Transportation Safety Board of Canada

Bureau de la sécurité des transports du Canada

AVIATION INVESTIGATION REPORT
A01P0003

LOSS OF MAIN ROTOR DRIVE

HAYES HELI-LOG SERVICES LTD.
SIKORSKY S-61N (SHORTSKY) HELICOPTER C-FHFS
PORTEAU COVE, BRITISH COLUMBIA
15 JANUARY 2001

Canada

Transportation Safety Board of Canada
Bureau de la sécurité des transports du Canada

The Transportation Safety Board of Canada (TSB) investigated this occurrence for the purpose of advancing transportation safety. It is not the function of the Board to assign fault or determine civil or criminal liability.

Aviation Investigation Report

Loss of Main Rotor Drive

Hayes Heli-Log Services Ltd.
Sikorsky S-61N (Shortsky) Helicopter C-FHFS
Porteau Cove, British Columbia
15 January 2001

Report Number A01P0003

Synopsis

A Sikorsky S-61N helicopter (C-FHFS), serial number 61702, was climbing to pick up logs on the side of a hill, at about 85 per cent torque from each engine and approximately 2500 feet per minute. It was pointing at the hill about 200 feet away when the two pilots heard a loud bang and the rotor rpm (revolutions per minute) started to decay. The pilot flying turned the helicopter away from the hill, but the helicopter descended into the trees and came to rest, nose down and left side down, on a steep hillside. The helicopter was refuelled just before the accident flight. On impact, its fuel tanks ruptured, spilling a large quantity of fuel. There was no fire. The pilots suffered serious but non-life-threatening injuries.

Ce rapport est également disponible en français.

Other Factual Information

The station of the pilot flying was encroached by impact damage. The area of the flight deck where the pilot not flying was stationed was not encroached, but the seat and restraint system of the pilot not flying broke free from its mountings. The pilot not flying was not wearing protective headgear.

A post-accident teardown inspection of the engines revealed that both engines had damage signatures consistent with those found when engines are not operating at impact. There was no apparent malfunction that would cause the engines to shut down; however, the engines were equipped with overspeed governors that would shut the engines down in the event of an overspeed. These governors do not leave any indication that a shutdown was triggered by an engine overspeed. The main- and tail-rotor blades demonstrated damage consistent with that found when there is little or no rotor rpm (revolutions per minute) at impact.

The main-rotor transmission, which had accumulated approximately 710 hours since its last overhaul, was also subjected to a post-accident teardown inspection, conducted at an approved Sikorsky main transmission overhaul facility in Richmond, British Columbia, under the supervision of TSB investigators. Initial disassembly of the front section revealed extensive wear and damage to both input freewheel units (IFWUs) (see Appendices A1 and A2).

The IFWUs had been replaced, as a matter of practice, about 500 hours after the last main-transmission overhaul. The IFWUs that were removed demonstrated normal wear. The replacement IFWU (part number 61047-35000-060) had accumulated approximately 210 hours of flight time and about 70 engagements since installation. They were made up of new cams and rollers. During routine maintenance before the accident, there was no significant metal found in the main-rotor transmission oil filters. Also, no illuminated chip lights were reported. After the accident, during a teardown inspection of the main-rotor transmission, metal particles were found in the transmission, but chip sensors were not activated. A more detailed inspection of the metal found in the transmission oil filters revealed numerous flakes of bronze, some flattened. The bronze Oilite bushings (part number S6135-20459-101), on which the roller retainer sits, showed damage consistent with that found when they are comprised of material that cannot withstand the normal forces, or that have been exposed to an abnormally high level of vibrations. Other components of the IFWUs showed the following signs of instability, slippage, and skidding:

- The camshaft flats were dented by the rollers.
- The rollers had flat spots and were contaminated with bronze.
- The input gear housing was contaminated with bronze, and the inner surfaces were heavily damaged by slipping and skidding of the rollers.

- The roller retainers had dents along the lower surface on the back side of the tangs, scores and grooves on the inside between the roller pockets, and uneven wear in the pockets.

- The bronze Oilite bushings were extremely worn and showed cracks and bending.

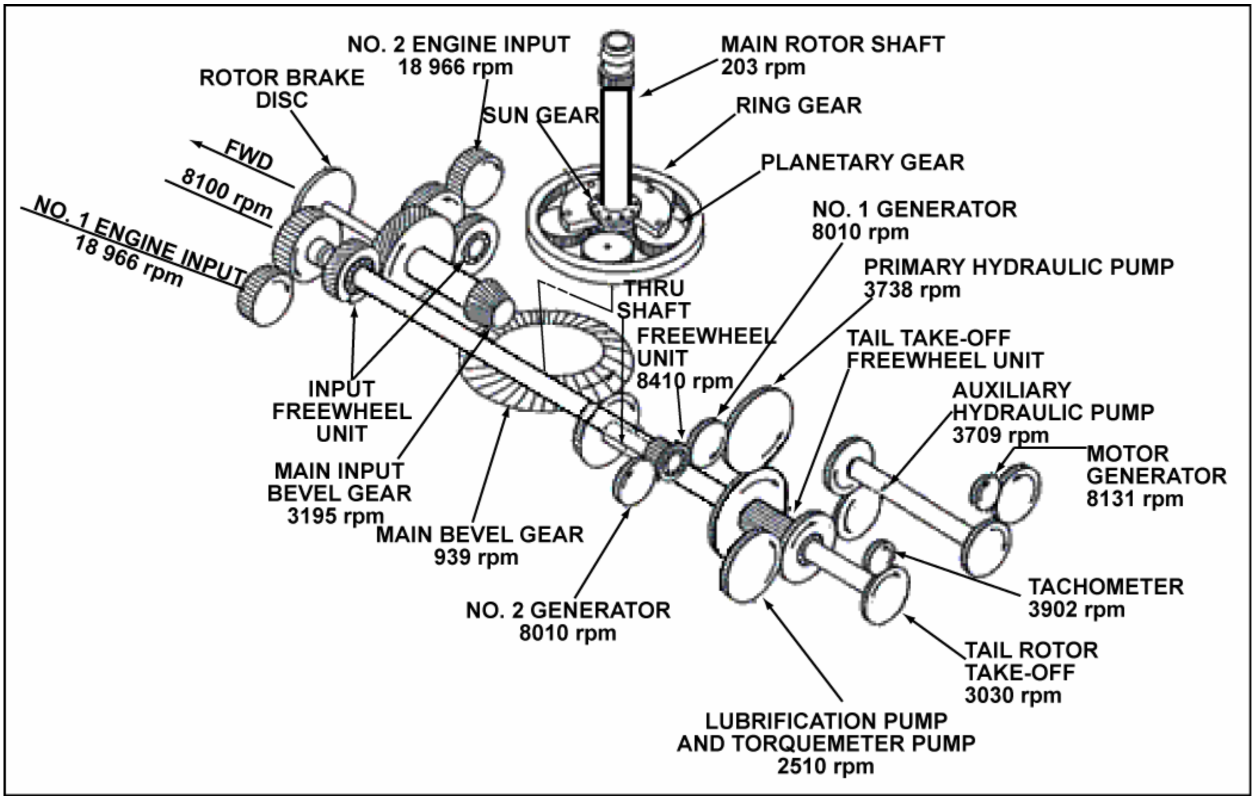

Figure 1. Main transmission

Further disassembly of the main transmission (see Figure 1) revealed unusual gear wear patterns, fretting, and misalignment of the No. 3 and No. 4 bearing outer races relative to the steel liners. This was evident by the following:

- The spiral bevel pinion and the main spiral bevel gears were worn excessively; however, every fifth tooth had relatively little wear.

- Measurements taken during this disassembly to determine the appropriate shim thickness between the input housing and the transmission lower housing varied from 0.039 inch to 0.048 inch (a difference of 0.009 inch). The required shim thickness was calculated to be 0.033 inch at the last overhaul. The same measurements taken at the last overhaul varied from 0.024 inch to 0.053 inch (a difference of 0.029 inch). Typical shim thickness in this application is 0.038 inch to 0.044 inch.

- At disassembly, the backlash between the spiral bevel pinion and the main spiral bevel gears was 0.022 inch. At the last overhaul, the backlash was set at 0.016 inch (the maximum allowable).

- Wear of the spiral bevel pinion and the main spiral bevel gears was not sufficient to account for the change in backlash measurements between overhaul and the post-accident teardown inspection.

- Dowels that align the cover and input housing were loose.

- Fretting, galling, corrosion, and scoring were found on the aluminum pilot liner around the No. 4 bearing.

- The steel liner ring in the lower housing was found to be skewed. (The side opposite to the dowel pin, which retains the liner, had shifted from the centre of the transmission.)

- Fretting was found under the No. 3 and No. 4 bearing inner races on the input pinion (spiral bevel gear).

- The input housing casting was found to have contacted and fretted the lower housing casting near the No. 6 bore.

- The input housing twist was measured to be right 0.110 inch. (The maximum allowable off centre is 0.125 inch, beyond which the housing must be scrapped.)

- The oversize liners machined for the bearing bores were of incorrect dimensions: the radius was 0.016 inch instead of 0.040 inch.

- The No. 3 and No. 4 liners were embossed with lettering and numbering stamped into the bearing outer races.

Dimensions of the cams, rollers, gear housings, retainers, Oilite bushings, and gears were precision charted and found to have been manufactured according to Sikorsky design dimensions.

Following the occurrence, selected main gearbox components from the accident helicopter were sent to Sikorsky for their analysis, and the TSB requested a copy of their report for purposes of the investigation. In early February, the TSB received a letter from Sikorsky, dated 05 February 2002, containing information based on their analyses.

In October 2005, the TSB received a copy of an internal Sikorsky Materials Engineering Report dated 07 February 2001, prepared in response to the investigation of the S-61 accident, but not previously seen by the TSB. The content of this internal report is very similar to the content of the letter provided to the TSB. However, there are differences between the letter and the report, particular with regard to the Oilite bushings.

In the letter, it is stated that "One axial and one circumferential crack in the RH 61350-20459-101 bushing had been mounted for metallographic examination"; there is no mention of what was discovered. In the internal report, the above sentence is followed by "The photomicrographic in Figure 80 (axial crack section) shows several large pores in the oilite bronze. The pores shown in Figure 81 (circumferential crack) appear to be more uniform and not as large as in the previous figure."

In the letter, there is a finding (7) that reads as follows: "The RH 61350-20459-101 oilite bushing had many axial and circumferential cracks." However, in the internal report, there is a similar finding (6) that reads as follows: "The RH 61350-20459-101 oilite bushing had many axial and circumferential cracks. Microstructural and SEM exam revealed large pores and areas of apparent incomplete sintering." Other Sikorsky internal communication revealed that large pores and areas of incomplete sintering[1] will allow the Oilite bushings to crush and crumble under loading associated with the application in the Sikorsky S-61 transmission.

The incomplete sintering traces back to Oilite bushing (part number 703-06331-103) failures in 1999 and 2000. Analyses by Sikorsky of these failures indicated that "Oilite bronze bushing does not meet radial crush strength requirements of MIL-B-5687D." This bushing does not have the same part number as the bushings in the accident helicopter, but the bushings are very similar and were made from the same materials.

The original equipment manufacturer (Sikorsky) is responsible for the quality of the end product, in this case the Oilite bushing. There is no limitation on the size of pores permitted in Sikorsky's specifications for the material used to make the Oilite bushings nor is there any requirement that the material be completely sintered.

The Sikorsky procedure to determine the shim thickness between the input housing and the transmission lower housing calls for a measurement between a fixture and the No. 4 bearing inner race. The overhaul facility took 10 measurements around the inner race and used an average to determine the shim thickness required. No upper or lower shim thickness limitations were specified in the Sikorsky or the overhaul facility transmission build-up procedures. There was also no requirement to carry out a gear pattern check.[2]

Information was not documented with regard to a vibration check that was conducted two days before the accident, as a result of an engine change. However, the technical logs indicated that the helicopter was maintained according to required standards. Power/topping checks were conducted about eight flying hours before the accident. One engine topped at 111 per cent torque and the other at 116 per cent, both well below the 123 per cent maximum the IFWUs are designed to hold. The pilots and maintenance crew reported no abnormal vibrations or noise before the accident.

Operating procedures were in place to limit freewheeling and engagements of the IFWUs. Minimum torque values were adhered to during descents, cool-downs were accomplished at 98 per cent rotor rpm, and both engines were used to turn up the rotor system during starts.

---

1 Sintering is a method of bonding powdered materials.

2 A gear pattern check is a means of determining how gears are meshing by preparing the gear surface with a paste, meshing the gears, and observing the pattern of contact on the paste.

Weight and balance calculations are not performed for every lift during repetitive lift operations. However, log sheets of the loads carried indicate that they were normal for the type of operation and likely within the limitations set out in the helicopter flight manual.

Analysis

Information received about three years after the accident revealed that the Oilite bushings supplied by Sikorsky were not manufactured properly. The bushings had areas of large pores and incomplete sintering. These Oilite bushings were subject to premature wear and damage from normal use. This created instability of the rollers because the roller retainer rests on the Oilite bushings. The instability, increased pinch angle of the rollers and cams (caused by dents in the cams), and bronze contamination caused the rollers to slip or spit out, disengaging one of the IFWUs. Because the other IFWU was also worn and contaminated, it failed within a very short time of the initial IFWU failure, and total drive to the main rotor was lost. (When one IFWU disengages, all power demanded by the rotor system is transmitted to the remaining IFWU, increasing the likelihood that the remaining IFWU will quickly fail.) When the load of driving the main rotor was lost, the engines oversped and shut down. Rotor rpm decayed, and control was lost.

Loss of drive from both engines, while a helicopter is climbing at a high rate (high pitch angle on the blades), contributes to rapid rotor rpm decay. Despite the reduction of collective to flat pitch, decay will not stop while the helicopter continues to climb. The main-rotor system does not enter an auto-rotative state until the relative air flow through the rotor system changes. As rotor rpm decays, the time and altitude required to regain rpm and generate lift increases. The Sikorsky S-61N flight manual does not contain warnings or limitations concerning the effects of rate of climb when total power loss is experienced.

The spiral bevel pinion and the main spiral bevel gears demonstrated wear patterns consistent with improper alignment. In addition, there was a difference of 0.029 inch in the measurements of surfaces between the No. 4 bearing inner race and the fixture at the time of overhaul build-up. It is therefore concluded that these gears were misaligned during the build-up at the time of the last main-rotor transmission overhaul. This would have substantial effect on gear operation and could cause torsional oscillations or torsional vibrations. Gear tooth wear measured during the teardown inspection was not sufficient to account for the change in backlash at overhaul and during the teardown inspection. Gear tooth wear and changes in measurements of the surfaces between the No. 4 bearing inner race and the fixture indicate that there was movement of the No. 3 and No. 4 bearings, the spiral bevel pinion, and the main spiral bevel gears since the time of the overhaul.

Fretting under the No. 3 and No. 4 bearing inner races on the input pinion and on the aluminum pilot liner around the No. 4 bearing, along with the loose dowel pins, is indicative of an abnormally high level of vibrations in the transmissions during their operation leading up to the accident. The only anomalies identified during the teardown that could cause such vibrations were the misalignment and subsequent movement of the Nos. 3 and 4 bearings, the spiral bevel pinion, and the main spiral bevel gears. It is therefore likely that vibrations and high forces initiated movement of the misaligned components and that movement caused the backlash to be extremely out of its specifications. This would then increase vibrations and movement of the casting as the dowel pins became loose. It was not determined why the spiral bevel pinion and the main spiral bevel gears had reduced wear on every fifth tooth. Torsional vibrations may be a possible explanation for the appearance of a cyclic wear pattern on the bevel gear teeth. Gear tooth profiles were precision charted and found to be above standard.

Since there were no indications of vibrations affecting the IFWUs during the first 500 hours, it is likely that vibrations, shown by signatures seen in other parts of the transmission, did not affect the IFWUs.

While metal particles were found during a teardown inspection of the main-rotor transmission, the chip detectors were not activated. This was attributed to oil flow characteristics of the transmission.

The seat and restraint system of the pilot not flying broke free from its mountings, likely because impact forces exceeded the design criteria of the seat.

Because neither engine was able to produce the maximum 123 per cent torque for the IFWUs, it was not likely that overtorques/loading of the IFWUs caused a failure.

Findings as to Causes and Contributing Factors

1. An Oilite bushing broke down because it was manufactured with large pores and incomplete sintering. This created instability of the rollers because the roller retainer rests on the Oilite bushings. The instability, increased pinch angle, and bronze contamination most likely caused the rollers to slip or spit out, disengaging the input freewheel unit (IFWU).

2. When the first IFWU disengaged, all power demanded by the rotor system was transmitted to the remaining IFWU, which was worn and contaminated, causing it to fail within a very short time of the first failure, and total drive to the main rotor was lost, leading to the loss of control of the helicopter.

Findings as to Risk

1. There is no limitation on the size of pores permitted in the original equipment manufacturer’s specifications for the material used to make the Oilite bushings nor is there any requirement that the material be completely sintered.

2. The spiral bevel pinion and the main spiral bevel gears were misaligned during build-up at the time of the last main-rotor transmission overhaul and moved during operation, likely causing an abnormally high level of vibrations.

3. No upper or lower thickness limitations were specified in either the Sikorsky or the overhaul facility transmission build-up procedures for the shim between the input and lower housings. There was also no requirement to carry out a gear pattern check.

4. Metal particles were found during the teardown inspection of the main-rotor transmission; however, chip detectors were not activated. This was attributed to oil flow characteristics of the transmission.

5. The pilot not flying was not wearing protective headgear.

6. The manual governing overhaul procedures for main-rotor transmissions in Sikorsky S-61 helicopters does not incorporate multiple measurements and maximum differential between measurements from the datum fixture and the No. 4 bearing inner race.

7. The manual does not prescribe that a gear pattern check be carried out at transmission build-up.

Other Findings

1. Neither engine was able to produce the maximum 123 per cent torque for the IFWUs. It was not likely that over torques/loading of the IFWUs caused a failure.

2. Sikorsky S-61 flight manuals do not incorporate information concerning flight regimes (rate of climb) where control is compromised when there is a total loss of power or drive to the rotor system.

Safety Action

On 30 January 2001, the TSB highlighted the facts from the initial investigation in an Occurrence Bulletin issued to Transport Canada (TC), the United States Federal Aviation Administration, the operator, the aircraft manufacturer, and the overhaul and repair centre.

The main-rotor transmission overhaul facility (ACRO Aerospace Inc.) has amended the build sheets to document the measurement of radial and axial play of the freewheel roller retainer. This measurement was made during overhaul, but in the past, the results had not been documented. This measurement will substantiate the condition of the freewheel roller and retainer fit at the time of overhaul.

On 16 July 2002, the TSB forwarded an Aviation Safety Advisory (A010049-1) to TC suggesting that, because of the consequences of total power loss during a high rate of climb, namely main-rotor decay and loss of control, it may wish to caution pilots regarding the risks of operating in these flight regimes.

On 10 September 2002, TC responded to the safety advisory. TC agreed that pilots may not be clear on possible adverse consequences of a high rate of ascent during a total loss of power and that many pilots may not be well versed, beyond the fundamentals, in the dynamics of autorotation.

On 03 October 2002, the TSB forwarded an Aviation Safety Advisory (A020028-1) to TC and Sikorsky Aircraft Corporation. The advisory suggests that, because of the consequences of gear misalignment during the build-up at main-rotor transmission overhaul, TC and Sikorsky Aircraft Corporation may wish to review the manual governing overhaul procedures for main-rotor transmissions in Sikorsky S-61 helicopters, and incorporate multiple measurements and maximum differential between measurements from the datum fixture and the No. 4 bearing inner race. Additionally, TC and Sikorsky Aircraft Corporation may wish to incorporate a gear pattern check at transmission build-up.

On 11 August 2003, Sikorsky Aircraft Corporation issued revision B of Alert Service Bulletin 61B35-67B establishing criteria for inspection, overhaul, and removal of the IFWUs. The bulletin defined external lift cycle and repetitive external lift (REL) operations, and it established a maximum time between overhaul (TBO) for REL operations at 500 hours or 7500 cycles, whichever comes first. It also made provisions for operators and repair facilities to document measurements and report their findings to Sikorsky. In part, the bulletin refers directly to the Oilites and requires that all Oilites be replaced during overhaul or repair of the IFWU. Sikorsky also indicated that it has upgraded the inspection criteria for the manufacturing of the Oilites.

This report concludes the Transportation Safety Board's investigation into this occurrence. Consequently, the Board authorized the release of this report on 20 December 2006.

*Visit the Transportation Safety Board's Web site (**www.tsb.gc.ca**) for information about the Transportation Safety Board and its products and services. There you will also find links to other safety organizations and related sites.*

Appendix A1 – Input Freewheel Unit Assemblies

Section II
Group Assembly Parts List

S-61N ILLUSTRATED PARTS CATALOG
SA4045-79

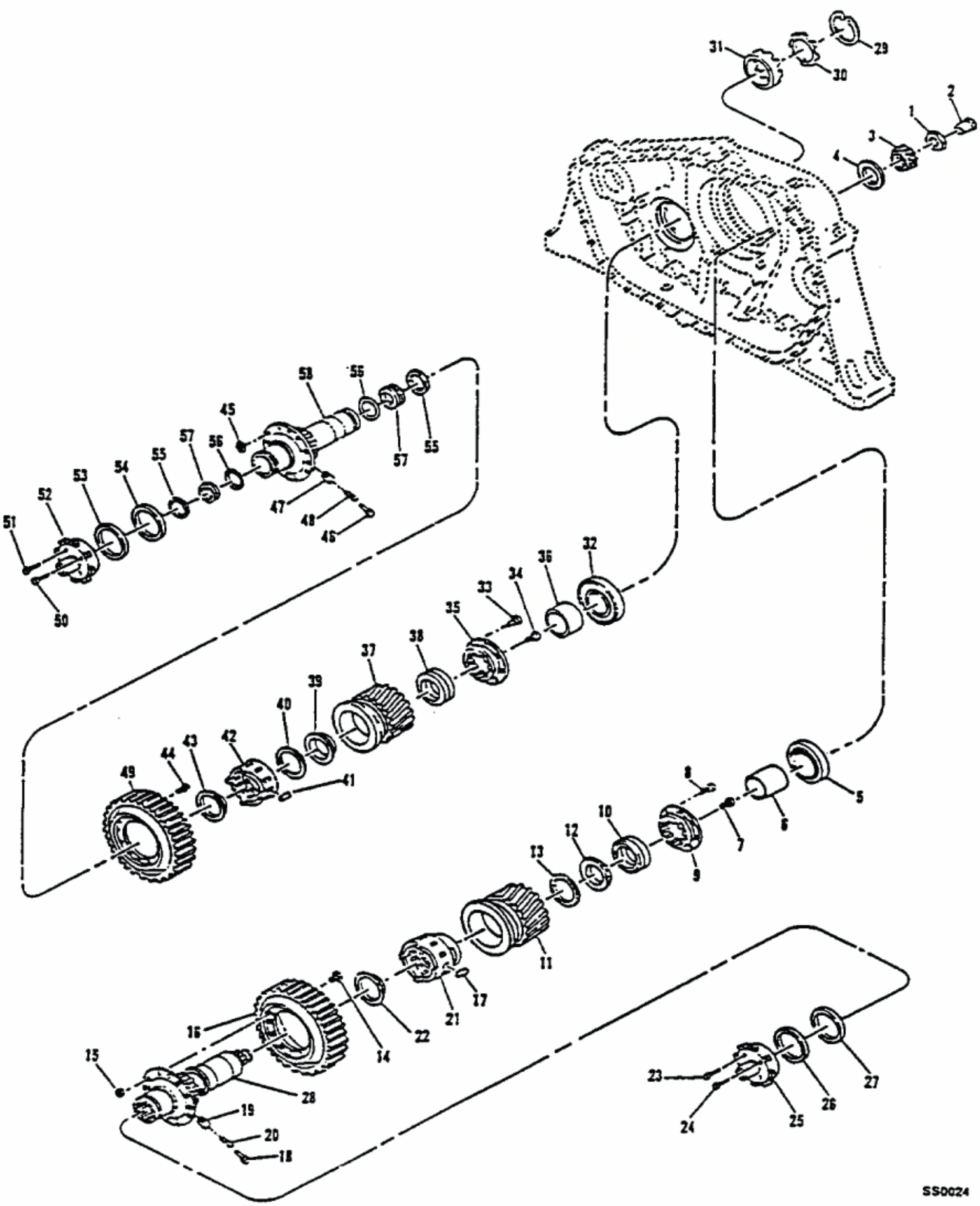

FIGURE 149A. MAIN GEAR BOX INPUT FREE WHEEL UNIT QUICK CHANGE ASSEMBLY

2-468B

30 SEPTEMBER 1992

Appendix A2 – Input Freewheel Unit Assembly Parts List

FIGURE INDEX NUMBER	PART NUMBER	DESCRIPTION 1 2 3 4 5 6 7	UNITS PER ASSY
149A -	61074-35000-059	**QUICK CHANGE ASSEMBLY. MAIN GEAR BOX INPUT WHEEL UNIT LH**	1
-1	61350-20700-101	. NUT	1
-2	56135-20723-000	. PLUG	1
-3	56135-20657-1	. COUPLING. SPLINE	1
-4	56135-20658-1	. SPACER	1
-5	SB2158-102	. BEARING	1
-6	56135-20653-103	. SPACER	1
-7	SSS242-2	. SETSCREW	1
-8	NA51081-3A4L	. SETSCREW	1
-9	56135-20654-102	. NUT	1
-10	SB1056-2	. BEARING. BALL	1
-11	S6135-20695-2	. GEAR. HOUSING	1
-12	56135-20610-102	. SPACER	1
-13	S6135-20748-1	. WASHER. OILITE BRONZE	1
-14	56135-20742-101	. BOLT	24
-15	47FLW-524	. NUT. /56818/	24
-16	56135-20608-3	. GEAR. SPUR	1
-17	SB2604-1	. ROLLER	12
-18	S6135-20755-103	. PIN	2
-19	56135-20754-104	. BUSHING	2
-20	56135-20776-001	. SPRING	2
-21	So'135-20730	. RETAINER. ROLLER	1
-22	S6135-20746-1	. SUPPORT	1
-23	NAS1081-3A4L	. SETSCREW	3
-24	555242-2	. SETSCREW	1
-25	56135-20612-1	. NUT	1
-26	56135-20642	. SPACER	1
-27	SB2103-105	. BEARING	1
-28	56135-20614-7	. CAM. ACTUATED	1
	61074-35000-058	**QUICK CHANGE ASSEMBLY. MAIN GEAR BOX INPUT WHEEL UNIT RH**	1
-29	P-RT-22S	. SPIROLOX../80756/	1
-30	61350-20879-101	. LOCK WASH	1
-31	61350-20878-103	. NUT	1
-32	SB2158-102	. BEARING	1
-33	NAS1081-3A4L	. SETSCREW	1
-34	555242-2	. SETSCREW	1
-35	56135-20654-102	. NUT	1
-36	56135-20653-104	. SPACER	1
-37	56135-20695-1	. GEAR. HOUSING	1
-38	SBI056-2	. BEARING. BALL	1
-39	61350-20458-101	. SPACER	1
-40	61350-20459-101	. BUSHING	1
-41	SB2604-1	. ROLLER	12
-42	61350-20457-101	. RETAINER ROLLER	1
-43	61350-20459-102	. BUSHING	1
-44	56135-20742-101	. BOLT	24
-45	47FLW-524	. NUT. /56818/	24
-46	56135-20755-103	. PIN	2
-47	56135-20754-104	. BUSHING	2
-48	So135-20776-001	. SPRING	1
-49	56135-20608-003	. GEAR. SPUR	1
-50	NAS1081-3A4L	. SETSCREW	3
-51	SS5242-2	. SETSCREW	1
-52	56135-X612-1	. NUT	1
-53	56135-20642	. SPACER	1
-54	SB21C3-105	. BEARING	1
-55	RR15o	. RING. RETAINING	2
-56	M83248/1-126	. 0-RING	2
-57	56135-20656-1	. PLUG	2
-58	So'135-20611-7	. CAM. ACTUATED	1

30 SEPTEMBER 1998 2-469