



Safety Investigation Report - Final **(Final Report)**

Accident File No. 53-17

VIBRATIONS DURING HOVER, DESCENT AND BREAKAGE ON GROUND

Date	28.8.2017
Aircraft	Schweizer 269
Registration	4X-BIM
Location	Herzliya Airport

For Safety Purposes Only

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Accordingly, it is not appropriate that IAI reports should be used to assign fault or blame or determine liability, since neither the investigation nor the reporting process has been undertaken for that purpose.

This report has been translated to the English language for other parties' convenience, and should adhere to the Original report in the Hebrew language - In any case of abstruseness or miss-understanding, the original report in the Hebrew language is taking over.

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Summary of event

On Monday, 28 August 2017, at 10:15 a.m., a Schweizer 269 two-seat helicopter, on a private flight, carrying a pilot and a passenger, has returned for landing at Herzliya airport, about 2 hours after departing it. The flight consisted of 2 flights: The first flight, lasted almost 2 hours (herein: "**The first flight**"), and second (following) flight carried out right after, immediately afterwards, lasted about 1-2 minutes, for testing while hover, as was decided by the pilot (herein: "**The accident hover**"). It was aimed at confirming the possibility of existing vibrations that he encountered at the cyclic and skid, upon the first landing. According to eye witnesses, during the hover the helicopter began to vibrate and the pilot immediately landed it, while the helicopter's shaking was increasing, and eventually, led to the destruction of the helicopter.

The pilot and passenger were slightly injured, evacuated the helicopter on their own, and vacated themselves independently for medical checkups at Kfar Sava "Meir" hospital. They were released after couple of hours. The helicopter suffered substantial damage and was considered as total loss.

The helicopter pilot reported to the Chief Investigator immediately after the event, and the Chief Investigator launched the investigation and dispatched investigators to the event site.

The investigation was led and the report was written by the lead investigator Mr. Gil Arnon.



The accident helicopter

1. Factual information

1.1 Flight history

1.1.1 Background

The Schweizer 269 helicopter was purchased abroad by two partners, and brought to Israel as a private helicopter for their private flying. Since this model of helicopter had been imported for the first time to Israel, the owners teamed with two senior and experienced flight instructors, who coordinated the acceptance and assimilation of the helicopter including its certification by the Civil Aviation Authority of Israel. Pilots' endorsements to this helicopter type, was carried out in the Czech Republic, attended by the two instructors and another private pilot holding helicopter rating, and accompanied by an owner of a same type of helicopter (who did not participate in the conversion training). The conversion was conducted at an approved CAAI- training institute at the , Czech Republic, who operated and instructed according to CAAI requirements and specification , defined beforehand, and included the training syllabus and the type rating checkout. Upon returning to Israel and following the helicopter's arrival, and its return to service, the two instructors began flying it to gain and accumulate experience, prior the initiation of the owners training.

1.1.2 The first flight

On Monday, 28-8-2017, at 07:30, the pilot/instructor arrived at Herzliya airport for the planned flight with the helicopter's owner/passenger. The pilot carried out external inspections, which among other things have included, per his report, checking the skid dampers for verifying no oil leak and also checking visually the 3 main rotor blade dampers. This inspection is visual only. After completing the external inspection, the two entered the cockpit and departed towards the "Sharon training area", in order to gain experience on the aircraft. From the training area, they proceeded to "Ein Vered" strip for breakfast, after which they returned to Herzliya airport at 10:14 am. The pilot received landing clearance by Herzliya tower. According to the pilot, during the landing, when the skids touched the ground surface, he experienced a kind of amotion/vibration at the cyclic (herein: "**The vibration**"). Although it was negligible and hardly felt, he was still concerned. He shut down the engine, went out, checked the skid dampers, the main rotor blade dampers, and the tail rotor. During this time, the passenger remained inside the helicopter.

The pilot then decided to take off for a brief hover in order to check the cyclic sensation of vibrating, he felt earlier, to rule out the possibility of potential malfunctions which might eventually ground the helicopter.

1.1.3 **The accident hover**

After visually checking the helicopter and since the pilot found nothing unusual, the pilot started the engine, waited for about 2 minutes at full RPM, while manipulating the throttles to check the dampers, and then took off for a hover, at a height which he estimated as about 20-30 CM (1 foot) above ground. During the short hover, the helicopter was stable and worked normally, so the pilot began descending for landing. From the pilot's interview it turned out, that during the descent to touch down, he monitored and maintained engine and rotor RPM. During this descent phase, until and including the touch down, the collective was lowered to about half of its travel (range) down. Just prior to touchdown, the rotor and engine indicators were in the green arc, and even after touch down there was no hint of what was about to happen. The pilot reported no vibrations or bounces up to this stage. As a part of the final stage for landing, upon touch down, the pilot lowered the collective to full down, and then the helicopter started to vibrate at all planes – up, down and sideways. The helicopter bounced to the air, hit the ground and yawed to left, with the pilot unable to control it. The pilot immediately retarded the throttle and the mixture lever. However, the helicopter vibrations were exacerbated and he felt that he had absolutely no control during those seconds. He reported that 2-3 seconds after the initiation of the vibrations it became quiet, he raised his head and saw that the main rotor and the mast are not above him as they should be. The pilot shut off the master switch, fuel valve and alternator, and confirmed switches down. Upon leaving the helicopter, an eyewitnesses on site, has informed them that the ELT was operating/squealing.

At 10:34 the Herzliya tower received a report of the helicopter crash at its landing spot.

1.1.3.1 Descriptions by hearing & eye witnesses

In addition to the pilot and passenger, 8 hearing & eye witnesses who were at the accident area, were interviewed, such as:

- ☒ Pilot standing nearby described the accident hover, with an emphasis on the helicopter's vibrations and a crushing noise of gears.
- ☒ Mechanic standing several meters away described that after the pilot shut down the engine, he restarted it and climbed to a hover at about 1-2 meters above ground, then descended a little to 1 meter and then the helicopter began severe shaking, immediately followed by descending, ground impact and beginning to break up.
- ☒ Flight instructor standing at the airport's western ramp reported seeing the helicopter hover at an estimated height of 1 meter, when it suddenly began swinging forward and aft, the swinging increased, and then it descended to the ground while breaking up, with parts falling off and scattering around.

The interviews with the witnesses raised the following facts:

- ✓ They were at various locations relative to the helicopter break up with a direct line of sight to the event occurrence.
- ✓ The witnesses had diverse backgrounds, such as: pilots, instructors, mechanics, office workers.
- ✓ Some have witnessed both the return from the first flight and the event flight, while some/most have only witnessed the event itself.
- ✓ Most of the reports described helicopter vibrations in the air phase, during hover, and descent to touch down – some described horizontal vibrations between the skids and some – forward and aft.
- ✓ While the helicopter was in the air, some witnesses heard an unusual noise, which reminded them off a stone hitting metal or abnormal gear noise.

1.2 Injuries

Injury	Pilot	Passengers	Other
Death	-	-	-
Severe	-	-	-
Light to none	Small cut to neck	-	-
None	-	None	-

1.3 Damage to aircraft

1.3.1 The helicopter was destroyed.

1.3.2 The helicopter experienced vibrations and strokes which were uncontrollable by the pilot and which led to the disintegration on the ground.

1.4 Other damage

N/A.

1.5 Flight crew information

1.5.1 The pilot

1.5.1.1 Age 59.

1.5.1.2 Commercial license groups: A, B, ATPL, Helicopter.

1.5.1.3 Instructor license.

1.5.1.4 Total flight hours: 15,000.

1.5.1.5 Total helicopter flight hours: 12,000.

1.5.1.6 Total flight hours in type (Schweizer): 7 hours in Czech Republic + 11 hours in Israel.

1.5.1.7 Last competency check on type in Czech Republic, after the conversion, on 22-5-2017.

1.5.1.8 Last competency check on Robinson 22: done in April 2017.

1.5.1.9 Last competency check on Robinson 44: done in January 2017.

1.5.1.10 Last competency check on Twinstar: done in August 2017.

1.5.1.11 Medical certificate: valid, until 4-9-2017.

1.5.2 The passenger

1.5.2.1 Age 59.

1.5.2.2 Holder of a ULM license.

1.5.2.3 Owner of the helicopter was planning to be trained by the pilot/instructor.

1.5.2.4 Flight trainee on Robinson 22 helicopter.

1.5.2.5 Total flight hours on R22: 40Hrs.

1.5.2.6 The accident flight was private, not a training flight.

1.6 The aircraft

- 1.6.1 Schweizer 269 helicopter.
- 1.6.2 Originally manufactured by Hughes Helicopters in July 1989.
- 1.6.3 The manufacturer was purchased by Schweizer company (model 269/300).
- 1.6.4 Schweizer company was sold to Sikorsky company.
- 1.6.5 Few years ago Sikorsky was purchased by Lockheed Martin company.
- 1.6.6 End of January 2018 the aircraft model was purchased by Schweizer RSG company.
- 1.6.7 Engine manufacturer: Lycoming piston, model HIO-360-F1AD.
- 1.6.8 Equipped with Main rotor 3 blades fully articulated.
- 1.6.9 Registration certificate: date of issue - 10-6-2017.
- 1.6.10 Total airframe hours: 3,489 hours.
- 1.6.11 Total engine hours: 790 hours.
- 1.6.12 The helicopter was purchased by its owners in Sweden, was maintained and prepared for export on 16-11-2016. Work included all inspections and maintenance required for an airframe with 3,489 hours.
- 1.6.13 According to maintenance records, the skid dampers were overhauled on 15-9-2016.
- 1.6.14 According to maintenance records, the main rotor dampers were only inspected per 300+600 hours on 15-8-2016.
- 1.6.15 The helicopter was imported assembled, except for the rotor blades which were assembled in Israel.

Note: In Israel, most civil helicopters in private use, and some in commercial use, have 2-blade "teeter"-type rotors, unlike the fully articulated 3-blade helicopters as in the subject accident.

1.7 Weather

- 1.7.1 Visibility: over 10 KM.
- 1.7.2 Clouds: Cumulus, 1-2/8.
- 1.7.3 Wind: South-West to West, 5-10 knots, gusting up to 15 knots.
- 1.7.4 Temperature: 29 Degrees Centigrade.
- 1.7.5 Relative humidity: 60-65%.

1.8 Systems & navigation aids

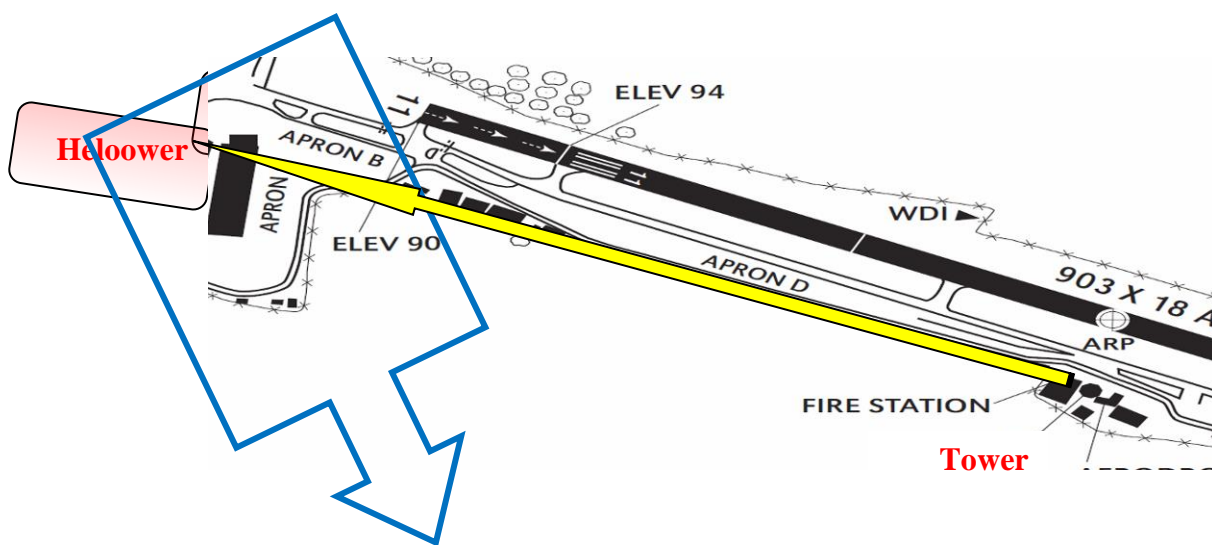
N/A.

1.9 Communications

The pilot reported the tower on his first landing preceding the event, and was cleared to land, yet the second start up and hover were not known to the tower, because the pilot did not request it. The tower was informed after the crash. It should be noted that the tower does not have line of sight with the accident site.

1.10 Herzliya airport

The illustration shows the line of sight of the tower to/from the helicopters parking ramp – is blocked.



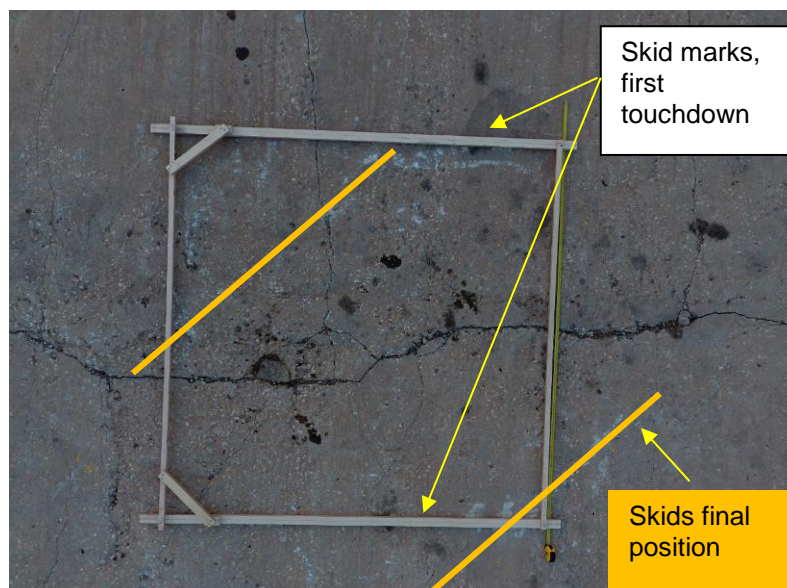
1.11 Recording equipment

CVR - N/A.

FDR - N/A.

1.12 Ground impact & debris

The helicopter has left skid marks on the landing surface, both of its first touchdown and of its final position after stopping.



- 1.12.1 Most damage to the helicopter is external to the cockpit.
- 1.12.2 The aircraft was found at the site with the main rotor separated from the airframe, located about 2 meters behind it.
- 1.12.3 The tail boom was found to the right of the helicopter, broken at its attachment to the fuselage.
- 1.12.4 The LH side of the tail stabilizer has an impact mark, which can be attributed at high probability to one of the main rotor blades.
- 1.12.5 The 3 main rotor blades were found connected to the disk, one of them bent at about 1 meter from the tip and the other had significant damage.
- 1.12.6 One rotor blade damper (herein: "The Red Damper") - The interior elastomer was found separated from the housing. Also, rubbing marks of the damper ring were found on the housing side.
- 1.12.7 The aft cross bar was found bent downwards.
- 1.12.8 Broken canopy.
- 1.12.9 Numerous helicopter debris scattered on the ground.
- 1.12.10 Skids span dimensions – Fwd: 180 CM, aft: 184 CM (small span is due to helicopter low weight without mast, blades and tail).
- 1.12.11 Types of the skids' marks on the ground: impression, dragging, bouncing.



Bouncing marks

Impression marks

Dragging marks



RH skid touching first

1.13 Medical & pathological information

The small cut on the neck is consequential, was caused by the aft Perspex located behind the seats, which fractured forward and hit the pilot.

1.14 Fire

N/A.

1.15 Survivability aspects

1.15.1 The ELT was found operating after the helicopter's break up. This device, when installed, is designed to be activated upon a ground impact of 2.5G. In the helicopter, this value changes to about 4G, due to its installation at an angle of 45 degrees.

1.15.2 The pilot was slightly wounded by a cut to the neck, due to impact of a fraction of the aft Perspex canopy. The passenger was not injured. The pilot's injury being so mild, can be attributed to the fact, that the cockpit did not break and was almost undamaged, while the helicopter suffered severe external damage.

1.16 Inspections & research

Relevant parts/debris of the helicopter were shipped by the investigating team for inspections in Israel, and overseas. The main components on which the investigators focused, included: the mast, main rotor head/hub and dampers.

Since the pilot described experiencing vibration, preceding the accident hover flight, the investigating team suspected an earlier suspected cause related to the main rotor system. This suspicion was strengthened by one damper found outside its housing, after crash, unlike the other dampers.

Metallurgic inspection of the fracture in the rotor shaft cover at a lab in Israel have yielded the following facts:

- ✓ The fracture was characterized as a mechanism of "time dependent fatigue" in Magnesium.
- ✓ The fracture's metallographic inspection revealed a microstructure that supports fatigue mechanism fracture due to inter-metallics network, backed by eutectic microstructure. This microstructure characterizes incomplete heat treatment of the Magnesium casting, the material from which the mast was manufactured. This in turn caused the component to be susceptible to cracking.

Note: The metallurgic lab report was forwarded to the helicopter's manufacturer for comments regarding the above findings and did not refer to it as a direct, originating root cause of the event.

1.16.1 Metallurgic inspections at NTSB's materials lab

The mast assembly was shipped to the NTSB labs for inspection and analysis. The assembly included: The external shaft of the broken main rotor mast, 2 of the pitch change links, complete rotor dampers and one damper housing, in a separate box at same shipment. The metallurgic inspection and analysis of the mast's various components have found that the various fractures are due to a momentary overload, such as in a case of heavy landing/ground impact.



The mast and dampers in the crate shipped to the lab

1.16.2 Dampers inspection at the manufacturer's lab and NTSB findings

Of the 3 dampers shipped for inspection, the red damper was found with the most significant witness marks, with linkage to its degraded performance, which could affect the phenomenon of blade lead/lag, which this aircraft has experienced in the past. The semicircular witness marks are a result of pressure contact of the damper's inside with the bottom of the cylinder, indicating an excessive blade movement in the horizontal plane (Lead-Lag). Both other dampers had such witness marks but they were slighter.



Figure 4- Interior of red damper housing showing semicircular witness marks.

Lab inspection summary

All 3 dampers were inspected and disassembled. The red damper exhibited evidence of corrosion, elastomer axial movement against the tube-form ring over an undetermined period of time resulted in the rolling of elastomeric material, and the elastomeric tube-form completely separated from the housing under an axial load.

The yellow damper center shaft had displaced laterally, and the rod end separated in overload under a bending moment.

1.16.3 Ground resonance and blades lead/lag phenomenon

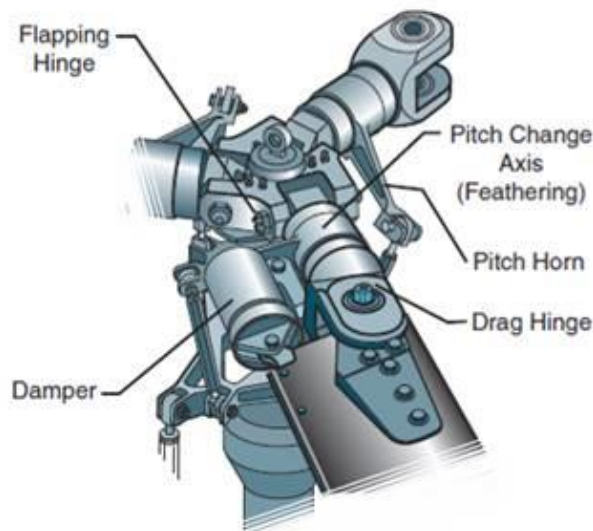
In articulated rotor system, each main rotor blade is connected to the rotor hub by means of a series of hinges, which enable each blade to move independent of the other blades. In general, such rotor systems have 3 or more blades.

Blade motion per axis:

Flapping hinge (horizontal), enables blade up/down motion. Its role is to compensate for the asymmetry of lift and enable the disk motion.

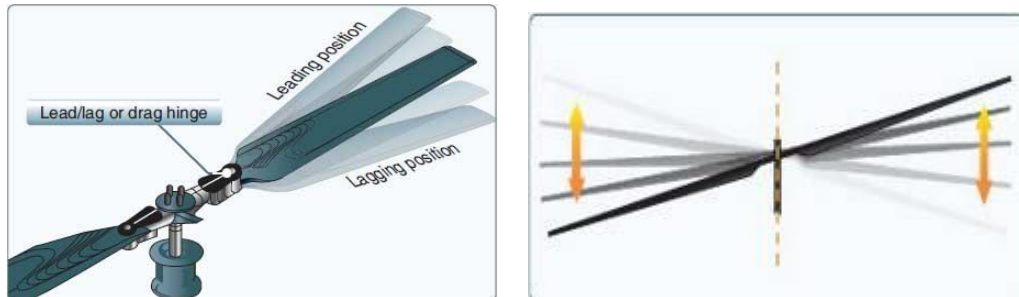
Lead-Lag (vertical) or drag hinge, enables blade forward/aft motion. Dampers which are part of the rotor assembly prevent excessive fwd/aft motion of the blade around the drag hinge. The role of this hinge and the dampers is to compensate for acceleration/deceleration caused by the Coriolis Effect.

The blade has **feathering ability**, i.e. **change pitch angle about its axis/hinge**. Feathering means change of blade angle, which enables controlling thrust and the direction of the rotor disk.



Each blade in articulated rotor can independently move up/down, fwd/aft and feather

Ground resonance effect is not common to all current helicopter types. For instance, all Robinson helicopter models, have 2-blades "Teeter" rotor where such phenomenon does not exist. On the other hand, helicopters with fully articulated rotors, which typically have 3 blades or more, are susceptible to such phenomena.



Fully articulated blade planes of motion

The phenomenon is characterized by vibrations with high self-destruction capability, and occurs when the helicopter is on the ground, with the engine running, and the rotor turning.

Ground resonance is a mechanical issue, stemming from the helicopter airframe vibrating at its natural frequency, which might be amplified by existing or evolving unbalance of the rotors. The unbalanced rotor system is exciting the airframe at its natural frequency, and might even double the intensity, which leads to an increase of harmonics due to increased engine power, resulting by increasing the vibrations, until airframe failure. When this phenomenon occurs, the helicopter will break up within seconds. A "heavy landing" on one skid side, can launch a shock wave towards the rotor head, that will cause a rotor with 3 or more blades to change the blades distance on the drag hinge. Normally the blades are 120 degrees from each other, but ground impact could cause varying angles between the blades, for instance 122, 122 & 116 degrees. When the other skid contacts the ground, the unbalance grows further. This "violent" condition might generate uncontrollable vibrations leading to a breakup of the helicopter, within few seconds. The severity of the breakup depends on the rotor blades energy. The intensity and acuteness can grow until exceeding the structural limitations of the mast, the gear housings, and the skids. Cockpit cyclic control becomes uncontrollable to the extent that the pilot will be hardly able to hold it, main rotor blade/s impact/s the helicopter tail boom and/or the cockpit, parts begin to fall off, until the helicopter's final breakup.

At low rotor RPM, the pilot corrective action is immediate retarding of the throttle and reduction of the cyclic control, concurrent with blades angle reduction. If rotor RPM is within normal operating range, the pilot should take off, to allow the rotor blade to synchronize. Any attempt to land before stabilizing the blades, will increase the vibrations and will lead to structural failure.



The accident helicopter with its complete cockpit



Two examples of helicopters of same type, which broke up due to ground resonance. Cockpit destruction is dominant and typical for this type of break up ("soft" parts fail first)



The accident helicopter, its boom folded on its RH side, the rotor behind, the cockpit intact

1.17 Organization & management

1.17.1 General

The flight has departed as a private flight and was conducted by an experienced commercial pilot, who also holds an instructor license. The helicopter has been certificated in Israel shortly before the event, it received the first Israeli type certificate on 3-8-2017, which is about 3 weeks before the accident. The pilot was checked out overseas according to CAAI's guidance, and was approved by CAAI. The aircraft owner was in the helicopter as a passenger.

1.17.2 CAAI's approval of the helicopter's training/conversion program

CAAI's final approval for conversion training of 4 pilots at the Czech DSA a.s. flight school, was obtained on 20-4-2017. The 4 applicant pilots included: the pilot/instructor at the event flight, and an additional instructor, who was also checked out for mechanical work on the helicopter. These 2 pilots were approved to conduct training and examination at commercial pilot level. Two private pilots, who owned an identical aircraft imported to Israel, requested to join the conversion course. They were trained and examined as a personal course at the private pilot level, separate from the 2 experienced pilots who were assigned to train the owner on the aircraft.

CAAI's approval for the instructors' proposed/required training course included:

- ☒ 12 ground training hours (per accepted list of topics).
- ☒ 5 flight training hours on the aircraft (per accepted list of maneuvers).

- ☒ Additionally - "A flight exam at the end of the course, to be conducted according to the Israeli requirements for obtaining rotorcraft type approval and according to CAAI's examination forms. The exam will be conducted with a local (Czech) instructor, who will be approved by CAAI's licensing branch to conduct the exam".

The investigating team checked CAAI's guidance and instructions for the conversion and reviewed the theoretical and practical lessons it required and were eventually executed by the Czech flight school. The team has found that neither CAAI nor the flight school have required or included phenomena with potential safety hazards, which are typically known in helicopters equipped with partially, or fully articulated rotors, such as: Ground Resonance and Lead/Lag. It should be noted, that CAAI does not employ dedicated helicopters inspector, who might have been able to consult regarding the training program. This issue was further amplified after the accident, during interviews with the accident pilot and with other pilots who went through the same conversion. The pilot, who has flown in the military and in civil aviation various helicopter types with partial or full articulation, such as the Twin Star, has never experienced the phenomenon and said that he hardly knew it.

1.18 Useful information about investigation techniques

The investigating team operated at several levels in order to cover all technical and operational issues, and was supported by dedicated professional entities in the following areas:

- ☒ The Chief Investigator has formally invited Sikorsky's investigators, via the NTSB, to come to Israel and support the investigation.
- ☒ Concurrently, the accident site at Herzliya airport was quarantined, to enable initial investigation with the Sikorsky team.
- ☒ The day after the accident, the site and the markings on the asphalt were photographed by a police drone. A model of the helicopter skids was used, to enable understanding of the ground marks.
- ☒ A senior pilot from the helicopter's maintenance facility and other pilots were consulted about professional issues.
- ☒ The NTSB and Sikorsky's investigators were integrated and fully and continuously consulted during the investigation and the technical examinations.

- ☒ Metallurgic examinations were carried out at Ruppin Academic Center's Institute of Failure Analysis.
- ☒ Examination of all failure scenarios of the helicopter known to Sikorsky, which might be manifested by in flight vibrations, and on ground.
- ☒ Examination of all relevant scenarios versus the findings in the field, and descriptions by eye witnesses, in order to reach the plausible scenario.

Sikorsky investigators' visit

Expert investigators from Sikorsky company were invited by the Chief Investigator office and the NTSB in September 2017 to support the investigation, with an emphasis on their vast experience as the helicopter manufacturer. They spent a week in Israel, visited the accident site at Herzliya airport, examined the aircraft debris and the ground marks, interviewed witnesses, talked with the accident pilot and eventually issued a preliminary internal report, which raised two potential scenarios, which will be evaluated herein:

- ✓ Main rotor unbalance.
- ✓ Helicopter self-resonance (PIO – Pilot Induced Oscillations) due to pilot actions while the aircraft is in "ground effect" and at high power setting.

During the visit the investigators ruled out the scenario of ground resonance as root cause and in general. The mast with rotor head and the 3 main blade dampers were flown to the manufacturer's facility for examination and analysis.

Among the tests they conducted at Herzliya airport, the engine was started and there was no indication for any possible malfunction which might have been a factor in the event.

2. Analysis

2.1 Introduction

The accident investigation focused on several aspects:

- ☒ Aircraft findings & analysis.
- ☒ Site findings & analysis.
- ☒ Technical aspects, including metallurgic and other examinations.
- ☒ Human factor from operational aspect - accident scenario.
- ☒ Pilot's decisions.

It should be emphasized that the findings at the site, along with the descriptions by the pilot and the eye witnesses, are leading to several fundamental assumptions to which the investigating team was exposed at the beginning of the investigation, such as:

- a. During the landing hover at the end of the first flight the pilot experienced slight vibrations at the cyclic.
- b. After the pilot shut down the engine and performed a general external inspection, he decided to and proceeded to conduct a low hover in order to check the helicopter behavior and his suspicion.
- c. The pilot took off for the accident hover with the passenger, and shortly afterwards the helicopter began vibrating in the air and he descended promptly.
- d. Helicopter break up began at the moment it touched the ground, while the helicopter was then seen bouncing, yawing, disintegrating and coming to rest.

On the basis of these assumptions, the investigating team has formulated the main issues for the analysis, such as:

- ☒ Analysis of the ground impact according to marks and findings on the aircraft and on site.
- ☒ Causes for the helicopter's vibrations at the end of the first flight and at the accident hover aspiring to expose the nature of those vibrations, in as much as can be characterized, considering the scarcity of objective evidence, and whether there is evidence for inflight breakup.

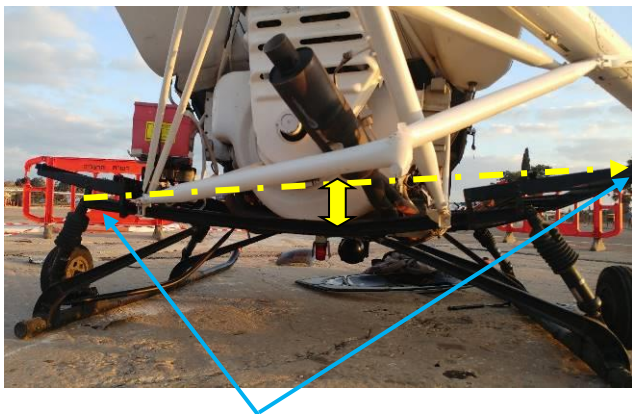
2.2 Aircraft findings analysis

The main visual findings at the aircraft, which are related to understanding the helicopter's initial breakup on the ground, are:

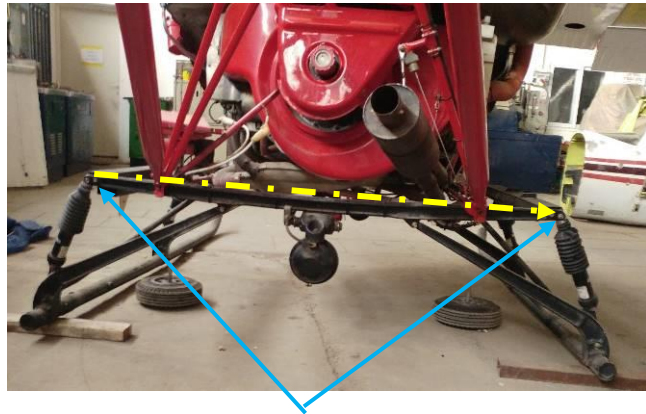
2.2.1 **Cross - bar bending** is an evidence of the aircraft vertical falling down towards the ground, at sufficiently high energy, to bend the cross - bar. This could indicate two possibilities:

- ☒ Heavy landing – with a high probability, on one side (on one skid or on part of a skid, in this case the RH skid), which spreads the skids outboard and causes the cross bar to bend.
- ☒ Regular landing – Followed by initiation of aircraft bouncing ("dancing") due to entering the "ground resonance" phenomenon.

The investigating team inquired the helicopter's manufacturer about the cross bar bending and was informed that based on the cross bar damage data, the observed damage is an outcome of a heavy landing. They further added that substantial energy is required to bend this bar, well beyond the energy values for ground resonance, and that ground resonance will not bend the cross bar.



Accident helicopter with twisted cross bar



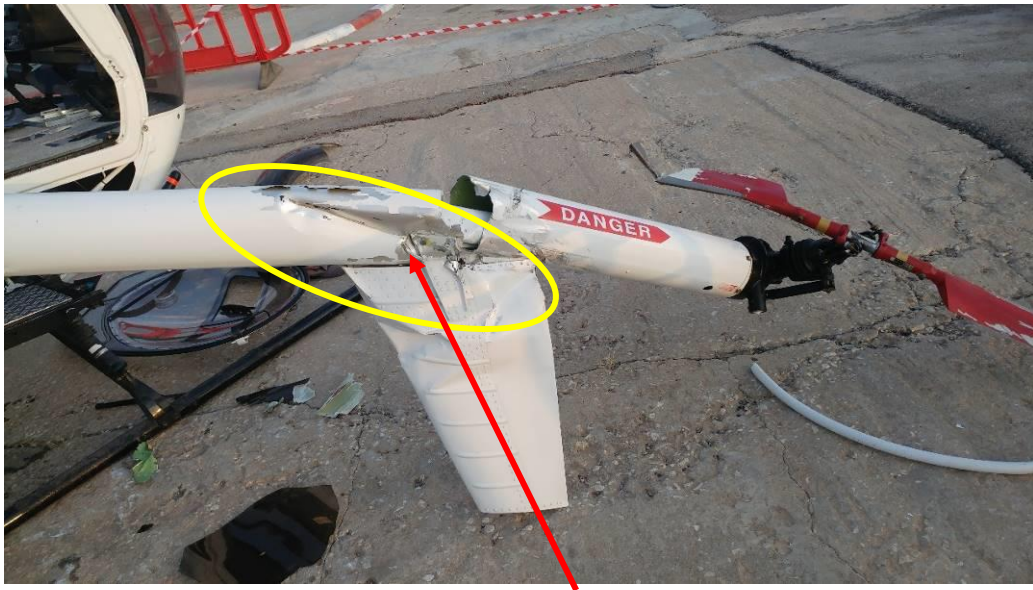
Normal helicopter with straight cross bar



Image of the accident helicopter, still under Swedish registration, the cross bar is straight

2.2.2 **Main rotor blade hitting the airframe**, which led to its separation, may have been caused by one of three possibilities:

- ☒ Heavy landing, causing a main blade to sag on the helicopter's LH side and impact the tail boom.
- ☒ Aircraft bouncing ("dancing") due to entering ground resonance phenomenon.
- ☒ Blade Lead/Lag phenomenon, leading to rotor head unbalance, which in turn might cause one of the rotor blades to strike the tail boom.



Mark of main rotor blade impact on the helicopter tail boom



Accident helicopter under Swedish registration. Dashed line indicates the blade sag which will hit the boom

2.2.3 Mast breaking and separation **can be caused by the following reasons:**

- ☒ Development of a fracture in the main rotor gear shaft, creating an unbalance situation, leading to eventual breaking and separation from the helicopter airframe. The mast was shipped to Sikorsky, the helicopter manufacturer's, for examination and analysis of the various components including the fracture surface. The findings indicated:
- ☒ A main rotor blade strike at airframe, either as a causal element or a consequential element (of another causal element), which generated a torqueing moment of the mast/ fracture it and leading to mast separation from the helicopter body.
- ☒ **Fracture of the mast housing.** Trying to understand the mast trajectory upon its separation, since it was found about 2 meters behind the helicopter. The rotor was rotating counterclockwise (left) and hence it was expected to separate forward, towards the cockpit. The fracture found at the mast's rear area might explain its separation to the rear. The fracture's metallographic inspection during the metallurgical examination at the lab in Israel has concluded, it has occurred under time-dependent mechanism of fatigue due to Inter-metallic network backed by eutectic microstructure. This microstructure is characterized by incomplete heat treatment of the Magnesium casting during the mast manufacturing, which made the casting susceptible to cracking, and in general, susceptible to stress and loads at various planes, long before the event. This could explain the location of the fracture after its structural overloading upon ground impact.

The investigating team's conclusion is, that the helicopter hit the ground hard in a rapid vertical motion, with the rotor blade striking the boom, breaking it, and causing a left yaw, accompanied by vibrations and helicopter breakage until it came to rest.

2.3 Ground marks analysis

The marks on the ground can be divided by the following features:

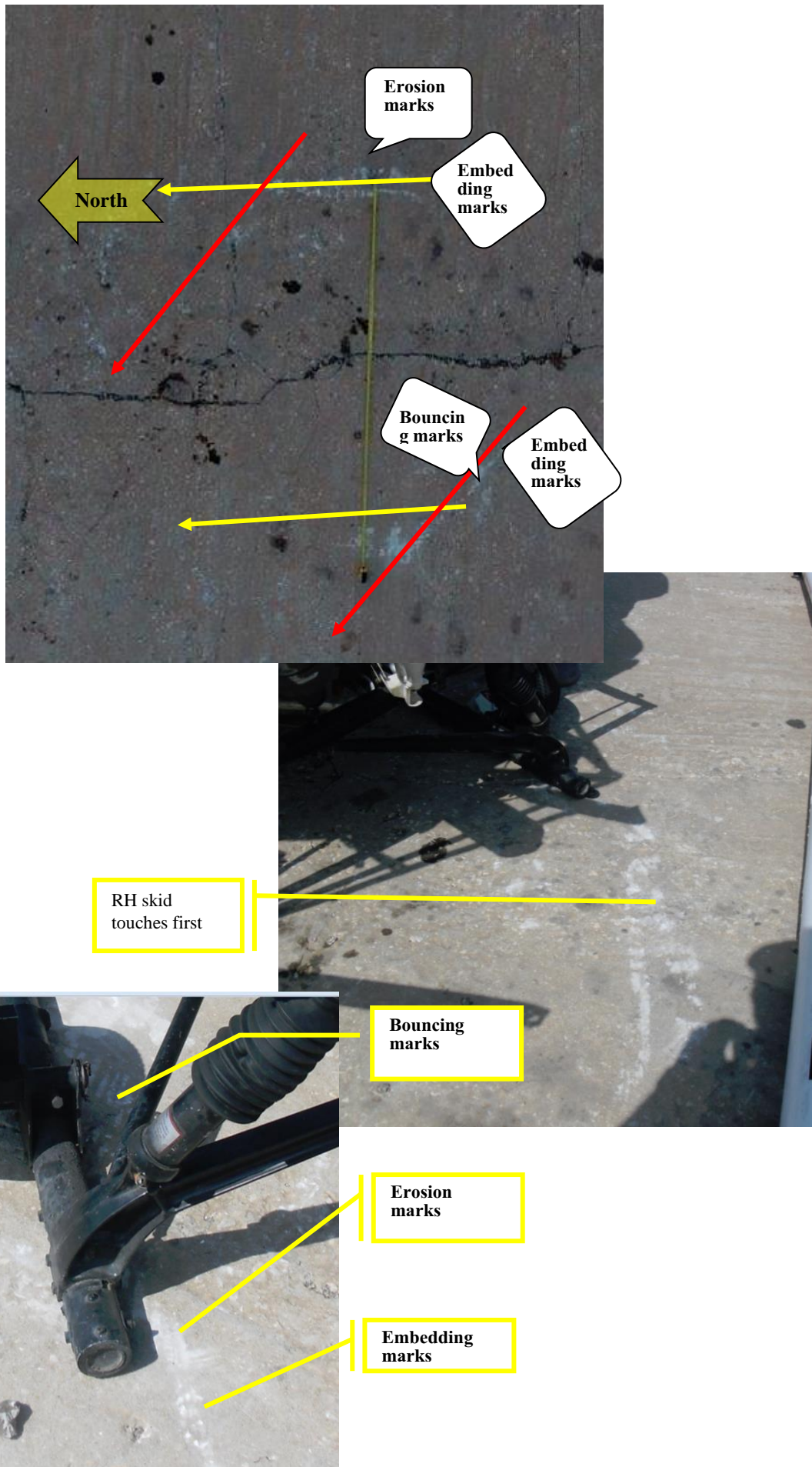
- ☒ Embedding ("stationary" points).
- ☒ Dragging (motion on the ground surface)
- ☒ Bouncing (motion in the air).

These marks are sub-divided according to directions:

- ☒ General direction North/South.

☒ General direction North-West/South-East.

Note: Angular difference is about 30 degrees to the left.



Analysis of these ground marks indicate, that the helicopter has impacted the ground with a rapid vertical component, touched down first with its RH skid, resulting in spreading of the skids. The helicopter was sliding slightly to the right, the rotor blade hit the boom, fractured it and caused a yaw accompanied by vibrations, with the helicopter breaking until coming to rest. The embedding marks are typical of a strong vertical sinking/falling, which is related to the skids' initial ground impact. The dragging marks (lateral) are typical to a secondary response, which followed the initial vertical motion and was driven by the momentum/acting forces such as rotor unbalance.

2.4 Technical aspects, including metallurgical and other examinations

2.4.1 Possible technical failure scenarios (from the manufacturer's publications).

The manufacturer's instructions for corrective actions upon main rotor vibrations are in the Troubleshooting chapter under the header "Main Rotor Vibrations", i.e. the vibrations are related to the phase of the blades' rotation plane and to the dampers condition.

Main Rotor Vibrations		
Symptom	Probable Cause	Corrective Action
Continuous vertical beat throughout helicopter, mainly in seat structure.	Rotor blades out of track. Damper torque incorrect.	Retrack rotor blades. Inspect and replace if necessary. Check damper torque.
Low frequency lateral beats. First encountered in high power settings, autorotation and turns. Noticeable in flight. May be felt on ground at warmup or shutdown.	Dampers out of adjustment. Faulty dampers. Binding in rotor blade attachment or pitch controls.	Adjust and synchronize the dampers. Check dampers. Check and correct.
Ground rock or shake felt when engaging rotor system or during low rotor RPM. As RPM is increased, there is a change in rate. Movement may increase or decrease and may be forward or aft.	Blades out of phase. Rotor blades out of balance.	Rephase and adjust dampers. Replace faulty blade(s).
Ground bounce: Continuous rocking motion from right rear to left front. (The harder the surface, the harder the bounce). May develop into a dangerous ground resonance condition.	Dampers out of phase. Damper torque incorrect.	Check and reset. Adjust dampers.

2.4.2 **Metallurgical examinations at Institute of failure analysis**

The Chief Investigator's office has involved metallurgy experts who examined a fragment brought from the site and is associated with the fractured main rotor mast.

The fragment was examined in several metallurgical techniques:

- ✓ Visual inspection (of the fracture).
- ✓ Microscopic examination, by both optical magnification through lenses and SEM (Scanning Electron Microscope).
- ✓ Fractography and EDS (Energy Dispersive Spectroscopy).
- ✓ Metallography.
- ✓ Chemical analysis of the fracture.
- ✓ Hardness test.
- ✓ Utilization of professional technical literature.

2.4.3 **Findings of the fracture's metallurgical examination at the lab in Israel revealed the following facts:**

- ✓ The fracture was characterized as a mechanism of "time dependent fatigue" in magnesium.
- ✓ The fracture's metallographic inspection has revealed a microstructure supporting fatigue mechanism, characterized as a network of intermetallic network backed by eutectic microstructure. Such microstructure is typical to incomplete heat treatment during the casting of magnesium, the material from which the mast was manufactured. This in turn caused the component to be susceptible to cracking.

Note: The metallurgic lab report was forwarded to the helicopter's manufacturer for comments regarding the above findings and did not refer to it as a direct, originating root cause of the event.

2.4.4 **Metallurgic inspections at NTSB's materials lab**

The mast assembly was shipped to NTSB labs for examination and analysis. The assembly included: The external shaft of the broken main rotor mast, 2 of the pitch change links, complete rotor dampers and one damper housing. The metallurgic inspection and analysis of the mast's various components have found that the various fractures are due to a momentary overload, such as in a case of heavy landing/ground impact.



The mast and dampers in the crate shipped to the lab

Examination and analysis of the parts revealed the following findings:

- ☒ The pitch change link in Figure 2 showed evidence of localized necking adjacent to the fracture surface. The fracture surface at this point also exhibited an approximately 45° orientation, with a dull luster and rough surface texture. NTSB lab conclusion: *These plane-stress fracture features are consistent with tensile overstress fracture of thin-walled structures.*



Figure 2 – One of the fractured pitch change links, as received

- ☒ Approximately 5 inches (about 127 MM) from the fracture surface, the link exhibited another fracture. This fracture (also shown in Figure 2a and 2b) exhibited buckling on both sides of the part. NTSB lab conclusion: *This fracture was consistent with compressive crushing at this location.*
- ☒ In the other fractured pitch change link, this fracture surface exhibited brown-colored corrosion product, consistent with iron oxide (rust). The link material adjacent to the fracture surface exhibited randomly-oriented out-of-plane deformation. The mating side of this link fracture surface, illustrated to the left in Figure 4, also exhibited inward buckling, along

with necking or thinning adjacent to the fracture surface. NTSB lab conclusion: *These features are consistent with overstress fracture on components subjected to multiple loads and loading directions, such as during ground impact.*



Figure 4 – The fracture surface of the main rotor mast, viewed from an oblique angle

- ☒ The fracture of the main rotor system outer shaft, along with an aforementioned link fracture (left) and a pitch support fracture (right). The support fracture on the right exhibited a general dull luster with a rough surface texture. NTSB lab conclusion: *These features were consistent with fracture from tensile overstress of the part.*
- ☒ The main outer shaft of the main rotor system had fractured about the entire circumference. The fracture surface showed a generally rough and tortuous texture. The fracture surface exhibited chevron marks and river patterns. These features are consistent with the fracture having initiated on the flat portion and having advanced around and upward, completing the fracture 180° on the opposite side. The orientations of the chevron marks and river patterns on the fracture surface were consistent with fracture emanating from the location in Figure 8 (as denoted by the dashed yellow arrows).

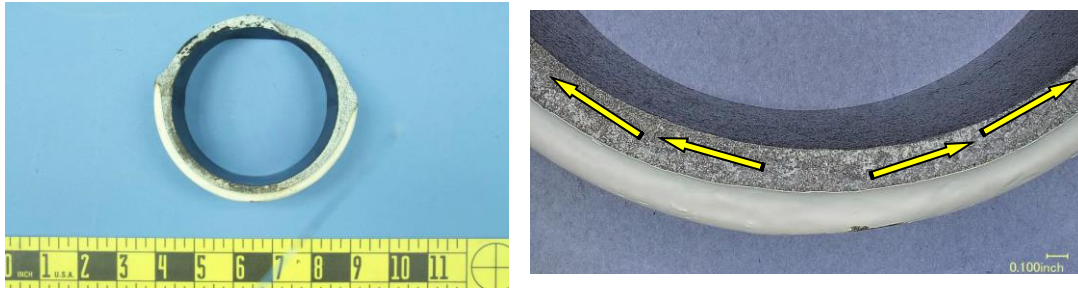


Figure 8 – Closer view of the bottom of the fracture surface shown in 7. The yellow arrows denote the general fracture direction.

The investigating team conclusion regarding the fractures examined, is that these fractures are consequential to the ground impact and are not defined as a direct cause of the accident.

2.4.5 Dampers examination at the dampers' manufacturer lab and NTSB findings

- ☒ **Red damper** – most significant damage of the three (dampers).
 - ✓ Full separation of both elastomer tube forms from outer housing.
 - ✓ Blade side tube form has material rolled towards the blade end along the circumference of the form.
 - ✓ Threaded stud intact. The stud end had powdery white deposits on the surface of the threads.
 - ✓ Clevis intact.
 - ✓ No visible bend to threaded stud.
 - ✓ Outer housing has no visible cracks. One witness mark on outer cover of housing aligned with the flange.
 - ✓ Outer housing interior has a semicircular witness mark on the end cap.
 - ✓ Based on visual examination, 10%-15% elastomer retention on the interior of the outer housing.
- ☒ **Microscope examination & disassembly**

The adhesive used to bond the elastomeric material to the aluminum tube-form ring was a silicone base primer (602), that was applied in a dipping process, that deposits a thin layer on to the elastomer circumference in a monomolecular layer. This layer is molecularly similar to the elastomer tube-form, and once cured, it is indistinguishable from the elastomer tube-form.

Red damper



**Figure 2 - Red damper tube form.
Corrosion at seam between disks**



Figure 3 - Red damper tube form housing interior.

- ❖ Optical microscope examination of the interior side of the red damper housing revealed areas of corrosion along the upper edge of the tube form ring.
- ❖ Interior sections of the upper tube form ring had areas of elastomeric adhesion to the surface of the ring, and areas of elastomeric smearing in the longitudinal direction.
- ❖ The elastomeric material on the upper tube-form had areas of torn out material on the outer circumference. Such tear is typical to and associated with abrupt tearing.
- ❖ Corrosion was observed in one quadrant of the aluminum tube-form inner core seam where the upper & lower disks meet. The corrosion is due to exposure to humidity, or associated with the damper housing duration of exposure after the accident.
- ❖ The elastomeric material on the lower tube-form had a ring of rolled elastomeric material along the lower circumference. This ring is most likely a result of the entire tube-form outer circumference rubbing back and forth longitudinally against the lower tube-form ring of the housing over a period of undermined amount of time.



**Interior of red damper housing
With semi-circular witness marks**

- ✓ The damper housing end cap had multiple semicircular witness marks that match the end of the aluminum tube form core.
- ✓ Note: Such witness marks, though slighter were also found on the two other dampers.

Summary of examination

All three dampers were examined and disassembled. The red damper exhibited evidence of corrosion, elastomer axial movement against the tube-form ring over an undetermined period of time resulted in the rolling of elastomeric material, and the elastomeric tube-form completely separated from the housing under an axial load. The yellow damper center shaft had displaced laterally, and the rod end separated in overload under a bending moment.

In view of the red damper's examination findings, the investigating team is at the opinion that it is highly probable that for an unknown of time before the accident, the blade attached to this damper performed axial horizontal motions and previously also behaved as a "lagging blade", due to degraded performance stemming from the separation of the elastomeric material. This can explain the vibration sensed by the pilot on the first flight.

2.4.6 Main rotor blade/s damper/s failure

As mentioned above, all three dampers were sent for examination both at NTSB lab and by NTSB at LORD, the dampers' manufacturer.

These examinations revealed that most findings such as separation/tearing of the elastomeric material in the three dampers, are associated with the stage of momentary overstress as in the case of blade striking the airframe or the ground, upon the rotor assembly break up and separation, while the partial corrosion detected inside the dampers housings is associated with either the post-accident stage, when the parts were exposed to the ambient air, or as a result of previous exposure to humidity for an undetermined duration.

The red damper had marks indicating that for certain, unknown period of time, it was moving axially against the damping rings. This can indicate blade motion in a "Lead/lag blade" phenomenon, with operative damping. A related finding is that one of the two parts of the damper's elastomeric material exhibited material fatigue. This finding can point to the inflight vibrations felt by the pilot. The red damper had its elastomeric material out of/separated from the damper. There was also evidence of corrosion at its inner parts, which can indicate that it was exposed to humidity before or after the event.

The damper's maintenance requirements mandate conducting an extension check per two criteria:

1. At 4,200 hours.
2. Prior to 4,200 hours, a visual inspection only. If a crack larger than 0.2 inch is found, the extension check should be performed (as if above 4,200 hours).

The helicopter components maintenance records showed that the dampers have accumulated only 1,973 hours, and therefore an extension check was not required, nor was there an evidence for performing it. Yet in accordance with NTSB lab finding, it was determined that the red damper performance was inferior, compared to the other dampers.



Red damper housing and separated elastomeric material



The fatigued elastomeric material

Note: A search with NTSB's assistance for similar cases of same type dampers has found a similar event with similar failure features of the damper.

(NTSB Accident Number WPR15LA249. Dated: 23.8.2015)

2.4.7 Failure of one or more metal component in main rotor system (Mast, swashplate, bearing, etc.)

Examination of the main mast fracture circumference at the lab in Israel (a mast fragment) and at overseas labs (main rotor system assembly) revealed indications for possible metal structure fatigue at an area on the fracture surface, which might point to time dependent fatigue mechanism (chevrons and river patterns) susceptible to cracking. However, since these marks were found at the fracture interior and did not reach the outside of the mast, the investigating team is at the opinion that the location of the failure is due to the helicopter's heavy landing and is not due to initiating of the event.

2.4.8 Ingestion of "turbulent contaminated" air by main rotor system during hover, while in "ground effect".

This is a known phenomenon and hence possible, either as causing the blade to lead/lag and the sensing of inflight vibration, regardless of the failure (beginning of the failure) in one or more main rotor dampers, or, as a standalone phenomenon.

2.5 Understanding "human factors" from operational aspect – accident scenario

2.5.1 Flight synopsis

The flight is divided to two related events, which apparently occurred in two different flights. One flight performed by the pilot and completed with a landing, and a second one (herein "**The Hovering flight**"), which ended with the helicopter's break up on the ground.

2.5.1.1 The flight performed and completed by the pilot (herein "**The preliminary flight**") was a routine flight and included: Takeoff, flying to "Sharon Bubble", executing local self exercises, landing at another location, and return to the departure airport (Herzliya). According to the pilot, at the landing phase, he felt kind of "slight and almost imperceptible vibrations at the skid and maybe also at the cyclic". He did not relate them to a possible malfunction or evolving of a malfunction. Therefore, after completing the landing and after a visual inspection of the helicopter, which included the skid dampers and the rotor dampers, he was determined to take off again for a hover, in order to "remove any doubt".

The human factor must be considered when analyzing the pilot's decision to take off again, despite the light, negligible (and unfamiliar) perception of vibrations. On one hand and in view of the severe outcome of the test flight (the break up), it could be associated with erroneous judgement and decision making in initiating this flight – considering his long experience flying helicopters (In the sense of best practices in aviation: "When there is a doubt – there is no doubt"). On the other hand, there is the "temptation" to take off and check, which may be attributed to the pilot's short experience and familiarity with the subject helicopter, which is different and has unique phenomena, which do not exist in other helicopters popular and operated in Israel, including its possible and typical malfunctions.

2.5.1.2 The test flight

The test flight can also be divided to two stages:

- ✓ **The aerial phase** – climbing to hover and rapid descent.
- ✓ **The ground phase** – ground impact and break up.

The aerial phase

Following a visual inspection of the helicopter which focused on the dampers, of both the skids and the main rotor, as well as on the tail, the pilot started the helicopter's engine, conducted "before take - off" checks, which included manipulating the throttles for checking the dampers, and climbed for a low hover at a height of up to 1 meter, in order to affirm, or rule out, the possibility of a malfunction, which "bothered" him while landing minutes earlier.

The investigating team grappled with the conflicts between the various interview reports of the pilot and of the eyewitnesses.

All the eyewitnesses reported seeing the helicopter vibrating abnormally in the air. They were divided to those who saw horizontal plane vibrations, and those who saw in the vertical plane, and maybe in both planes. Some even reported seeing the helicopter beginning to break up while in the air, although there was no evidence for it, such as debris/parts located further.

In contrast, the pilot reported (except for his initial report where his perceptions about a phase of the flight cannot be understood and associated), that throughout the aerial phase, while hovering up to, and including the touch down, there were no vibrations, and they existed only on the ground when taking the collective down ("to the floor").

One of the issues the investigators had to resolve was the question: has the event begun/occurred while the helicopter was airborne at the test flight and/or even at the first flight, or only when it was on the ground. The investigators' opinion is that it is possible that a discrepancy related to the main rotor system, which caused the rotor blades to go out of balance and hence caused the center of gravity to change, has evolved prior to the ground break up, namely in an aerial phase, whether in the test flight or in the preceding first flight. This is despite what the pilot's report is indicating, that vibrations were only felt with the collective down (at the floor). Findings by the

NTSB lab and the dampers' manufacturer lab indicated that the red damper's performance was inferior to the other 2 dampers, which led to the investigators' conclusion that it is highly probable that the inferior damping of a Lead/Lag blade, has initiated in flight vibrations, which led the pilot to promptly descend to the ground, and thus may have prevented a more severe accident, if the damper would have completely failed in flight.

There is a less **probable** aerodynamic scenario at the low altitude hovering stage, which could have caused the rotor to lose tracking, and go out of balance.

At a low hover within ground effect, as was the case of the test flight, the

helicopter blades are operating in "turbulently contaminated" air (vertical airflow from the blades hits the ground and is partly reflected upwards and hits the blades) created by the blades themselves, which might then develop unbalance or out of tracking condition. It is considered less probable since the investigators think that the slight, apparently "negligible" vibrations felt by the pilot, who reported in the interview that he could not attribute them to a malfunction, happened in the first flight, which preceded his accident hover. Hence the investigating team opines that the elastomeric material in the red damper, began to develop a failure of internal detachment from its adhesion, which caused inferior performance in damping causing an excessive movement of that blade while creating a lead/lag phenomenon. Evidence to it can be witnessed, by the rubbing and grooving marks at the damper housing, indicating a significant, substantial blade motion in the horizontal plane. This failure deteriorated at the test flight and actually drove the rotor out of balance.

The ground phase

Whether the vibrations began in the air or on the ground upon the skids touch down, the pilot actually felt them increasing, while lowering the collective "to the floor", and the helicopter began uncontrollably hopping in all directions. Since the pilot did not identify the problem, he elected to refrain from getting out of the situation by becoming airborne. In spite of the difficulty and the "frenzy" of the cyclic, the cockpit levers panel and switches, he succeeded in shutting down the engine and in turning off the required switches, and waited helplessly until the vibrations ceased and the helicopter reached its final position. At a certain stage he raised his head, saw and realized that the main rotor, including the mast have separated from the helicopter.

As mentioned above, according to the pilot the rotor RPM indicator was in the green band, i.e. 100%, and under these conditions, and based on his report that the landing was soft and a ground resonance phenomenon has developed, the correct action as being trained was to lift the helicopter off the ground and thus to prevent the airframe vibrations due to ground contact, until the blades would balance and then return to landing. This action is in contrast to low rotor RPM conditions (startup/ RPM increase/ RPM decrease/shut down), in which the technique being trained prescribes reducing rotor RPM, engine shut down and operating of the rotor brake (where installed).

The pilot's testimony that apparently everything has happened on the ground after landing is attributed by the investigating team to understanding that the

pilot's traumatic memory was the severe vibrations leading to the break up after landing on the ground, while bouncing uncontrollably with increasing vibrations. Researches regarding memory loss due to a trauma have proven that one of the ways in which the human brain and memory/loss of memory is coping with an event/sub-event, which is perceived by an individual (the pilot in this case) as difficult to cope with, is a (partial) loss of memory from that event, which is the most difficult to cope/contain. It is embedded in every helicopter pilot that in a case of abnormal and unexplained vibrations, whether in the air or on the ground – not to take off. The pilot's recognition that the mere decision to take off after his reported feeling, of a slight, unexplained vibration of the cyclic, is the one which eventually caused the outcome of the event, was grasped by the pilot as "hard to digest". Therefore, the investigators conclude at a high probability that in the pilot's perception the "central" event (the primary and most significant) has happened on the ground.

2.5.2 Helicopter breakup mechanism

In general, it is important to understand that the breakup of a helicopter on the ground, under a condition of main rotor system unbalance, while it encounters increasing vibrations in a ground resonance effect, is typically lasting few seconds until it disintegrates. When the equal distance between the main blades is changed in a non-uniform way for whatever reason, it causes the blade center of gravity to deviate from the axis of rotation. Once the deviation occurred, it will cause a periodic oscillation. When the helicopter fuselage begins shaking forward and aft due to the rotor's periodic oscillation, the oscillation is amplified and becomes an increasing, self-propelling force, which causes the rotor center of gravity to oscillate further beyond the rotation axis, until it exceeds the blade dampers capability to damp, absorb and reduce the vibrations intensity.

A commonly and typical feature of such a breakup is the helicopter's sequence of integration, namely: First to dismantled/break are small things in the cockpit, cabin and the various interior parts, such as plastic parts, panel instruments, canopy, etc. The reason they are the first to dismantle/break is the low capability of their various attachments to withstand severe vibrations. Subsequent breakup stage is occurring externally and affects rigid components, such as the mast, rotor, blades, fuel cells, skids, tail boom and other rigidly attached bars.

In the investigated case it can be stated that the cockpit/cabin remained intact (relatively intact – except for the canopy fracture), while the airframe incurred significant external fractures. This has led the investigating team to the conclusion, supported by Sikorski's investigators, that the nature of the failures is not consistent with the helicopter entering "ground resonance", but rather another factor, which has relatively quickly led to rotor unbalance (in a short time frame), such as: heavy landing, failure of one or more damper, ingestion of "turbulently contaminated" air during hover in ground effect, or as a result of failure/fracture in a component of the main rotor system (mast, bearings, swash plate, etc.). Therefore, the investigators think that at the accident hover, or even earlier during the first flight, the helicopter experienced some kind of blade lead/lag, which caused the vibrations that urged the pilot to initiate a quick descent to the ground, and to a heavy landing. As a consequence, in turn, it led to a blade striking the tail boom, as well as, main mast fracture and the eventual result. The mast failed at the weak point which was found and was described as "fatigue", a process which may have begun prior to the event.

2.5.3 **Helicopter conversion program**

The investigators checked the training program approved for the four pilots. All the topics and exercises required by the theoretical and practical syllabus were executed during the conversion.

Yet, neither the theoretical material nor the practical exercises included any reference on teaching about safety phenomena which are probable in and typical to this helicopter type, with three fully articulated blades, such as: ground resonance and blades lead/lag. These phenomena are unique to this "family" of helicopters with articulated rotor system and 3 or more blades, unlike the 2-blades helicopters common in Israel for private and even commercial use. When interviewed, the pilots who attended the conversion told the investigators that they were neither required nor trained for these phenomena at the Czech flight school, and essentially had no awareness or knowledge on this subject. At least some of these phenomena were experienced at some stage during this event.

3. Conclusions

- 3.1** The accident is classified as pilot error, combined with a technical failure (damper), began with an erroneous decision to take off for a low hover in order to affirm/rule out the existence of vibration felt by the pilot before landing, and culminated in the pilots' operational error of descending rapidly after the vibrations reappeared, causing the helicopter to impact the asphalt hard, following by bouncing, then yawed till broke up.
- 3.2** Towards the end of the first flight, while touching down, the helicopter began a vibration or vibrations, due to a technical fault and the pilot landed (first flight) and shut down the engine, without any damage at this stage.
- 3.3** The inflight vibrations seen by eyewitnesses were at a high probability caused by degraded performance of one of the main rotor blade dampers (the red damper). This condition can explain blade unbalance leading to blade lead/lag, which apparently occurred during the hover, and may have also been caused by flying within ground effect, with air flow returning from the ground to the blades could divert them out of track. A combination of both these factors might played a role in this event.
- 3.4** The red damper showed witness marks, indicating that for a certain undetermined time frame, the elastomeric damper apparently moved along its axis against the damping rings. This may indicate a blade movement as in a lead/lag phenomenon, for an unknown period of time, during the helicopter previous flights, with the damping being "active" (i.e. lead/lag). An additional, related evidence is fatigue of the elastomeric material, which was found in one of the damper's two elastomers. These findings can indicate a probability for the existence of vibrations felt by the pilot during the first landing.
- 3.5** The pilot's decision after landing from its first flight, in which he felt "kind of slight vibration", that he could not determine the reason, to take off again and check the feeling he has experienced, was erroneous, much more so, with a passenger. On the other hand, it is also an evidence that the pilot has attributed little importance to "that slight unknown vibration".
- 3.6** The ground marks revealed, that the helicopter made a "hard/heavy landing", which at a high probability caused several sub-failures, such as: rotor blades sagging, whipping of one blade at the tail boom, which separated the tail to the right of the

helicopter. The crossbar was bent due to relatively high energy drop to the ground under the weight of the helicopter.

- 3.7** All other examined fragments, pointed to fractures, due to "short duration over loading", typical for the moment the helicopter impacted the ground.
- 3.8** The pilot's decision to descend to the ground and not to ascend higher, may have prevented a severe catastrophic disaster. Had he climbed to a higher altitude and encountered uncontrollable rotor vibrations, and had the (inferior performance) damper failed in flight, a worse accident could have happened.
- 3.9** The helicopter conversion training material, both theoretical and practical, included no reference to safety phenomena typical for helicopters with three or more blades. According to the interviews with some of the conversion participants, it was also reported, that these topics were not included and they did not experience such phenomena in their aviation background.
- 3.10** The pilot was properly certified and performed all the obligations in the type conversion as required by CAA-I, and even more than required, since he wanted to accumulate more flying hours prior to beginning to train the helicopter's owner.
- 3.11** With this helicopter being the first of its type in Israel, it was certified according to CAAI requirement and received a type certificate.

4. Recommendations

4.1 Appoint a dedicated operations inspector for rotorcraft, which can provide professional response in general and regulatory guidance in particular, to public applications for pilot licenses on primary aircraft requiring type certification for the first time in Israel.

Responsibility: CAAI director

Recommended completion date: 1-12-2019

4.2 Direct owners of helicopters equipped with same type main rotor head dampers, to perform extension check at intervals shorter than the current intervals, and on the basis of experience gained in similar events with dampers of the same type.

Responsibility: CAAI director

Recommended completion date: 1-12-2019

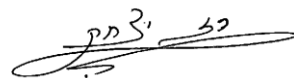
4.3 Review and revise the knowledge required for pilots interested in becoming qualified on helicopters, according to the specific features of the aircraft. In the investigated case, malfunctions/phenomenon typical to 3-blade articulated rotor head were neither required nor included in the training by the flight school approved to perform the pilots' conversion.

Responsibility: CAAI director

Recommended completion date: 1-12-2019

The occurrence had been investigated by the lead investigator Mr. Gil Arnon

Regards



Adv. Itzhak Raz (Razchik)
Chief Investigator

Date: 15 July 2019

Reference: 4000-0098-2018-0014603