Piper PA-34-200-2 G-EXEC

AAIB Bulletin No: 3/2002	**Ref: EW/C1999/10/05**	**Category: 1.3**
Aircraft Type and Registration:	Piper PA-34-200-2 G-EXEC	
No & Type of Engines:	2 Lycoming IO-360-C1E6	
Year of Manufacture:	1974	
Date & Time (UTC):	28 October 1999 at 1705	
Location:	Stapleford Airfield	
Type of Flight:	Private	
Persons on Board:	Crew - 1	Passengers - 0
Injuries:	Crew - 0	Passengers - 0
Nature of Damage:	Both propellers severely bent, engines shock loaded, Nose cone and nose landing gear doors damaged	
Commander's Licence:	Commercial Pilots Licence	
Commander's Age:	28 years	
Commander's Flying Experience:	1,116 hrs of which 237 hrs were on type	
	Last 90 days -	121 hours
	Last 28 days -	61 hours
Information Source:	AAIB Field Investigation	

History of the accident

After an uneventful positioning flight, the aircraft was landed at Stapleford on the tarmac portion of Runway 22; the landing was made with full flaps and full aft elevator was applied. The main wheels touched down softly and the nosewheel was then lowered to the ground. Gradual braking was applied and, at the same time, full back elevator was reapplied. However, the nose continued to lower until it came into contact with the runway. The pilot then, immediately, shut down both engines and the electrical system and closed the fuel cocks. The aircraft slid to a stop, still on the tarmac section of the runway, and the pilot left the aircraft.

The aircraft was recovered from the runway and the nose landing gear was pulled down. Initial examination by the engineers who recovered the aircraft revealed that the upper, adjustable, eye end of the lower downlock link assembly had broken in its threaded portion. The nose landing gear was made safe by bracing the drag link into the 'over-centre' position.

Operation and adjustment of the nose landing gear (See Figures 1, 1a & 1b)

The nose landing gear of the Seneca is of the forward retracting type which, when extended, has the wheel axle forward of the oleo pivot. When retracted, the gear is held up by hydraulic pressure in the actuator and, when extended, it is held in the down position by a geometric downlock mechanism. There are no locking hooks for either position. The primary brace against collapse, when the nose landing gear is extended and under load, is the drag link assembly. When the landing gear is fully extended, the drag link centre pivot should be offset below the line between its two end pivots and, in this position, the fixed stops of the drag link centre joint, which limit the over-centre travel of these links, should be in abutment. (See Figure 1 Details *(jpg 97kb)*).

The overall geometry of the landing gear is such that aircraft weight on the nose-wheel applies a compressive load to the drag link assembly which tends to drive it more firmly into the safe 'over-centre' condition when the gear is properly extended. Conversely, it will tend to cause the drag link to fold, and the gear to retract, if the load is applied when the drag link assembly is in an 'under-centre' condition.

The downlock assembly, which forms the geometric lock to keep the drag links in the extended position, also acts as an integral part of the retraction/extension mechanism. The retraction actuator attaches to the centre pivot bolt of the two part, articulating, downlock linkage. (See Figures 1a & 1b) During the retraction cycle, the first movement of the actuator causes the downlock linkage to pull the drag link out of the over-centre condition; during the extension cycle the final movement of the actuator causes the downlock assembly to push the drag link into the fully over-centre position. There is a downlock *(jpg 155kb)* spring, which pulls the downlock centre pivot aftwards, assisting the downlock assembly into the 'gear locked down' position, particularly during 'free fall' extensions.

The lower part of the downlock link assembly is a sprung strut (see Figure 2 *(jpg 135kb)*) which has a spring force of about 2-3 lbs (see AAIB Bulletin 12/2000, ref C2000/12/06) and is compressible by about 0.06 inch. The sprung travel is limited by a cross-pin, fitted through the shank of the lower eye fitting, running in a control aperture in the skirt of the lower downlock link body. This aperture is described in the Service Manual as a 'slot'. The length of the lower downlock link is adjustable and is correct if, when the drag link assembly is driven to the fully over-centre position, the lower downlock link is almost fully compressed; the clearance of the cross-pin from the upper end of the slot, established by the rigging procedure, is a half turn of the adjustment thread, which is about 0.018 inch.

The procedure for rigging the nose landing gear drag links, retraction actuator and downlock mechanism is laid down in the PA34-200-T (Seneca II) Service Manual, Chapter VII (Landing gear and brake system), Paragraph 7-11d. The relevant pages of this are replicated at Appendix A.

Examination of the nose landing gear.

Further examination of the failed landing gear, by the AAIB, showed that the upper eye end of the sprung lower downlock link had failed in a single bending overload event, at the point where its adjustment threads entered the lock-nut at the top of the link body. The cross pin and the slot in the skirt of the link body also exhibited evidence of high compressive axial loading of the link, which took the form of severe bearing crushing of the upper edge of the aperture and bending of the cross-pin. (See Figure 2b) Although there were slight wear marks indicating that the link had been extended to its maximum length in service, this link had been fitted, new, only five flights before the accident flight, and thus evidence of the most compressed length regularly achieved during the landing gear extension cycle had not yet developed.

There was evidence that there had been some distortion of the upper downlock link, consistent with severe upward loading of the downlock link centre pivot. The lateral stagger of the joint between the two parts of the downlock link results in twisting forces being applied to the upper link and the bulkhead support structure as a result of high compressive loads in the link assembly. (see Figure 1a *(jpg 97kb)*)

Analysis

1 Loads in the downlock link

The observed pattern of damage to the nose landing gear down-locking system components was all consistent with a high compressive load having been applied to the downlock link.

Under normal static conditions, with the mechanism free of significant wear and correctly adjusted, the downlock is only required to sustain a relatively light compressive load, sufficient to keep the drag link assembly in a safe over-centre position (See para. b below). However, relatively large compressive loads can be generated in service either as a result of misrigging of the length of the lower downlock link or through shock loads transmitted from the oleo strut.

a Sources of compressive load in downlock linkage due to rigging

Study of the geometry of the nose landing gear retraction system reveals two ways of generating high compressive loads in the downlock linkage during normal operation, as a result of rigging, if the mechanism and its supporting structure are both intact and there is no significant wear.

a (i) Lower downlock link too long

If the lower link has been adjusted to be too long, the action of the landing gear actuator driving the two parts of the downlock linkage, and, through them, the drag link assembly, into the 'locked' position will, after the drag link stops come into abutment, put a compressive load into the downlock links. The magnitude of this load will depend on the degree to which the lower downlock link is over-length.

a (ii) Lower downlock link too short

If the lower downlock link has been adjusted to be too short, only the relatively weak spring of the lower downlock link will be driving the drag link assembly towards over-centre, but no further than to the limit of the movement available to the cross-pin in the slot. If the link is very much too short, this may result in enough sprung compressibility being available in the link for the drag link assembly to move into an under-centre position before the cross-pin bottoms out in the slot. If aircraft weight is put on the nosewheel with the mechanism in this condition, the drag link assembly will tend to fold upwards, putting the downlock mechanism into compression.

Because of the distortions and failures which had occurred in the lower downlock link, as a result of its collapse, it was not possible to determine the pre-collapse rigging of this landing gear.

b Effects of wheel loads transmitted to the downlock link

As a result of the overall geometry of the nose landing gear, both drag loads on the nose-wheel, and the unsupported weight of the landing gear, apply a tensile loading to the drag link assembly. This, in turn, will tend to pull the drag link centre pivot point towards the 'on-centre' state. If the nose gear is correctly adjusted according to the Manual, the effect of pulling the drag link assembly towards the 'on centre' state results in a compressive reaction in the downlock link which should prevent significant movement of the drag link towards 'on centre'. It should be noted, however, that correct adjustment of the link should leave a clearance of about 0.02 inch between the cross pin and the top of the slot.

Taking the geometry of the gear into account, each 100 lbs of aircraft weight on the wheel causes a compressive force of about 136 lbs in the drag link and each 100 lbs of drag load on the wheel results in about 550 lbs tension. The resolved component of this force drawing the drag link centre pivot into alignment with its end pivots will be about 0.04 of the tension in the link for each 0.1 inch of over-centre offset and the resultant compression in the downlock link to resist this force will be 3.6 times that.

During groundborne operation, if the aircraft is on a grass or a rough surface, the longitudinal and vertical loads on the nosewheel will tend to vary rapidly. Such loading will tend to flick the centre pivot of the drag link assembly, repeatedly, towards the 'on-centre' condition and the force with which this occurs will be greater if the initial 'over-centre' set of the drag link is larger. It will result in 'hammering' on the thin line contact between the cross pin and the upper end of the slot of downlock link, leading to high bearing stresses in, and crushing of, the upper end of the slot. This, in turn, will lead to an effective maladjustment of the downlock link length by producing an effective shortening of its hard strut length. The resulting increased travel will allow greater inertial flicking of the drag link centre pivot and result in an increased rate of damage as slack in the downlock link increases. Any slack in the pivots of the drag link will also be exploited in allowing additional movement to the components and increase the hammering impulses. The relative flexibility of the downlock link support structure will also allow more movement than is apparently available statically, further exacerbating the situation.

2 Review of the procedure for rigging the nose landing gear. (see Appendix A)

The fundamental intention of the part of the procedure for rigging the nose landing gear laid down in the Service Manual sub-para. 7.11d, is to ensure that , in the 'landing gear extended' condition, the drag link assembly centre pivot stops are held securely in abutment and in an over-centre state. There are two adjustable dimensions which can influence this which are the extended length of the retracting cylinder and the compressed length of the lower downlock link.

The stops on the drag link assembly are not adjustable, being machined butting faces but the 'through centre' travel of the centre pivot is stated to be critical and if the geometric requirements laid down in the manual are not met, the drag links must be replaced. At the time of this accident, the part of the procedure in which the over-centre position of the drag link centre pivot, with the stops in abutment is checked, (sub-sub-para 7-11d-10) was the final step. If it is found not to be satisfactory, all the adjustments made, up to that point, will have been a wasted effort. This does not appear to be the right place in the setting up sequence for the determination of the basic geometric requirement to be satisfied, even though, with an established assembly, an incorrect over-centre travel should be unlikely.

In the Service Manual, this procedure, to check the over-centre travel, is only described with the drag links installed in the aircraft, which allows only restricted access to the nosewheel bay and is awkward to perform. Since, with the aircraft in this state, it is very simple to remove the drag link assembly, it would appear preferable to make this critical measurement on the bench where it is likely to be more accurate. In the manual for the Seneca II there is also an inconsistency in the required value of the 'through centre' dimension. There is a difference between that given in the text (0.3 inch or greater, acceptable if greater than 0.24 and Customer Service informed, replace drag links if less than 0.24 inch) and that given at the reference in the text, Figure 7.2 Sketch E (0.25 inch or greater, no less than 0.19 inch). There is another diagram in Figure 7.2, close to Sketch E and also referring to the over-centre measurement, which is dimensionally at odds with Sketch E but in accordance with the text. It is further noted that there is no specified upper limit to the over-centre measurement, the manufacturer appearing to rely on individuals to judge what they consider to be excessive.

The possibility was examined, that this apparent anomaly arose because the dimension in Sketch E was specified through bolt centrelines and that in the text and the second diagram was across the bolt shanks. The three bolts used at the drag brace pivots are all of different diameter; that at the attachment to the leg being 7/16" (AN7-35), the centre pivot 3/8"(NAS464 P6L21) and the bulkhead attachment being 5/16"(AN5-16A). With the centre pivot being almost exactly at the geometrical centre of the assembly and the three bolts decreasing progressively in diameter by 1/16", the 'through centres' and 'across shanks' measurements should be essentially identical. The through centre travel specified in the procedures for the Seneca I and for the Seneca III, IV and V is the same as that given in Sketch E of the Seneca II manual.

The procedure for installing and rigging the nose landing gear is performed with the aircraft placed on jacks. In this state, the unsupported weight of the landing gear will tend to pull the drag link centre pivot towards alignment with the end pivots, although the weight of the links will bias it back towards an over-centre state but not sufficiently to bring the stops into abutment. Ensuring a firm abutment of the drag link stops, throughout the downlock link adjustment process, can most easily be achieved if the weight of the landing gear is taken up by wedging up under the nosewheel, once the drag link assembly is in position. The method proposed in the procedure is to push the centre pivot downwards by hand, but when the hand is removed to make any required adjustments, the position of the centre pivot will revert to its 'at rest' position and thereby make correct adjustment more problematic.

Whilst reviewing the procedure for rigging the landing gear, in sub-para. 7.11d, it was noted that step 9 appeared to be a repeat of the combination of steps 7 & 8. There appears to be an error of identification of the 'downlock link assembly' (41) in step 8 (Item 41 on the reference drawing Fig 7.2 is a 'rod end bearing') which is of concern in a part of the rigging procedure involving four components which are described as '- link'.

Another matter of concern was that there appear to be no Service Tolerances specified for the drag link pivots in the Table VII-I which, together with the accompanying Figure 7-1A, was added to the Service Manual in March 1981. The only point at which the wear in these pivots is specifically addressed in the procedures is at 7-10b.1 where it is implicit in a global requirement for inspection of bolts, bearings and bushings; even then, a subjective assessment is all that is required. Since a slack fit in the drag link pivots is likely to increase any tendency for hammering of the lower downlock link, it would be desirable to keep any such slack to a minimum. It was also noted, in passing, that nowhere in the procedures for inspection and assembly of the nose landing gear is any attention drawn to this table of tolerances.

3 Occurrence of nose landing gear collapses on Seneca aircraft relative to other Types

From the number of nose landing gear collapses involving Senecas which had been investigated by the AAIB, it appeared that the type might be more prone to nose gear malfunction than other similar types in the same weight category. A statistical comparison over the last 15 years, using data from the CAA occurrence reporting system, was made, relating the number of occurrences to the number of aircraft years on the UK register for each type. The survey was restricted to types of which there were, on average, 20 or more on the UK register; there were, on average, 118 Senecas on the register in each year representing just under one third of the significant light twin fleet.

The result of this survey indicated that nose landing gear collapses on the PA 34 Series fleet were more than twice as frequent as the average on the remainder of the light twin fleet and nearly three times that of the numerically similar PA 23 Aztec series (average of 125 on the register in each year). Over the 15 years of the survey there were 35 recorded collapses on Senecas against 13 for Aztecs. If the analysis is taken over the last 10 years the results, although marginally better for the Seneca, are broadly similar, the Seneca representing just over one third of the fleet and accounting for half of the nose landing gear collapses.

Although, over the 15 year period, the majority of all collapses had occurred during the landing phase, of the collapses which occurred during take-off, one out of four involved Senecas, and of collapses during taxying, two out of three.

Conclusions

The PA 34 Seneca type has persistently suffered a noticeably higher rate of nose landing gear collapses than all but one of the other numerically important light twin types. The AAIB has investigated 4 of the most recent ones in detail and a common feature observed in all cases has been the failure, in bending, of the upper rod end of the lower downlock link. Crushing damage to the upper arc of the 'slot' has also been a regular finding.

It is unclear, because of the distortions which have occurred during the subsequent collapses, whether these failures are the result of actual misrigging or of maladjustment which has developed as a result of accrued crushing damage on the upper arc of the downlock link slot. The accumulated evidence from the previous AAIB field investigations into PA 34 nosewheel collapses, however, indicates that both the instructions for rigging the nose landing gear mechanism and the robustness of the downlock link require to be addressed. The susceptibility of the upper end of the 'slot' to crushing damage, which will lead to increasing effective misrigging of the downlock with the number of landings since the last time checked, is also an issue of robustness.

The consistency of the rigging instructions, particularly those related to the over-centre travel of the drag link assembly, should be improved and a maximum limit for this over centre should be specified.

The wear limits allowed in the various pivot points of the nose landing gear should also be reviewed, since this affects the degree of 'hammering' damage inflicted on the 'slot'.

Safety Action

A memorandum was received from the FAA on 29 January 2002 indicating some proposed action on two previous AAIB recommendations, which are reiterated below:

Safety Recommendation 2000-45

It is therefore recommended that the New Piper Aircraft Company should review and amplify the instructions for rigging the nose landing gear downlock mechanism contained in the Piper PA-34 Maintenance Manual.

Safety recommendation 2000-46

The FAA and the CAA, in conjunction with the New Piper Aircraft Company, should investigate the causes of reported cases of Piper Seneca nose landing gear collapse. Consideration should be given to design modification which should minimise movement of the drag brace resulting from loads applied to the nose landing gear, and to ensure sufficient force is applied to the drag brace to retain it in the locked condition.

Annex A

Annex A: Piper Seneca II service manual *(Adobe Acrobat 12kb)*

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The *Adobe Acrobat Reader* can be freely downloaded.
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