NATIONAL TRANSPORTATION SAFETY BOARD
Office of Aviation Safety
Washington, D.C. 20594

February 14, 2018

HELICOPTER SPECIALIST'S FACTUAL REPORT

NTSB No: ERA17LA263

A. ACCIDENT

Operator: Sikorsky Aircraft Corp

Aircraft: S-97 Raider

Location: Jupiter, FL

Date: August 2, 2017

Time: 0720 eastern daylight time

B. GROUP

No group was formed

LIST OF ACRONYMS

06FA	William P. Gwinn Airport
EPC	electric propeller control
FCC	flight control computers
GE	General Electric
IIC	Investigator-in-charge
PG	propeller gearbox
RVDT	rotational variable differential transducers
SAR	search and rescue

C. SUMMARY

On August 2, 2017, about 0720, eastern daylight time, an experimental Sikorsky S-97A, N971SK, experienced a hard landing while hovering at the William P Gwinn Airport (06FA), Jupiter, Florida. Both airline transport pilots received minor injuries. The test flight was conducted under the provisions of 14 Code of Federal Regulations Part 91. Visual meteorological conditions prevailed and no flight plan was filed for the local flight. The aircraft sustained substantial damage.

The helicopter taxied to the runway hold short line for runway 9/27 at taxi way A (alpha), lifted into a low hover, and immediately experienced excessive roll oscillations which lead to intermeshing of the counter-rotating coaxial rotor system, and a hard landing. The flight crew shut down the helicopter, allowed the rotors to coast to a stop, and egressed the helicopter normally. Damage to the helicopter included collapsed landing gear, structural cabin damage, and dynamic component damage, including rotor blade tip separation of all 8 rotor blades.

On August 3 the National Transportation Safety Board (NTSB) helicopter specialist along with participants from Sikorsky performed an examination of the helicopter.

D. DETAILS OF THE INVESTIGATION

1.0 HELICOPTER INFORMATION

The helicopter is registered as a research and development category aircraft, under the experimental classification, as a Sikorsky S-97A, serial number 0001. The airworthiness certificate was issued on June 6, 2016. The helicopter is configured with two rigid rotors, each consisting of four blades, stacked coaxially one over the other, and rotate in opposite directions. The rotors are powered by one General Electric (GE) YT706-GE-700R, 2,514-hp turboshaft engine. The tail consists of a horizontal stabilizer with vertical stabilizers at the tips in a H-configuration, and a drive shaft that extends to gearbox that drives a 6 blade controllable pitch pusher propeller. Total airframe and engine time was 104.0 hours. The cockpit seating is a side-by-side configuration with the pilot in command seated in the right seat. The cabin area behind the cockpit was equipped with flight test and recording equipment. The helicopter utilizes two forward retractable main landing gear, and a retractable tail wheel.

2.0 PILOT'S DESCRIPTION OF EVENTS

The pilot-in-command was in the right seat and manipulating the controls at the time of the accident. He stated that he applied collective to get the aircraft light on the wheels and then applied forward cyclic to initiate a roll forward (forward taxi). He ground taxied the aircraft to the runway just as he had done on other flights. He intended to hold short of the runway and wait to be notified that the SAR (search and rescue) aircraft was on station. As the aircraft approached the runway, a slight left roll developed. The pilot decided to lift the helicopter into a 5-foot hover and stabilize. As he applied collective and got airborne the helicopter rolled quickly left and then right, continuing with 2-3 roll reversals of increasing roll attitudes eventually exceeding estimated 60º angle of bank. The pilot applied counter roll control inputs, but roll rates experienced were excessive. After 2-3 roll reversals and after a large right angle of bank roll, as the helicopter reversed its roll, the pilot lowered the collective to full down to execute a landing. After the landing, he shut the engine down, and completed the emergency shutdown procedure. He and the copilot egressed the helicopter normally.

3.0 VIDEO SUMMARY

Video of the accident sequence of events was reviewed. The video was filmed from the right rear quadrant of the helicopter. It showed the helicopter slowly taxing forward with all 3 landing gear wheels in contact with the ground. As the helicopter approaches the edge of the runway, the tail wheel lifts off the ground followed by the main landing gear lifting off the taxiway simultaneously. As the helicopter gets airborne, the nose pitched upward slightly with a slight right roll. The helicopter then rolls to the left about 20º angle of bank and the left landing gear contacts the ground. A right roll followed that went slightly past horizontal. The roll reversed to the left, exceeding 30º angle of bank, then reversed to the right, and as the helicopter rolled through the vertical plane, the upper and lower rotors intermeshed about the 1 o'clock position (as viewed from the cockpit), creating a cloud of blade fragments and gray dust. The right roll continued, exceeding 60º angle of bank, then reversed to the left, and then landed hard as the helicopter passed through the vertical plane. The rotors continued to turn, decelerating until they come to a stop 43 seconds later. The time between when the helicopter got airborne and landed hard was approximately 5 seconds.

4.0 WRECKAGE EXAMINATION

On August 3 the National Transportation Safety Board (NTSB) helicopter specialist along with participants from Sikorsky performed an examination of the helicopter.

The helicopter was resting upright on the south side of the runway at the intersection of taxiway A and runway 9/27. The two main landing gear and the tail wheel had collapsed outward, with the helicopter resting on its belly. The helicopter is configured with two 4-bladed counter rotating rotors, with the rotor stacked vertically one over the other. All 8 rotor blades remained attached to their respective hubs and all rotor blade ends had been separated from each blade at approximately the same location along the length of each blade. The tail has a horizontal stabilizer with rudders attached at each end of the stabilizer in a H-configuration. The vertical stabilizers and attached rudders had fractured at the attach points on the horizontal stabilizer as a result of ground impact. A 6-bladed composite variable pitch pusher propeller was positioned at the end of the tail section. All six blade tips exhibited leading edge damage and upward bending as a result of ground contact. The tail wheel fractured at the strut mount and was displaced to the left of the central vertical tail fin.

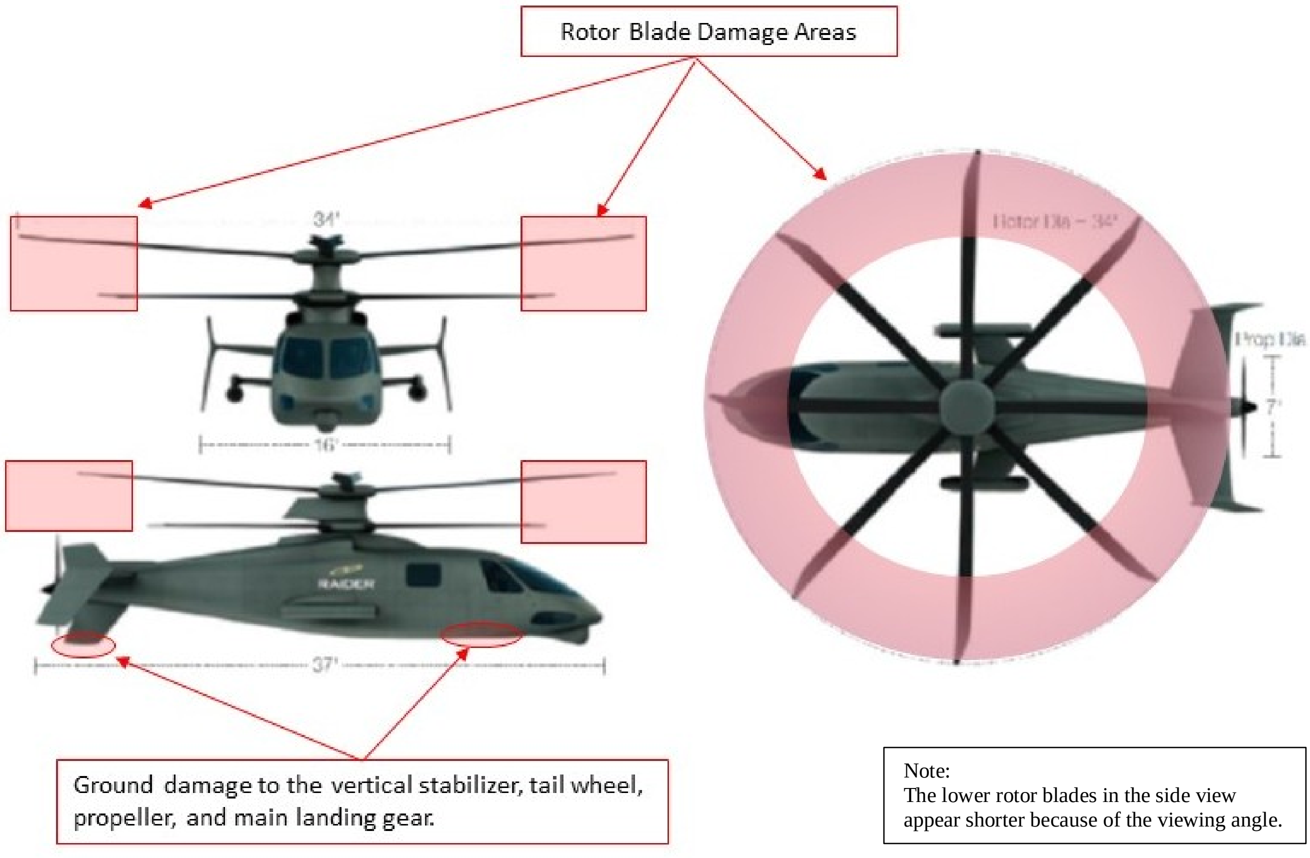

Figure 1 - 3-view diagram illustrating helicopter damage areas.

4.1 ROTOR SYSTEM

The main rotor consists of two four-bladed coaxial rotors with counter-rotating blades. The rotor head consists of an upper and lower hub, incorporates blade retention, and stationary and rotating controls. The upper and lower rotor blades are similar with the exception of some mounting differences to account for the different rotation directions. The diameter of the rotor is 34-ft. Both the upper and lower rotor heads appeared visually undamaged. All 8 blades were missing the outboard 4-feet of each blade span.

4.2 TRANSMISSION

The gearbox, including support struts, mounting feet and bolts, remained attached to the airframe and exhibited no external damage. Sikorsky deemed that the transmission was not reusable.

4.3 PROPELLER SYSTEM

The propeller is a composite six bladed thrusting device that is geared directly to the main gearbox. The propeller can be engaged or disengaged via the prop gearbox clutch. A clutch switch is located on the center instrument panel as the only means to manually engage and disengage the prop. A prop driveshaft extends from the aft end of the main gearbox and connects to the prop gearbox (PG), on the tail, via a single prop driveshaft. The prop is located aft of the prop gearbox. Prop pitch is hydraulically controlled through pilot inputs coupled with logic within the flight control computers (FCC) and electronic prop control (EPC).

Propeller gear box remained attached to the tail pylon, no external damage was observed. Propeller drive shaft appeared to be completely intact with no external damage observed. All 6 propeller blades remained attached but exhibited damage from ground contact, with blade tips curled 90º toward the blade back (cambered side).

Sikorsky engineers reported that telemetry data showed the propeller was turning but provided no thrust.

5.0 FLIGHT CONTROL SYSTEM

The flight control system is a full authority fly-by-wire system with redundant sensors and processors suitable to a full authority system. Three UTAS flight control computers (FCC) process inputs to manage the flight control system.

The cockpit controls consist of two passive side arm controllers mounted to the left and right adjacent to the doors. The side arm controllers have grips relative to their respective left/right positions. A single centrally mounted collective provides collective control for both pilot stations. The control response type is rate command with attitude hold in both pitch and roll and proportional collective in the vertical axis. Yaw control is achieved via traditional pedals mechanically linked between the two pilot stations. The collective is a proportional controller with full time trim engaged.

Flight Control Modes

The flight control laws are divided in to three modes or paths and are referred to as the feed forward[1] command paths. These three paths are: fully on ground path, fully in air path, and in transition path. While the aircraft is on the ground, as detected by any one of three weight-on-wheels switches, it is in the fully on ground path (fig 2). In this mode the pilots side arm controller provides input to the rotor head proportional to the displacement of the stick (stick to head gain), such that at maximum stick deflection, the rotor head is limited to 40% of its maximum range of movement (40% attenuation factor). There is also a stick filter that removed high frequency signals from the stick and softens the connection between the stick and the swashplate.

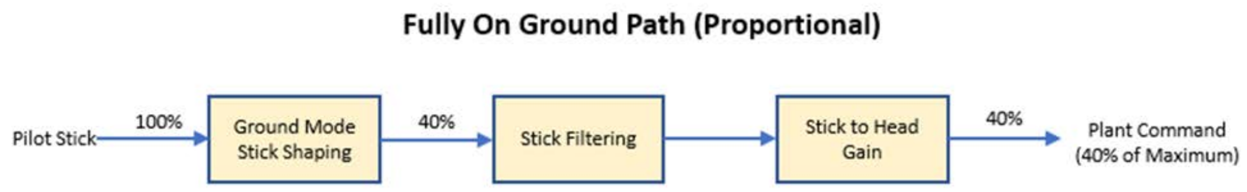

Figure 2 - On-ground path diagram.

When all three weight-on-wheels switches are disengaged for more than 3 seconds, the helicopter utilizes the fully in air path (fig 3). In this mode the pilot's stick provides pitch and roll rate commands, such that stick deflection commands a rate and the rate is nulled out once the stick returns to center. The

[1] In a feed-forward system, the control variable adjustment is not error-based. Instead it is based on knowledge about the process in the form of a mathematical model of the process and knowledge about or measurements of the process disturbances. (Haugen, F. (2009). Basic Dynamics and Control)

stick shaping signal is processed through a command model followed by an inverse plant[2] which restricts the authority to approximately 20% of maximum head displacement.

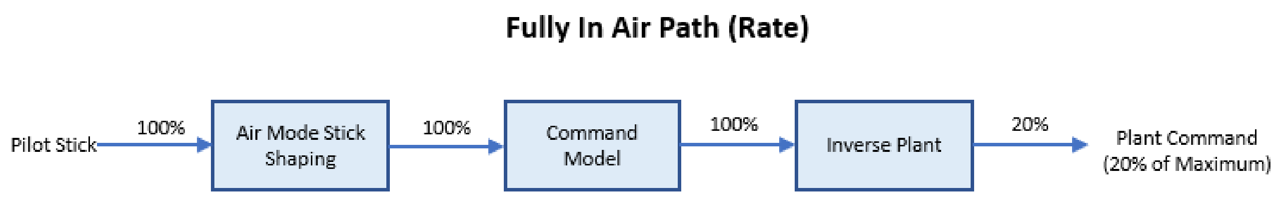

Figure 3 – In-air path diagram

These two modes are blended during the transition from air-to-ground, or ground-to-air, creating a temporary third mode. During the 3 seconds after the last weight-on-wheel switch is disengaged, or 0.5 seconds after a weight-on-wheels is first engaged, the flight controls are in the in-transition path (fig 4). When in this mode the pilot's stick shaping is transitioning from proportional mode (ground mode) to rate mode (air mode) or vice-versa. The control laws performed this transition by using a ground mode stick shaping function, a transient free switch, stick filter, direct stick to rotor head gain on the ground path, and an air mode stick shaping function, transient free switch, command model, and inverse plant on the air path; both signals were then processed through the asymmetric fade switch which provided a single command to the roll inverse plant (flight control hardware). The transient free switch takes the difference between the newly selected stick input and the output from the previous frame, then computes a new output command at a fixed rate and adds that to the new stick input. This process is done one time and is not updated when the command signal changes. The smaller the difference, the faster the switch completes its function. The output of the transient free switch is routed through the ground path and air path simultaneously, then the two signals are blended in the asymmetric fade switch into a single command signal.

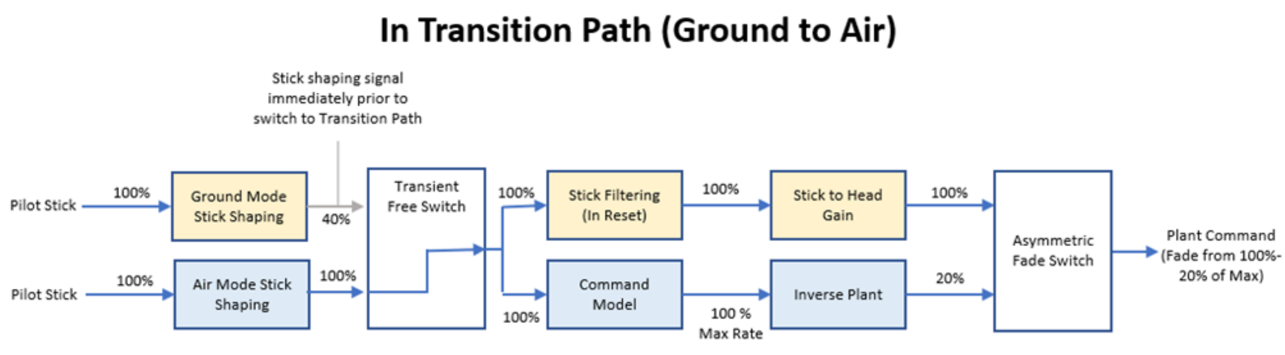

Figure 4 - In-transition path diagram.

[2] A plant, in control theory, is the combination of process and actuator.

Control law changes were introduced in late 2015 to improve ground to air transitions. The key update was changing the switch functionality at the end of the feed forward command path, from a transient free switch to an asymmetric fader switch and reset to zero the proportional path stick filter. The change from a transient free switch to a fader switch eliminated the 40% stick to head attenuation and replaced it with the full 100% proportional signal. The results of these two changes was an unintended increase of the cyclic stick sensitivity by 2.5 times during the transition to flight.

While pitch, roll, and yaw axis all share the same architecture, the helicopter's lower roll inertia as compared to the pitch and yaw inertia, made the problem most apparent in the roll axis.

6.0 INCIDENT TIME LINE

Event No.	Elapsed Time (sec)	Event Description
1	54.8	Taxi (ground mode) Helicopter is light on wheels, forward pitch stick, high collective setting.
2	55.7	Weight on wheels switch disengages. Transition mode initiates.
3	56.2	Forward pitch stick commands nose down.
4	56.6	Pilot inputs aft stick pitch correction. A negligible left roll input is introduced.
5	56.9	Pilot counters small left roll with small right stick input. Pilot adds collective to increase altitude. Helicopter responds with a disproportionately large right roll.
6	57.4	Pilot counters large right roll rate with large left stick input. Helicopter's left roll is disproportionally large.
7	57.6	Left main landing gear contacts ground and transition to ground mode is momentarily initiated. Left main landing gear raises off the ground, resetting transition to flight mode. Helicopter continues to rapidly roll to the right.
8	59.2	Blades contact each other due to gyroscopic moments generated by the high roll rate.

The event occurred while taxiing on the runway with light weight on wheels, high collective pitch, and a slight forward cyclic pitch stick. Due to the light weight on wheels during the taxi, the flight control mode transitioned from ground mode to flight mode. The slight forward pitch stick in combination with flight mode initiated a nose down pitch rate. The pilot took corrective action inputting aft cyclic stick to correct the nose down rate. The initial pitch axis correction led to a small initial left roll rate due to aircraft coupling. The pilot countered the small left roll rate with an appropriate magnitude right stick input. In conjunction with the right stick input, the pilot raised the collective to increase the altitude. The aircraft right roll response to the right stick input was larger than expected and the pilot countered with a large left stick input. The aircraft left roll response was also larger than expected.

The larger than expected roll response to the pilot roll stick input was the effect of a flight control system design error that resulted in unintended changes in the pilot input sensitivity in the roll axis during the transition from ground control mode to flight mode.

During the ensuing dynamic response, the left main landing gear momentarily came in contact with the ground and aircraft transitioned from flight mode back to ground mode. Shortly thereafter, flight mode re-engaged which in turn reset the mode transition timeline and re-introduced the erroneous control sensitivity gain. At this point the roll oscillations became extreme and the counter rotating blade tips contacted each other due to the gyroscopic moments generated by the high resulting roll rates leading to loss of lift, and a hard landing occurred.

7.0 ADDITIONAL INFORMATION

Sikorsky reported that the increased control sensitivity was never encountered in the initial piloted simulation evaluation, nor in the 15 subsequent aircraft flights after the flight control software revision was made. However, once the incident timeline was precisely determined, the increased sensitivity to pilot control input could be consistently replicated in the simulator.

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