

National Transportation Safety Board

Office of Aviation Safety

Washington, DC 20594



CEN22LA153

AIRWORTHINESS

Group Chair's Factual Report

June 23, 2022

A. ACCIDENT

Location: Olive Branch, Mississippi
Date: March 23, 2022
Time: 1028 central daylight time (CDT)
1528 coordinated universal time (UTC)
Airplane: Piper PA-46-600TP, S/N 4698190, N627PR

B. AIRWORTHINESS GROUP

Group Chair	Clinton R. Crookshanks National Transportation Safety Board Denver, Colorado
Group Member	Brooks "Chip" Vaughan Federal Aviation Administration Jackson, Mississippi
Group Member	Damian Galbraith Piper Aircraft, Inc. Vero Beach, Florida

C. DETAILS OF THE INVESTIGATION

The group examined the accident airplane, runway markings, and ground scars at the Olive Branch Airport on March 30, 2022. The nose landing gear (NLG) was removed from the airplane and shipped to Piper Aircraft, Inc. in Vero Beach, FL.

The group examined and disassembled the NLG at the Piper facility on May 11, 2022.

D. FACTUAL INFORMATION

1.0 Aircraft

The Piper PA-46-600TP (M600) is a single turbine engine, propeller driven, low wing airplane that was certified in June 2016, Figure 1. The airplane is equipped with a conventional tail, retractable tricycle landing gear, and can carry a single pilot and 5 passengers. The airplane is 29.7 feet long, 11.3 feet high at the tail and has a wingspan of 43.16 feet. The airplane is powered by a Pratt & Whitney Canada PT6A turbine engine that drives a Hartzell four or five-blade constant speed, full feathering, reversible propeller. The accident airplane was equipped with a five-blade composite propeller.

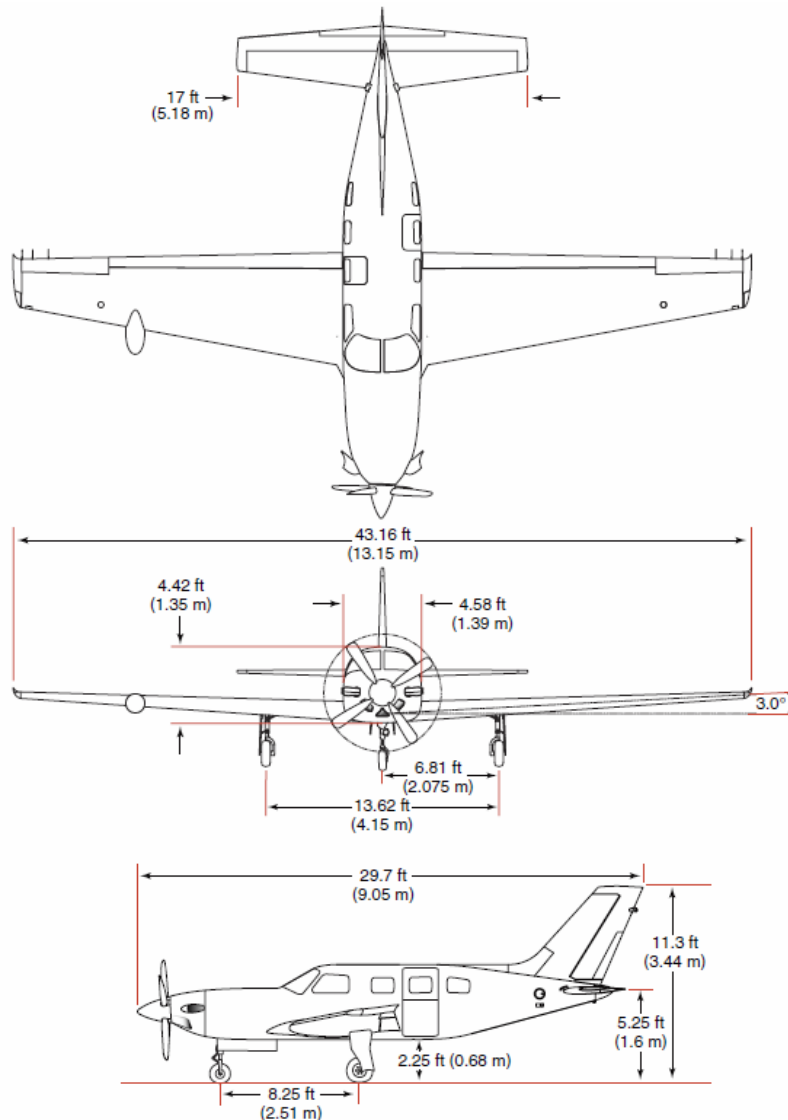


Figure 1. Piper M600 3-view drawing

1.1 Nose Landing Gear Steering

The retractable nose landing gear (NLG) is attached to the engine mount at the upper end of the trunnion assembly by two trunnion bolts. The NLG strut assembly is installed inside the trunnion assembly where it can rotate for nose wheel steering. The retract actuator is attached to the NLG trunnion assembly and engine mount to allow the NLG to retract aft into the wheel well. A down spring is also attached to the trunnion assembly and engine mount to assist with NLG extension if there is a hydraulic failure. During retraction, the NLG strut and tire rotate 90° left through a mechanism that stows the NLG tire in a horizontal position. The NLG is steerable through a 50° arc by use of the rudder pedals, 20° left and 30° right, Figure 2. The pilot and right seat rudder pedals are hung from a torque tube assembly below the instrument panel that connects both right rudder pedals to each other and both left

rudder pedals to each other. The rudder is connected by cables to sectors on the rudder pedal torque tubes. The rudder cables run aft through the fuselage to the rudder sector. The pilot right rudder pedal and the right seat left rudder pedal are connected to the steering bell-crank through pushrods that translate the linear motion of the pedals to a rotational motion of the bell-crank. The steering bell crank is attached to a fitting in the aft end of the NLG wheel well. Bellows assemblies are installed around the pushrods where they pass through the pressure bulkhead. The primary rudder mechanical stops are located adjacent to the rudder sector in the empennage to limit the deflection of the rudder and thus the motion of the rudder pedals. Secondary rudder pedal mechanical stops are installed in a machined aluminum fitting aft of the steering bell-crank. The secondary stops allow for a small amount of additional motion of the rudder pedals as the rudder cables stretch before the stops engage the steering bell-crank. The steering bungee is connected to the left side of the steering bell-crank at the aft end and to the left side of the steering arm at the forward end to translate the rotational motion of the bell-crank to a rotational motion of the steering arm. A spring is installed in the bungee to isolate any vibrations from the NLG. The steering arm is attached to a mount plate on the engine mount with a bolt and can be adjusted forward and aft for proper rigging through a locking assembly. The NLG steering horn is attached to the top of the NLG strut with 3 bolts. With the gear in the extended position the right and left forward faces of the steering arm engage the right and left pads and rollers on the steering horn to transmit the rotational motion of the steering arm to a rotational motion of the NLG strut. When the NLG retracts, the strut rotates aft about the trunnion and the steering horn disengages from the steering arm preventing rudder pedal motion from being translated to NLG steering.

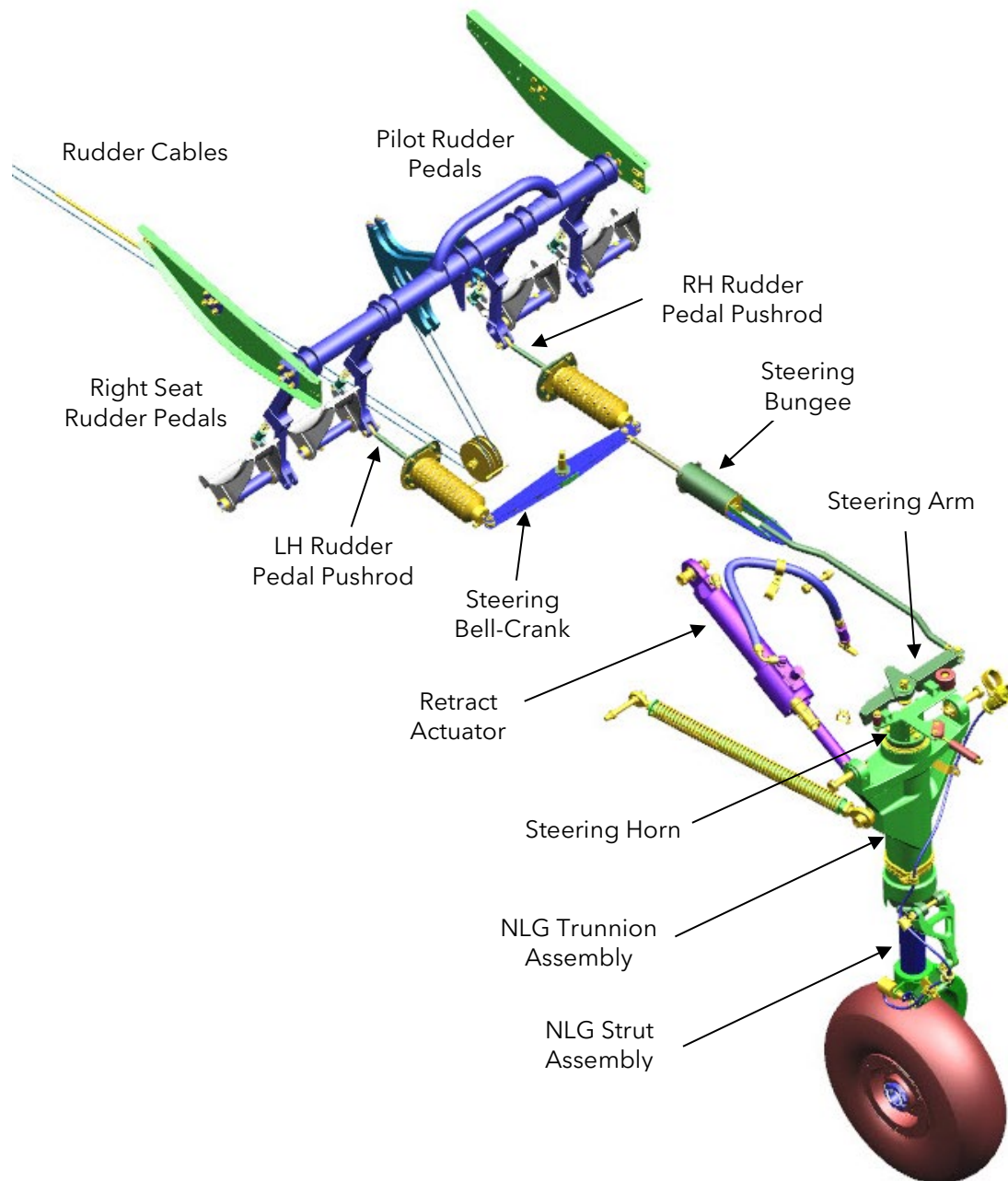


Figure 2. M600 steering system illustration

1.2 NLG Design Considerations

The tire contact patch is the portion of the tire contacting the runway at any given moment. The size and shape of the tire contact patch is directly related to the weight on the wheel, the stiffness of the tire sidewalls, and the amount of pressure in the tire. As the weight increases and the stiffness or pressure decreases the tire will deflect more so that the size of the contact patch increases. The size of the contact patch determines the amount of friction force that can be transmitted from the ground to the tire. Typically, the contact patch will be elliptical in shape. The friction

forces are distributed around the contact patch but can be assumed to be resolved into a single force that acts at the center of the contact patch.

NLG trail (t_M) refers to the location of the steering axis in relation to the vertical axis through the axle and can be positive, neutral, or negative. Caster is synonymous with trail and typically used in the automotive industry. Neutral trail (Figure 3, item A) occurs when the steering axis is vertical and coincident with the vertical axis and axle location resulting in minimum steering forces required and no appreciable torque about the steering axis when the wheel is rolling (neutral dynamic stability). This configuration has neutral static stability. Positive trail (Figure 3, item B) occurs when the steering axis intersects the ground forward of the vertical axis and results in a self-aligning torque about the steering axis when the wheel is rolling (positive dynamic stability). This configuration requires increased steering forces and is statically unstable if not restrained. Negative trail (Figure 3, item C, except angle is aft) occurs when the steering axis intersects the ground aft of the vertical axis and results in a torque about the steering axis that acts to increase the turn angle (negative dynamic stability) and is typically not used for NLG. This configuration requires increased steering forces and is considered statically unstable if not restrained. One way of obtaining trail on a NLG is to angle the NLG strut to some value known as the rake angle (θ). A positive rake angle results in positive trail, a neutral rake angle results in neutral trail, and a negative rake angle results in negative trail. The trail for a landing gear with rake is directly related to the angle of rake and the radius of the tire (R) as defined by $t_M = R \tan(\theta)$.

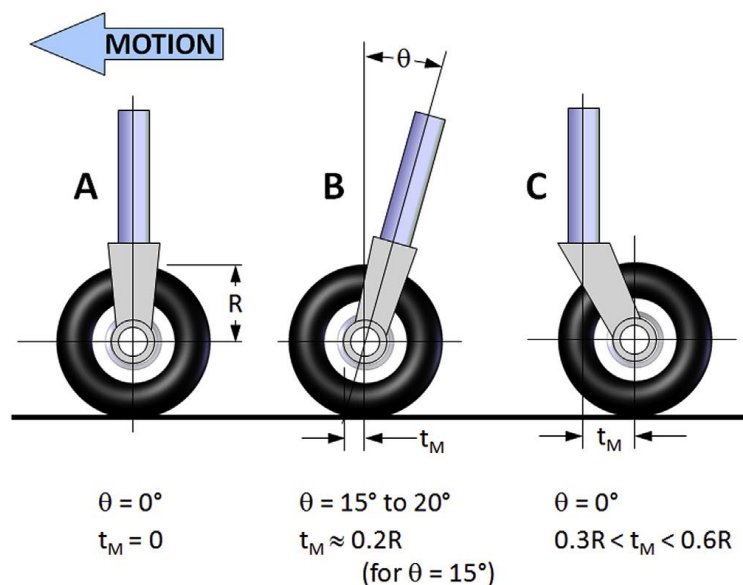


Figure 3. Nose landing gear design options¹

¹ Reproduced in part from Snorri Gudmundsson, *General Aviation Aircraft Design: Applied Methods and Procedures*, First Edition, Elsevier, Inc., 2014.

Another way to achieve positive trail on the NLG is through the use of offset. In this scenario the axle is moved aft of the steering axis through the design of the lower end of the landing gear (Figure 3, item C) and is similar to the front wheels on a shopping cart. This configuration has neutral static stability and positive dynamic stability but is more susceptible to shimmy than neutral trail landing gear. For a landing gear with offset and zero rake the trail (t_M) is the horizontal distance between the location of the axle and the vertical centerline (steering axis) of the landing gear.

With the tire rolling on the runway straight the frictional force generated by the NLG wheel is aligned with the longitudinal axis of the tire. Once the NLG is rotated left or right for steering the frictional force has a component aligned along the longitudinal axis of the tire and a component aligned 90° to the longitudinal axis of the tire. It is this side force that can affect the stability based on the trail. Positive trail results in positive dynamic stability and negative trail results in negative dynamic stability.

1.3 M600 NLG Rake Angle

The NLG rake angle on the M600 is defined as the angle between the lower fuselage skin and the centerline of the NLG strut. The rake angle is set at the factory to be 90° with a tolerance of +0.5°/0.0°. Service Letter 1286 issued on August 18, 2020, provides instructions for inspection and adjustment of NLG steering components including rake angle (Figure 4). The Service Letter has been revised 4 times since, but the rake angle has not changed.

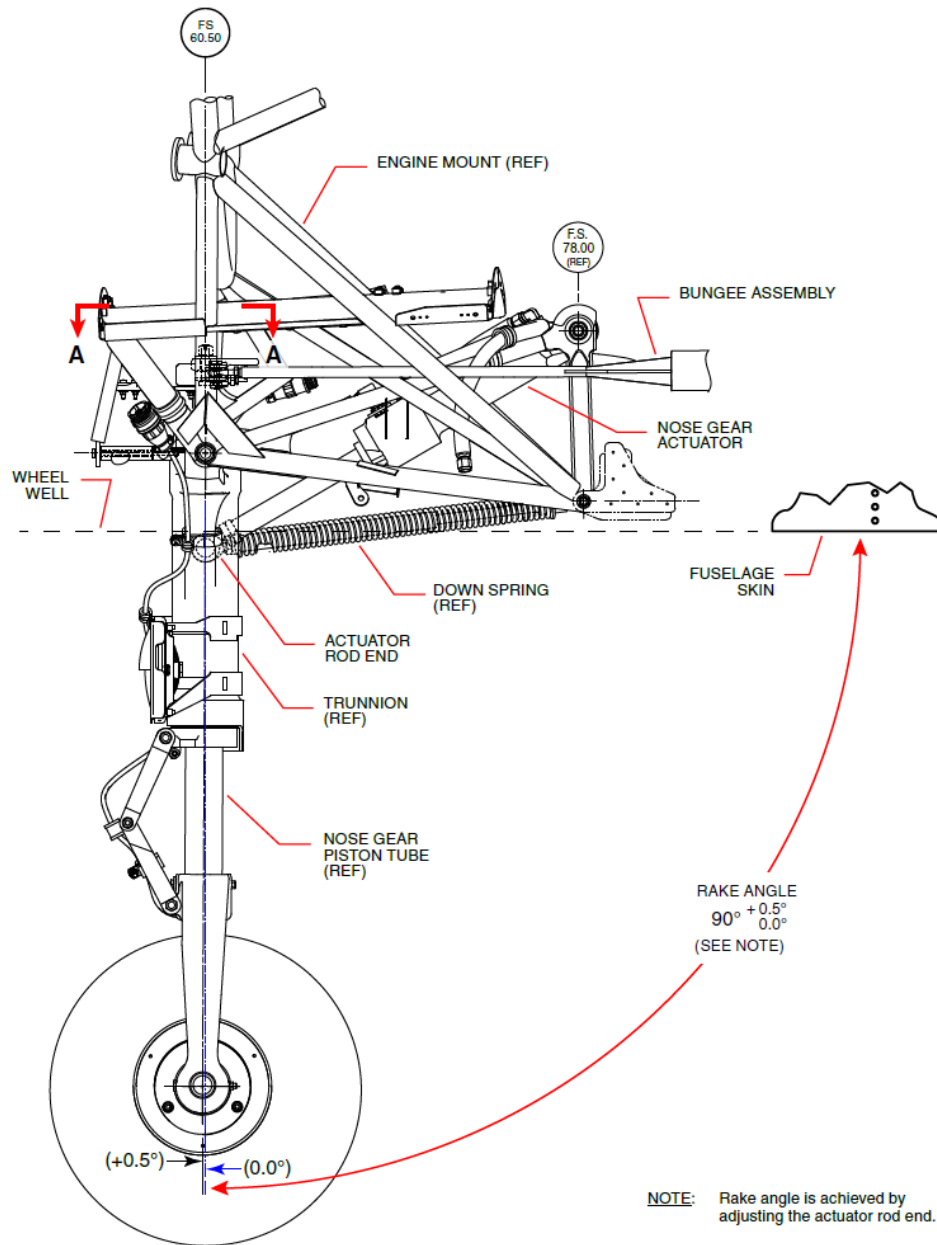


Figure 4. NLG rake angle drawing from Piper Service Letter 1286A

At a rake angle of 90° for the M600, the steering axis passes through the NLG axle and intersects the ground coincident with the center of the tire contact patch with the airplane stationary (zero trail). At a rake angle of 90.5° for the M600, the steering axis still passes through the NLG axle but intersects the ground slightly forward of the center of the tire contact patch with the airplane stationary (positive trail). Examination of the structural response of a landing gear at wheel touchdown shows that the gear will deflect aft initially due to wheel spin-up loads and then undergo a damped oscillation about its equilibrium point. The deflection can be as much as a few inches for tall landing gear on a heavy airplane.

1.4 Aircraft Towing

The airplane can be maneuvered on the ground by hand or power equipment using a tow bar attached to the NLG axle. Piper has established turn limits for towing and a placard is installed on the lower end of the NLG trunnion assembly. A corresponding red line on the NLG strut allows the operator to see the relationship between the turn angle of the NLG strut and wheel and the towing limits, Figure 5. The placard towing limits allow for turning about 20° right and left.



Figure 5. M600 NLG turn limits placard

The Piper M600 Pilot's Operating Handbook (POH) contains a caution about towing in Section 8 – Handling, Servicing and Maintenance as shown in Figure 6. Similar cautions are contained in the M600 Aircraft Maintenance Manual (AMM), Section 9-10-00 and the M600 Training Manual, Chapter 12.

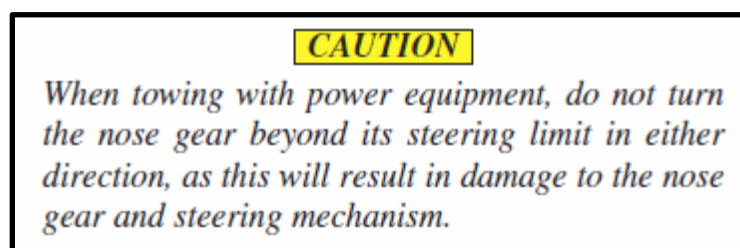


Figure 6. M600 POH towing caution

If the NLG is externally turned beyond the left or right placard limits, mechanical stops will engage where portions of the NLG and steering mechanism come into contact. If turned beyond limits to the right, a machined stop on the lower portion of the rotating strut assembly will contact a machined stop on the lower end of the stationary trunnion assembly, Figure 7. The right stops will engage when the NLG tire is turned about 36° right. Further turning to the right may damage the machined stops and will load the strut-trunnion interface but will not affect the steering arm or steering horn. If turned beyond limits to the left, the steering arm left

flange aft face will contact the steering arm mount plate on the engine mount, Figure 8. The left stops will engage when the NLG tire is turned about 30.5° left. Further turning to the left may damage the steering arm or mount plate or may apply a torsional load to the steering horn installed on top of the NLG strut. The rudder primary and secondary mechanical stops do not allow the mechanical turn limit stops to engage through pilot input at the rudder pedals. There are machined stops on the left side of the lower strut and trunnion assemblies similar to those on the right. These stops can only engage during NLG retraction as the strut rotates 90° to stow in the wheel well.



Figure 7. M600 right turn mechanical stop between trunnion and strut just prior to engagement



Figure 8. M600 left turn mechanical stop between engine mount and steering arm just prior to engagement

1.5 Aircraft Landing Procedures

The POH contains the airplane normal procedures in Section 4 and the landing procedures are contained in section 4.5p, as shown in Figure 9. The procedures caution the pilot about centering the rudder prior to nose wheel touchdown.

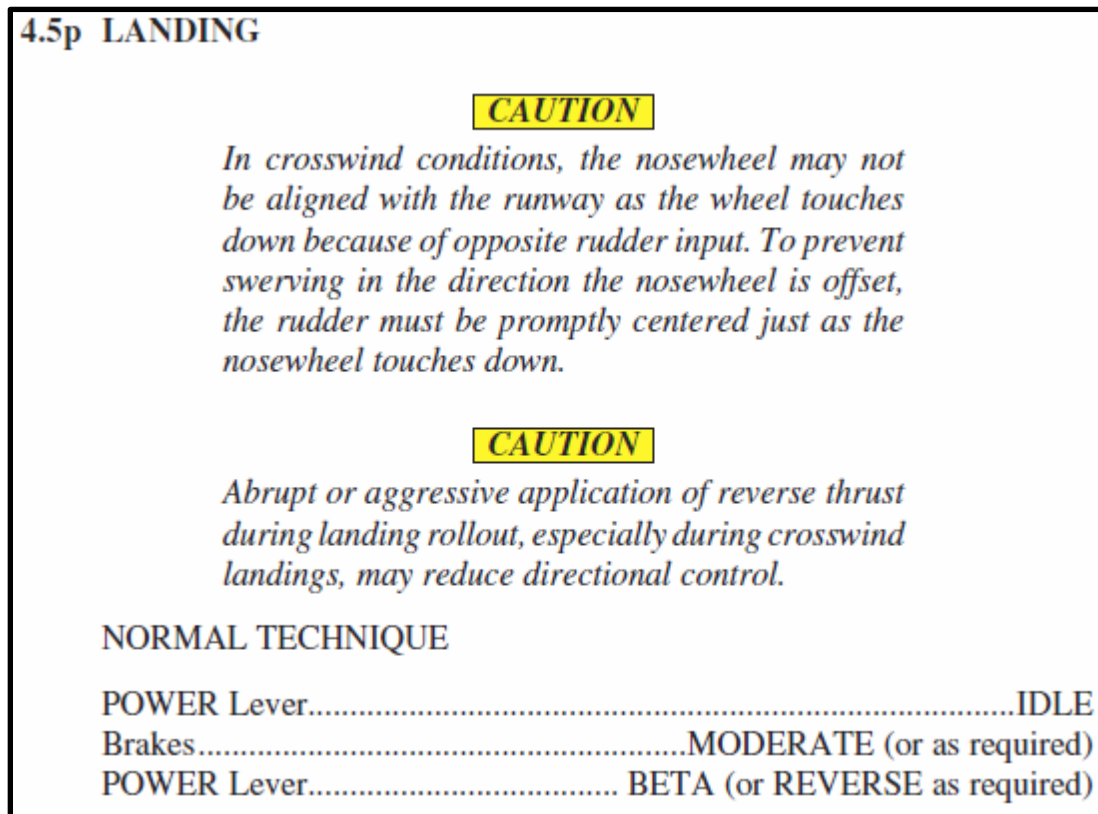


Figure 9. POH normal landing procedures

2.0 Accident Aircraft Examination

The airplane came to rest in the grass off the right side of the runway after the incident. The NLG was collapsed, and all 5 propeller blades were separated near the hub. The airplane had dirt and mud embedded in the nose wheel well and stuck all over the fuselage and wings. The airplane was moved to the ramp and tied down by airport personnel. The group examined the incident airplane on the ramp at Olive Branch Airport a week after the event.

The pilot recalled that the winds were 220° at 16 kts gusting to 22 kts during the landing. He stated that the airplane was drifting left after touchdown, and he was tapping the right rudder pedal to bring it back to the right. As the airplane reached the centerline it went hard right, and he could not control it. He felt that the nose wheel had a mind of its own.

The propeller blades were all fractured, the NLG was collapsed aft into the wheel well, the NLG doors were deformed, the lower fuselage skin was damaged in front of the wheel well, and there was a small dent in the upper engine cowling. The NLG, retract actuator, and emergency extension spring all sustained damage. The engine mount was fractured in three places.

The NLG right trunnion lug was fractured, and the bolt remained installed in the engine mount. The left trunnion lug was intact. The left trunnion bolt remained installed in the engine mount, but the nut was stripped off the threads and the bolt was bent. The steering horn was intact and remained attached to the top of the NLG, but the centering arm was deformed upward. The steering arm was intact and installed with no damage noted. There was no damage or missing paint on the mechanical steering stops. There was no damage noted to the steering bell crank and each rudder pedal pushrod rod end had about two threads exposed. The steering bungee remained installed and there was no grease protruding from the spring area. The NLG actuator was in the down and locked position and the forward rod end was deformed. The NLG wheel and tire were installed and rotated freely. The NLG tire pressure measured 84 psi. There was some crosswise scuffing on the NLG tire tread but no evidence of scuffing on the sidewalls. The damage precluded examination of the rake angle and NLG steering adjustments. The NLG assembly was removed from the airplane and shipped to Piper Aircraft for further examination.

There was no damage to the left or right main landing gear (MLG). The tire pressure on each MLG measured 90 psi. There was some crosswise scuffing on both MLG tires but no sidewall scuffing or flat spots noted.

3.0 Runway Examination

The first evidence of runway marking from the accident airplane was a light rubber transfer mark with the tread pattern evident from the LMLG that began about 760 feet from the runway 18 threshold and about 17 feet left of the centerline. The LMLG rubber transfer mark was continuous until it departed the right side of the runway and varied in intensity. There was a light rubber transfer mark with the tread pattern evident from the NLG that began about 900 feet from the runway 18 threshold and about 10 feet left of the centerline. The NLG rubber transfer mark was mostly continuous until it departed the right side of the runway and varied in intensity. The LMLG and NLG rubber transfer marks were aligned, separated by about 80 inches, and drifted to the left until about 1140 feet from the threshold when they veered sharply to the right (Figure 10). A rubber transfer mark from the RMLG was not discernable until about 1170 feet from the runway 18 threshold and was not continuous to the departure point. At the point where the RMLG mark became evident, the perpendicular distance between the RMLG and NLG marks measured 51 inches and between the LMLG and NLG measured 106 inches. Throughout the right veer the LMLG rubber transfer mark varied from moderate to heavy intensity with the tread pattern evident consistent with moderate to heavy braking. The NLG rubber

transfer mark during the veer was initially of moderate intensity with the tread pattern evident but transitioned to heavy intensity with no tread pattern evident consistent with a skidding tire. Between the centerline and the departure point, the NLG skipped once and transitioned to light intensity with a tread pattern just before the departure. The RMLG rubber transfer mark was sporadic from its beginning to departure with moderate intensity. At the runway centerline the perpendicular distance from the RMLG to NLG measured 33 inches and from the LMLG to NLG measured 119 inches. Between the centerline and the right edge, the perpendicular distance from the RMLG to NLG measured 41 inches and between the LMLG and NLG measured 107 inches. At the departure point the perpendicular distance between each MLG and the NLG measured 82 inches. The airplane departed the right side of runway 18 centered about 1330 feet from the threshold (Figure 11). There was no disturbance of the grass for about 10 feet beyond the runway edge. From this point forward there were 3 deep ruts in the grass and each had the tread pattern evident in the mud. The NLG rut stopped after about 68 feet and the airplane came to rest about 80 feet further along the path. The path through the grass was essentially straight until the NLG rut disappeared and veered a small amount right after.



Figure 10. Rubber transfer marks on runway (viewed opposite direction of travel)



Figure 11. Rubber transfer marks and ruts in grass at departure point (viewed in direction of travel)

4.0 Maintenance Records Examination

The accident airplane, S/N 4698190, received its airworthiness certificate on November 9, 2021. The airplane manufacturer's Warrantable 1st 50-hour inspection was completed by Flightline Group, Inc., Tallahassee, FL, on January 12, 2022, at an airplane total time of 46.6 hours. During this maintenance visit both MLG and the NLG were removed, painted black, and reinstalled. The maintenance entry indicated the work was done in accordance with the Piper PA-46-600 Maintenance Manual, chapters 32-10-00 and 32-20-00. Service Letter 1286D NLG Steering Components Inspection and Adjustment was also complied with. See Attachment 1 for the pertinent maintenance records.

The most recent maintenance on the airplane was performed on March 11, 2022, at an airplane total time of 64.5 hours when a new autothrottle and autopilot controller were installed. At the time of the accident the airplane had accrued 74.8 hours total time.

5.0 Tests and Research

5.1 NLG Teardown examination

The NLG was shipped to Piper Aircraft after the on-scene examination and placed in quarantine. The group met May 11, 2022, to tear down the NLG with the assistance of Piper personnel.

The NLG tire spun freely and there was barely perceptible play between the wheel and axle. The axle nut was installed finger tight. The wheel, torque links, and wire harness were removed, and the NLG was disassembled. The tire pressure measured 77.2 psi. The dimensions of the various components were measured and compared to the drawing requirements. All dimensions are in inches and the drawing specification is in parentheses following the measurement. The strut tube bearing assembly small end outer diameter (OD) measured 2.247 (2.247-2.248), small end inner diameter (ID) measured 1.755 (1.7489-1.7535), large end OD measured 2.375 (2.375-2.376), and large end ID measured 1.756 (1.7489-1.7535). The oleo tube had no apparent wear, the OD measured 1.750 (1.148-1.749), and the axle offset measured 2.2° (2°). The upper tube assembly lower end OD measured 2.751 (2.752-2.753), lower end ID measured 2.377 (2.377-2.378), and the upper end OD measured 2.752 (2.752-2.753). The trunnion assembly upper end ID measured 2.759 (2.7576-2.7628) and lower end ID measured 2.759 (2.7576-2.7628). The left trunnion ID measured 0.751 (0.752-0.753). The steering horn and torque links were left with core inspection for a full dimensional check.

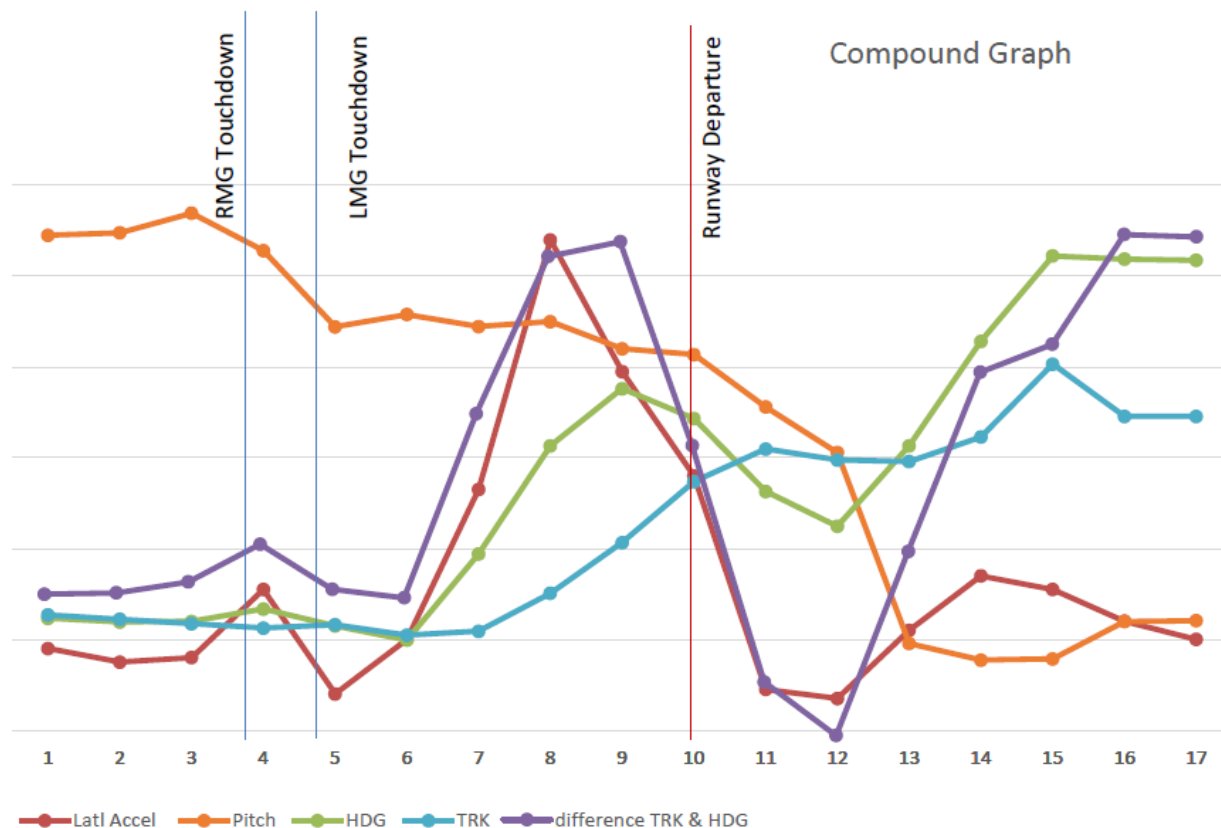
The upper and lower torque links were not stripped of powder coating prior to inspection. Most of the dimensions measured were slightly greater than the drawing tolerance due to the powder coating. The Piper inspectors stated "no dimensions were recognized as concerning and all dimensions would be within standards with the coating removed". The inspectors could not measure all of the steering horn dimensions due to deformation sustained from the NLG collapse. The dimensions that could be measured were all within the specified drawing tolerance with the exception of 2. The distance between the top plate and base was larger than allowed but the top plate was deformed in several areas. The location of one of the mounting holes in the base was 0.003-inch greater than the maximum tolerance. The small roller was damaged and deformed and could not be measured.

5.2 Recorded Flight Data

The Garmin G3000 Integrated Avionics System on the airplane records certain flight parameters at a rate of 1 Hertz for each flight. A maintenance-oriented data set (CMC data) is recorded and stored internally in the unit. The airplane manufacturer defines a flight-oriented data set (log data) to be recorded directly to an SD card, when installed, that can be easily removed and analyzed. New data files are created each time the airplane power and avionics system are turned on, and the file naming

convention provides the date and starting point (airport identifier) if a valid GPS signal is obtained. The CMC data can be retroactively retrieved by copying it to an SD card. Both the CMC and available log data for the accident flight were downloaded from the airplane after the accident. The raw data files are provided in the public docket.

Piper plotted the lateral acceleration, pitch, heading, track, and the calculated difference between heading and track for the accident landing from the SD card at the request of the NTSB, Figure 12. The y-axis values are not displayed on this plot to show the relational differences in the parameters but were obtained from the raw data. The RMLG and LMLG touchdown points were established with the wheel speed information contained in the internal CMC data. The timing of the internal dataset is slightly different from the log data. The runway departure timing was estimated based on the airplane position information. The NLG touchdown can be estimated based on the pitch parameter. The RMLG touched down first at a recorded indicated airspeed about 76 kts followed by the LMLG about 1 second later at a recorded indicated airspeed about 74 kts. The NLG touched down about 1-2 seconds after the RMLG. Starting about 2 seconds after LMLG touch down the heading and track diverge with the nose to the right of the track that continues until runway departure indicating the airplane is in a skid. The maximum divergence occurs about 1 second prior to runway departure when the heading is about 223° and the track is about 195°. At the same time the lateral acceleration increases to a maximum of about 0.88 g about 2 seconds prior to runway departure confirming the airplane is in a left skid. The airplane departed the runway about 6 seconds after the RMLG touchdown at a ground speed about 47 kts with the heading and track mostly aligned. The pitch parameter shows a sharp decrease about 2 seconds after runway departure indicating collapse of the NLG.



NOTE: This compound graph simply displays similar changes in different metrics over time. The y value is not needed to illustrate this relationship.

Figure 12. Plot of data from N627PR accident landing

5.3 NLG Design Change

In preparation for an unpaved field operational environment, Piper began installing a new NLG on the PA-46-600TP airplanes starting at S/N 4698198. The new NLG, PN 46N32A020-001, incorporated an updated lower NLG strut assembly with a different fork and redesigned torque links. The new fork is a machined aluminum structure, sized by analysis and testing to accommodate the loads generated by the increase in geometric trail. The new fork offsets the NLG axle aft 0.5 inch from its previous position which results in a trail (t_M) value of 0.5 inch where the steering axis is 0.5 inch forward of the center of the tire contact patch. The right wall of the NLG wheel well is also modified to provide clearance for the NLG tire. Piper offers a kit with the new NLG for installation on airplanes with S/N 4698001 through S/N 4698197.

Piper provided information on the NLG tires installed on the M600 airplane. The specifications show that the tire has a static loaded radius of 5.7 inches when properly inflated. Utilizing this radius and the $t_M = 0.5$ inch, the new NLG with offset is equivalent to 5° of forward rake angle resulting in positive trail and increased positive dynamic stability which Piper desired for unpaved field operations.

6.0 Piper Published Service Information

On July 24, 2020, Piper issued Service Letter (SL) 1285 Proper Tire Pressure Maintenance after a similar accident. The SL affected all models of the PA-46 airplane and for the PA-46-600TP increased the tire pressures. The NLG tire pressures increased from 88 psi to 88-92 psi unloaded and 92-97 loaded. The MLG tire pressures increased from 95 psi to 95-99 psi unloaded and 99-104 psi loaded. The SL recommended compliance prior to the first flight each day. SL 1285A was issued on January 12, 2021, to supersede SL 1285 and added information on replacement placards and a revision to the POH. The increased tire pressures remained the same in SL 1285A. SL 1285B was issued on June 15, 2021, to supersede SL 1285A for all PA-46 airplanes and contained corrected tire inflation pressures, an added note regarding changes in ambient temperatures, and announced new placards for the M600 aircraft. The NLG tire pressure for the M600 airplane was changed to 88 psi maximum unloaded and 88-92 psi loaded. The MLG tire pressure was changed to 95 psi maximum unloaded, and 95-99 psi loaded. The added note for temperature correction informed operators that tire pressures should be adjusted to the colder temperature prior to takeoff if the ambient temperature difference between the takeoff and landing locations exceeds 50°F. The SL also identified the correct placard part number for the M600 airplane. SL1285C was issued on March 29, 2022, to supersede SL 1285B for all PA-46 airplanes and contained updated placard part numbers for the M500 airplane. The tire pressures for the M600 remained unchanged. The recommended compliance prior to the first flight of the day did not change with any of the revisions.

Piper issued SL 1286 Nose Landing Gear Steering Components Inspection and Adjustment on August 18, 2020, applicable to all PA-46 airplanes. The SL highlighted existing Airplane Maintenance Manual (AMM) procedures for NLG alignment, NLG rake angle adjustment, and rudder cable tension and updated the procedures for measuring and adjusting the clearance between the NLG steering arm and steering horn rollers. It recommended compliance within 50 hours and recurring inspection every 100 hours. SL 1286A was issued on January 21, 2021, to supersede SL 1286 for all PA-46 airplanes and contained updated nose landing gear alignment procedures for the M600 airplanes. The recommended compliance remained the same as the original, but it recommended compliance at the next scheduled maintenance visit for M600 airplanes. SL 1286B was issued on January 28, 2021, for all PA-46 airplanes to supersede SL 1286A and added new information on rigging of the rudder-aileron interconnect for M600 airplanes. The recommended compliance remained the same as the original, but it recommended compliance at the next scheduled maintenance visit for M600 airplanes that were compliant with SL 1286 and prior to further flight for M600 airplanes that were compliant with SL 1286A. SL 1286C was issued on March 24, 2021, to supersede SL 1286B and contained clarification of the procedures to check and adjust the clearance between the NLG steering arm and steering horn rollers and the NLG alignment. The recommended compliance remained the same as

the original, but it recommended no further action until the next recurring action for M600 airplanes that already complied with SL 1286B, compliance before further flight for M600 airplanes that already complied with SL 1286A, and compliance at the next maintenance visit for M600 airplanes that already complied with SL 1286. SL1286D was issued on October 15, 2021, to superseded SL 1286C for all PA-46 airplanes and corrected some measurements. The recommended compliance time for the M600 airplanes was at the next 100 hour/annual inspection for airplanes that were compliant with SL 1886B or SL 1286C or at the next regularly scheduled maintenance event not to exceed 100 hours for airplanes that were compliant with SL 1286. The recommended clearance between the steering horn rollers and the steering arm was changed from 0.010-0.030 inch to 0.010 inch minimum and the dimensions of the dowel rod were changed.

E. LIST OF ATTACHMENTS

Attachment 1 - N627PR Maintenance Records

Submitted by:

Clinton R. Crookshanks
Aerospace Engineer (Structures)