feel a bit weightless and above 1 g we feel more weight pressure. Learn to feel this for yourself. We refer to this sometimes as an increase or decrease in loading.

It does not need to be negative to cause an issue in a 2-bladed helicopter.

Robinson have typically flight tested down to about 0.5g. A Pull-up and push-over in an R66 from 124 knots created a 0.478 g loading and a right roll that was on the limit of what the test pilot was comfortable recovering from in a timely manner. In the days when Low G was a demonstration the power setting for the demonstration in an R22 was typically 18-20 inches in a gentle pushover. The right roll was reasonably gentle and anticipated for recovery. However if the roll is commenced from high cruise power then the resulting roll is significantly faster and remember that's a recovery *with* anticipation. Generally in the real-deal the low G rolls are unexpected. Please remember Low G demonstration is now strictly prohibitted in flight.

By the time it goes negative (below 0) the roll rate is likley to be extremely high (and possibly unrecoverable) depending on the power in use.

The killer with Low G is the pilot's incorrect input of cyclic control when it is encountered. The recovery should become second nature.

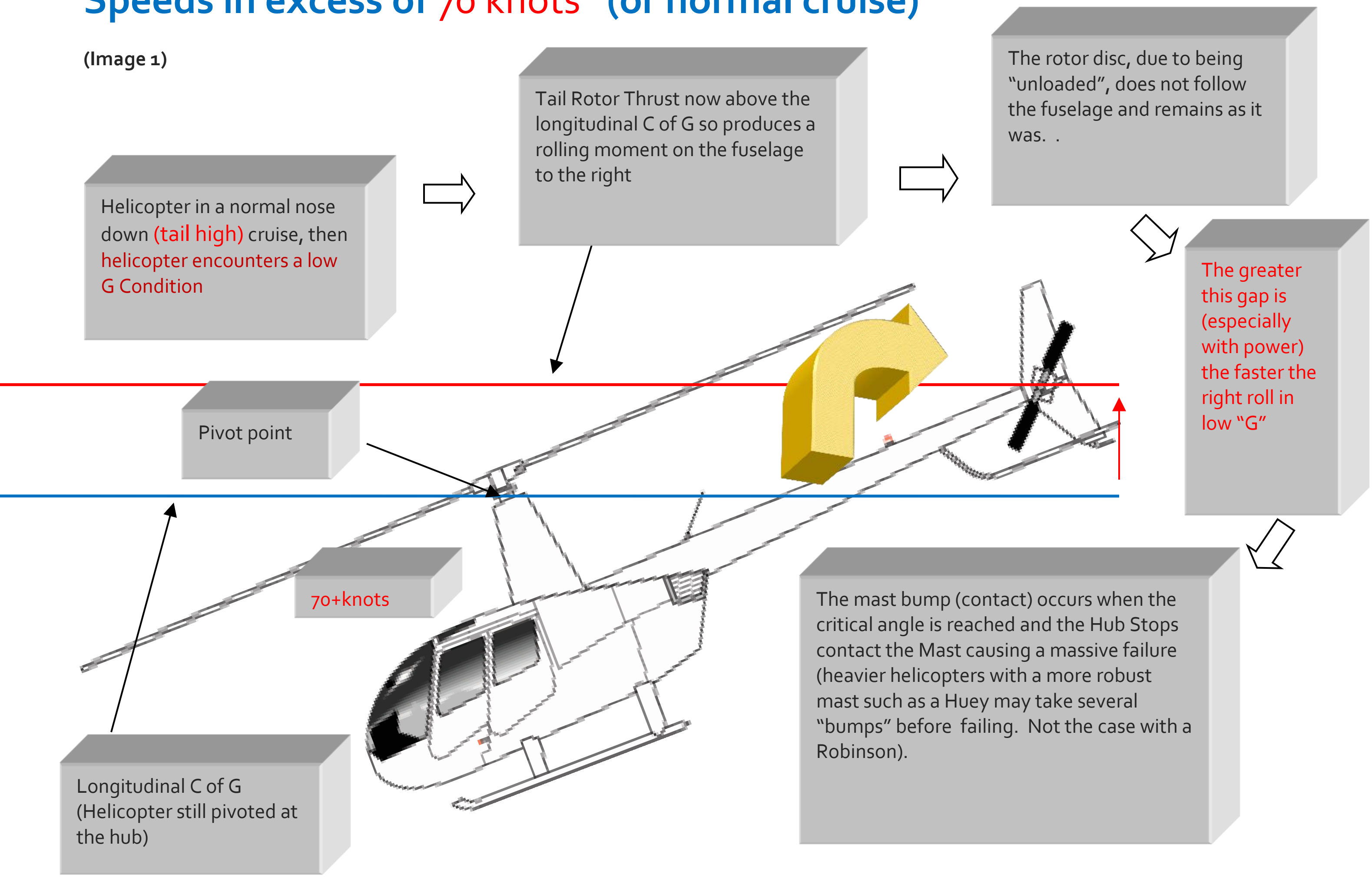
Often in bad turbulence you will feel a combination of an increase and decrease in loading as the helicopter reacts to the disturbed air. Often its not worth chasing as it will correct by itself. However be prepared should you be exposed to a prolonged decrease in loading as Low G issues may develop.

The best defence is avoid a Low G condition. Speed control is one means of achieving this.

Let me explain with some diagrams:

Speeds in excess of 70 knots (or normal cruise)

(Image 1)



- Helicopter speed **70+ Knots**
- Nose down, tail high attitude.
- The higher the speed the higher the tail
- The higher the tail is above the longitudinal C of G then the higher the right roll rate.

Practical examples of where this may be a problem.

Crossing a ridge or saddle at 70+ knots and then allowing the nose to drop excessively on the downside or leeward side is not a good time to encounter turbulence and Low G.

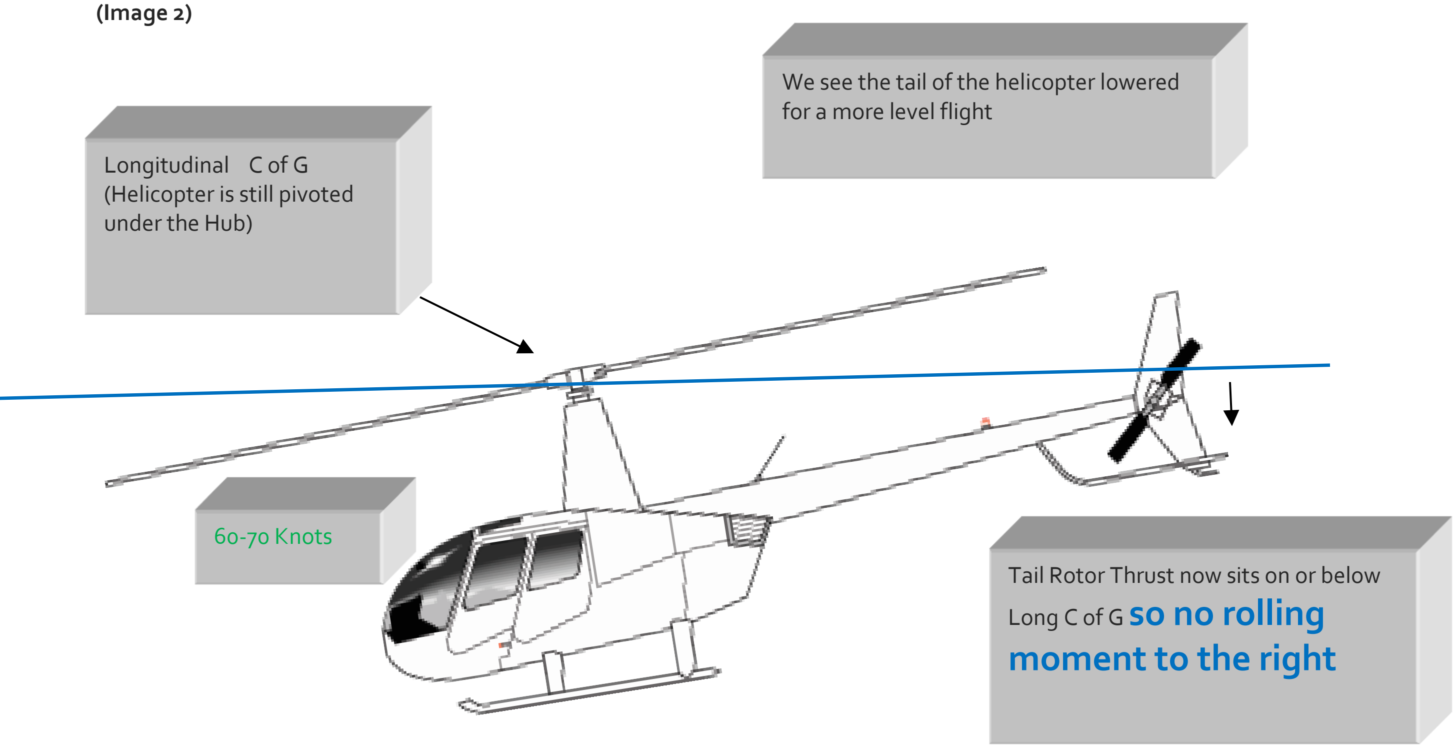
Any 'map of the earth' flying, especially in the mountains. Remember in a two bladed helicopter always lead with collective and watch where the nose + tail attitude is.

The lighter the helicopter, the more susceptible it is to Low G.

The faster the helicopter (i.e. an R66 at 130 knots), the longer it takes to reduce speed to 60-70 knots. Also this higher speed may indicate a high power setting and an extremely high roll rate if Low G is encountered.

Now we reduce Speed to 60-70 Knots

(Image 2)



- Helicopter Speed is now **60-70 knots**.
- Helicopter loses the tail high attitude.
- No rolling moment as T/R thrust is below pivot point on Hub (longitudinal C of G)
- So if in turbulence and Low G occurs in this attitude there is no right rolling moment to allow the mast bump.

**Caution note **However even with low airspeed if the tail is well above the Long C of G and Low G is hit then the helicopter will still roll. As long as the tail rotor is producing thrust (It may be on a low power setting) the roll rate will just be lower.

Example

Watch out for climbing up to a high saddle from a valley in turbulence and then aborting the crossing and turning downwind and downhill and in the process allowing the nose to excessively drop (loss of horizon)and putting the tail high even at low speed. Not a good time to hit Low G (keep aware).

Helicopter may experience a Low G and get bounced around. This in itself is not an issue unless it rolls. Keep control movements to a minimum. Ride with it as much as possible.

With experience you should learn to anticipate where turbulence is hiding and if possible avoid it but at least prepare for it by **SLOWING DOWN**.