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S-61N FREE WHEEL UNIT MALFUNCTIONING

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Abstract:

In 1987 Sikorsky S-61 operations were affected seriously by a number of free wheel unit (FWU) malfunctions. The FWU is an overrunning clutch between each engine and the rotor drive system, located in the main gearbox (MGB) (input side).

The malfunctions appeared to be related to excessive wear of the FWU. The introduction, late 1986, of the 'dash 102' roller cage retention spring with approximately double the stiffness of the formerly used 'dash 1' spring, enhanced wear rates. The designers had not foreseen this unfavourable effect. Appropriate action was taken though and similar FWU problems have been reduced since.

Starting September 1987, as a means of prevention, FWU wear is monitored frequently at KLM Helikopters by measuring the critical components of the FWU. In the mean time Sikorsky has developed an improved version of the FWU that should be less vulnerable to wear.

As a consequence of the experience gained at KLM Helikopters by monitoring the wear pattern of the FWU's, a lead-the-fleet program is now being performed trying to achieve two goals set for the modified FWU, i.e. delete the present midlife inspection (at 1250 hrs), and extend FWU 'life' from 2500 to 3000 hrs.
Four aircraft will be involved, 2 at KLM Helikopters (Netherlands) and 2 at Helikopter Service (Norway). Their FWUs are to be inspected at preset intervals. The decision whether or not to proceed with the program at a certain interval will depend on the actual value and trend of the so-called roller contact angle, a characteristic parameter for FWU wear.

The paper deals with the analysis of roller contact angles and the current status of the Lead-the-Fleet Program.

1. Introduction

During the second half of 1987 Sikorsky S-61 operations were affected seriously by a number of free wheel unit (FWU) malfunctions, as can be seen in figure 1. (One should take into account that there are only some 100 aircraft (both S-61L and S-61N) operational worldwide.)

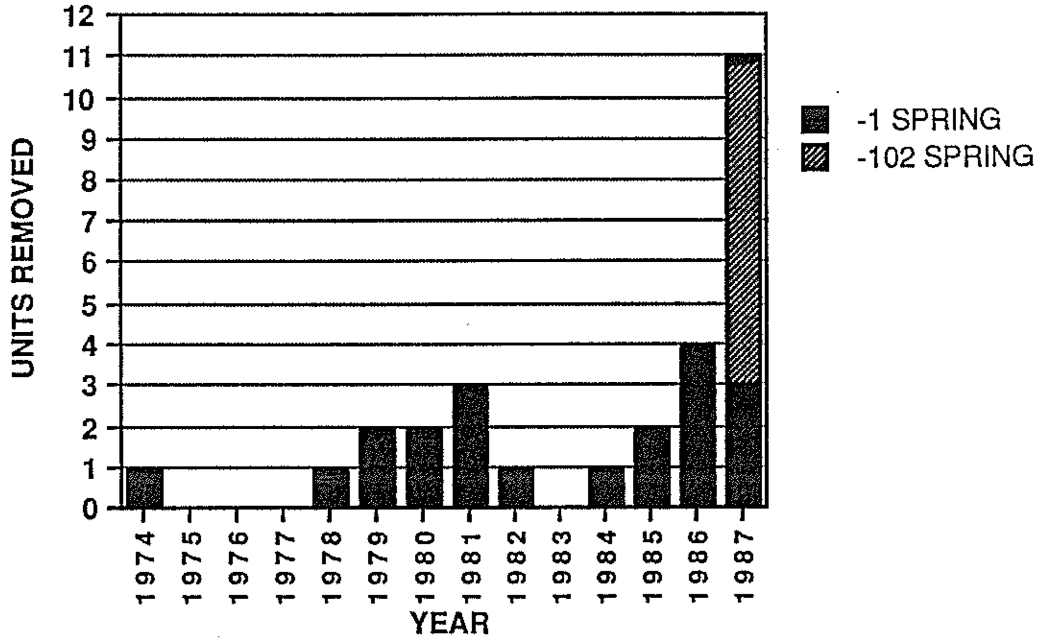


Figure 1: FWU spitouts vs. years, 'dash 1' and 'dash 102' springs

Figure 1 also shows that in 1987 most of the failed units incorporated the so-called 'dash 102' roller cage retention spring, introduced in that year with the objective to reduce FWU failures.

Before discussing the failure mechanism in further detail, the working of the S-61L/N FWU will be described.

2. Description of the S-61L/N FWU

The S-61L/N FWU, also called ramp roller clutch, acts as an overrunning clutch between each engine (or rather their power turbine) and the rotor system. Figure 2 shows the (input) freewheel units as part of the main transmission. They are located at the input side of the MGB.

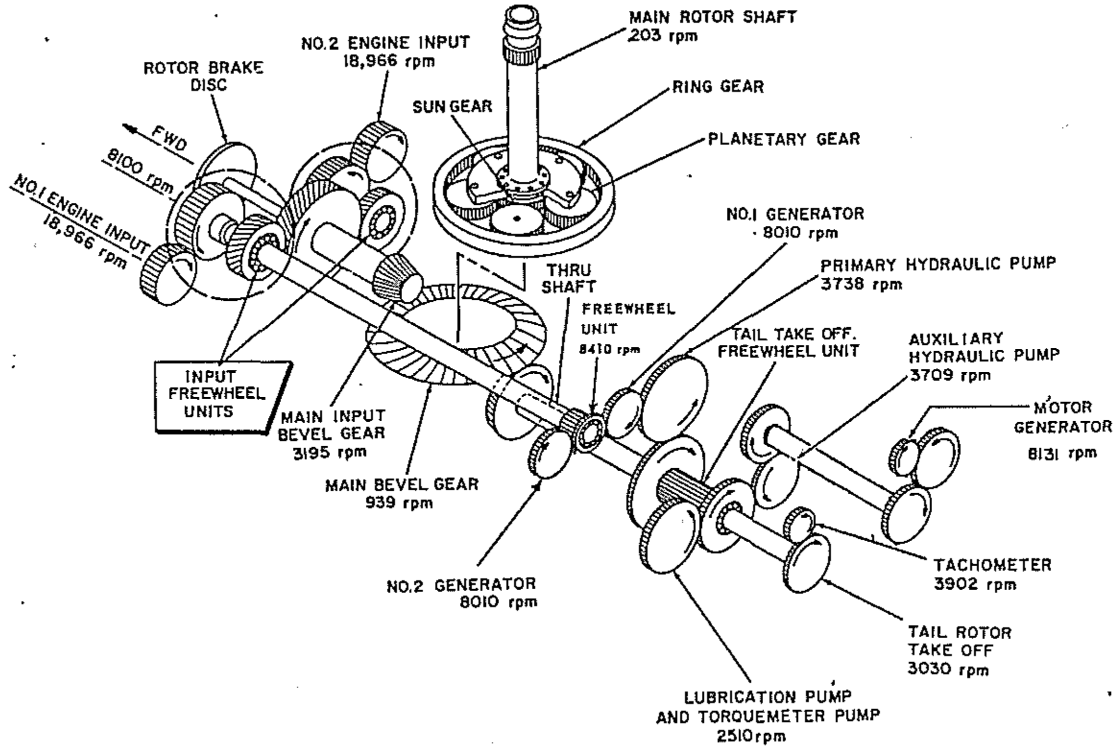


Figure 2: S-61N main transmission (schematic)

The main function of the FWUs is to allow single engine operation without driving the power turbine of the other engine, which would result in extra loss of power. Furthermore they allow the rotor to disengage from the power turbines during autorotation. Figure 3 shows the basic working of these FWUs in more detail.

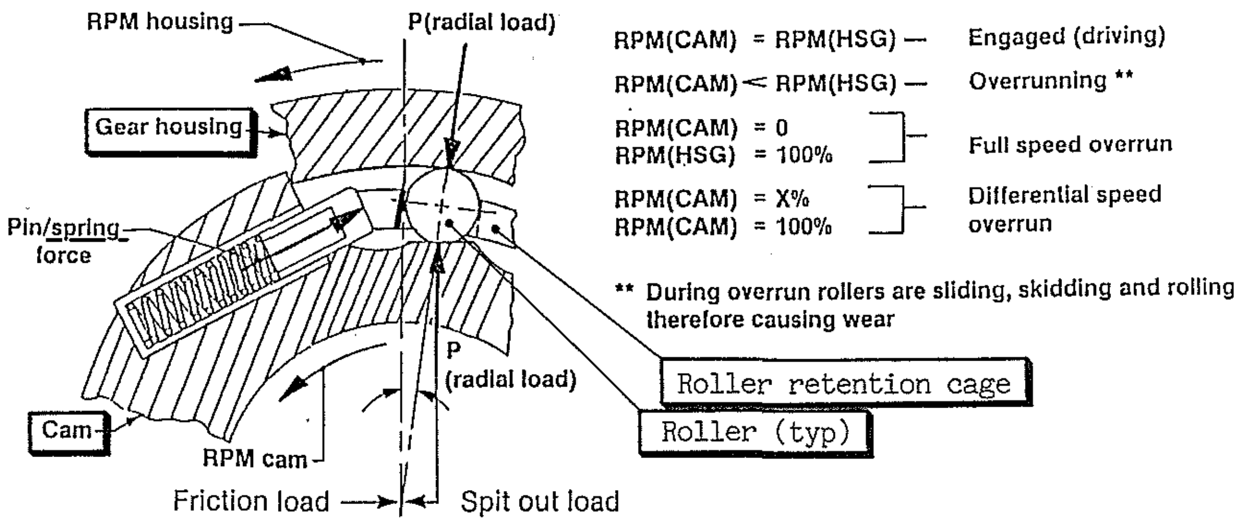


Figure 3: part of the ramp roller clutch (FWU) cross section; operating conditions

Suppose the main rotor is running at 100% rpm, then so does the gear housing; further suppose the cam shaft is still stationary (full speed overrun condition, occurring when one engine is running while the other still has to be started up). Then the gear housing is continuously trying to move the rollers (12 per unit) down the 'ramp', rolling them free so to speak. This movement however is counteracted by the tangential component of the spring force (2 springs per unit) acting on the rollers through the roller retention cage, ensuring that the rollers make contact with both gear housing and cam shaft continuously.

If the second engine is started up, that cam rpm will increase (differential speed overrun) until it becomes equal to that of the gear housing. At that point both the gear housing and cam are stationary relative to the rollers, while the roller retainer cage ensures contact between all members. If the cam would now rotate a little further relative to the gear housing in an anti-clockwise direction, the rollers would move up the ramp a little thus ensuring a tight clamp-up between cage and housing (engaged condition).

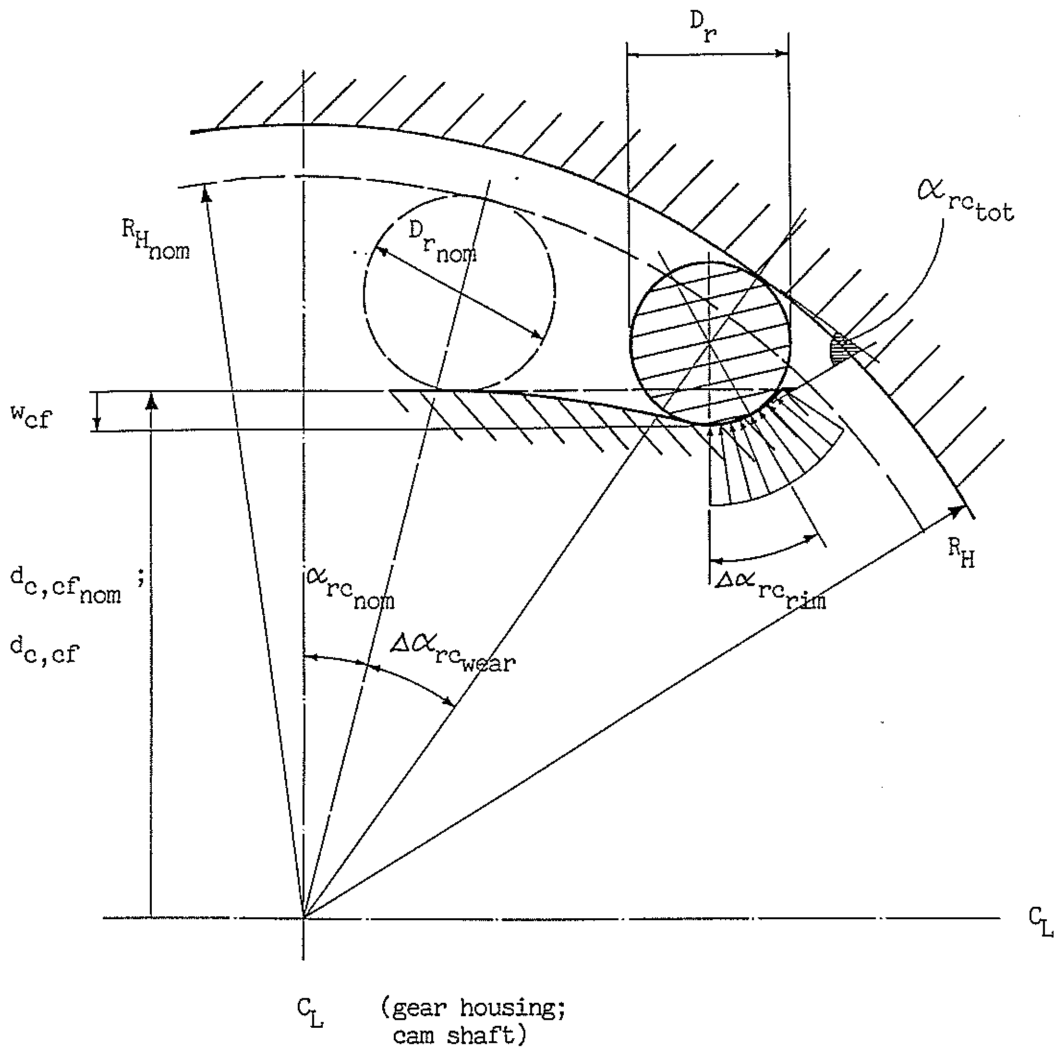
During normal operation FWU rpm is equal to 8100.

3. Failure mechanism

The FWU malfunctions appeared to be related to excessive wear of the unit components. The key parameter in the FWU failure mechanism is the total roller contact angle, the mean angle between the roller contact surfaces with the gear housing inner race and the cam flat respectively, see figure 4. If gear housing, cam shaft, roller cage and rollers are all new (no wear) and would have nominal dimensions (nominal value = average of lower and upper blue print limit) the (nominal) roller contact angle would be equal to 3,5 degr. At full working load this angle increases with approximately 2,5 degr due to elastic deformations. Roller spit out occurs at a critical roller contact angle of appr. 12 degr, see figure 5, leaving a margin of some 6 degr for wear on the main components.

If the total angle exceeds 12 degr, spit out may occur, a phenomenon that can best be compared with a pee held by thumb and index-finger: if too much pressure is exercised, the pee will be pushed out. Something similar may happen to a roller, see figure 6 which also summarizes the possible consequences of one roller leaving drive position. In the worst case FWU drive is lost for a period long enough to shut down the fuel supply to the applicable engine. This automatic fuel shut off is a built-in protection against excessive overspeeding of the engine.

Late 1986 a stiffer roller cage retention spring (see figure 3) was introduced with the purpose of improved coupling characteristics. This so-called 'dash 102' spring had approximately twice the stiffness of the formerly used 'dash 1' spring (2,57 N/mm (14,7 lb/in) and 4,20 N/mm (24 lb/in) respectively). An unforeseen side-effect of this tougher spring however was an enhanced wear rate during periods of free-wheeling. The components would thus wear too quickly and the critical roller contact angle would be reached prematurely.

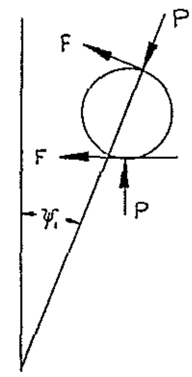


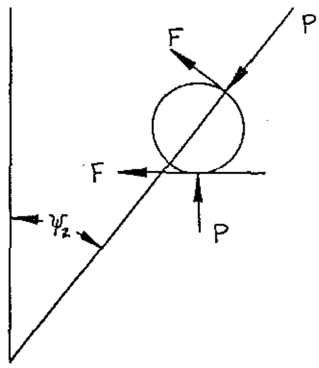
———— — ————	nominal contours
————————	worn contours

α_{rc}	= roller contact angle	(rad, degr)
$d_{c,cf}$	= distance from center(line) to cam flat	(mm)
w_{cf}	= wear on cam flat	(mm)
D_r	= diameter of roller	(mm)
R_H	= radius of housing	(mm)
(nom	= nominal)	

Figure 4: Effect of wear on dimensions of FWU components; definition of characteristic angles

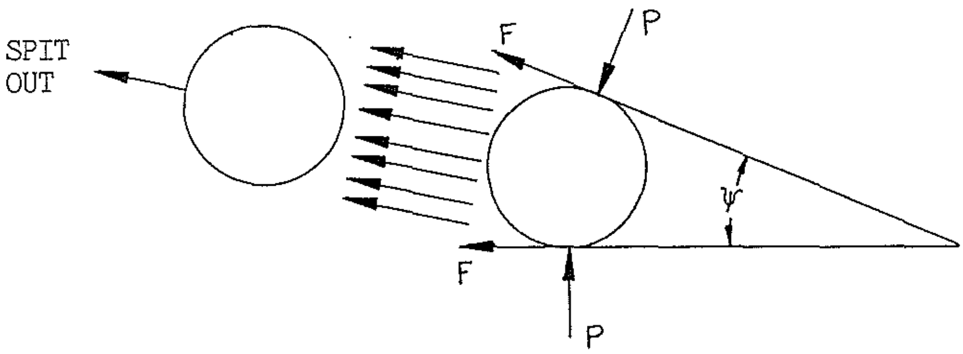
T=11670
n=12 ROLLERS
R=1.876
μ=.1





CASE 1- ψ_1=6°		CASE 2- ψ_2=12°
T=nFR		T=nFR
F=11670/(12)(1.876)=518#	=	F=11670/(12)(1.876)=518#
F=Ptan(ψ_1/2)		F=Ptan(ψ_2/2)
P=518/tan3=9880#		P=518/tan6=4930#
Fmax=μP=.1(9880)=988#		Fmax=μP=.1(4930)=493#
518#<988#		518#>493#
DRIVE		SPIT OUT

Figure 5: Maximum roller contact angle



- ROLLER EXITS DRIVE POSITION
- CAGE CARRIES ALL OTHER ROLLERS
- DRIVE IS LOST
  - MAY REENGAGE
  - MAY CAUSE ENGINE SHUT DOWN

Figure 6: Roller spit out and consequences

In November and December 1987 all 'dash 102' springs were replaced by the original 'dash 1' springs again and a mid-point inspection (at 1250 hrs) was introduced for all operators. Furthermore rotor starting procedures were changed. Nowadays both engines are started up prior to releasing the main rotor brake (gear housing stationary) so that the FWUs engage with low torque and are already locked when the brake is released. Then both engines are to be advanced to speed together, again avoiding the overrun condition. Before this procedure was issued, the main rotor was started up with one engine, thus causing wear on the other FWU. Similar FWU problems have been reduced considerably since these measures have been implemented.

4. Experience KLM Helikopters; spit out angle analysis

Starting September 1987, as a means of prevention, FWU wear is monitored frequently at KLM Helikopters. The inspections involved comprise extensive measurements on camshaft, gear housing, rollers and roller cage - the FWU components that are most susceptible to wear - and take place prior to installing a 'new' MGB on the aircraft, at mid-life and before a MGB is sent back to Sikorsky (the measurements being carried out by KLM's Central Measuring Department). The dimensions measured are:

1. cam shaft: distance from cam shaft centerline to each cam flat; distance between opposite cam flats
2. gear housing: inside diameter (3 locations; scans)
3. roller retainer: width of slots
4. rollers (12): diameter (3 locations).

With these data (except for the roller retainer) and figure 4 the total increase in roller contact angle due to wear can be determined as follows:

$$\Delta\alpha_{rc_{wear_{tot}}} = \Delta\alpha_{rc_{wear}} + \Delta\alpha_{rc_{rim}} =$$

$$= \left\{ \arccos\left[\frac{(d_{c,cf} - w_{cf}) + \frac{D_r}{2}}{R_H - \frac{D_r}{2}}\right] - \arccos\left[\frac{d_{c,cf} + \frac{D_r}{2}}{R_H - \frac{D_r}{2}}\right]_{nom} \right\} + \tfrac{1}{2}\arccos\left[\frac{\frac{D_r}{2} - w_{cf}}{\frac{D_r}{2}}\right]$$

Of these three terms the second represents the nominal roller contact angle (3,5 degr), assuming that all components have nominal dimensions and have no wear at all; the first term represents the worn condition: it accounts for wear on gear housing, cam flat and roller, and for the deviation of the distance cam centerline to cam flat from the nominal value.

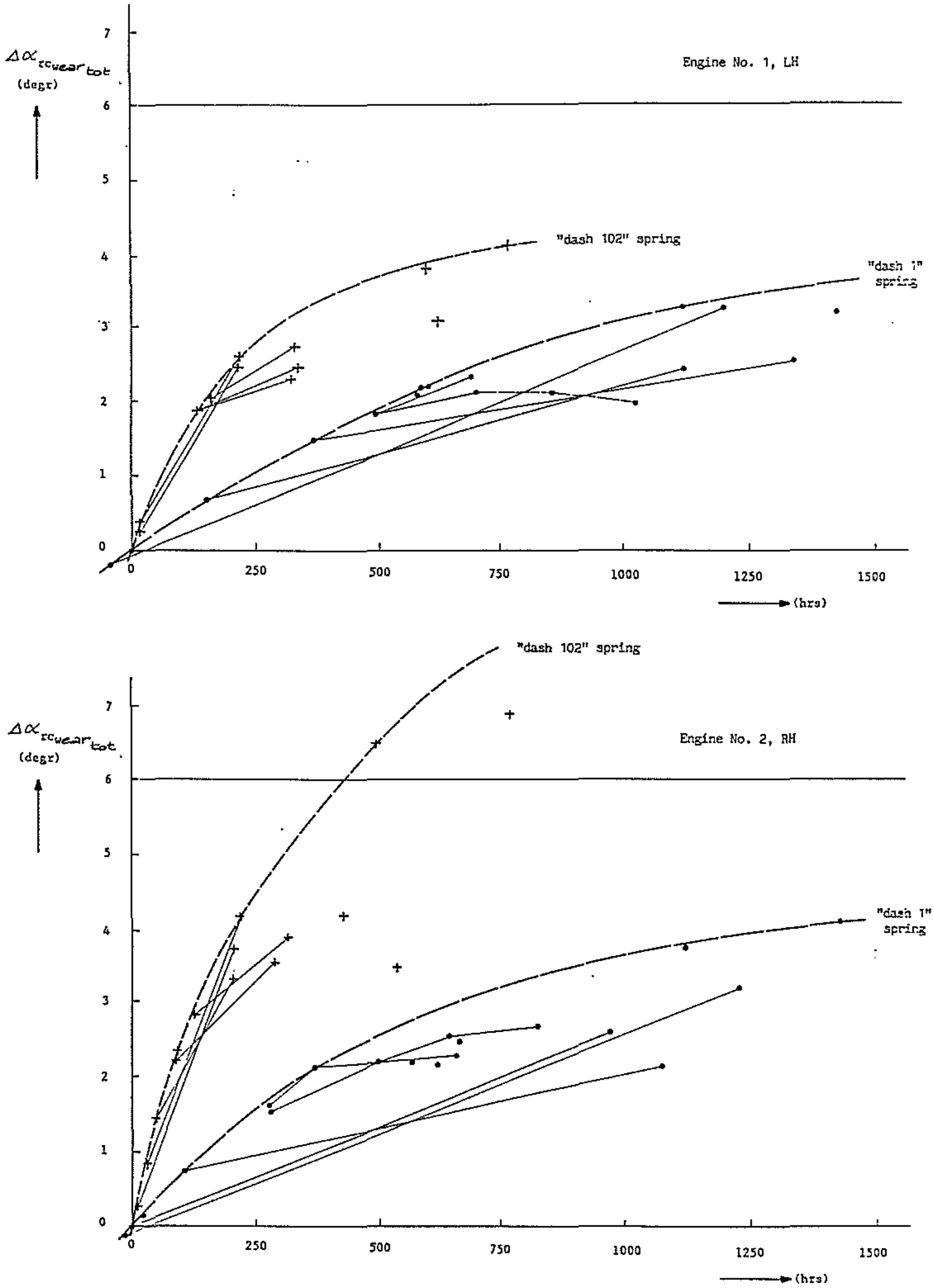


Figure 7: Increase in roller contact angle due to wear and imperfections versus flghthrs, for LH and RH engine and both 'dash 1' and 'dash 102' spring (experience KLM Helikopters)

The last term represents the increase in roller contact angle due to tilting of the pressure distribution between roller and cam flat as a result of the small rim (see figure 4) that is created by the wear process (FWU in overrunning condition).

Results for the total wear angle are shown in figure 7: the dashed curves are limiting curves (worst cases to date) for LH and RH engine respectively and both for the 'dash 1' and 'dash 102' springs.
The graphs reveal the following:

1. the 'dash 102' springs were causing considerably more wear than the originally and presently used 'dash 1' springs, especially on the RH FWU;

2. the difference between LH and RH FWU wear is remarkable for the 'dash 102' spring, but marginal in case of the 'dash 1' spring;

3. in all four cases the wear rate decreases with increasing no. of hrs which may be attributed to the earlier mentioned rim in the cam flats, that increases the contact surface, thus decreasing contact pressure between rollers and cam flats;

4. the critical wear angle of 6 degr was confirmed by two engine flame-outs due to roller spit outs experienced by KLM Helikopers on two RH FWUs incorporating the 'dash 102' springs, with wear angles exceeding 6 degr.
   It also explains the sudden increase in FWU failures in 1987 after incorporation of the 'dash 102' roller cage retention spring: according to the lower graph RH FWUs with this spring would very likely have failed long before reaching a time between overhauls (TBO) of 2500 hrs;

5. there is a considerable spread in results, which may be due to hardness differences between the components, excentricity of gear housing and/or cam shaft, more than normal play on roller cage, (MGB) vibrations, etc;

6. considering the results with the 'dash 1' spring, experience gained sofar seem to justify the assumption that the increase in roller contact angle due to wear remains well below the critical angle even when operating the FWUs from 0 to 2500 hrs.

The considerable difference in wear rate for the 'dash 102' spring made Sikorsky decide to implement some changes mainly to the RH FWU. Together with other small modifications this led to an improved FWU.

5. Improved FWU

In addition to the improvements already mentioned in the last paragraph of chapter 3, Sikorsky recently developed a modified FWU with the objective to reduce wear and improve reliability.

Basically the modification consists of a redesign of the righthand roller cage support (only one ring up until now), so that it almost becomes identical to that of the lefthand (two support rings). Furthermore the pins are somewhat shorter (appr. 1,5 mm) so that the spring force is decreased a little which should also reduce wear. Prior to implementation of the modifications to all S-61L/N FWUs though, the improved units will be tested on a small number of commercial aircraft.

6. Lead-the-Fleet-Program

As a consequence of the experience gained at KLM Helikopters by monitoring the wear pattern of the FWU's, a lead-the-fleet program is now being performed trying to achieve two goals set for the improved FWU:

1. delete the present midlife inspection (at 1250 hrs);
2. extend FWU-'life' from 2500 to 3000 hrs.

Deleting the midlife inspection will save many manhours involved per complete FWU inspection and hopefully bring back the good old days where nobody worried about FWUs. Extending their life to 3000 hrs should be seen in the light of a possible increase in MGB TBO from 2500 hrs to 3000 hrs.

Four aircraft will be involved, 2 at KLM Helikopters (Netherlands) and 2 at Helikopter Service (Norway). Their FWUs are to be inspected at preset intervals, i.e. at 0, 300, 600, 1200, 2500 and 3000 hrs. Flying with an average of approximately 1000 hrs/yr for the S-61N the program will last for 3 to 3,5 years in case 3000 hrs can be reached. Early September '89 the improved FWUs installed in KLM Helikopters' aircraft (installation: July '89) had accumulated 200 and 115 hrs respectively. Helikopter Service is expected to install their units soon.

This will be the first opportunity to monitor FWU wear for so long a period since no components will be changed during the program, even if they are out of blue print or ORI limits, contrary to nowadays common practice where those out of limits components have to be replaced. The continuity of the program will depend on the actual value and trend of the roller contact wear angle. The actual value should remain below 6 degr while the program should reveal whether the theory about FWU wear as outlined in chapter 4 is correct.