

National Transportation Safety Board

Office of Research and Engineering

Washington, DC 20594



CEN22LA153

PIPER PA46 RUNWAY EXCURSIONS STUDY

by John O'Callaghan

April 20, 2026

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A. ACCIDENT

Location: Olive Branch, Mississippi
Date: March 23, 2022
Time: 10:38 Central Daylight Time (CDT)
15:38 Coordinated Universal Time (UTC)
Airplane: Piper Aircraft Inc. PA46-600TP, registration N627PR

B. AIRCRAFT PERFORMANCE GROUP

Chairman: John O'Callaghan
National Transportation Safety Board (NTSB), RE-60
Washington, D.C.

Members: N/A

C. SUMMARY

C.1. Introduction

On March 23, 2022, at 10:38 CDT, a Piper PA46-600TP (M600) airplane, N627PR, was substantially damaged when it veered off the right side of runway 18 after landing at Olive Branch Airport / Taylor Field (KOLV), Olive Branch, Mississippi. The pilot and passenger were not injured. The airplane was operated as a Title 14 *Code of Federal Regulations* (CFR) Part 91 personal flight.

The pilot reported that he conducted the instrument landing system approach to runway 18 in visual meteorological conditions (VMC) with the wind reported as 220° at 16 knots (kts) gusting to 22 kts. As the airplane approached the final approach fix, the pilot reduced engine power and extended the landing gear. About 550 ft above ground level, he disconnected the autopilot. The airplane landed "softly", at about 85 kts, to the left of the runway centerline. The airplane rolled about 1,200 ft as the speed decreased, and the pilot reported that he was in control moving toward the centerline.

The pilot further reported that at about 68 kts as the airplane approached the runway centerline, he had both hands on the yoke, holding it back slightly, and was making light rudder inputs to get the airplane to the runway centerline. At that time, the airplane entered a hard right turn at about 45° from the runway heading. The pilot stated the left directional input was not working and that he applied more pressure with the left rudder. He reported, "It felt as if the nose quit rolling for a nano second, and the tail of the plane was skidding to the left." The pilot said he applied neutral rudder pedals and the skid reduced.

The airplane exited the right side of the runway and continued across wet and muddy grass. The nose landing gear (NLG) collapsed, and the airplane came to rest nose down. The airplane departed the runway about 1,330 ft from the threshold and about 570 ft after touchdown. The engine mount sustained substantial damage.

On March 22, 2023, the NTSB published its final report on this accident (Reference 1), which states:

The National Transportation Safety Board determines the probable cause(s) of this accident to be:

The airplane's uncommanded hard right turn and loss of directional control during landing in crosswind conditions. Contributing to the accident were the dynamic instability of the nose landing gear and the crosswind conditions.

On August 1, 2023, Piper Aircraft Inc. (Piper) submitted a Petition for Reconsideration (PFR) concerning this accident (Reference 2). The PFR states:

The basis of this petition is that the NTSB Final Report includes erroneous findings and analysis that are unsupported and/or contradicted by the factual record and inconsistent with engineering principles. Simply stated, the NTSB Report is replete with speculation and incorrect conclusions. These mistakes and errors are so fundamental that the NTSB should reconsider and modify its findings and determination of probable cause related to this accident.

Specifically, the PFR alleges the following "factual errors in the accident investigation NTSB Final Report:"

- A. There is no factual evidence of an "uncommanded" right turn after touchdown.
- B. The incontrovertible evidence clearly establishes the absence of a dynamic instability.
- C. The NTSB Report has no analysis or discussion of pilot performance other than relying upon the pilot's statements of what happened, which are inconsistent with the objective evidence.
- D. The NTSB Report misrepresents the work cited in the report (Dr. Gudmundsson's book *General Aviation Aircraft Design: Applied Methods and Procedures*, First Edition, Elsevier, Inc., 2014) upon which the NTSB relies to support its engineering analysis, findings and conclusions.
- E. Communications with the pilot indicates confirmation bias played a role in the investigation leading to erroneous findings, analysis and probable cause.

The PFR includes, as an attachment, a technical memorandum prepared by Dr. Snorri Gudmundsson titled *Review of NTSB Report CEN22LA153* (Reference 3). This memorandum uses photographs of the tire marks on the runway, recorded avionics data, and a classical definition of "dynamic instability" to argue that the movements of N627PR during the accident were not "uncommanded" and did not exhibit "dynamic instability," thereby concluding that the NTSB Probable Cause is unsupported.

C.2. Objective and scope of the *Runway Excursions Study*

The objective of this *Runway Excursions Study* is to review and further analyze the motion of the airplane and the physical forces that produce that motion during the N627PR accident and, by necessity, other PA46 runway excursions for which information is available. In particular, the *Study* attempts to define each airplane's position and orientation during the relevant portion of its landing roll, and determine its response to control inputs, external disturbances, ground forces, and other factors that could have affected its trajectory. In addition, some of the specific concerns raised in References 2 and 3 regarding the NTSB's CEN22LA153 investigation are examined and addressed considering this review.

The data used to determine and analyze the airplane motion includes the following:

- Data recorded by the airplane's Garmin G3000 avionics suite.
- Runway tire marks.
- Wreckage location and condition.
- Weather information.
- Airplane performance information in the Airplane Flight Manual (AFM).
- Simulations of the controls-free airplane motion assuming different locations of the NLG tire contact point relative to the NLG steering axis.
- Simulations of the CEN22LA153 accident using a "math pilot" to generate rudder pedal inputs that approximately match the motions recorded by the CEN22LA153 G3000 data.

The most helpful data in defining the precise motion of the airplane in each case are the runway tire marks and the recorded avionics data. However, while the avionics data includes several important parameters, such as speeds, latitude and longitude, altitude, and Euler angles (pitch, roll, and heading angles), it does not include several parameters critical to a rigorous analysis of the pilot's control inputs and the corresponding airplane response. Such an analysis is fundamental to determine both the appropriateness of the pilot's control behavior and the responsiveness of the airplane. Without measures of rudder pedal position, rudder pedal force, NLG steering angle, rudder angle, left and right brake pressures, and similar parameters in other control axes, it is impossible to know with certainty what the pilot "commanded" and whether the airplane's response was consistent with these commands or not.

Given the absence of this critical information, the origins of the forces and moments that drove the recorded aircraft motion in each case cannot be determined. If the problem at hand concerned a single event and aircraft, then most likely nothing further could be done, and the cause of the event would have to be left as "undetermined." However, the number of post-landing lateral runway excursions involving the PA46

series of aircraft (compared to similar makes and models) provides an aggregate base of evidence that, together with the available avionics data and consideration of the airplane's NLG original design and subsequent revisions, supports a plausible explanation for the runway excursion events.

Since 2001, the NTSB has investigated 19 post-landing lateral runway excursion events involving Piper PA46 series aircraft in which the pilots involved complained of or recorded data indicated an airplane "veer" following NLG touchdown (see Table 1 starting on page 64). For the purposes of this *Study*, a "veer" is defined as an abrupt, surprising, and undesired deviation of the airplane's heading away from the runway heading that risks or results in the airplane crossing over a runway edge. This definition excludes post-landing lateral runway excursions in which the pilots involved do not allege that the airplane veered or was unresponsive to corrective rudder inputs.¹ In addition, the NTSB has been made aware of an additional 6 PA46 veer events (including one event involving a Piper engineering flight test pilot) that did not result in sufficient aircraft damage to be classified as an "accident" or "incident" and consequently do not have an associated NTSB case number; these events are included in this *Study* and are listed at the end of Table 1.² In sections D.4 and D.5 of this *Study*, Garmin G3000 data from the CEN22LA153 accident is compared to that from several other turbine-powered PA46 veer events and to computer simulations of the response of the airplane under different NLG stability scenarios.

The number of turbine-powered PA46 runway veer events has been noted by organizations outside the NTSB. In 2023, the Aircraft Owners and Pilots Association (AOPA) partnered with the Piper M-Class Owners and Pilots Association (PMOPA³) to initiate a study of these events, and a February 2021 Wall Street Journal (WSJ) article noted several NTSB investigations involving the PA46-600TP (M600) variant and the related concerns of M600 pilots. In addition, PA46 instructor pilots have posted YouTube videos discussing PA46 runway excursion events, the PA46 nose gear steering system, and maintenance and operational practices that can mitigate the risk of a runway excursion. These items are considered in section D.7.

¹ For example, events in which the pilot indicated that "that there were no preaccident mechanical malfunctions or failures that would have precluded normal operation" are not counted as relevant post-landing runway excursion events in this *Study*, regardless of the circumstances.

² (a) Per 49 CFR §830.2, "*Aircraft accident* means an occurrence associated with the operation of an aircraft which takes place between the time any person boards the aircraft with the intention of flight and all such persons have disembarked, and in which any person suffers death or serious injury, or in which the aircraft receives substantial damage ... *Incident* means an occurrence other than an accident, associated with the operation of an aircraft, which affects or could affect the safety of operations." (b) Cases ERA21NA108 and ERA21NA116 in Table 1 differ from other NTSB cases in that no probable cause or report was issued for these events, nor do they appear in the NTSB database accessible to the public.

³ The Malibu Mirage Owners and Pilots Association (MMOPA) was rebranded as PMOPA in 2023 to include all Piper M-Class aircraft (Malibu, Matrix, M350, M500, M600, & M700) .

The NTSB is unaware of similar AOPA studies or media articles concerning the post-landing lateral control of other airplane types. However, for comparison, the NTSB CAROL database was searched for veer events involving PA46 airplanes (both turbine and piston-powered) and several other aircraft types of similar power and weight to the PA46 series, including the Cessna 208 and 210, the Beechcraft Bonanza, the Pilatus PC-12, the Socata / Daher TBM series, and the Daher / Quest Kodiak series.

The results of this database search are described in detail in section D.1, and indicate that the number of veer events in the database involving PA46 airplanes is significantly higher than that of all the other aircraft types combined. This suggests that there is something unique about the PA46 series itself that increases the risk of a veer event. The physical factors that can affect the nose wheel steering behavior, and the differences between the PA46 NLG geometry and other designs, are considered in sections D.2 and D.3.

As discussed in those sections, the 0° NLG caster angle on the PA46 makes its directional stability (self-centering behavior) rely on pneumatic trail, that is, the movement of the tire contact patch aft when the tire is rolling due to its deformation under load. The pneumatic trail itself is dependent on several variables, including speed, runway friction, NLG tire pressure, and steering angle. In addition, the NLG caster angle *relative to the runway* depends on the pitch angle of the airplane, and will become negative (destabilizing) if the pitch angle becomes negative. When NLG components are rigged correctly, NLG tire pressure is within specifications, and correct pilot technique (neutral rudders on NLG touchdown with no drift) is used, the risk of a veer is minimized (clearly, the overwhelming majority of PA46 landings do not exhibit veer). However, the frequency of PA46 veer events compared to other types, the effects of varying pitch angle and pneumatic trail on the NLG's stability, and the series of Piper service letters, bulletins, and other communications emphasizing the importance of the NLG system rigging and tire inflation pressure tolerances, suggest that the stability and control feel of the NLG are sensitive to out-of-tolerance conditions that can result in a veer, an adverse Airplane-Pilot Coupling (APC) event, or a combination of these phenomena. These possibilities are considered in section D.6.

In addition to querying the CAROL database, the NTSB attempted to ascertain whether the post-landing lateral control of the PA46 is remarkable or different compared to other types by surveying pilots that fly the PA46 and so are most acquainted with it. The NTSB developed a survey to explore pilots' opinions about the handling qualities of the M600 PA46 variant in general, and its post-landing lateral control characteristics specifically. Different versions of the survey were developed for M600 pilots and for M600 instructor pilots. The survey was provided to 6 flight schools that provided M600 instruction, and to PMOPA. The NTSB only received 2 responses to these surveys (both from instructor pilots), but both respondents indicated that they had experienced

unexplained veer events in the M600 (but managed to keep the airplane on the runway). The survey and its results are presented in section D.7.3 and Appendix B.

In late 2022, Piper started manufacturing M600 airplanes (from serial number 198 on) with a new, curved NLG fork that moves the contact point of the tire with the runway 0.5 inches aft. No veer events have been reported with this new fork design. In addition, with the new fork the airplane can be operated on unimproved fields, whereas with the original fork such operations were prohibited (a Piper engineer told an NTSB investigator that the original fork was inoperable on unimproved fields because of the resulting difficulty in steering the airplane with the rudder pedals). As described in section D.7.5, the new fork has been well-received among the PA46 pilot community, and is perceived to improve the ground handling qualities of the airplane and to be a solution to the “veering” problem. These circumstances support the hypothesis that the root of the veer events lies with the 0° caster angle and straight fork of the original PA46 NLG design, which places the tire contact point very close to the steering axis and reduces the robustness of the design to out-of-tolerance rigging, improper NLG inflation pressures, and lateral NLG motion relative to the runway at touchdown.

The sections that follow present the data used in this *Study* (as listed above), and describe the methods used to calculate additional performance information from this data. The results of these calculations are presented in the Figures and Tables described throughout the *Study*.

D. DETAILS OF THE INVESTIGATION

D.1. Summary of landing veer events with PA46 and comparable airplanes

As noted above, the NTSB is aware of 25 landing veer events involving PA46 series airplanes, where a “veer” is defined as an abrupt, surprising, and undesired deviation of the airplane's heading away from the runway heading that risks or results in the airplane crossing over a runway edge. These events include closed NTSB accident cases, open NTSB accident cases, and events not investigated by the NTSB but that the NTSB became aware of through the investigation of other events.

For closed NTSB cases, veer events were identified by searching the NTSB database for the words “directional control” in the probable cause, and in which the pilots involved reported veer-like behavior. For open NTSB cases, events were identified by the similarity of the circumstances with closed NTSB cases and pilots’ reports of veer-like behavior.

The PA46 veer events identified in this *Study* are listed in Table 1 starting on page 64. These events do not include ten NTSB cases that exhibited veer-like behavior on landing, but which were attributed to a collapse of the NLG or other breakage in the

NLG steering system due to the structural fatigue failure of the engine mount.⁴ This failure mechanism has been addressed by Piper Service Bulletin No. 1103F (*Engine Mount Inspection*), dated September 1, 2015, which calls for the inspection of PA46R-350T engine mounts on a recurring basis if the mount has not been replaced by the redesigned mount specified in the Service Bulletin. Consequently, these ten cases are not relevant to or included in this *Study*.

The Probable Cause of NTSB case ERA20LA237 was determined to be “the loss of directional control during landing due to the fracture of the steering horn bolts, which rendered the nose wheel steering ineffective and resulted from the airplane being towed over the left turn limits at an undetermined time before the accident.” Nonetheless, this case is included in this *Study* because the NLG’s inherent directional stability is relevant to the controllability of the airplane when direct steering control is lost.

Veer events in the NTSB CAROL database involving other aircraft types similar to the PA46 series (listed above) are summarized in Table 2. No veer events were found in the database for the Cessna 208, Daher/Quest Kodiak, or Daher TBM airplanes.

The number of veer events for a particular airplane type does not by itself indicate whether such events are more probable for that airplane type than others. Instead, the number of events must be normalized by some measure of exposure to such events. In this case, the number of veer events would ideally be normalized by the total number of landings for all airplanes of a given type. However, a record of the historical total number of landings of different airplane types is not available. In lieu of this ideal measure, the estimated total production number of airplanes of a given type is used as a measure of exposure, assuming that the total number of landings of a given airplane type is approximately proportional to the number of airplanes produced. Table 3 summarizes the number of veer events and the estimated total production for each airplane type considered in this *Study*.

The sources of the estimated production numbers in Table 3 include:

- *Wikipedia.com*

⁴ The ten cases referenced are NTSB accident numbers MIA06LA002, DEN07LA030, SEA07IA058, ERA10LA237, WPR12LA261, CEN14LA006, ERA14IA019, CEN14LA196, CEN15LA078, & ERA21LA238.

- The General Aviation Manufacturers Association's (GAMA's) published *General Aviation Aircraft Shipment Reports* for production years beyond those cited in the *Wikipedia* articles
- For the PA46, Piper's letter to the PA46 Owner Community dated 2/24/2021, which cites "At the end of [2020] 2,406 Piper P46 aircraft ... delivered in total since 1984)" (supplemented by GAMA shipment reports for 2021-2024)
- For the Beechcraft 35/36 Bonanza, Textron's *Beechcraft and Hawker Serialization List, 1945 through 2024*

The veer events for the PA46 in Table 3 are counted both as those in the NTSB database (19), and those in the database plus the 6 others the NTSB is aware of (total 25). There might be veer events involving other airplane types that did not result in an NTSB investigation and that are therefore not counted in Table 3. In addition, the C210 and BE35 have been in production since before the creation of the NTSB in 1967, and so any veer events involving those aircraft prior to 1967 would not be counted in the NTSB database. Even with these potential errors and uncertainties, however, the data in Table 3 indicates that the rate of veer events on the PA46 series is significantly higher than that for the other types listed.

D.2. The Piper PA46 airplane series

D.2.1. General

The Piper PA46 series are six-seat, single-engine, low-wing airplanes powered by either Continental or Lycoming reciprocating (piston) engines producing 310 to 350 brake horsepower (*BHP*) or by Pratt & Whitney Canada (P&WC) PT6A turboprop engines producing 500 to 700 shaft horsepower (*SHP*), depending on the model. The engine type, power, and gross weight of each model in the series is summarized in Table 4a on page 70. The breakdown of the PA46 veer events listed in Table 1 by model is presented in Table 4b. As of 2024, the series is referred to as the Piper "M-Class" (M350, M500, M600, & M700) in lieu of the distinct model names listed in the table. All of the models are pressurized except for the PA46R-350T Matrix.

Figure 1 presents a 3-view schematic of the M600, taken from Reference 1. Figure 2a is a photograph of an M600 airplane (not N627PR). Figure 2b is a photograph of N627PR after the CEN22LA153 accident.

Per the FAA aircraft registry, N627PR is a PA46-600TP (M600), serial number 4698190, manufactured in 2021.

D.2.2. The PA46 nose landing gear design

The geometry and mechanical design of the PA46 NLG and steering system is illustrated in Figures 3 and 4 and described in Reference 5 as follows:

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 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.

...

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 [see Figure 4].

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).

Note that the “rake angle” defined above and depicted in Figure 4 is measured from a line parallel to the lower fuselage to the axis the of NLG strut. The NLG “caster angle” referred to in this *Study* is measured from a line orthogonal to the lower fuselage to the axis of the NLG strut (see Figure 5), and hence is offset 90° from the rake angle:

$$\text{Caster angle } (\theta) = \text{Rake angle} - 90^\circ \quad [1]$$

Piper’s Service Letters refer to the NLG rake angle, but References 6 and 7, which consider the geometry and properties of landing gear in general, refer to the caster angle. This *Study* refers to the caster angle θ when considering the effect of this angle on the directional stability of the NLG, and to the rake angle when referencing Piper’s Service Letters addressing the proper rigging of the NLG.

The “trail” mentioned in Reference 5 is the distance between the contact patch of the tire and the point where the steering axis intersects the ground. As will be discussed below, positive trail (where the tire contact patch is aft of the steering axis ground intersection) is critical to the NLG’s directional stability, and can be achieved by both “mechanical trail” (through selection of the caster angle and other geometries) and “pneumatic trail” (the movement of the tire contact patch aft when the tire is rolling due to its deformation under load).

The PA46 NLG tire pressure and rudder pedal and steering arm adjustment / rigging have been the subject of several Piper Customer Information Letters, Service Letters, and Service Bulletins. These are summarized in Table 5. Of note, Piper’s letters to M600 owners (dated 2/4/2021) and to the PA46 owner community at large (dated 2/24/2021) address several of the runway excursion events listed in Table 1, and are included in their entirety in Appendix A.

D.2.3. M600 NLG fork design change

Section 2 of the M600 Pilot’s *Operating Handbook and Airplane Flight Manual* (POH/AFM, Reference 4), titled *Limitations*, states that “takeoff and landing operations

are limited to paved runways.”⁵ In an October 2024 phone conversation with an NTSB investigator, a Piper engineer stated that a primary reason for this limitation is the difficulty in maintaining directional control on unpaved runways using NLG steering through the rudder pedals.

Reference 5 describes a change to the M600 NLG fork design intended to allow operations on unpaved runways:

In preparation for an unpaved field operational environment, Piper began installing a new NLG on the PA46-600TP airplanes starting at S/N 4698198⁶. 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 angle⁷ resulting in positive trail and increased positive dynamic stability which Piper desired for unpaved field operations.

As of this writing, the NTSB is unaware of any “veer” events involving a PA46 airplane with the updated NLG fork design.

D.2.4. Comparison of PA46 NLG design with similar airplanes

As noted above, Table 3 summarizes, for each airplane type considered in this *Study*, the number of veer events contained in the NTSB database, the estimated total number of airplanes produced, and the ratio of these two numbers. Table 6 compares some characteristics of the NLG geometry for each of these airplane types, including the NLG design caster angle, the NLG tire axle offset, and the “effective” caster angle, which

⁵ Although Reference 4 notes that “icing conditions can exist ... during ground operations when operating on contaminated ramps, taxiways or runways where surface snow, ice, standing water or slush are present,” it does not indicate whether or not a runway contaminated with a particular depth of snow, ice, standing water or slush can still be considered “paved.”

⁶ N627PR is serial number 4698190, and so has the original fork design.

⁷ This is equivalent to a 95° rake angle per Piper’s definition as shown in Figure 4, or to a 5° caster angle.

results from the combination of the design caster angle and the NLG tire axle offset (see Figure 5). The significance of these quantities for the directional stability of the NLG is discussed in section D.3. Note that the design caster angles and tire axle offsets listed in Table 6 are rough estimates based on publicly available drawings and photographs, except for the PA46 data, which were provided by Piper.

Table 6 indicates that all of the airplanes, except for the PA46, have effective NLG caster angles that range between 12° and 17°. The M600 with the redesigned NLG fork has an effective caster angle of 5°. The PA46 aircraft with the original fork are unique in that they have an effective caster angle of 0°, and a significantly higher incidence of veer events.

All of the aircraft listed in Table 6 have retractable landing gear, except for the Cessna 208 and the Quest Kodiak series. For comparison purposes, the NTSB researched the design and maintenance requirements of the NLG assemblies of the Cessna P210R, Beechcraft BE36TC, and Daher/Socata TBM700, which most closely match the size and occupancy of the Piper PA46 series.

As already mentioned, the 0° effective caster angle of the PA46 NLG (with the original fork) is unique. Another apparently unique feature of the PA46 NLG mechanism is the 90° rotation of the tire about the steering axis as the NLG retracts; the NLG of the other three airplanes retract without this 90° turn. To accommodate the 90° rotation of the tire, the PA46 NLG physically disconnects from the steering mechanism (by the separation of the steering horn rollers from the steering arm) when retracted. On the B36TC and the P210R, the steering mechanism remains physically connected to the NLG, but the steering arm loses its mechanical leverage when the NLG is in the retracted position. The NTSB could not find any publicly available information about the nose wheel steering engagement/disengagement mechanism for the TBM700.

The NTSB also compared the NLG maintenance requirements of the P210R, BE36TC, and TBM700 with those of the PA46. The multiple PA46 service letters and bulletins that introduce or reiterate inspection requirements for the rigging and condition of NLG components, including the NLG rake angle and alignment, steering horn roller gaps, rudder cable tension, and NLG tire pressure are listed in Table 5.

A review of inspection requirements, service bulletins, special airworthiness information bulletins (SAIBs), and airworthiness directives (ADs) for the BE36TC, P210R

and TBM700 revealed that these airplanes do not require recurrent dimensional inspections to maintain reliable steering and directional control. The inspection requirements for these airplanes are limited to visual inspections only. Any ADs, SBs, or SAI Bs related to the NLG of these airplanes address component failures or manufacturing or maintenance escapes.

Common elements of the PA46 NLG and those of the other airplanes reviewed are the warnings and instructions concerning proper towing procedures, with clear warnings against exceeding the nose gear turning angle limits, as doing so can result in damage to the gear and steering mechanisms.

D.3. Factors affecting NLG directional stability and control feel

D.3.1. Clarification of different definitions of stability

In this *Study*, “NLG directional stability” refers to the tendency of the NLG to self-align with the direction of travel of the airplane when disturbed from that alignment. If the forces and moments on the NLG tend to return the NLG into alignment, the NLG is considered directionally stable; if the NLG tends to deviate further from alignment, it is considered directionally unstable. “NLG directional stability” as used here is equivalent to the term “dynamic stability” used in some texts⁸ to describe the tendency of NLG to self-align *while rolling*, and is contrasted with “static stability” which refers to the yawing tendency of the gear while the airplane is *stationary* and the tires are *not rolling*.

The terms “dynamic stability” and “static stability” as used in reference to landing gear can be confusing in light of how these terms are typically used to describe dynamic systems. In general, “static stability” refers to a system’s tendency to return to equilibrium when disturbed, which is analogous to the “NLG directional stability” used in this *Study* and the “dynamic stability” used elsewhere in reference to rolling landing gear. Further, in general “dynamic stability” refers to the tendency of the amplitude of the oscillations in a dynamic system to grow or decay over time, and in the context of the behavior of the steering angle of landing gear can be referred to as “shimmy.” The “static stability” of landing gear (the yawing behavior of the gear when the airplane is not rolling) does have a classical analogue in the example of a marble balanced on top of a ball; if disturbed from equilibrium, the marble will not return to equilibrium but deviate further way, seeking a point of minimum potential energy. Similarly, a statically

⁸ See, for example, Reference 6, which is also cited in References 7 and 8.

unstable landing gear can be aligned with the centerline of the airplane while the airplane is parked, but if disturbed in yaw, the yaw angle will grow until constrained by hitting a stop or until the point of minimum potential energy (lowest height of the airplane's center of gravity) is reached.

Systems can also be "neutrally stable." In the static case, once disturbed from equilibrium these systems remain in the disturbed state, without deviating further from or returning to the original state. In the dynamic case, the amplitude of a neutrally stable system's oscillations neither grows nor decays over time.

To add to the potential confusion, some texts (Reference 7 for example) also use the term "dynamic instability" to refer to a divergent shimmy oscillation, and to the ground-looping tendency of taildragger airplanes compared to tricycle-gear airplanes. So, the interpretation of the term depends heavily on the context in which it is used.

In its discussion of the NTSB's final report concerning case CEN22LA153 (Reference 1), the *Review of NTSB Report CEN22LA153* submitted by Piper (Reference 3) appears to consider that Reference 1's use of the term "dynamic instability" refers to oscillations of the NLG about the steering axis and / or a vibratory response of the NLG strut due to touchdown loads, and then argues that photographic evidence of the tire marks left by N627PR do not support a conclusion that such oscillations or response were present during the accident. However, although Reference 1 states that "on NLG touchdown, the NLG strut will deflect aft due to spin-up loads, increasing the negative rake that could cause instability, and will undergo a damped oscillation," the "instability" mentioned is associated with the potential for "negative rake" and consequent *directional* instability as defined in this *Study* and in Reference 6.⁹ It is not associated with vibrations or oscillations of the NLG.

The hypothesis that spin-up loads can increase the NLG "negative rake" (actually negative caster) and cause a directional instability¹⁰ was advanced previously in the NTSB final report concerning case ERA21LA065 (Reference 9): "on NLG touchdown, the NLG strut will deflect aft due to spring-back, increasing the negative rake that could cause an instability." This hypothesis appears to originate in Piper's *Customer*

⁹ By "negative rake," Reference 1 appears to mean a rake angle (as defined in Figure 4) less than 90°, or a caster angle (as defined in Figure 5) less than 0°.

¹⁰ This hypothesis is considered further in section D.3.3.

Information Letter dated March 27, 2008 (Reference 10; see also Appendix A), which states:

Nose Gear Rake Angle

The proper nose gear rake angle for all Malibu models is zero to one-half degree forward from vertical, measured using the airframe lower skin just aft of the nose gear doors as a horizontal datum with the aircraft on jacks. In other words, the relative angle between the lower (belly) skin and the nose gear strut should range from 90.0 degrees to 90.5 degrees. See figure [4].

A rake angle outside of this range may result in dynamic instability, creating steering forces that exceed the pilot's ability to control. This angle is set by adjusting thread engagement in the nose gear actuator's rod end bearing as described in the maintenance manual.

The nose gear rake angle is properly adjusted and verified at the factory and should be inspected and/or adjusted by an FM-licensed mechanic according to the schedule and instructions in the maintenance manual, any time the pilot experiences poor steering, or there is replacement or service to the nose gear trunnion, the nose gear actuator, or the engine mount.

This letter associates "dynamic instability" with an improperly rigged rake angle (not an improper rake angle resulting from spin-up loads, as hypothesized in References 1, 5, and 9), but it is clear that the instability referred to is the directional instability defined above, and not the shimmy or other NLG oscillation that Reference 3 argues against.

With the understanding that the term "dynamic instability" in References 1, 5, and 9 refers to *directional* instability (the tendency of a yawed, rolling NLG to yaw further away from its centered position), we can examine some of the physical factors that affect this instability.

D.3.2. Mechanical, pneumatic, and dynamic trail and tire self-aligning torque

The self-aligning tendency of a yawed NLG is described in Reference 6. Reference 6 considers this tendency in the context of "castering nose wheels and tail wheels," which are free to rotate about the yaw axis of their struts (called "spindles" in Reference 6; see Figure 5). Nonetheless, the principles discussed also apply to steerable NLG, since the resulting moments about the strut axis will act to rotate those gears as well, though the rotation might be constrained by the steering system (mechanical stops and / or steering actuators). In the case of many general aviation airplanes, including the PA46, the "steering actuators" are the pilot's legs and feet that exert pressure on the rudder pedals. Consequently, the moments generated about the NLG spindle axis by the NLG tire's contact with the ground directly affect the steering forces felt by the pilot through

his feet, and can affect the handling characteristics of the airplane. Hence the caution in Reference 10 that “a rake angle outside of this [prescribed] range may result in dynamic instability, creating steering forces that exceed the pilot’s ability to control.”

The resultant of the ground reaction forces on a tire acts at the “contact point” of the tire. When the tire is static (not rolling), the contact point is directly under the center of the tire. The distance between the tire static contact point and the intersection of the strut rotation axis with the ground line is called “static trail” or “mechanical trail” (t_M) and is positive when the tire contact point is aft of the strut rotation axis. When the tire is rolling, the contact point moves aft, and the resulting distance between the rolling contact point and the strut rotation axis is called “dynamic trail” (t_D). The difference between dynamic trail and mechanical trail is the “pneumatic trail” (t):

$$\begin{aligned} t &= t_D - t_M \\ t_D &= t_M + t \end{aligned} \tag{2}$$

(See Figure 5, taken from Reference 6.)¹¹ In the case of the PA46, by design $t_M = 0$ and so $t_D = t$. As discussed further below, t is not constant under all conditions of speed, runway friction, NLG vertical load, NLG tire pressure, and tire slip angle, which can affect the directional stability and control feel of the NLG under different conditions.

The dynamic trail t_D (equivalent to the pneumatic trail t for the PA46) has a strong effect on the directional stability and steering forces of the NLG, as can be seen in Figure 6. This Figure depicts a top-down view of the NLG strut and tire in a yawed condition (that is, the angle the longitudinal axis of the tire makes with the tire’s velocity vector is not zero). As in Figure 5, the red dot indicates the intersection of the strut rotation axis with the ground line, and the yellow dot indicates the location of the contact point where the resultant of the ground reaction forces on a tire acts.

The situation depicted in the top half of Figure 6 corresponds to a NLG with zero offset and a positive caster angle ($+\theta$). In this case, the red dot is forward of the yellow dot and the dynamic trail is positive ($+t_D$). Hence, when the tire is yawed, the resulting side

¹¹ Different sources sometimes use different terms to describe the quantities and dimensions depicted in Figure 5. For example, the angle θ is called the “caster angle” in References 6 and 7 and the “cant angle” in Reference 8. Similarly, what Piper and References 7 and 8 call the “strut” Reference 6 calls the “spindle.” Also, the distance t_M is called “mechanical trail” here and in Reference 7, but “caster trail” in Reference 8 and “static trail” in Reference 6. Reference 8 calls “mechanical trail” what References 6 and 7 and Figure 5 label the “offset.” In this *Study*, the definitions of all these terms are as shown in Figure 5.

force acting at the yellow dot creates a moment (torque)¹² about the red dot that will act to yaw the tire back towards the zero-yaw condition. This moment is said to be “self-aligning,” and the situation is directionally stable.

The situation depicted in the bottom half of Figure 6 corresponds to a NLG with zero offset and a negative caster angle ($-\theta$). In this case, the red dot is aft of the yellow dot and the dynamic trail is negative ($-t_D$). Hence, when the tire is yawed, the resulting side force acting at the yellow dot creates a moment about the red dot that will act to yaw the tire further away from the zero-yaw condition. The moment is *not* self-aligning, and the situation is directionally unstable.

The PA46 NLG is designed with zero offset and zero caster angle ($\theta = 0^\circ$). Consequently, $t_M = 0$ and $t_D = t$, and the magnitude of the moments generated by tire side forces about the steering axis of the NLG depend directly on the value of the pneumatic trail (t). These moments in turn affect the steering forces felt by the pilot through the rudder pedals. A change in the magnitude of the pneumatic trail t can affect the control feel of the NLG, and if t changes sign from positive to negative, the NLG can become directionally unstable.

References 6 and 8 indicate that the value of t is approximately 1/6 of the length of the footprint of the tire (the “contact patch” illustrated in Figure 5). However, research into the behavior of t in pneumatic tires indicates that t is not a constant, but depends on variables such as the tire vertical load, inflation pressure, tire speed, runway friction, and the slip angle of the tire.¹³ The slip angle (α) is the angle between the longitudinal axis of the tire (x_t) and its velocity vector ($\vec{V}$), and is equal to the difference between the tire steering angle (ϕ) and the tire drift angle (ψ) (see Figure 7):

$$\alpha = \phi - \psi \quad [3]$$

The drift angle ψ is the angle between the velocity vector $\vec{V}$ and the longitudinal axis of the airplane (x_b). The NLG tire steering angle ϕ is the angle between x_t and x_b , and is controlled by the pilot through the rudder pedals and steering system illustrated in Figure 3.

¹² In this *Study*, the terms “moment” and “torque” are used interchangeably.

¹³ See, for example, References 11-14.

The dependence of t and the resulting self-aligning moment of the tire on α , vertical load, and inflation pressure (p_i) is described qualitatively in Reference 13:

... with a given normal load, the aligning torque first increases with an increase of the slip angle. It reaches a maximum at a particular slip angle, and then decreases with a further increase of the slip angle. This is mainly caused by the sliding of the tread in the trailing part of the contact patch at high slip angles, which results in shifting the point of application of the cornering force forward.

...

Inflation pressure and normal load also have noticeable effects on the aligning torque because they affect the size of the tire contact patch. Higher normal load and lower inflation pressure result in longer tire contact length, and hence pneumatic trail. This causes an increase in the aligning torque.

Similarly, Reference 14 states:

... the pneumatic trail decreases substantially as the steer angle increases. This is related to the shape of the cornering force intensity curve with increasing steer angle, since the greater slip in the contact patch results in a more symmetric cornering force distribution.

...

Due to the decrease of the pneumatic trail t with increasing slip angle $[\alpha]$, the [self-aligning] moment M_z reaches a maximum, and then drops to lower values.

...

The self-aligning torque M_z increases with increasing normal load due to the increasing contact length ...

...

The self-aligning torque M_z decreases with increasing inflation pressure p_i because the contact length decreases, resulting in a decrease of the pneumatic trail t .

Reference 14 also presents several plots of the behavior of the self-aligning torque M_z of automotive tires with variations in α , vertical load, and p_i . These are duplicated here as Figures 7-12.

Reference 14 indicates that the M_z of automotive tires also depends on the tire construction (and specifically, the "lateral carcass stiffness" and the "tread rubber stiffness"), and on the surface condition of the road (dry or wet). These dependencies are illustrated in Figures 9 and 13 (see Reference 14 for a discussion of the associated tire mechanics). Note in particular in Figure 13 how the slip angle α at which the M_z becomes positive (unstable) decreases substantially on wet pavement (from about 14° on dry pavement to about 8° on wet pavement). Since the friction coefficient (μ)

between a tire and wet pavement decreases as speed increases¹⁴, it appears that the α at which M_z becomes destabilizing will decrease with μ on wet pavements or those contaminated with standing water, slush, or ice, particularly at higher speeds.

Reference 16 indicates that t and M_z are sensitive to tire speed even on dry surfaces. Figure 14 presents the tire lateral force (F_y) and aligning moment (M_z) as a function of slip angle (α) at four different tire speeds, as computed by a mathematical model (red lines) and measured from test data (symbols). Figure 14 indicates that while F_y increases to a maximum value at about $\alpha = 6^\circ$ and remains relatively close to that value above $\alpha = 6^\circ$ at all speeds, M_z increases to a maximum value as α increases, but then decreases as α increases further, and that the magnitude of the decrease in M_z increases as the speed increases. For example, the test data in Figure 14b show that at 3 km/h, M_z reaches a maximum of about 60 Nm at about $\alpha = 5.5^\circ$ and then decreases to about 23 Nm at $\alpha = 15^\circ$, but at 100 km/h, M_z reaches a maximum of about 78 Nm at about $\alpha = 3^\circ$, decreases to about 10 Nm at $\alpha = 9^\circ$, crosses 0 Nm at about $\alpha = 12^\circ$, and then remains slightly negative (unstable) at $\alpha > 12^\circ$. Since the corresponding F_y values at these speeds remain close to their maximums above $\alpha = 6^\circ$, the decreases in M_z must result from a decrease in t (with t even becoming negative at high speed and α).

References 13, 14, and 16 are concerned with the performance of automotive tires, and do not consider the performance of aviation tires specifically. However, Reference 11 investigates the shimmy oscillations of airliner NLG tires specifically, and makes observations similar to those presented in References 13 and 14. In particular, Reference 11 states

Similar to the case of cornering force, for small slip angles, self-aligning moment increases linearly with an increase in the slip angle, and decreases for higher slip angles. However, with further increase in slip-angle magnitude, it changes sign and becomes a destabilizing moment The self-aligning moment is a direct consequence of the cornering force ... acting at an offset, called the pneumatic trail [t] from the center of the tire contact patch. Now we investigate how t is influenced by the changes in the tire inflation pressure. Figure [14] shows the normalized self-aligning moment $\tilde{M}_{K\alpha}$ for three different normalized vertical loads $\tilde{F}_z$ on the gear and for three different normalized pressures. One of the apparent features in the graph is that the slip angle α at which the self-aligning moment changes its direction from being negative to positive is practically constant for all inflation pressures and vertical loads. The self-aligning moment variations increase with an increase in the vertical load. Specifically, the maximum magnitude of the moment, which occurs at $\alpha \approx 6^\circ$, increases with the vertical load. The self-aligning moment

¹⁴ See, for example, Reference 15.

is significantly influenced by changes in the pressure. Specifically, in Figure [14], the maximum magnitude of the moment for a given vertical load has largest magnitude for $\tilde{p} = 0.7$ and least for $\tilde{p} = 1.0$. Therefore, the figure suggests that as inflation pressure increases the self-aligning moment decreases. This behavior can be explained as follows: the pneumatic trail t , which is the moment arm to generate the self-aligning moment, decreases with increase in the tire inflation pressure. Since the cornering force is assumed to be independent of the tire inflation pressure, a reduction in the pneumatic trail t implies a reduction in the self-aligning moment.

For small slip angles, the cornering force acts behind the center of the contact patch, so that the self-aligning moment is stabilizing. Beyond a certain slip angle (of approximately 10° - 15° , see Fig. [14]) the self-aligning moment changes direction and becomes a destabilizing moment. This is a direct consequence of the shifting of the point of action of the cornering force from behind the center of the contact patch to the front.

The normalized vertical load ($\tilde{F}_z$), aligning moment ($\tilde{M}_{K\alpha}$), and inflation pressure ($\tilde{p}$) are defined in Reference 11 as follows:

$$\tilde{F}_z = F_z / F_{zmax} \quad [4]$$

$$\tilde{M}_{K\alpha} = M_{K\alpha} / F_{zmax} \quad [5]$$

$$\tilde{p} = p / p_n \quad [6]$$

Where F_z is the vertical load on the gear, F_{zmax} is the "maximum takeoff load," $M_{K\alpha}$ is the "self-aligning moment due to tire force," p is the tire inflation pressure, and p_n is the nominal tire inflation pressure. Reference 11 does not define "maximum takeoff load." Moreover, the computation of $\tilde{M}_{K\alpha}$ given by Equation [5] is confusing, since it involves a moment divided by a force, which will produce a length and not a non-dimensional number. Reference 11 does not explain this discrepancy, though the values of $\tilde{M}_{K\alpha}$ plotted in Figure 14 appear to be dimensionless. Nonetheless, it is the shape of the curves in Figure 14, their dependence on $\tilde{F}_z$ and $\tilde{p}$, and the values of $\tilde{M}_{K\alpha}$ changing from negative (stable) to positive (unstable) at $\alpha \approx 15^\circ$ that are of most interest in the Figure; the change in stability mirrors that depicted in Figures 9-11 from Reference 14.

As noted above, the PA46 NLG is designed with zero offset and zero caster angle ($\theta = 0^\circ$), and consequently $t_M = 0$. However, it should be noted that $t_M = 0$ will only be achieved, even with $\theta = 0^\circ$, when the longitudinal axis of the airplane is parallel to the runway surface (i.e., pitch angle = 0°). If the pitch angle is negative, then the airplane will sit slightly nose-down on the runway, and the caster angle *relative to the runway* will be negative, moving the rotation axis of the NLG relative to the NLG tire contact point aft. This is destabilizing (see the bottom image in Figure 6). Consequently,

conditions that could lower the pitch angle on the runway (such as low NLG tire pressure or strut extension, or a higher than anticipated vertical load on the NLG) can decrease the directional stability of the NLG. Conditions that raise the pitch angle on the runway introduce a positive caster angle (relative to the runway) and can increase the directional stability of the NLG.

D.3.3. The effects of landing loads on NLG caster angle and mechanical trail

As noted above, the NTSB's final report for CEN21LA065 (Reference 9) hypothesizes that "on NLG touchdown, the NLG strut will deflect aft due to spring-back, increasing the negative rake that could cause an instability" on PA46 airplanes. The NTSB final report for CEN22LA153 (Reference 1) similarly states "on NLG touchdown, the NLG strut will deflect aft due to spin-up loads, increasing the negative rake that could cause instability, and will undergo a damped oscillation." Prior to this statement, Reference 1 notes that "examination of the structural response of a landing gear at wheel touchdown showed that the gear will deflect aft initially due to wheel spin-up loads and then undergo a damped oscillation about its equilibrium point."

Reference 1 does not provide any record or details of how the structural response of the NLG was observed or examined, though this examination is also referenced in the CEN22LA153 *Airworthiness Group Chair's Factual Report* (Reference 5). Per the author of Reference 5, the examination referenced was performed during the investigation of NTSB case # DCA06FA058, during which the structural responses of the left and right main landing gear (MLG) of an MD-10 airplane during landing touchdown and braking were evaluated using recorded accelerometer and strain gage data obtained from an instrumented in-service airplane.¹⁵ A video of the nose gear touchdown of a PA46-310P airplane as it was landing (taken from a camera mounted on the right wing) indicates that the general characteristics of the structural responses of the MD-10 MLG and PA46 NLG (an aft deflection followed by a damped oscillation) are similar.¹⁶

Figure 16 depicts several frames from the video of the PA46-310P's landing that clearly show the aft deflection of the NLG strut upon touchdown and its rapidly damped oscillation. The 16 video frames following NLG touchdown are shown, which suffice to portray the initial deflection of the gear and the entirety of the oscillation. The frame

¹⁵ For further information, see the public docket for NTSB case DCA06FA058, accessible from the NTSB's Carol query tool at <https://carol.nts.gov/>.

¹⁶ See <https://youtu.be/3LTAtlNSe0w> at 6:30-6:37. This video is not associated with the NTSB or its staff.

rate of the video is 60 frames per second (fps), so each frame is $1/60 = 0.017$ seconds apart; the frame corresponding to NLG touchdown is labeled as $t = 0$ seconds. The 16 frames shown cover 0.25 seconds, so the oscillation is damped out within this time.

At $t = 0$, the axle of the NLG wheel is slightly ahead of the vertical yellow line drawn in the image. At $t = 0.067$ s., the wheel axle is behind the vertical yellow line, indicating that the NLG strut has deflected aft. At $t = 0.100$ s., the wheel axle is ahead of where it was at $t = 0$ s., indicating that it has oscillated back towards the front of the aircraft and overshoot its initial position at $t = 0$ slightly. By $t = 0.25$ s., the differences in the position of the axle from its position at $t = 0$ are minimal.

Figure 16 makes it clear that the aft deflection and damped oscillation of the NLG strut on touchdown described in References 1 and 5 occurs, and that the initial aft deflection of the strut introduces a negative caster (θ) and mechanical trail (t_M) angle that reduces the dynamic trail (t_D) of the NLG tire, reducing its directional stability (see Equation [2]). What is not clear is whether the time during which this condition exists is long enough to introduce a divergence in the steering angle of the NLG (ϕ), particularly since during the oscillation of the NLG θ and t_M will at times be positive, increasing the dynamic stability of the NLG. The structural dynamics portrayed in the video and Figure 16 occur on every landing, but since the veer events examined in this *Study* are relatively rare, the deflection of the NLG strut cannot by itself explain them (for example, the landing shown in the video did not result in a veer event). The aft deflection of the NLG strut and consequent momentary reduction in t_M might temporarily contribute to a loss of directional stability, but additional factors (such as a negative pitch angle or a significant reduction in t at large α , for example) must be present in order to sustain the instability long enough to result in a divergence in ϕ and a veer event.

The following sections of the *Study* compare recorded avionics data from several of the veer events listed in Table 1 with each other and with simulations of the controls-free (no pilot input) lateral response of the airplane under various assumptions of NLG dynamic stability. A sense of the time from NLG touchdown over which the veer events occur can be gleaned from these comparisons.

D.4. Comparisons of Garmin G3000 data from several M600 veer events

The Piper M600 is equipped with a Garmin G3000 Integrated Avionics System. According to Reference 5,

The Garmin G3000 ... 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.

Figures 17 and 18 compare six different flight parameters based on CMC and / or log data from fourteen M600 veer events listed in Table 1. These parameters are either recorded directly in the data or computed from other parameters recorded in the data. Figure 17 plots the parameters vs. the time elapsed since NLG touchdown (Δt), and Figure 18 plots them vs. the distance (runway x -coordinate) from NLG touchdown (Δx).¹⁷ NLG touchdown is estimated from the behavior of the pitch angle (θ)¹⁸ during the landing de-rotation. In most cases, the NLG touchdown is identified as the point in the de-rotation where the pitch rate ($d\theta/dt$) changes rapidly from a negative value to a much smaller negative value or becomes approximately zero. In cases where identifying the NLG touchdown in this way would place sudden changes in lateral load factor (n_y) or heading (ψ_{HDG}) slightly prior to the identified touchdown point, the touchdown is shifted to coincide with the n_y or ψ_{HDG} changes. Note in Figures 17 and 18 that the pitch angle corresponding to the identified NLG touchdown point ranges from -2.5° (for event N115NX_KINW) to 1.7° (for event N917DB_KBOI).

The dependent parameters plotted in Figures 17 and 18 are as follows:

- Pitch angle (θ): as recorded in the avionics data.
- Ground speed: as recorded in the data or computed from smoothed Global Navigation Satellite System (GNSS) positions when recorded data was not available.
- Drift angle: $\psi_{DRIFT} = \psi_{TRK} - \psi_{HDG}$, where ψ_{TRK} = ground track angle and ψ_{HDG} = heading angle. ψ_{TRK} is as recorded in the avionics data or computed from smoothed GNSS positions when recorded data was not available. ψ_{HDG} is as recorded in the avionics data.

¹⁷ The origin of the runway coordinates is the intersection of the runway centerline with the runway threshold. The runway $+x$ coordinate extends towards the departure end of the runway coincident with the runway centerline, and the runway $+y$ coordinate extends 90° to the right of the runway centerline.

¹⁸ The symbol θ is also used elsewhere in this *Study* to represent the NLG caster angle. Whether pitch angle or caster angle is meant should be clear from the context in each case.

- Heading deviation from runway bearing: $\Delta\psi_{HDG} = \psi_{HDG} - \psi_{RWY}$, where ψ_{RWY} is the runway bearing.
- Runway y-coordinate: as computed from recorded GNSS positions transformed into runway coordinates. The runway edges are depicted as dashed lines using the color corresponding to each event.
- Lateral load factor (n_y): as recorded in the avionics data.

The events plotted in Figures 17 and 18 can be associated with those listed in Table 1 by the naming convention used in the Figure legends. For NTSB cases, the naming convention is the NTSB case number followed by the airplane registration number. For non-NTSB events, the naming convention is the airplane registration number followed by the identifier of the airport at which the event occurred. All of the plots in Figures 17 and 18 include case CEN22LA153 as a common reference / comparison case.

Note that several of the runway excursion events plotted in Figures 17 and 18 (that is, events that resulted in the airplane y-coordinate crossing a runway edge) exhibit some common traits, including a $|\Delta\psi_{HDG}| > 10^\circ$ within $\Delta t < 6$ sec., and an associated $|n_y| \geq 0.4$ G. Also, several of the events show the pitch angle decreasing below -1° early in the landing roll. As described above, a negative pitch angle will result in a destabilizing negative NLG caster angle relative to the runway, even if the rake angle relative to the fuselage is the nominal 90° . It is uncertain whether the pitch angle recorded by the G3000 is perfectly aligned with the bottom of the fuselage, so that a recorded 0° pitch angle truly corresponds to a 0° NLG caster angle on a correctly rigged airplane. Consequently, there is some uncertainty in determining that a negative pitch angle recorded by the G3000 indicates negative caster angle relative to the runway.

The trends of ψ_{DRIFT} , $\Delta\psi_{HDG}$, y , and n_y in Figures 17 and 18 are generally similar for events CEN22LA153, ERA20LA230, ERA20LA237, N115NX_KOJC, ERA21LA065, and N13HL_K7V7 (if the direction of the excursion is reversed for these last two). The CEN22LA153 and N115NX_KOJC events are particularly similar, especially in the timing of the ψ_{DRIFT} and $\Delta\psi_{HDG}$ parameters. CEN22LA153 is the subject of Piper's PFR, and N115NX_KOJC is the event involving a Piper engineering test pilot.

Event CEN23LA137_N13HL in Figures 17 and 18 exhibits some unique characteristics compared to the other events. In addition to the data being available at a higher sample rate (5 Hz vs. 1 Hz for other events), the ψ_{DRIFT} , $\Delta\psi_{HDG}$, and n_y parameters exhibit undamped oscillations that start at $\Delta t = 0$ and then diverge after 4 cycles at about $\Delta t = 9$ sec. These oscillations call to mind the "classic" definitions of neutrally stable and unstable dynamic systems described above, as distinct from the "dynamic instability" term used to refer to the self-centering tendencies of NLG. Similar oscillations are not observed in any of the other events plotted in Figures 17 and 18, though the 1 Hz sample rate might mask oscillations that could be present in event

N115NX_KDIJ, in which the magnitude of the ψ_{DRIFT} , $\Delta\psi_{HDG}$, and n_y excursions are much smaller than in the other events.

D.5. Ground roll simulations with different NLG behavior assumptions

To better understand how a directionally unstable NLG would affect an airplane's ground roll absent any rudder pedal inputs from the pilot, a simple six-degree of freedom (DOF) simulation of an airplane generally representative of an M600 was built in the NTSB's *MATLAB*-based simulation program. The simulation was also used to estimate the NLG steering angle (driven by rudder pedal inputs) that would be required to approximately match the airplane trajectory recorded in the G3000 data for case CEN22LA153.

This section of the *Study* describes the airplane model used in the simulations, the simulation scenarios tested, and the corresponding results. The simulations indicate that while full nose-right deflection of the NLG is required for the model to approximately match the dynamics recorded in the CEN22LA153 data, the model matches the data better if the NLG rotates from centered to full-right over about 3 seconds, as opposed to snapping to full-right almost instantly after NLG touchdown. The simulations also indicate that as expected, with no opposing pedal inputs from the pilot, a directionally unstable NLG swings to full deflection within a fraction of a second after NLG touchdown, whereas a directionally stable NLG tends to remain centered. The behavior of the NLG in the simulations is similar regardless of the magnitude of the dynamic trail (t_D) assumed, and depends only on the *sign* of t_D (unstable for $t_D < 0$, and stable for $t_D > 0$), consistent with the simple manner in which the moments about the steering axis are modeled.¹⁹

D.5.1. Piper M600 simulation model

The airplane model used in the simulations is based on aerodynamic and mass properties models from an M600 Advanced Aviation Training Device (AATD) provided by a flight simulator manufacturer, and simple flight controls, engine, and landing gear models developed by the NTSB. The requirements for Federal Aviation Administration (FAA) approval of Basic Aviation Training Devices (BATD) and AATD are described in Advisory Circular (AC) 61-136B, *FAA Approval of Aviation Training Devices and Their Use for Training and Experience*. Notably, the AC states that it "does not apply to full flight simulators (FFS) and flight training devices (FTD) that are regulated under 14 CFR part 60." The qualification standards for BATD/AATD and FFS/FTD devices are quite different regarding the level of fidelity required of the associated flight dynamics models, and so BATDs and AATDs cannot be considered engineering flight simulators

¹⁹ The model assumes a constant value of t_D regardless of the NLG steering angle (α) or any of the other factors affecting pneumatic trail (t) described in section D.3.2.

that are shown to match the performance of the real aircraft to specified standards. In keeping with these limitations, the simulations presented here are intended to provide only a first-order understanding of the effects of changes in NLG directional stability, and of the magnitude and timing of NLG steering inputs required to approximately match the CEN22LA153 G3000 data. The simulations cannot, and are not presumed to, represent the dynamics of the M600 to any given standard, or to indicate the actual NLG steering angles present during the CEN22LA153 accident.

As noted above, the gear model for the simulations was developed by the NTSB. The model computes the vertical, longitudinal, and lateral forces acting at the contact point of each tire with the runway, and the self-aligning torque (M_z) of the NLG. However, the rudder pedal forces associated with M_z are not computed. The vertical tire forces are determined by the airplane dynamics and the requirement that the tires cannot penetrate the runway surface. The longitudinal and lateral tire forces are determined using the “composite” analytical tire model described in Reference 18. The model allows for main gear braking through the specification of a main gear tire slip ratio:

$$s = 1 - \frac{V_{WHEEL}}{V_G} \quad [7]$$

Where V_G is the airplane’s ground speed, and V_{WHEEL} is the tangential speed of the tire:

$$V_{WHEEL} = \omega_{WHEEL} r_{TIRE} \quad [8]$$

Where ω_{WHEEL} is the angular velocity of the wheel, and r_{TIRE} is the effective radius of the tire (the distance from the center of rotation of the wheel to the point where the tire contacts the runway). Per Eq. [7], when the tires are free-rolling and $V_{WHEEL} = V_G$, then $s = 0$. Conversely, when the tires are locked and $V_{WHEEL} = 0$, then $s = 1$.

The longitudinal and lateral friction coefficients acting on the tires are computed in the composite tire model as functions of s , the tire slip angle α , and the maximum friction coefficient available from the runway surface (μ_{max}). The corresponding tire forces are equal to the friction coefficients multiplied by the vertical forces on each tire. A constant μ_{max} of 0.85 corresponding to a dry, paved runway is assumed.

The simulations use an airplane weight of 4,900 lb. and a center of gravity (CG) location of 141 inches aft of datum (28.4% mean aerodynamic chord (MAC)).

In certain simulation scenarios, a “math pilot” controller is used to manipulate the rudder pedals so as to achieve a “target” trajectory during the ground roll. The target

trajectories include tracking the runway centerline, and tracking the trajectory recorded in the CEN22LA153 G3000 data. The math pilot detects a deviation of the airplane from the target trajectory, and generates rudder pedal inputs to correct the deviation and return the airplane to the target.

The math pilot is also used during the airborne portion of the landing simulations to make control column and control wheel inputs as required to match “target” pitch and roll angles defined by the CEN22LA153 G3000 data. Once the airplane is on the ground and the pitch angle decreases below 0.1° , the math pilot ceases targeting pitch and roll control and a simple bias of 1° forward column is used to keep the nose wheel on the runway.

The engine power during the landing simulations is defined by the torque and propeller RPM parameters recorded in the CEN22LA153 G3000 data. The resulting power is used in a propeller momentum theory model to compute thrust.

D.5.2. Simulation scenarios

The simulation scenarios tested consisted of the following variations of a landing and ground roll maneuver:

- Controls-free (no applied rudder pedal force) landing (touchdown, de-rotation, and ground roll) with NLG dynamic trail (t_D) = +0.5 inches and +0.05 inches.
- Controls-free landing with $t_D = 0$.
- Controls-free landing with $t_D = -0.05$ inches.
- Landing with the math pilot using pedal inputs to track the runway centerline.
- Landing with a forced NLG “hardover” (full right deflection) at NLG touchdown.
- Landing with the math pilot using pedal inputs to approximately track the CEN22LA153 trajectory.

For the controls-free landings and the match of the CEN22LA153 event, main wheel braking with $s = 0.12$ is applied 10 seconds after the start of the simulation. For the centerline tracking scenario, main wheel braking with $s = 0.05$ is applied at 10 seconds. NLG touchdown occurs at 3.2 seconds for the controls-free landings, and at 4.0 seconds for the others.

The initial conditions for all the scenarios are presented in Table 7. The airplane configuration for all scenarios is landing flaps (35°) with gear down.

The weather conditions for the CEN22LA153 matching, centerline tracking, and NLG “hardover” scenarios were selected to approximately match those of the CEN22LA153 case, as follows: wind: 220° at 16 kt., temperature 47° F, altimeter setting 29.73 “Hg. These winds correspond to about a 12 knot headwind and 10 knot right crosswind for runway 18. The winds for the “controls-free” scenarios was set to 180° at 14 knots (a 14 knot headwind and 0 knot crosswind for runway 18).

D.5.3. Simulation results

The results of the “controls-free” simulations are presented in Figure 19, and the results of the CEN22LA153 matching, centerline tracking, and NLG “hardover” simulations are presented in Figure 20. The “a” versions of these Figures present the results as a function of time, and the “b” versions present them as a function of the runway x -coordinate.

As noted above, Figure 19 indicates that with no opposing pedal inputs from the pilot, a directionally unstable NLG ($t_D < 0$) swings to full deflection within a fraction of a second after NLG touchdown, whereas a directionally stable NGL ($t_D > 0$) tends to remain centered. Only the sign, and not the magnitude, of t_D has a noticeable effect on the behavior of the NLG; the NLG response (and that of the airplane) are almost identical for both $t_D = 0.5$ inches and $t_D = 0.05$ inches. For $t_D = -0.05$ inches, the NLG deviates full left immediately after it touches down, and the airplane yaws hard left. For a neutrally stable NLG ($t_D = 0$), the response of the gear and airplane lies between that of the stable and unstable conditions, with the NLG remaining centered but the airplane drifting left under other influences (such as small differences in the braking force between left and right main gear tires).

The match of the CEN22LA153 accident in Figure 20 (the “accident simulation”) is far from perfect, even with the math pilot driving the rudder pedals in an attempt to duplicate the recorded ground track, indicating that the simulation gear model does not account fully for all of the physics involved. However, the simulation does match the recorded data fairly well during the initial seconds of the veer to the right, and indicates that while full nose-right deflection of the NLG is required to approximately match the dynamics recorded in the CEN22LA153 data, a better match is obtained if the NLG rotates from centered to full-right over about 3 seconds (the “accident simulation”), instead of snapping to full-right almost instantly after NLG touchdown (the “hardover simulation”).

The sudden jumps and ringing in the “accident simulation” rudder pedal data in Figure 20 are artifacts of the logic of the math pilot. Similar results could be obtained with a rudder pedal trace that “smooths” through the jumps shown in Figure 20.

Figure 20 also indicates that the math pilot can track the runway centerline with relatively small rudder pedal inputs (the “centerline simulation”).

D.6. Pilot flight control input considerations

D.6.1. Uncertainties due to lack of data

Because the G3000 data does not include rudder pedal force, rudder pedal position, rudder surface position, or NLG steering angle parameters, the actual value of these parameters during the CEN22LA153 accident landing cannot be determined. However, the “accident simulation” shown in Figure 20 indicates that a substantial right rudder pedal input is required shortly after NLG touchdown in order to approximately match the heading and track data that the G3000 does record. Further, the magnitude and suddenness of the veer are hard to explain without a substantial deviation of the NLG steering angle. The similarity of the CEN22LA153 event with the other M600 veer events plotted in Figures 17 and 18 suggests that the NLG steering angle likely deviated shortly after NLG touchdown in those events as well (with the exception, perhaps, of case CEN23LA137_N13HL). Granting that the NLG steering angle (and rudder pedals) in the CEN22LA157 case did behave approximately as depicted in the “accident simulation” scenario plotted in Figure 20, it is of interest to consider whether the rudder pedal movements could have been the result of forces applied by the pilot with his feet, or of a destabilizing M_z on the NLG that “drove” the pedals through the mechanical linkage to the NLG, or of a combination of these factors.

Because of the lack of relevant data concerning the rudder pedal position and NLG steering angle noted above, it is not possible to explain with certainty the root causes of their movements. One possible explanation is that of the NLG becoming directionally unstable at relatively high slip angles (α) as described in section D.3.2; a high α could result from some drift combined with a pilot rudder pedal input at or shortly after NLG touchdown. In this scenario, once the NLG is deflected sufficiently to the right, the dynamic trail t_d becomes negative and the resulting M_z tends to rotate the NLG further to the right. Unless the pilot applies sufficient left rudder pedal force to overcome this M_z , he will not be able to return the NLG to the left. The pilot might perceive that he is applying left rudder (because of the force exerted through his left

leg and foot), but the NLG might still be deflected to the right. This could be a potentially very confusing situation for the pilot.

Another possible explanation for the large right rudder pedal input depicted in Figure 20 is that the pilot, for whatever reason (confusion or inexperience, for example), commanded the NLG deviation by applying force on the rudder pedals with his feet, with the NLG remaining stable and the resulting M_z remaining as expected (force on the right pedal required for right pedal deflection, and force on the left pedal required for left pedal deflection). Piper's PFR (Reference 2) asserts that this is indeed the case, stating:

... other than citing the POH and noting the proper technique, the NTSB Report does not analyze the pilot's technique or engage in any analysis or review of whether the pilot in fact used proper crosswind technique and rudder control (by promptly centering the nose-wheel) at the point of touchdown, or at any other point during the landing. It is far more probable and perhaps understandable that the pilot, when landing in the crosswind, resorted to his past experience with a castering nose gear and failed to operate this aircraft properly.

As noted in the Gudmundsson Report the photographic evidence demonstrates that the pilot used improper technique for landing a steerable nose-wheel aircraft in crosswind conditions, and after touching down applied incorrect braking and steering technique, essentially "driving" the aircraft off the runway.

The "accident simulation" scenario in Figure 20 indicates that the pilot's application of "incorrect braking and steering technique," per the PFR's assertion, must have been egregious indeed, since it indicates that full-right rudder deflection (and not simply a non-centered NLG at touchdown) is required to approximately match the G3000 data.

As noted above, the motions of the airplanes in the CEN22LA153 accident and the N115NX_KOJC event (which involved a Piper engineering flight test pilot) exhibit remarkable similarities (see Figures 17d and 18d). Piper's February 24, 2021 letter to the PA46 Owner Community (Reference 22; see Appendix A) acknowledges the N115NX_KOJC event, stating that

... a Piper pilot delivering a new M600 to a dealer experienced a runway excursion to the right. The pilot could have kept it on the runway but elected to continue across the level grass onto a taxiway.

The letter does not provide a reason for the pilot's decision, and it is hard to understand why a pilot would "elect" to leave the paved surface of the runway if remaining on the

runway was an option.²⁰ A different possibility is that the pilot in the N115NX_KOJC event had as little “choice” in the matter as the pilot in the CEN22LA153 accident, or as the pilots in any of the other veer events listed in Table 1.

Unlike the PFR, which attributes the CEN22LA153 accident to pilot error (“incorrect braking and steering technique”), Piper’s letter appears to attribute the N115NX_KOJC event to low NLG tire pressure:

Tire Pressures. We reviewed earlier [in this letter how the pilot involved in] the M600 runway excursion in December 2019 was a Piper pilot. Our pilot and our delivery team did not follow the POH when it came to tire pressure preflight and care.

After additional tire pressure checks were taken throughout the combined owner, dealer and Piper factory fleets, it became apparent that a substantial portion of the PA46 fleet is operating with low tire pressures. As a result, we issued **SL1285** in July 2020 reminding all owners the importance of this key maintenance item.

D.6.2. Use of the rudder pedals for directional control on the ground

An overview of the proper use of the rudder pedals for directional control on the ground, and some factors that might affect the pilot’s application of force on the rudder pedals, are considered in this section.

Pilots begin learning to use the rudder pedals to steer an airplane on the ground on their first flight lesson, and this skill is practiced on every flight. The airplane must be taxied to the runway, kept on the runway during the takeoff and landing, and taxied back from the runway. Many of the basic training aircraft in which pilots learn to fly – such as the Cessna 150/152/172 and the Piper PA-28 – are tricycle-gear airplanes with steerable NLG, and so pilots trained in these airplanes learn control of the NLG through the rudder pedals very early; it would be rare for a pilot who transitioned to a high performance, complex aircraft such as the PA46 not to have significant previous exposure to steerable NLG designs.²¹

²⁰ Per the Piper letter, the airplane’s propeller was replaced as a result of the event.

²¹ Tricycle gear airplanes with steerable NLG are generally considered easier to control on the ground than “taildragger” airplanes equipped with a tailwheel, particularly during landings. This is because on airplanes with NLG the CG is in front of the main gear, and so braking forces have less of a tendency to “ground loop” the airplane than on taildraggers, where the CG is behind the main gear. Airplanes with NLG also eliminate the risk of nosing the aircraft over (perhaps through excessive braking) and causing a ground strike of the propeller.

The FAA *Airplane Flying Handbook* (AFH, Reference 19) describes the normal use of the rudder pedals for yaw control on the ground, and some challenges pilots might encounter maintaining directional control on the ground with the rudder pedals. Some relevant excerpts from the AFH are cited below.

From Chapter 2, *Ground Operations*:

Preflight Assessment of the Aircraft

...

Landing Gear, Tires, and Brakes

The landing gear, tires, and brakes allow the airplane to maneuver from and return to the ramp, taxiway, and runway environment in a precise and controlled manner. The landing gear, tires, and brakes should be inspected to ensure that the airplane can be positively controlled on the ground. ...

...

The following provides guidelines for inspecting the landing gear system; however, the AFM/POH should be the pilot's reference for the appropriate procedures.

...

- Tires should be inspected for proper inflation, an acceptable level of remaining tread, and normal wear pattern. ...
- On tricycle gear airplanes, a shimmy damper is used to damp oscillations of the nose gear and should be inspected to ensure that it is securely attached, is free of hydraulic fluid leaks, and is in overall good condition. Some shimmy dampers do not use hydraulic fluid and instead use an elastomeric compound as the dampening medium. Nose gear links, collars, steering rods, and forks should be inspected to ensure the security of fasteners, minimal free play between torque links, crack-free components, and for proper servicing and general condition.

Taxiing

Taxiing is the controlled movement of the airplane under its own power while on the surface. Since an airplane is moved under its own power between a parking area and the runway, the pilot needs to understand and be proficient in taxi procedures.

...

Steering is accomplished with rudder pedals and brakes. To turn the airplane on the ground, the pilot should apply the rudder in the desired direction of turn and use the appropriate power or brake to control the taxi speed. The rudder pedal should be held in the direction of the turn until just short of the point where the turn is to be stopped. Rudder pressure is then released or opposite pressure is applied as needed.

...

When taxiing with a quartering tailwind, the elevator should be held in the DOWN position, and the upwind aileron, DOWN. Since the wind is striking the airplane from behind, these control positions reduce the tendency of the wind to get under the tail and the wing and to nose the airplane over. The application of these crosswind taxi corrections helps to minimize the weathervaning tendency and ultimately results in easier steering.

...

Normally, all turns should be started using the rudder pedal to steer the nose wheel. To tighten the turn after full pedal deflection is reached, the brake may be applied as needed. When stopping the airplane, it is always advisable to stop with the nose wheel straight ahead to relieve any side load on the nose wheel and to make it easier to start moving ahead. Note that certain makes and models have no nose wheel steering and the brakes need to be used to control any turns.

During crosswind taxiing, even the nose wheel-type airplane has some tendency to weathervane. However, the weathervaning tendency is less than in tailwheel-type airplanes because the main wheels are located behind the airplane's center of gravity, and the nose wheel's ground friction helps to resist the tendency. The nose wheel linkage from the rudder pedals provides adequate steering control for safe and efficient ground handling, and normally, only rudder pressure is necessary to correct for a crosswind.

After-Landing

During the after-landing roll, while maintaining ... heading down runway with rudder pedals, the airplane should be gradually slowed to normal taxi speed with normal brake pressure before turning off of the landing runway.

From Chapter 6, *Takeoffs and Departure Climbs*:

Takeoff Roll

For takeoff, the pilot uses the rudder pedals in most general aviation airplanes to steer the airplane's nose-wheel onto the runway centerline to align the airplane and nose-wheel with the runway. After releasing the brakes, the pilot should advance the throttle smoothly and continuously to takeoff power. An abrupt application of power may cause the airplane to yaw sharply to the left because of the torque effects of the engine and propeller. This is most apparent in high horsepower engines. As the airplane starts to roll forward, assure both feet are on the rudder pedals so that the toes or balls of the feet are on the rudder portions, not on the brake.

...

As the airplane gains speed, the elevator control tends to assume a neutral position if the airplane is correctly trimmed. At the same time, the rudder pedals are used to keep the nose of the airplane pointed down the runway and parallel to the centerline. The effects of engine torque and P-factor at the initial speeds tend to pull the nose to the left. The pilot should use whatever rudder pressure is needed to correct for these effects or winds. The pilot should use aileron controls into any crosswind to keep the airplane centered on the runway centerline. ...

From Chapter 9, *Approaches and Landings*:

After-Landing Roll

The landing process should never be considered complete until the airplane decelerates to the normal taxi speed during the landing roll or has been brought to a complete stop when clear of

the landing area. Accidents may occur as a result of pilots abandoning their vigilance and failing to maintain positive control after getting the airplane on the ground.

A pilot should be alert for directional control difficulties immediately upon and after touchdown due to the ground friction on the wheels. Loss of directional control may lead to an aggravated, uncontrolled, tight turn on the ground, or a ground loop. ...

The rudder serves the same purpose on the ground as it does in the air—it controls the yawing of the airplane. The effectiveness of the rudder is dependent on the airflow, which depends on the speed of the airplane. As the speed decreases and the nose-wheel has been lowered to the ground, the steerable nose provides more positive directional control.

The brakes of an airplane serve the same primary purpose as the brakes of an automobile—to reduce speed on the ground. In airplanes, they are also used as an aid in directional control when more positive control is required than could be obtained with rudder or nose-wheel steering alone.

To use brakes, on an airplane equipped with toe brakes, the pilot slides the toes or feet up from the rudder pedals to the brake pedals. If rudder pressure is being held at the time braking action is needed, the pilot should not release that pressure as the feet or toes are being slid up to the brake pedals because control may be lost before brakes can be applied.

Putting maximum weight on the wheels after touchdown is an important factor in obtaining optimum braking performance. During the early part of rollout, some lift continues to be generated by the wing. After touchdown, the nose-wheel is lowered to the runway to maintain directional control. During deceleration, applying brakes may cause the nose to pitch down and some weight to transfer to the nose-wheel from the main wheels. This does not aid in braking action, so back pressure is applied to the controls without lifting the nose-wheel off the runway. This enables directional control while keeping weight on the main wheels.

Careful application of the brakes is initiated after the nose-wheel is on the ground and directional control is established. Maximum brake effectiveness is just short of the point where skidding occurs. ...

During the ground roll, the airplane's direction of movement can be changed by carefully applying pressure on one brake or uneven pressures on each brake in the desired direction. Caution must be exercised when applying brakes to avoid over-controlling.

...

Common Errors

Common errors in the performance of normal approaches and landings are:

...

15. Loss of aircraft control during touchdown and rollout.

Crosswind Touchdown

If the crab method of drift correction is used throughout the final approach and round out, the crab needs to be removed the instant before touchdown by applying rudder to align the airplane's longitudinal axis with its direction of movement.

If the wing-low method is used, the crosswind correction is maintained throughout the round out, and the initial touchdown occurs on the upwind main wheel. During gusty or high wind conditions, prompt adjustments are made in the crosswind correction to assure that the airplane does not drift as the airplane touches down. As the forward momentum decreases after initial contact, the weight of the airplane causes the downwind main wheel to gradually settle onto the runway.

In those airplanes having nose-wheel steering interconnected with the rudder, the nose-wheel is not aligned with the runway as the main wheels touch down because opposite rudder is being held for the crosswind correction. To prevent swerving in the direction the nose-wheel is offset, the corrective rudder pressure needs to be relaxed as the nose-wheel touches down.

Crosswind After-Landing Roll

Particularly during the after-landing roll, special attention should be given to maintaining directional control by the use of rudder or nose-wheel steering, while keeping the upwind wing from rising by the use of aileron.

Common Errors

Common errors in the performance of crosswind approaches and landings are:

...

6. Failure to touch down with the longitudinal axis aligned with the runway.

7. Touching down while drifting.

...

9. Failure to apply appropriate flight control inputs during rollout.

10. Failure to maintain direction control on rollout.

...

12. Loss of aircraft control.

The "Takeoff Roll" section of Chapter 6 of the AFH also describes how pilots learn to discern the amount of rudder and elevator input required to keep the airplane tracking down the runway through experiencing the airplane's reaction to applied pressures on the flight controls at different speeds. These observations are relevant to the landing roll as well:

As the speed of the takeoff roll increases, more and more pressure will be felt on the flight controls, particularly the elevators and rudder. ... As the speed continues to increase, all of the flight controls will gradually become effective enough to maneuver the airplane about its three axes. At this point, the airplane is being flown more than it is being taxied. As this occurs, progressively smaller rudder deflections are needed to maintain direction.

The feel of resistance to the movement of the controls and the airplane's reaction to such movements are the only real indicators of the degree of control attained. This feel of resistance is not a measure of the airplane's speed, but rather of its controllability. To determine the degree of controllability, the pilot should be conscious of the reaction of the airplane to the control pressures and immediately adjust the pressures as needed to control the airplane. The pilot should wait for the reaction of the airplane to the applied control pressures and attempt to sense the control resistance to pressure rather than attempt to control the airplane by movement of the controls.

A student pilot does not normally have a full appreciation of the variations of control pressures with the speed of the airplane. The student may tend to move the controls through wide ranges seeking the pressures that are familiar and expected and, as a consequence, over-control the airplane.

The situation may be aggravated by the sluggish reaction of the airplane to these movements. The flight instructor should help the student learn proper response to control actions and airplane reactions. ... The flight instructor should have the student pilot follow through lightly on the controls, feel for resistance, and point out the outside references that provide the clues for how much control movement is needed and how the pressure and response changes as airspeed increases. With practice, the student pilot should become familiar with the airplane's response to acceleration up to lift-off speed, corrective control movements needed, and the outside references necessary to accomplish the takeoff maneuver.

Developing a "sense" or "feel" for the response of the airplane in this way depends on the airplane responding consistently to control inputs at a given speed. If the relationship between applied control pressures and airplane response changes from what the pilot expects suddenly or unexpectedly, the pilot might apply inappropriate control inputs for the situation, and undesired airplane motions might result. If this situation persists, it can lead to what is commonly referred to as a "Pilot-Induced Oscillation" (PIO) and a loss of control. PIOs are a subset of unfavorable control interactions between the pilot and the aircraft included under the term "Aircraft-Pilot Coupling" (APC). APC and its potential relevance to PA46 runway excursions are considered in the next section.

D.6.3. Aircraft-Pilot Coupling (APC)

The ψ_{DRIFT} , $\Delta\psi_{HDG}$, and n_y parameters for event CEN23LA137_N13HL plotted in Figures 17c and 18c exhibit undamped oscillatory behavior that starts at NLG touchdown and ultimately diverges about 9 seconds after NLG touchdown, resulting in a runway excursion. The NTSB preliminary report for this accident (Reference 20) states:

The pilot reported that during landing, when the nose wheel made contact with the runway, the airplane began to veer to the right. He attempted to use left rudder and brake to keep the airplane on the runway, but as the airspeed decreased, directional control became harder to maintain and the airplane subsequently departed the right side of the runway.

A post-accident pilot statement recorded by Piper states in part:

... The airplane continues down center line with torque set to idle I continue a normal landing. The main gear touching first with the nose gear soon to follow. As the nose wheel touches down, the plane veers right, I apply light left rudder and the plane responds back to center. As the plane centered it started a hard veer right, I applied more left rudder with [toe] brakes also. At this point it is taking full left rudder to keep plane on runway and will not come back to center line. ... I continued using the left brake and full left rudder by now we are about a thousand feet down the runway and as the airspeed drops the problem worsens. When we cross the intersecting taxiway the right main drops off the concrete surface with the nose wheel soon to follow, at this point the nose wheel hits a runway light and the plane starts to spin to the left. Being at an uncontrollable state the plane comes to a stop and the gear collapses and the prop strikes. ...

The oscillatory behavior of the heading and n_y parameters suggests that the airplane was likely responding to oscillatory rudder pedal inputs made by the pilot, though not in a way the pilot expected or could manage, per his statement above. The situation appears to meet the definitions of an "APC event" generally, and a "PIO" specifically, provided by a report prepared by the National Research Council (NRC), titled *Aviation Safety and Pilot Control: Understanding and Preventing Unfavorable Pilot-Vehicle Interactions* (Reference 21):

Unfavorable aircraft-pilot coupling (APC) events are rare, unexpected, and unintended excursions in aircraft attitude and flight path caused by anomalous interactions between the aircraft and the pilot. The temporal pattern of these pilot-vehicle system (PVS) excursions can be oscillatory or divergent (non-oscillatory). The pilot's interactions with the aircraft can form either a closed-loop or open-loop system, depending on whether or not the pilot's responses are tightly coupled to the aircraft response. When the dynamics of the aircraft (including the flight control system [FCS]) and the dynamics of the pilot combine to produce an unstable PVS, the result is called an APC event.

Although it is often difficult to pinpoint the cause of specific APC events, a majority of severe APC events result from deficiencies in the design of the aircraft (especially with regard to the FCS) that result in adverse coupling of the pilot with the aircraft. In certain circumstances, this adverse coupling produces unintended oscillations or divergences when the pilot attempts to precisely maneuver the aircraft. If the PVS instability takes the form of an oscillation, the APC event is called a "pilot-involved oscillation" (PIO)^[22]. ...

APC events can result if the pilot is operating with a behavioral mode that is inappropriate for the task at hand, and such events are properly ascribed to pilot error. However, the committee

²² The NRC report uses the PIO acronym to refer to both "pilot-induced oscillations" and "pilot-involved oscillations." The report notes that it has adopted the APC phraseology, in part, to "remove the presumption of blame implicit in the term 'pilot-induced.'"

believes that most severe APC events attributed to pilot error are the result of adverse APC that misleads the pilot into taking actions that contribute to the severity of the event. It is often possible, after the fact, to carefully analyze an event and identify a sequence of actions that the pilot could have taken to overcome the aircraft design deficiencies. However, it is typically not feasible for the pilot to identify and execute the required actions in real time.

Note that what the NRC report calls “design deficiencies” could also include discrepancies in the condition of the airplane that affect its dynamics. Specifically, and as will be considered further below, out-of-tolerance conditions in the PA46 NLG tire pressures and / or rigging might change the feel characteristics of the NLG steering in unexpected ways, and thereby increase the risk of an APC event or PIO.

A key finding of the NRC report is that “APC events usually occur when the pilot is engaged in a highly demanding, closed-loop control task”²³ and are “triggered” by changes in the PVS that cause the aircraft response to be different from what the pilot expects:

Finding. Adverse APC events are rare, unintended, and unexpected oscillations or divergences of the pilot-aircraft system. APC events are fundamentally interactive and occur during highly demanding tasks when environmental, pilot, or aircraft dynamic changes create or trigger mismatches between actual and expected aircraft responses.

Regarding the items that can trigger an APC, the report states that

Typical triggers include shifts in the dynamics of the effective aircraft (the combination of the aircraft and FCS) caused by increases in the amplitude of pilot commands, FCS changes, minor mechanical malfunctions, or severe atmospheric disturbances. Other triggers can stem from mismatches between the pilot's expectations and reality.

Much of the NRC report focuses on modern, fly-by-wire aircraft in which changes in flight control laws, control surface rate and position limiting, and phase lags between the cockpit control and control surface can trigger APC events. These items are not relevant to the simple mechanical rudder and NLG control systems of general aviation airplanes. However, the general principle that changes in the flight control system can “trigger mismatches between actual and expected aircraft responses” and potentially contribute to APC is relevant. As Piper has emphasized in several PA46 Service Bulletins and Letters, if the NLG rake angle, tire pressures, and steering system rigging are not maintained within prescribed tolerances, the “feel” of the NLG steering system can change in adverse ways. Piper communications that address the NLG steering system include (see also Table 5):

²³ Tracking the runway centerline with the rudder pedals during the landing roll could be considered such a “highly demanding, closed-loop control task.”

- SB 1106, *Nose Gear Steering System Improvement* (M500):

There have been field reports of turning tendency immediately following nose wheel touch down during landings ... a contributing cause of the turning tendency has been identified as reduced nose gear steering authority which, under certain conditions, can allow the nose gear steering rotation to momentarily exceed the pilot's input. This Service Bulletin recommends mandatory incorporation of the following nose gear installation modifications that increase the pilot's steering authority. Failure to incorporate these modifications may increase the possibility of a turning tendency during landing.

- Customer Information Letter, *PA46 Operational & Maintenance Information, Nose Gear Steering* (3/27/2008, Reference 17) (see Appendix A): Emphasizes the importance of "several operational factors ... identified as critical for optimum steering function on all Malibu models," including tire pressure, nose gear rake angle, steering arm / roller gap, rudder cable tension, and pilot technique. The letter also outlines the changes introduced by SB 1106, including replacing the NLG tire with a different type, increasing the NLG tire pressure from 50 psi to 70 psi, and replacing the steering bungee with a stiffer version "to increase the pilot's authority in controlling steering forces." Of note, the letter states that:

- "A [NLG] rake angle outside of [the specified] range may result in dynamic instability"
- "Excessive clearance between [the two nylon rollers mounted on the NLG steering horn] and the steering arm will result in loose steering and allow the nose wheel to point in a different direction than is commanded by rudder pedal inputs"
- "Low rudder cable tension can create variations between rudder angle and nose wheel steering angle. Operating with excessively low rudder cable tension could result in the nose wheel pointing in a direction that differs from the aircraft line of travel at the instant of touchdown, even though proper pilot technique ... is followed."

- SL 1285, *Maintenance Alert: Proper Tire Pressure Maintenance* (all PA46 models except M700): Notes that "there are several safety benefits to proper tire maintenance, including its effect on ground steering. Maintaining proper aviation tire inflation pressure reduces the size of a tire's rolling contact patch, which reduces the magnitude of the force associated with ground steering."

- SL 1286, *Maintenance Alert: Nose Landing Gear Steering Components Inspection and Adjustment* (all PA46 models except M700):

Several aircraft components, and their rigging, are important for proper ground steering and directional control. These components require regular, proper inspection and adjustment, and,

on condition, replacement, to maintain proper ground steering and directional control. This service letter provides a review of the best practices for maintaining ground steering system components ... : rudder cable tension, nose landing gear alignment, nose gear rake angle, and nose gear steering arm clearance.

- *Piper Letter to M600 Owners (2/4/2021)* (Reference 17; see Appendix A): States “maintaining proper [tire] pressure is most critical on the M600 with the associated higher operating weights”, and emphasizes the importance of compliance with SL 1286 and its revisions, which

directed adjustments to the length of the rudder pedal connection arms. In general this procedure shortens (or tightens) the control rod lengths via adjustment bolts resulting in a more positive rudder pedal engagement, better rudder to pilot feedback and controllability throughout the rudder pedals normal travel range.

- *Piper Letter to PA46 Owner Community (2/24/2021)* (see Appendix A): Reiterates the importance of compliance with SL 1285, SL 1286 & 1286A, & SB 1350, including the statement that “as operators of PA46 aircraft we all have the duty to strictly adhere to tire pressure requirements highlighted in the POH and Maintenance Manuals. There is no grey area here.”

These communications indicate that the PA46 NLG steering system is sensitive to out-of-tolerance conditions in the NLG rake angle, alignment, tire pressure, rudder cable tension, and nose gear steering arm / steering horn roller clearance. It is plausible that, in certain circumstances, the potential changes in steering forces, steering authority, and NLG orientation cited by the communications as potential consequences of out-of-tolerance conditions could alter the control feel of the NLG steering system sufficiently to contribute to pilot confusion and an APC event.

As noted in section D.3.2, low NLG tire and / or strut extension or heavy NLG loading can lower the pitch angle of the airplane on the runway, introducing a negative caster angle relative to the runway and decreasing the directional stability of the NLG (recall Piper’s warning in Reference 10 that “a [NLG] rake angle outside of [the specified] range may result in dynamic instability, creating steering forces that exceed the pilot’s ability to control”). Another factor that can plausibly alter the control feel of the NLG steering system, even at a nominal 90° rake angle, is variation in the directional stability of the NLG with changes in the length of the dynamic trail (t_D), as a result of its dependency (given zero mechanical trail (t_M)) on NLG tire inflation pressure, NLG vertical load, ground speed, runway μ , and (most critically) NLG tire slip angle (α). As suggested in section D.6.1, at a sufficiently high α the dynamic trail t_d can become negative and the resulting M_z tends to rotate the NLG further away from neutral, requiring greater opposing pedal force to overcome the M_z and center the NLG. The pilot might perceive that he is applying rudder in one direction (because of the pedal force he exerts), but the NLG could in fact be deflected in the opposite direction,

resulting in a potentially confusing situation that could trigger an APC event. Even apart from this extreme case (in which t_d becomes negative), a reduction in t_d will decrease the magnitude of the self-aligning M_z moment, changing the ratio of the pedal force to NLG steering angle and the consequent control feel of the system.

The 0.5" t_M introduced by the redesigned PA46 NLG fork increases t_d by 0.5" in all conditions (equivalent to 5° of positive caster angle), making the directional stability of the NLG more robust.

The sensitivity of the original NLG to the mechanical tolerances listed above and to the factors affecting t_d helps to explain the rigor with which the tolerances must be maintained and the care with which the airplane must be landed. As stated in Piper's 2/24/2021 letter to the PA46 Owner Community,

It has also become apparent that M600s are being landed 1) too fast, 2) with low tire pressures and 3) the nose wheel is not being "flown down" as speed decreases. In essence, keeping the nose wheel unloaded for as long as possible. This simple "technique" is taught by Piper approved Legacy Flight Training. It's also taught by some independent instructors but not all. Note from a recent forum post: "...the M600 lands much like the DC-9, where it is important to fly the nose gear down to the runway, and not give up on the back pressure until slower airspeeds. Which is precisely the way Legacy (Vero Beach) teaches. I can still hear my instructor, Dave, telling me "once the nose gear settles, bring the yoke back into your lap, don't relieve the back pressure until you're slowed down." We agree.

The advice to keep the load on the NLG light by maintaining back pressure on the yoke until low airspeeds is consistent with a goal of keeping the pitch angle, and consequent NLG caster angle relative to the runway, as positive as possible, thereby maximizing the directional stability of the NLG.

All aircraft must be maintained and flown properly to mitigate the risk of incidents and accidents. However, if the PA46 NLG were not particularly demanding in this regard, and everything else being equal, one would expect a more even distribution of landing veer events across airplane makes and models than that presented in Tables 3 and 4b.

D.7. Pilot community concerns regarding PA46 veer events

The relatively high incidence of runway veer events involving the PA46, and the M600 in particular, compared to other aircraft types (see Tables 3 and 4b) has not gone unnoticed by the PA46 pilot community. Of note, these events have occasioned the following items:

- A WSJ article that noted several NTSB investigations involving the M600 variant and the related concerns of M600 pilots. Piper's 2/24/2021 letter to the PA46 Owner Community (see Appendix A) includes a response to this article.

- The initiation of a study of PA46 runway excursions by the Aircraft Owners and Pilots Association (AOPA) in partnership with the Piper M-Class Owners and Pilots Association (PMOPA).
- Instructor-hosted YouTube videos mentioning the PA46 runway excursion events and discussing the operation and maintenance of the PA46 NLG system.
- Posts to online forums discussing M600 events and NLG steering (for example, <https://www.beechtalk.com/forums/viewtopic.php?f=49&t=183020&start=15>).
- Favorable receptions of the redesigned NLG fork that moves the tire contact point 0.5" aft.

In addition, as part of this *Study* the NTSB developed surveys to solicit the views of the M600 pilot and instructor communities concerning the M600 in general and control of the NLG in particular.

These items are considered in more detail in the sections that follow.

D.7.1. The Wall Street Journal article

On February 15, 2021, the WSJ published an article by Andy Pasztor titled *NTSB Probes Runway Steering Issues With High-End Piper Private Planes*, and subtitled *U.S. air-crash investigators look for links among steering difficulties affecting certain Piper turboprop models*:

U.S. crash investigators are examining half a dozen accidents in which private turboprop airplanes built by Piper Aircraft Inc. experienced difficulties with steering on runways after touchdowns.

The probe by the [NTSB] ... focuses on six events between December 2019 and January 2021 in which pilots of high-end Piper M600 aircraft reported loss of directional control while landing, according to a safety-board spokesman. Pilots involved in some of the accidents have expressed concern about potential problems affecting nose wheels.

...

An informal group of M600 pilots involved in the accidents is pushing for government action, arguing the common link appears to be a nose-gear problem during otherwise normal touchdowns, causing the planes to veer from the center of the runway. ...

The article goes on to mention that

The company has issued a handful of service bulletins over the past eight months calling for owners to take measures ranging from maintaining proper front tire pressure to stepped-up inspections, adjustments and sometimes replacement of parts affecting the nose gear. Piper M600 owners are demanding further explanations and data, while people familiar with the matter said the [FAA] is considering mandatory safety directives.

The article also notes that an NTSB spokesman stated that “we have not identified a single common issue present” in the veer events, and that the NTSB’s investigation is ongoing.

The article also refers to Piper’s February 4, 2021 letter to M600 owners (Reference 17) and (presumably) to SB 1350A (see Table 5), and to excerpts from an interview of the retired Air Force pilot involved in case ERA20LA237 (see Table 1), including the statement that “investigators need to find answers to M600 steering problems, [the pilot] said, ‘if experienced pilots can’t keep them on the runway.’”

Finally, the article mentions the Garmin Autoland system²⁴ on the M600, and that “pilots and safety experts” said that the system “doesn’t appear to have any connection to the accidents.”

Piper included a response to the WSJ article in its February 24, 2021 letter to the PA46 Owner Community (see Appendix A):

We have elected to take a direct approach in addressing the marketplace discussions surrounding some recent M600 landing excursions. We are doing so because some simple facts are being lost in a growing sea of false narratives that at times, are distorting the truth in not so subtle ways, both in this forum and in a recent Wall Street Journal article.

The letter notes that

The WSJ article incorrectly states [SB 1350] was issued “less than a week after” our M600 owner letter was sent on February, 4, 2021. No real impact other than implying there was some confusion or uncertainty at Piper. There was none.

Though SB 1350 was issued on December 17, 2020, it is plausible that the WSJ was referring to SB 1350A, which was issued on February 10, 2021 (within a week of Piper’s February 4, 2021 letter) (see Table 5).

Piper’s letter also states that

Throughout the [veer event] reviews, company testing and analysis and NTSB feedback to date, there appears to be one primary constant in these excursions which has been correctly repeated in market forums and in the WSJ article. That is for each event, the aircraft mechanical, pilot operational and environmental parameters were different. ... this likely comes as no surprise knowing the myriad of both controllable and uncontrollable forces that are in play during any landing sequence. *Note: This aligns with an NTSB quote made in the WSJ article, “We have not identified a single common issue present.” We agree.*

²⁴ The Garmin Autoland system is part of Piper’s HALO safety system. See <https://www.piper.com/blog/taking-safety-to-new-heights-meet-garmin-autoland-and-the-halo-safety-system/>.

The letter also agrees with the WSJ article's statement that the HALO system, which includes Garmin Autoland, "does not appear to have any connection... to any incidents". However, the letter disagrees with the WSJ article, and with the interview with the pilot involved in the ERA20LA237 case in particular, in a section titled "The Difficult Conversations and Communications:"

What is difficult is balancing the market conversation between fact, rumor, innuendo and posturing. Or in the case of some statements in the WSJ article just a lot of nothing. Those include:

- *Pilots involved in **some** of the accidents..... concern about **potential** problems...*
- *An **informal** group of M600 pilots.....**appears** to be a nose gear problem...*
- *....while **people familiar with the matter** said FAA is considering mandatory safety directives...*

Also difficult is how to delicately address a key point in the WSJ article quoting a seasoned military pilot. That individual painted a dark picture of the aircraft in general and a landing he flew as PIC in the 2,331st manufactured PA46 aforementioned in excursion #3. What the pilot may not have known is that the landing in question was likely executed with a broken steering horn that might have been prevented if published tow limit guidelines and/or a proper preflight inspection had been followed. That is a difficult communication.

D.7.2. AOPA / PMOPA PA46 Runway Excursion Study

In 2023, the CEO of PMOPA posted the following message on his LinkedIn account:

MMOPA / AOPA Air Safety Institute PA-46 Runway Excursion Study

The increase of runway excursions, including Piper PA-46 aircraft, has been alarming for all of us in aviation. MMOPA is partnering with the AOPA Air Safety Institute to conduct a study of Runway Excursions - or what might have resulted in a runway excursion - and we encourage you to participate in this study.

A runway excursion is a veer off or overrun from the runway surface. These surface events occur while an aircraft is taking off or landing, and involve many factors ranging from unstable approaches to the condition of the runway.

If you have experienced a runway excursion - or you had issues with aircraft stabilization that could have resulted in a runway excursion - your participation in this survey is critical. AOPA Air Safety Institute has developed an online form for MMOPA members to complete, which will help them develop recommendations for the PA-46 community. If your aircraft is equipped with avionics that allow for data collection, providing your data (e.g, from a Garmin 1000, Garmin 3000, etc.) will provide additional, valuable insights.

The online form, which will go directly to AOPA Air Safety Institute and their research team, is available at: <https://app.smartsheet.com/b/form/281d8180fcf148df80c4e98478f06c0a>

We appreciate your participation in this important Study and look forward to sharing the results with the MMOPA community.

The online form referred to in the post is still available as of 12/15/2025, though as noted below the AOPA/PMOPA study is discontinued. The form states:

**MMOPA and AOPA Air Safety Institute PA46 Runway Excursions and Flight Data
Reporting Form**

Please use this form to report any PA46 runway excursions or potential excursion you have encountered. To the extent you are able to upload supporting flight data, that data will help our researcher identify common elements. Your individual mishap information will be kept confidential by the AOPA Air Safety Institute and MMOPA. Your contact information is used only to clarify reported information, but is not a mandatory field. Fields may be left blank.

Among the information requested by the form is contact information for the person filling out the form, the aircraft make, model and registration number of the airplane involved, a description of the event, and whether the event was reported as an incident or accident. The form also asks if the airplane was damaged and whether the research team can follow-up with further questions. The form also includes the ability for flight data to be uploaded along with the form information.

In January 2025, the NTSB contacted AOPA by email to inquire about the status of the PA46 Study. AOPA responded that

The MMOPA study was never completed. We began the data collection, as referenced by your email, but we ended that effort and deleted the data. The original goal of the project was to study PA-46 runway excursion events, but ultimately efforts stalled due to resource constraints. Sorry, we do not have any findings to share with you. Please feel free to reach out ... directly if you have any questions.

The NTSB followed up with an inquiry about the genesis of the AOPA/PMOPA Study:

Thanks for the update, this helps. [We] do have one follow-up question ... can you provide any information regarding the motives for initiating the study in the first place? [We] understand from the information available that the study was motivated by concern over the apparent number of PA-46 runway excursion events. However, any additional information about how these concerns ultimately resulted in an effort in cooperation with MMOPA to study the problem would be helpful to us, since the NTSB is undergoing a similar effort at the moment. It would be useful to see where our concerns and observations overlap (and whether your initial concerns included observations we have overlooked so far).

The NTSB did not receive a reply to this follow-up question. The NTSB also asked AOPA if the PA46 study was unique, or if AOPA had initiated similar studies on other aircraft, but again did not receive a reply.

D.7.3. NTSB surveys of M600 pilots and instructors

In an effort to gather more information concerning pilots' perceptions of the ground handling qualities of the PA46, the NTSB developed separate surveys to distribute to

PA46 pilots and instructors (see Appendix B). The surveys ask questions in the following areas:

- Pilot / instructor information (flying hours, contact information, etc.)
- General impressions of the flying qualities of the M600 in general, and during takeoff and landing in particular
- Impressions of M600 control forces and ground handling qualities in general, and compared to other airplane types, particularly in regard to NLG steering
- Awareness / opinions of pilot community concerns regarding the M600 runway excursion events and NLG steering
- Descriptions of crosswind landing technique (wing-low vs. crabbed), whether it depends on the airplane model being flown, and reasons for the preference
- Control techniques during takeoff and landing rolls
- Experiencing or witnessing a runway veer event in an M600
- Any particular challenges or areas of attention during transition to M600
- Open-ended solicitation for information that might be useful to the NTSB

The NTSB distributed these surveys between October and December 2024 to six flight schools that provide instruction in the M600, and to PMOPA.

An instructor at one of the flight schools, who was the chairman of the PMOPA M-Class Standardized Instructor Pilot Program, offered to make the surveys available to all PA46 training providers who attended a Certified Flight Instructor (CFI) meeting at PMOPA's convention in Austin, Texas in November 2024. The instructor noted that

nose gear issues are well known with all of the PA46 models. Piper recently reengineered the nose gear to change it from a neutral to a positive caster in the M600. The piston series is unchanged.

The instructor also mentioned that he would suggest that the PMOPA COO post the surveys on the PMOPA website, and later noted that the PMOPA CEO "fully supports the idea." On November 18, 2024, the instructor reported that the CEO "did send out an e-mail blast to the membership with the links [to the surveys] and did talk about [them] during the convention," and suggested the NTSB contact the CEO as he was sure the CEO would be "interested in the details."

The NTSB only received two completed surveys from flight instructors, and no completed surveys from non-instructor pilots. The completed surveys are included in Appendix B. The NTSB emailed the PMOPA CEO in November and December 2024 to inquire about the surveys and information about the PA46 NLG that might have been published in PMOPA's magazine. The NTSB never received any response to those messages.

Both of the flight instructors who did complete and return the survey reported experiencing or witnessing a "veer" event in an M600. In response to the question, "Have you ever experienced, or seen a trainee experience, a veer or momentary loss of directional control during the takeoff or landing roll in the M600?," the instructors responded:

Instructor 1: Yes; teaching in a 2020 model (new from the factory), we had a near excursion on landing at one point. No obvious reason for it. Cross winds were light. When nose wheel touched the runway the aircraft veered hard left. Immediate right rudder was applied to correct. We were in Roswell NM with a very wide runway. Had the runway been more narrow, we would have departed the runway. This occurred before any Piper service bulletins were issued on the M600 related to the nose wheel.

Instructor 2: Yes. Even experienced pilots can have issues with this if they're not thinking about their landing technique, practiced, and on their game. This aircraft is not a trainer.

In response to the question, "Please note anything else you would like to say about the M600 airplane (and its ground handling characteristics in particular), that you think the NTSB should consider during its investigations of the runway departure events," the instructors responded as follows:

Instructor 1: Based on my limited knowledge, I think Piper had (past tense) an engineering issue with the nose wheel, hence the service bulletins, etc. It appears to me it may be something as simple as the additional weights of the M600 over the Mirage/Meridians. The higher weights may have been a bit much for the existing nose wheel system. Piper addressed this with at least one service bulletin. In summary, I would have no problem instructi[ng] in (or owning if had the financial assets) any M600/700 that had completed Piper's service bulletins. I have a lot of time in a Piper Dakota (PA32-236) and it has a similar nose wheel function in that the nose wheel turns with the rudder. I know of no major problems in that aircraft. Overall, Piper needed to modify (via service bulletin) the nose wheel system and did so. To my knowledge, this has significantly improved the problem and may have eliminated it altogether. That said, pilots will continue to have difficulty with cross wind landings. It's a common issue related to bent metal in all types of aircraft. At present, with proper instruction, I don't feel the M600/700 types are any more prone to trouble in that area than any other particular aircraft.

Instructor 2: I would very much appreciate a recommendation from the NTSB to the insurance industry to insist that the instructors in these aircraft are properly trained as type specific instructors.

Instructor 2 describes his view of the proper M600 landing technique throughout his responses to the survey, and in particular in response to the questions "please describe your impressions of the airplane's braking abilities" and "describe your crosswind landing technique (and what you teach students):"

Instructor 2 braking response: Braking with the PA46 is easy safe and reliable when using proper specific techniques. I note with interest that my observation of pilots flying these aircraft is that very few take advantage of these ironclad techniques. Specifically, the pilot needs to keep his or her feet off the top of the rudder pedals during rotation and de-rotation. During the landing, Before lowering the nose, the rudder pedals need to be centered to ensure that the nose wheel is centered. This is

critical. Then the toes come up to the top of the rudder pedals. Firm pressure is then applied to the brakes accompanied by back pressure on the elevator. Without back pressure on the elevator, excessive coefficient of friction exists on the nose tire. If there is any abrupt steer on the nose tire, it will be impossible to correct without pressure.

Instructor 2 crosswind response: I don't teach student pilots anymore. I train specifically rated and current pilots transitioning to the PA 46, all variants. Many of these pilots have never completely mastered the art of landing. I observe that greater stability is available to the pilot when holding the crosswind crab to the flare. Align the aircraft with the centerline and lower the upwind tire. Once the upwind main tire contacts the ground, the pilot must be patient and allow the downwind main tire to touch on its own; and then just one word "Center the pedals and lower the nose." Keep firm pressure on the bottom of both rudders to obviate oscillation until the roll out line is stable; then toes up on the brakes. Balance the brake pressure with elevator back pressure to keep the weight even on all 3 tires.

D.7.4. Instructor-hosted YouTube videos

Three PA46 instructor-hosted videos posted on YouTube discuss PA46 veer events and emphasize proper NLG maintenance and pre-flight inspections to minimize the risk of such events. These videos are:

- *PA46 Runway Excursion - Why It Happens*, posted by Aircraft Training Services LLC and running 30 minutes.²⁵
- *PA46 Landing Gear Briefing: The Nose wheel*, posted by Lakefront Aviation and running about 8 minutes.²⁶
- *A Quick Pre-Flight Check of the Nose Wheel Steering in Piper Meridian and Other PA46 Models*, posted by Lakefront Aviation and running 4.5 minutes.²⁷

D.7.4.1. The Aircraft Training Services video

The Aircraft Training Services host has been instructing in PA46 aircraft for 35 years, and introduces his video as follows:

The topic I want to talk about ... is the runway excursion issue in the entire line of PA46. We've had way too many runway excursions in this aircraft for the number of aircraft that are in the fleet. ... Now the turbines, the Meridians, the M500s, M600s seem to be the worst offenders, however all the PA46 line is problematic in this area.

...

First, I want to clear up a couple of misunderstandings about these nose wheel collapses. Some have said that it's due to a weak nose gear on the PA46 and that the nose gear collapses and

²⁵ See <https://www.youtube.com/watch?v=01EMaxKDBOs&t=23s>.

²⁶ See <https://www.youtube.com/watch?v=mm6gWaPvj8M>.

²⁷ See <https://www.youtube.com/watch?v=XsUjzhwzGoc>.

then the excursion happens. Others have said it's poor pilot technique. Neither one of those are entirely true. What happens is we have an excursion off the runway, a veering off the runway, and then ... the nose gear collapses.

As far as poor piloting technique, there's some training that we can do to help this situation, and needs to be done by us instructors, but by and large it's not poor piloting ability.

The instructor then goes through a detailed description of the PA46 NLG system with several illustrations and photographs, including those presented in Figures 3 and 4, paying particular attention to the importance of the proper NLG rake angle, steering horn roller gaps, and compliance with SB 1286D. The instructor also mentions the CEN22LA153 accident and the NTSB's investigation of that case, along with the NTSB final report (Reference 1). The instructor provides a description of neutral, positive, and negative stability using the example of a ball bearing on a flat, concave, and convex surface. He discusses the effect of rake angle on the NLG directional stability, but like the CEN22LA153 final report, does not refer to the effects of pneumatic or dynamic trail.

Regarding pre-flight checks, the instructor states that it is "next to impossible to check the rake angle" but that "there is a very easy way on a pre-flight to check to see if the [steering horn] roller gap is proper" by checking for free play in the rudder surface. Excessive play in the surface (1" to 1.5") is evidence of an excessive gap. He notes that an excessive gap could be due to an improper rake angle (NLG raked aft), or an improper rigging of the steering arm roller gap itself.

The instructor states that "Piper solved the problem" with the M600 NLG instability on serial numbers 200 and above²⁸ through the new fork design that moves the tire contact point 0.5" aft. He says that with the new design,

now all of a sudden you have a self-centering nose wheel that's dynamically stable ... it's actually less of an issue if your roller gap opens up on this because this is like a shopping cart wheel - it will self-center.

The instructor provides the following operational advice for avoiding a loss of control and runway excursion. To mitigate the initiation of a lateral deviation or oscillation, he advises pilots to:

- Be sure the nose gear, tire, and rudder cable tensions are all within the factory specifications, and that weight and balance are within limits
- Center the rudder trim on final approach
- Be sure the yaw damper is off prior to final

²⁸ Per reference 5, the new fork design is incorporated on S/N 4698198 and above.

- Check that both brake pedals are solid
- Release any crosswind use of the rudder before nose wheel touchdown (always center rudder pedals before nose wheel touchdown)
- Land in a full stall attitude holding the nose wheel off as long as possible

If, however, an excursion starts, the following actions should be used to recover:

- Hold yoke full aft and apply moderate pressure to both brakes while using the rudder pedals to align the aircraft's path with the runway centerline
- Fly the airplane all the way to the taxiway; don't relax until the aircraft is stopped

Finally, the instructor advises PA46 operators to take ownership of the proper maintenance of their aircraft, and to challenge mechanics regarding compliance with SB 1286D.

D.7.4.2. The Lakefront Aviation videos

The Lakefront Aviation instructor (who is wearing a PMOPA shirt) introduces the first video as follows:

In this video, I will describe what PA46 pilots need to know about the nose gear. All PA46 models have the same nose gear design, so this video will be useful for your model.

As you may know, PA46 aircraft have been involved in a number of loss of control incidents on landing. In some cases, the problem was attributed to damage to the nose gear from towing, or perhaps to lack of proper maintenance of the nose gear mechanism. These problems were not discovered on the pre-flight by the pilot. Now, if we understand the mechanism, we can detect nose gear problems before we fly.

The instructor then describes the PA 46 NLG mechanism, with the aid of video footage of the NLG retracting and extending into the NLG wheel well, emphasizing the engagement and disengagement of the steering system. He also uses diagrams to illustrate the parts of the NLG steering system, including the steering horn, rollers, and steering arm. He points to items that pilots should check on the pre-flight, including the bolts that hold the NLG torque link together, marks on the trunnion that could be evidence of excessive NLG rotation during towing, and the NLG rake angle (using a level set on the top of the NLG fork).

The instructor describes the NLG steering arm, steering horn and rollers, and the criticality of the gap between the steering arm and the steering horn rollers, stating that "when the gear is extended, the rollers and the steering arm must be in close proximity, or the steering will be sloppy." Later he says, "we do not want too much gap [between the steering arm and the rollers] because it will be difficult to control the nose wheel."

The instructor concludes the video as follows:

Some final thoughts: make sure your tires are inflated properly. Check the Piper service letter on tire inflation. At the time of the creation of this video, it is service letter 1285C. Also, make sure that the struts are serviced. Leaking hydraulic fluid can lead to trouble. It may be tempting to replace missing fluid with nitrogen to get the proper strut extension, but the strut will not provide the proper shock absorption. Try to develop a feel for the steering, including the amount of play in the pedals. If you sense a change in the feel, stop and check it out.

The instructor then refers to a separate video that describes “a simple pre-flight check of the gap between the rollers and the steering arm based on wiggling the rudder.”

This second video is titled *A Quick Pre-Flight Check of the Nose Wheel Steering in Piper Meridian and Other PA46 Models*. The introduction to the video states

We've been hearing a lot about runway excursions in the PA46, followed by collapse of the nose gear and often wing damage. We've always known that it's possible to damage the steering in the Malibu, the Mirage, and the Matrix. In the past, the damage has caused various nose gear collapses requiring a new prop and an engine inspection. These days about half the PA46 fleet has a PT6 on the front, and a problem causing collapse of the nose gear is about 10 times more expensive to repair than it is in the piston models. This is getting the attention of the insurance companies. People are quick to blame the pilot, but in many cases it is caused by towing damage to the steering. In this video I'll show you a quick way to check on the health of the steering

The instructor then demonstrates wiggling the rudder to check for play in the steering system in the same way that the instructor in the Aircraft Training Services video does. The Lakefront Aviation instructor adds, “the rudder should move about the width of your pinky and not much more.” The video then describes the NLG steering mechanism, including the required gap between the steering and steering horn rollers. The instructor states:

The clearance between the steering arm and the rollers is very small. The allowable distance is between a quarter millimeter and three quarters of a millimeter on each side. By moving the rudder, we're making a quick check that the gap is in the correct range. If there is too much play, we must crawl under the wheel well and look for the trouble. And also, if there is *no* play, we need to crawl under and look for the trouble.

The same check can be made with the rudder pedals. Become familiar with the amount of play in the pedals when you are parked. It is the same as moving the rudder: if you have too much play, something is wrong and the gap between the steering horn and the steering arm is too much and you'll have trouble controlling the plane when it is rolling at high speed. On takeoff, people get into trouble, but they can get off the ground before running into the grass. On landing, poor steering will put you in the weeds.

The instructor then notes that over-towing (exceeding the NLG steering angle tow limits) can damage the NLG steering mechanism, and states that this was the cause of some runway excursions (referring to NTSB case ERA20LA237). He advises pilots who

suspect a problem to check the steering horn, steering arm, and the three bolts that hold the steering horn to the nose gear trunnion. He also advises pilots to be present when the aircraft is towed, and to place a "Do Not Tow" banner on the nose wheel.

D.7.5. Reception of the new NLG fork design

Anecdotal evidence suggests that the new NLG fork design is well-received among the PA46 pilot community, in part because of a perception that it solves directional stability problems with the NLG. The Aircraft Training Services instructor, quoted above, explicitly states in his video that the new fork design "solved the problem."

Other pilots have praised the new fork design on internet discussion forums. For example, one commenter stated

The new nose gear is definitely better. Never had any problem with the older ones, but less forgiving of sloppy landings. I think mainly over control. ... In the M600, gentle pressure will turn the nose wheel pretty instantaneously, and actually moving the rudder pedals will turn the plane aggressively, little to no self-centering. You get used to it, and gently under-correct if anything, until tracking straight. Interesting with the new design, the wheel wants to stay centered (a lot of self-centering force), so takes a lot of rudder pressure to turn the nose, more like what you would be used to in a heavier nose steerable aircraft. I have landed the new gear well beyond the max demonstrated x-wind of 17 knots, and seems to do OK. Not a wobble in many landings that I can recall.²⁹

The pilot involved in NTSB case CEN22LA153 (the subject of the PFR) wrote to the NTSB to express his impressions of the new NLG with which his airplane was repaired:

I wanted to share with you my experience of the new nose gear on the M600.

The original nose gear on the plane felt very squirrely to me. In fact, I had it checked out after taking delivery and I was told that it was normal to have to "dance the pedals." Dancing the pedals was normal to keep it moving in a straight line on the ground. This would include normal taxi as well as take off and landings. There was emphasis on this in training as well as with my mentor pilot before training. I always thought it was odd to have the description of ground handling as squirrely, I was told I would get used to it.

I had an excursion in my plane where the nose wheel stuck in a full deflection and that was not normal. That is the bad news.

²⁹ See <https://www.beechtalk.com/forums/viewtopic.php?f=49&t=183020&start=15>.

The good news is my plane was fixed and the new nose landing gear was installed on my plane. I will tell you that I am very happy with the feel of the plane with the new nose gear. The plane now tracks straight, the nose wheel tracks straight, the pedals are very firm and now require a deliberate amount of pressure to move the nose wheel in either direction. The old gear the nose wheel would go left and right, back, and forth over and over requiring the pilot to have to “dance” the pedals to correct the back and forth during all ground operations. The plane feels very stable during all ground operations now, from taxi, to takeoff and landing the feel is solid. I am very impressed with the difference in the ground handling of the aircraft now and would highly recommend that all aircraft be required to receive the new nose gear.

E. CONCLUSIONS

The material in this *Study* supports several observations and conclusions regarding runway “veer” events involving Piper PA46 airplanes, the NTSB’s final report concerning the CEN22LA153 accident, and Piper’s PFR concerning that accident:

- The PA46, and the M600 variant in particular, are over-represented in the NTSB’s CAROL database with respect to veer events. The PA46 has the highest number of veer events per the number of airplanes produced at 7 per 1000 (of which 8 out of 19 events (42%) involve M600s), followed by the Cessna 210 at 0.54 veer events per 1000 airplanes produced. The PA46 events do not include six additional M600 veer events that did not qualify as an incident or accident and so are not in the CAROL database.
- Piper’s PFR apparently considers, mistakenly, that the use of the term “dynamic instability” in the NTSB’s final report for case CEN22LA153 refers to oscillations of the NLG about the steering axis (such as “shimmy”) and / or a vibratory response of the NLG strut due to touchdown loads. However, this term, which is used in Piper’s 03/27/2008 *Customer Information Letter*, actually refers to the directional instability exhibited by a rolling NLG tire that does not self-center when yawed away from the direction of motion, but yaws further away from that direction.
- The dynamic stability of the NLG, understood as its directional stability as defined in section D.3.1, depends on the dynamic trail t_D , which is the sum of the mechanical trail t_M and pneumatic trail t (Equation [2]). Positive t_D results in directionally stable NLG, and negative t_D results in directionally unstable NLG.
- The PA46 is designed to have a 90° NLG rake angle relative to the fuselage (0° NLG caster angle), which makes $t_M = 0$ if the pitch angle of the airplane on the runway is 0°. However, if the NLG rake angle relative to the fuselage is 90°, then the caster angle *relative to the runway* will equal the airplane’s pitch angle on

the runway, and will result in negative t_M (destabilizing) at negative pitch angles and positive t_M (stabilizing) at positive pitch angles (see the bottom diagram in Figure 6).

- A video of a PA46 landing indicates that an aft deflection and damped oscillation of the NLG strut occurs on touchdown, as described in the NTSB's final report concerning the CEN22LA153 accident. While the initial aft deflection of the strut introduces a negative caster angle that can reduce directional stability, it is not clear that this condition exists long enough to introduce a divergence in the steering angle of the NLG.
- The structural dynamics portrayed in the video occur on every landing, but since PA46 veer events are relatively rare, the deflection of the NLG strut on nose wheel touchdown cannot by itself explain them (for example, the landing shown in the video did not result in a veer event).
- At the PA46's nominal 90° NLG rake angle (0° NLG caster angle), $t_M = 0$ and so $t_D = t$. Consequently, the directional stability of the NLG depends on maintaining positive pneumatic trail.
- Research into the behavior of pneumatic trail (t) in pneumatic tires indicates that t is not a constant, but depends on variables such as the tire inflation pressure, tire speed, runway friction, and the slip angle (α) of the tire. The slip angle is equal to the difference between the tire steering angle and the tire drift angle.
- The research indicates that t :
 - Decreases with increasing slip angle
 - Decreases with increasing ground speed
 - Decreases with decreasing runway friction
 - Decreases with increasing tire pressure
- The NLG's self-aligning moment, M_z , depends on the product of the lateral force on the tire and the pneumatic trail t . M_z increases with α to a maximum and then decreases. Beyond a certain α (that varies with runway friction and speed), t and M_z can change sign, resulting in a directionally unstable condition.
- If the dynamic trail t_d becomes negative, the resulting M_z tends to rotate the NLG further away from neutral, requiring greater opposing pedal force to overcome the M_z and center the NLG. In this situation the pilot might perceive that he is applying rudder in one direction (because of the pedal force he exerts),

but the NLG could in fact be deflected in the opposite direction. This is a potentially confusing situation that could trigger an APC event.

- Even apart from this extreme case (in which t_d becomes negative), a reduction in t_d will decrease the magnitude of the self-aligning M_z moment, changing the ratio of the pedal force to NLG steering angle and the consequent control feel of the system.
- Pilots develop a “sense” or “feel” for the response of the airplane to rudder pedal inputs at different speeds by experiencing a consistent response of the airplane to those inputs. If the relationship between applied rudder pedal pressure and airplane response changes from what the pilot expects suddenly or unexpectedly, the pilot might apply inappropriate inputs for the situation, and a PIO and loss of control might result (PIOs are a subset of APC events).
- Piper’s Service Letters, Service Bulletins, and other communications concerning the PA46 NLG indicate that the steering system is sensitive to out-of-tolerance conditions in the NLG rake angle, alignment, tire pressure, rudder cable tension, and NLG steering arm / steering horn roller clearance. It is plausible that, in certain circumstances, the potential changes in steering forces, steering authority, and NLG orientation cited by the communications as potential consequences of out-of-tolerance conditions could alter the control feel of the NLG steering system sufficiently to contribute to pilot confusion and an APC event.
- The airplane motions for NTSB case CEN23LA137_N13HL plotted in Figures 17c and 18c exhibit characteristics consistent with a PIO.
- A simulator match of the CEN22LA153 accident, while not perfect, indicates that a rotation of the NLG from centered to full-right over about 3 seconds is required to approximately match the initial dynamics recorded in the CEN22LA153 data.
- The trends of ψ_{DRIFT} , $\Delta\psi_{HDG}$, y , and n_y in Figures 17 and 18, computed from recorded G3000 data, are generally similar for events CEN22LA153, ERA20LA230, ERA20LA237, N115NX_KOJC, and ERA21LA065 and N13HL_K7V7 (if the direction of the excursion is reversed for these last two).
- The CEN22LA153 and N115NX_KOJC events are particularly similar, especially in the timing of the ψ_{DRIFT} and $\Delta\psi_{HDG}$ parameters. CEN22LA153 is the subject of Piper’s PFR, and N115NX_KOJC is the event involving a Piper engineering test pilot.

- The similar airplane motions in the CEN22LA153 accident and N115NX_KOJC event suggest that the experience levels of the pilots, though different, were not a significant factor in the initiation of the events and the resulting runway excursions, even though the consequent damage to each airplane was different.
- Unlike Piper's PFR, which attributes the CEN22LA153 accident to pilot error ("incorrect braking and steering technique"), Piper's February 24, 2021 letter to the PA46 community appears to attribute the N115NX_KOJC event to low NLG tire pressure ("our pilot and our delivery team did not follow the POH when it came to tire pressure preflight and care").
- All aircraft must be maintained and flown properly to mitigate the risk of incidents and accidents. However, if the PA46 NLG were not particularly demanding in this regard, and everything else being equal, one would expect a more even distribution of landing veer events across airplane makes and models than that presented in Tables 3 and 4b.
- The relatively high incidence of runway veer events involving the PA46, and the M600 in particular, has not gone unnoticed by the PA46 pilot community, and has occasioned the initiation of a study by AOPA / PMOPA, an article in the WSJ, YouTube videos concerning the subject, and commentary on internet pilot forums.
- Anecdotal evidence suggests that the new NLG fork design is well-received among the PA46 pilot community, in part because of a perception that it solves directional stability problems with the NLG.
- The perception that the new NLG fork design improves the directional stability of the NLG is consistent with the fact that the fork increases t_M , and consequently t_D , by 0.5", and that this increase enables the airplane to be operated from unpaved fields – a capability that was not available with the original NLG fork.

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F. REFERENCES

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G. GLOSSARY

Acronyms

AATD	Advanced Aviation Training Device
AFM	Airplane Flight Manual
AGL	Above ground level
AOPA	Aircraft Owners and Pilots Association
APC	Aircraft-Pilot Coupling
BATD	Basic Aviation Training Device
BHP	Brake horsepower
CDT	Central Daylight Time
CEO	Corporate Executive Officer
CFR	Code of Federal Regulations
CG	Center of Gravity
CMC	Central Maintenance Computer
DOF	Degree of freedom
FAA	Federal Aviation Administration
FCS	Flight control system
FFS	Full Flight Simulator
FTD	Flight Training Device
GNSS	Global Navigation Satellite System
GPS	Global Positioning System
"Hg	Inches of mercury
HRRR	High Resolution Rapid Refresh atmospheric sounding model
KCAS	Knots calibrated airspeed
KIAS	Knots indicated airspeed
KOLV	Olive Branch Airport / Taylor Field, Olive Branch, Mississippi
KTAS	Knots true airspeed
MMOPA	Malibu Mirage Owners and Pilots Association
MSL	Mean Sea Level
NLG	Nose landing gear
NRC	National Research Council
NTSB	National Transportation Safety Board
PFR	Petition for Reconsideration
PIO	Pilot-induced oscillation
PMOPA	Piper M-Class Owners and Pilots Association
POH	Pilot's Operating Handbook
PVS	Pilot-vehicle system

SHP	Shaft horsepower
UTC	Universal Coordinated Time
VMC	Visual meteorological conditions
WSJ	Wall Street Journal

Symbols

α	NLG tire slip angle
θ	NLG caster angle or airplane pitch angle, depending on context. Note caster angle = rake angle - 90° (Equation [1])
μ	Friction coefficient between tire and runway
ϕ	NLG steering angle
ψ	NLG tire drift angle
ψ_{DRIFT}	Drift angle
ψ_{HDG}	True heading angle
$\Delta\psi_{HDG}$	Heading deviation from runway bearing
ψ_{RWY}	Runway true bearing
ψ_{TRK}	True ground track angle
ψ_T	Ground track angle
ω_{WHEEL}	Angular velocity of the wheel
F_y	Lateral force on NLG tire
$\tilde{F}_z$	Normalized vertical load in Reference 11
F_{zmax}	Maximum takeoff vertical load in Reference 11
n_y	Lateral load factor
$M_{K\alpha}$	Self-aligning moment due to tire force in Reference 11
$\tilde{M}_{K\alpha}$	Normalized aligning moment in Reference 11
M_z	Moment about NLG strut axis (self-aligning torque)
N_e	Yawing moment produced by the operating engine in an OEI situation
p, p_i	NLG tire inflation pressure
$\tilde{p}$	Normalized tire inflation pressure in Reference 11
p_n	Nominal tire inflation pressure in Reference 11
r_{TIRE}	Effective radius of the tire
s	Tire slip ratio
t	Pneumatic trail or time, depending on context
Δt	Time elapsed since NLG touchdown
t_D	Dynamic trail
t_M	Mechanical trail
$\vec{V}$	Velocity vector of NLG tire
V_G	Airplane ground speed
V_{WHEEL}	Tangential speed of tire
x	Runway x coordinate (centerline distance from threshold)
Δx	Runway x coordinate measured from NLG touchdown
$\{x_b, y_b, z_b\}$	Airplane body axis coordinate system (see Figure 7)
$\{x_t, y_t, z_t\}$	NLG tire axis coordinate system (see Figure 7)
y	Runway y coordinate (normal to centerline distance from threshold, +right)

TABLES

NTSB#	City State	Date	Airplane N#	Model	Relevant report language (emphasis added)
CEN09IA153 (incident)	Aspen Colorado	2/4/2009	N535JR	PA46-500TP	The pilot stated that ... <i>as soon as the nose wheel touched down the airplane began veering left and right uncontrollably.</i>
CEN21LA137 (accident)	Kansas City Missouri	2/22/2021	N560CA	PA46R-350T	The pilot reported he made a normal approach and landing on runway 19 and <i>during the landing roll, the nose wheel "pulled" uncontrollably to the right. The pilot lost control of the airplane and it departed the right side of the runway.</i>
CEN21LA186 (accident)	Aspen Colorado	2/28/2021	N6962S	PA46-350P	The pilot reported that during landing <i>when the airplane's nose landing gear contacted the runway the airplane veered "very sharply" to the left. The pilot attempted to correct using the rudder and brakes; however, the airplane departed the side of the runway.</i>
CEN22LA153 (accident)	Olive Branch Mississippi	3/23/2022	N627PR	PA46-600TP	[The pilot reported that after landing] the airplane <i>entered a hard right turn about a 45° angle.</i> The pilot stated the left directional input was not working and that he applied more pressure with the left rudder. ... <i>The airplane exited the right side of the runway.</i>
CEN23LA137 (accident)	Thedford Nebraska	3/4/2023	N131HL	PA46-600TP	The pilot reported that during landing, <i>when the nose wheel made contact with the runway, the airplane began to veer right.</i> He attempted to use left rudder and brake to keep the airplane on the runway, but as the airspeed decreased, <i>directional control became harder to maintain and the airplane subsequently departed the right side of the runway.</i>
CEN23LA282 (accident)	Brookshire Texas	7/4/2023	N600BJ	PA46-600TP	The pilot reported that ... the airplane ... touched down normally. <i>As the nose landing gear came down, the airplane pulled to the left, so he applied right rudder to straighten it out, then the airplane suddenly veered hard to the right. The airplane did not respond to rudder pedal inputs as expected...</i>
ERA20LA230 (accident)	Williston Florida	6/15/2020	N117PR	PA46-600TP	According to the pilot's written statement ... <i>when the nose wheel touched down, the airplane made an "immediate hard right turn."</i> [The pilot] stated that <i>he applied left rudder but that the nose wheel steering was unresponsive, and the airplane would not turn to the left.</i> The airplane subsequently departed the right side of the runway.

Table 1. List of PA46 landing veer events (page 1 of 4).

NTSB#	City State	Date	Airplane N#	Model	Relevant report language (emphasis added)
ERA22LA079 (accident)	Cornelia Georgia	11/29/2021	N172MA	PA46-500TP	[The pilot stated that] <i>as soon as the nose wheel touched down, the airplane pulled to the left.</i> The pilot initially corrected with right rudder input, but <i>the airplane pulled again to the left</i> and the pilot again put in right rudder deflection. The pilot relaxed right rudder pressure a second time and then <i>the airplane pulled very aggressively to the left.</i> ... the airplane departed the left side of the runway.
ERA21LA065 (incident)	Leesburg Virginia	12/6/2020	N282ST	PA46-600TP	The pilot reported that, <i>after touchdown, while rolling straight down the runway, the airplane "went careening to the left."</i>
ERA20LA237 (accident)	Titusville Florida	7/3/2020	N89MA	PA46-600TP	[The pilot reported that] <i>as soon as the nose landing gear (NLG) touched down, the airplane immediately veered right. He attempted to correct the veer by applying left rudder and left and right brakes; however, the airplane did not respond.</i> The airplane then exited the right side of the runway ...
WPR19LA060 (accident)	San Diego California	12/30.2018	N4161X	PA46-350P	The pilot stated that ... <i>shortly after the nose landing gear made contact with the ground, the airplane started to pull to the left. He applied corrective control inputs, but the airplane continued to turn left.</i> The airplane then departed the runway surface
ERA11LA466 (accident)	Manasses Virginia	8/19/2011	N133SR	PA46-500TP	According to the pilot ... <i>about another 3 to 4 seconds after the nose wheel touched down, the airplane started veering to the left.</i> The pilot first added some right rudder, and <i>as the nose did not correct, he added more right rudder.</i> When the nose still wouldn't correct, he "jumped" on the brakes ... the airplane veered off the left side of the runway ...
WPR11FA093 (accident)	Phoenix Arizona	1/9/2011	N5365D	PA46-500TP	... the pilot reported that during the landing roll ... <i>the airplane veered "hard" right of runway centerline. The pilot attempted to realign with the runway, but the airplane exited the right side of the paved surface.</i>

Table 1. List of PA46 landing veer events (page 2 of 4).

NTSB#	City State	Date	Airplane N#	Model	Relevant report language (emphasis added)
LAX05LA116 (accident)	Flagstaff Arizona	3/15/2005	N504SR	PA46-500TP	The pilot reported that ... <i>as soon as the nose landing gear touched down, the aircraft "immediately pulled left without normal rudder control."</i> He added that, <i>"it was if the nose gear was not responding to normal input."</i> The airplane veered off the left side of the runway ...
CHI04LA059 (accident)	Marine City Michigan	1/18/2004	N46WD	PA46-350P	The pilot stated that <i>immediately after touchdown he noticed the airplane was "pulling to the left."</i> The pilot reported that he attempted to correct the left turning tendency with use of right rudder. The airplane continued turning to the left until it impacted the four-foot high snow bank positioned alongside the runway.
IAD03LA028 (accident)	Laconia New Hampshire	1/18/2003	N9170X	PA46-350P	The pilot reported that ... <i>as the airplane touched down, it veered "dead left"</i> slid off the runway, and impacted a snow pile.
FTW01FA107 (accident)	Rockwall Texas	4/28/2001	N61PK	PA46-500TP	The pilot reported that <i>after touchdown ... the airplane started to veer right. Rudder control inputs were ineffective,</i> and the airplane continued off the right side of the runway
ERA21NA108 (non-reportable event)	Manchester New Hampshire	1/19/2021	N641WA	PA46-600TP	[Per the pilot's NTSB Form 6120 report], the aircraft responded as expected upon main landing gear touch down. <i>When the nose landing gear touched down the plane veered hard to the right.</i> Left rudder pedal was used to counter the un-commanded right turn and <i>the plane veered left and immediately began skidding to the left. The plane did not respond to input</i> and skidded off the runway ...
ERA21NA116 (non-reportable event)	Baltimore Maryland	12/19/2020	N831PS	PA46-600TP	[Per the pilot's NTSB Form 6120 report], touchdown was normal and on centerline. Held nose off per established POH procedures. <i>When nose lowered and touched down aircraft veered "hard" to the left.</i> Was concerned that I might lose control, but was able to correct back to near centerline. Did not come close to edge of runway, <i>but severity of veering to the left caused concern.</i>

Table 1. List of PA46 landing veer events (page 3 of 4). "Non-reportable events" are those that do not meet the NTSB immediate notification requirements specified in 14 CFR 850.5.

NTSB#	City State	Date	Airplane N#	Model	Relevant report language (emphasis added)
N/A (non-reportable event)	Driggs Idaho (KDIJ)	6/3/2020	N115NX	PA46-600TP	[Per CFI account in Piper N115NX summary PowerPoint presentation], initially landed to left before correcting right. At around 75 knots the wandering got worse and at one point around 70 knots <i>the pilot was pushing the rudder hard stop to stop</i> . Stopped almost 90° to centerline. <i>Little response from rudder input until sudden hard over with 'no connection felt with nose wheel.'</i> "
N/A (non-reportable event)	Winslow Arizona (KINW)	6/10/2020	N115NX	PA46-600TP	[Per CFI account in Piper N115NX summary PowerPoint presentation], the landing was performed with a normal round out and flare. Nose went left and CFI felt pilot inputting right rudder to correct, however, the NG had not made contact with the ground as yet. <i>As soon as the NG touched down, the aircraft veered right</i> . The CFI took control of the aircraft and using backpressure to pick up the nose, was able to regain control of the aircraft. The CFI indicated that no damage or ground handling issues were noted ..., <i>but he felt that something was wrong with the NG tire</i> .
N/A (non-reportable event)	Olathe Kansas (KOJC)	12/23/2019	N115NX	PA46-600TP	[Per Piper N115NX summary PowerPoint presentation], ... upon landing touchdown ... <i>experienced degraded directional control and departed the runway to the right</i> The PIC ... is a <i>Piper Engineering Flight Test pilot</i>
N/A (non-reportable event)	Boise Idaho (KBOI)	11/24/2020	N917DB	PA46-600TP	[In a phone interview with the NTSB, the pilot stated] "while landing ... <i>I experienced a hard dart to the right when the nose gear touched down</i> . I got the airplane straightened out before the left main crossed the center line, <i>but it shook me up</i> ."
N/A (non-reportable event)	Vero Beach Florida (KVRB)	5/7/2020	N131HL	PA46-600TP	[No pilot comments available to NTSB]
N/A (non-reportable event)	Red Cloud Nebraska (K7V7)	1/12/2021	N131HL	PA46-600TP	[Per pilot's account in a Piper summary PowerPoint of the incident], on landing "Nose wheel gently tapped the runway with a very slight pull to the right, then lifted. <i>On the second tap the aircraft veered hard left. It felt like the plane was going to roll over it was pulling so hard.</i> "

Table 1. List of PA46 landing veer events (page 4 of 4). "Non-reportable events" are those that do not meet the NTSB immediate notification requirements specified in 14 CFR 850.5.

NTSB#	City State	Date	Airplane N#	Airplane	Relevant report language (emphasis added)
CEN11LA178 (accident)	Danville, Illinois	2/7/2011	N6XZ	Beech A36 Bonanza	Approximately 500 feet into the landing roll, [the pilot] applied right brake pressure, <i>and the airplane immediately entered a right swerve. He stated that he was unable to regain directional control with the full application of left rudder and brake inputs. The airplane continued in the right swerve, departing off the right side of the runway.</i>
WPR19LA138 (accident)	Reno, Nevada	5/4/2019	N6684Z	Beech 36 Bonanza	After touchdown, <i>the airplane veered off the runway to the left, despite the pilot's corrective inputs.</i> Subsequently, the airplane exited the runway ...
CEN21LA289 (accident)	Watkins, Colorado	6/21/2021	N5596D	Beech H35 Bonanza	The pilot stated that ... <i>when on touching the airplane's nose wheel onto the runway, the airplane immediately tracked 10° left of the runway centerline. The pilot attempted to correct with right rudder, but the airplane did not respond to his input and the airplane departed the left side of the runway ...</i>
ERA22LA074 (accident)	Perry, Georgia	11/23/2021	N2033D	Beech C35 Bonanza	[The pilot stated that] he proceeded to his destination and performed a normal landing. <i>As the airplane decelerated, it began drifting left. He applied right rudder, then when the rudder input failed to correct the drift, he applied more right rudder and brake, at which time, the airplane immediately turned left.</i> The airplane travelled off the runway ...

Table 2. List of veer events in the NTSB CAROL database involving airplane types comparable to the PA46 series (page 1 of 2).

NTSB#	City State	Date	Airplane N#	Airplane	Relevant report language (emphasis added)
LAX91LA230 (accident)	Palm Springs, California	5/30/1991	N818BF	Cessna P210N	<i>The airplane drifted to the left during the landing roll as the pilot decelerated the airplane with application of the brakes. The pilot reported he applied full right rudder. The airplane continued to turn left and departed the runway.</i>
CHI95LA025 (accident)	Beulah, North Dakota	10/25/1994	N526HK	Cessna T210L	<i>The pilot was practicing night touch and go landings. On the second landing he stated the airplane veered to the right, departed the runway and nosed over.</i>
LAX97LA043 (accident)	Mesa, Arizona	11/16/1996	N911JB	Cessna T210L	<i>The pilot reported that during touchdown, the aircraft began to pull strongly to the left. He was unable to maintain directional control, and the aircraft veered off the runway ...</i>
SEA07CA072 (accident)	Boulder City, Nevada	3/7/2007	N6520B	Cessna T210M	<i>The pilot reported that when brakes were applied, the airplane "veered slightly right" and left brake and rudder were applied. The pilot stated the corrective action momentarily corrected the situation, however, the airplane again veered sharply to the right, exited the runway ...</i>
WPR17LA053 (accident)	Buckeye, Arizona	1/14/2017	N6366B	Cessna T210	<i>The pilot reported that, during the landing roll, the airplane veered to the left. He applied flight control inputs; however, the airplane exited the side of the runway ...</i>
SEA02LA029 (accident)	Sunriver, Oregon	11/29/2001	N852AL	Pilatus PC-12	<i>After touchdown, the aircraft veered left despite the pilot's corrective control inputs, and collided with a snow bank 1/3 of the way down the runway.</i>

Table 2. List of veer events in the NTSB CAROL database involving airplane types comparable to the PA46 series (page 2 of 2).

Aircraft	Production	Period	Veer events	Veer events / 1000 airplanes produced
Piper PA46 series	2705	1984-2024 (40 years)	19 / 25	7.02 / 9.24
Cessna 210	9240	1957-1986 (29 years)	5	0.54
Cessna 208	3149	1984-2024 (40 years)	0	0
Beech 35/36	15258	1947-2024 (77 years)	4	0.26
Pilatus PC-12	2159	1994-2024 (30 years)	1	0.46
TBM series	1246	1990-2024 (34 years)	0	0
Kodiak series	361	2007-2024 (17 years)	0	0

Table 3. Production numbers and veer events for the different airplane types considered in this *Study*. Veer events for the PA46 are listed as those in the NTSB database only (19), and those in the database plus 6 events otherwise known by the NTSB (total 25).

Model	Name	Year certified	Engine & power	Maximum takeoff weight, lb.
PA46-310P	Malibu	1983	Continental TSIO-520BE, 310 BHP	4,100
PA46-350P	Malibu Mirage / M350	1988	Lycoming TIO-540-AE2A, 350 BHP	4,340
PA46-500TP	Malibu Meridian / M500	2000	P&WC PT6A-42A, 500 SHP	5,092
PA46R-350T	Matrix	2007	Lycoming TIO-540-AE2A, 350 BHP	4,340
PA46-600TP	M600	2016	P&WC PT6A-42A, 600 SHP	6,000
PA46-701TP	Fury / M700	2024	P&WC PT6A-52, 700 SHP	6,000

Table 4a. List of different PA46 models. Sources: *Wikipedia*, *Janes All the World's Aircraft 1909-2009* (<https://janes.migavia.com/>), and FAA Type Certificate Data Sheets.

Model	NTSB cases in Table 1	Other events in Table 1	Total events in Table 1
PA46-310P (Malibu)	0	0	0
PA46-350P (M350)	4	0	4
PA46-500TP (M500)	6	0	6
PA46R-350T (Matrix)	1	0	1
PA46-600TP (M600)	8	6	14
PA46-701TP (M700)	0	0	0
Total	19	6	25

Table 4b. Breakdown of PA46 veer events in Table 1 by model.

Item	Title / Models Affected	Date	Summary
SB 1106	Nose Gear Steering System Improvement / M500	1/28/2002	- States "There have been field reports of turning tendency immediately following nose wheel touch down during landings ... a contributing cause of the turning tendency has been identified as reduced nose gear steering authority which, under certain conditions, can allow the nose gear steering rotation to momentarily exceed the pilot's input. This Service Bulletin recommends mandatory incorporation of the following nose gear installation modifications that increase the pilot's steering authority. Failure to incorporate these modifications may increase the possibility of a turning tendency during landing." - Replaces 6-ply NLG tire inflated to 50 psi with 8-ply NLG tire inflated to 70 psi. - Replaces bungee with stiffer version to increase the pilot's authority in controlling the steering forces.
Customer Information Letter (Ref. 10) (See Appendix A)	PA46 Operational & Maintenance Information, Nose Gear Steering / Malibu Series	3/27/2008	- Explains Piper's response to customer concerns expressed "about the nose gear steering on the PA46 'Malibu' series and provides specific actions that owners can take to ensure that their aircraft continues to operate properly and conform to factory specifications." - Reiterates changes to NLG tire pressure and tire type and stiffer bungee specified in SB 1106. - Emphasizes importance of "several <i>operational</i> factors ... identified as critical for optimum steering function on <i>all</i> Malibu models," including tire pressure, nose gear rake angle, steering arm / roller gap, rudder cable tension, and pilot technique. - Of note, the letter states that "a [NLG] rake angle outside of [the specified] range may result in dynamic instability, creating steering forces that exceed the pilot's ability to control."
SL 1285	Maintenance Alert: Proper Tire Pressure Maintenance / All PA46 models except M700	7/24/2020	- Notes that "there are several safety benefits to proper tire maintenance, including its effect on ground steering. Maintaining proper aviation tire inflation pressure reduces the size of a tire's rolling contact patch, which reduces the magnitude of the force associated with ground steering." - Increases the M600 NLG tire pressures from 88 psi to 88-92 psi unloaded and 92-97 loaded, and recommends checking pressures prior to first flight each day.

Table 5. List of Piper Customer Information Letters, Service Letters (SL), and Service Bulletins (SB) concerning the NLG of PA46 models (p. 1 of 4).

Item	Title / Models Affected	Date	Summary
SL 1286	Maintenance Alert: Nose Landing Gear Steering Components Inspection and Adjustment / All PA46 models except M700	8/18/2020	- States "Several aircraft components, and their rigging, are important for proper ground steering and directional control. These components require regular, proper inspection and adjustment, and, on condition, replacement, to maintain proper ground steering and directional control. This service letter provides a review of the best practices for maintaining ground steering system components ... : rudder cable tension, nose landing gear alignment, nose gear rake angle, and nose gear steering arm clearance." - Updates the procedures for measuring and adjusting the clearance between the NLG steering arm and steering horn rollers. - States compliance is to coincide with the next regularly scheduled maintenance event, but not to exceed the next 50 hours time in service (TIS). After that, compliance is to occur every 100 hours, in accordance with the applicable maintenance manual.
SB 1350	Nose Landing Gear Steering Horn and Arm Assemblies Inspection / M350, M500, M600	12/17/2020	- States "the steering pads, which are components welded onto the nose wheel steering horn assembly, may be protruding beyond the steering horn rollers on the affected airplanes. This may result in the steering pads making improper contact with the nose wheel steering arm assembly. Left uncorrected, this condition may cause damage to the steering arm assembly." - Mandates steps to inspect the steering horn assembly and replace it with an improved replacement assembly if the steering pads protrude beyond the steering horn rollers, and to repair or replace the steering arm assembly if damaged. - States compliance to coincide with the next regularly scheduled maintenance event, but not to exceed the next 50 hours time in service.
SL 1285A	Same as SL1285	1/12/2021	Announces the availability of placards for the M600.
SL 1286A	Same as SL1286	1/21/2021	- Contains updated nose landing gear alignment procedures for the M600. - Recommended compliance remains the same as SB 1286, but recommends compliance at the next scheduled maintenance visit for the M600.

Table 5. List of Piper Customer Information Letters, Service Letters (SL), and Service Bulletins (SB) concerning the NLG of PA46 models (p. 2 of 4).

Item	Title / Models Affected	Date	Summary
SL 1286B	Same as SL1286	1/28/2021	- Adds rigging of the rudder-aileron interconnect to procedure for the M600. - Recommends compliance at the next scheduled maintenance visit for M600s that are compliant with SL 1286 and rigging of the rudder-aileron interconnect prior to further flight for M600s that are compliant with SL 1286A.
Piper Letter to M600 Owners (See Appendix A)	N/A	2/4/2021	- Notes that Piper is "reviewing some landing excursions within the 158 M600 fleet ..." - States "maintaining proper [tire] pressure is most critical on the M600 with the associated higher operating weights." - Emphasizes importance of compliance with SL 1285, SL 1286 and revisions, and SB 1350.
SB1350A	Same as SB1350	2/10/2021	Updates the torque of the bolts for the steering horn base in SB 1350.
Piper Letter to PA46 Owner Community (See Appendix A)	N/A	2/24/2021	- States "We have elected to take a direct approach in addressing the marketplace discussions surrounding some recent M600 landing excursions. We are doing so because some simple facts are being lost in a growing sea of false narratives that at times, are distorting the truth in not so subtle ways, both in this forum and in a recent Wall Street Journal article." - Briefly describes six M600 excursion events. These appear to be NTSB cases ERA20LA230, ERA20LA237, ERA21NA108, & ERA21LA065, plus the non-NTSB case events in Olathe, KS and Red Cloud, NE listed in Table 1. - Regarding the Olathe event, the letter states "a Piper pilot delivering a new M600 to a dealer experienced a runway excursion to the right. The pilot could have kept it on the runway but elected to continue across the level grass onto a taxiway." The letter does not provide a reason for the pilot's decision. - Reiterates importance of compliance with SL 1285, SL 1286 & 1286A, & SB 1350, including the statement "as operators of PA46 aircraft we all have the duty to strictly adhere to tire pressure requirements highlighted in the POH and Maintenance Manuals. There is no grey area here."
SL 1286C	Same as SL1286	3/24/2021	Clarifies the procedures to check and adjust the clearance between the NLG steering arm and steering horn rollers and the NLG alignment.

Table 5. List of Piper Customer Information Letters, Service Letters (SL), and Service Bulletins (SB) concerning the NLG of PA46 models (p. 3 of 4).

Item	Title / Models Affected	Date	Summary
SL 1285B	Same as SL1285	6/15/2021	• Corrects tire inflation pressures for multiple models. Maximum pressures for all models except the PA46-310P were reduced by up to 5 psi on both the NLG main landing gear tires. • Adds a note regarding significant changes in ambient temperatures: "When tires are going to be subjected to ambient temperature differences between two locations in excess of 50°F (27°C), inflation pressures should be adjusted to the colder temperature prior to takeoff. An ambient temperature change of 5°F (3°C) produces a pressure change of approximately one (1) percent." • Announces new placards for the M600.
SL 1286D	Same as SL1286	10/15/2021	• Corrects some measurements given in figures, and adds mention of a relevant maintenance manual.
SL 1285C	Same as SL1285	3/29/2022	• Adds updated placards for the M500. • Updates instructions for placards and POH revisions for affected models.

Table 5. List of Piper Customer Information Letters, Service Letters (SL), and Service Bulletins (SB) concerning the NLG of PA46 models (p. 4 of 4).

Airplane	NLG caster angle (degrees)	NLG caster length or offset (inches)	NLG tire radius (inches)	Effective NLG caster angle (degrees)	Veer events / 1000 airplanes produced (from Table 3)
Piper PA46, original NLG fork	0	0	5.7	0	7.02 / 9.24
Piper M600, new NLG fork	0	0.5	5.7	5	(0)
Cessna 210	17	0	7.0	17	0.54
Cessna 208	9	1	9.4	15	0
Beech 35/36	17	0	7.0	17	0.26
Pilatus PC-12	8	1	8.8	14	0.46
TBM 700	15	0	7.0	15	0
Kodiak 100	12	0	9.9	12	0

Table 6. Comparison of NLG gear geometries for the different airplane types considered in this *Study*. NOTE: values shown are rough estimates based on publicly available drawings and photographs, except for the PA46 data, which were provided by Piper.

Parameter	CEN22LA153 match, centerline tracking, and NLG "hardover" scenarios	"Controls-free" scenarios
Altitude above sea level (MSL)	405 ft.	405 ft.
Altitude above ground level (AGL)	9 ft.	9 ft.
Calibrated airspeed	83 KCAS	84 KCAS
True airspeed	83 KTAS	84 KTAS
Ground speed	70 kt.	70 kt.
Rate of climb	-12.4 ft/min	-12.4 ft/min
Flight path angle	-0.1°	-0.1°
True heading	180°	180°
True ground track	180°	180°
Sideslip angle	6.9°	1°

Table 7. Initial conditions for simulation scenarios.

FIGURES

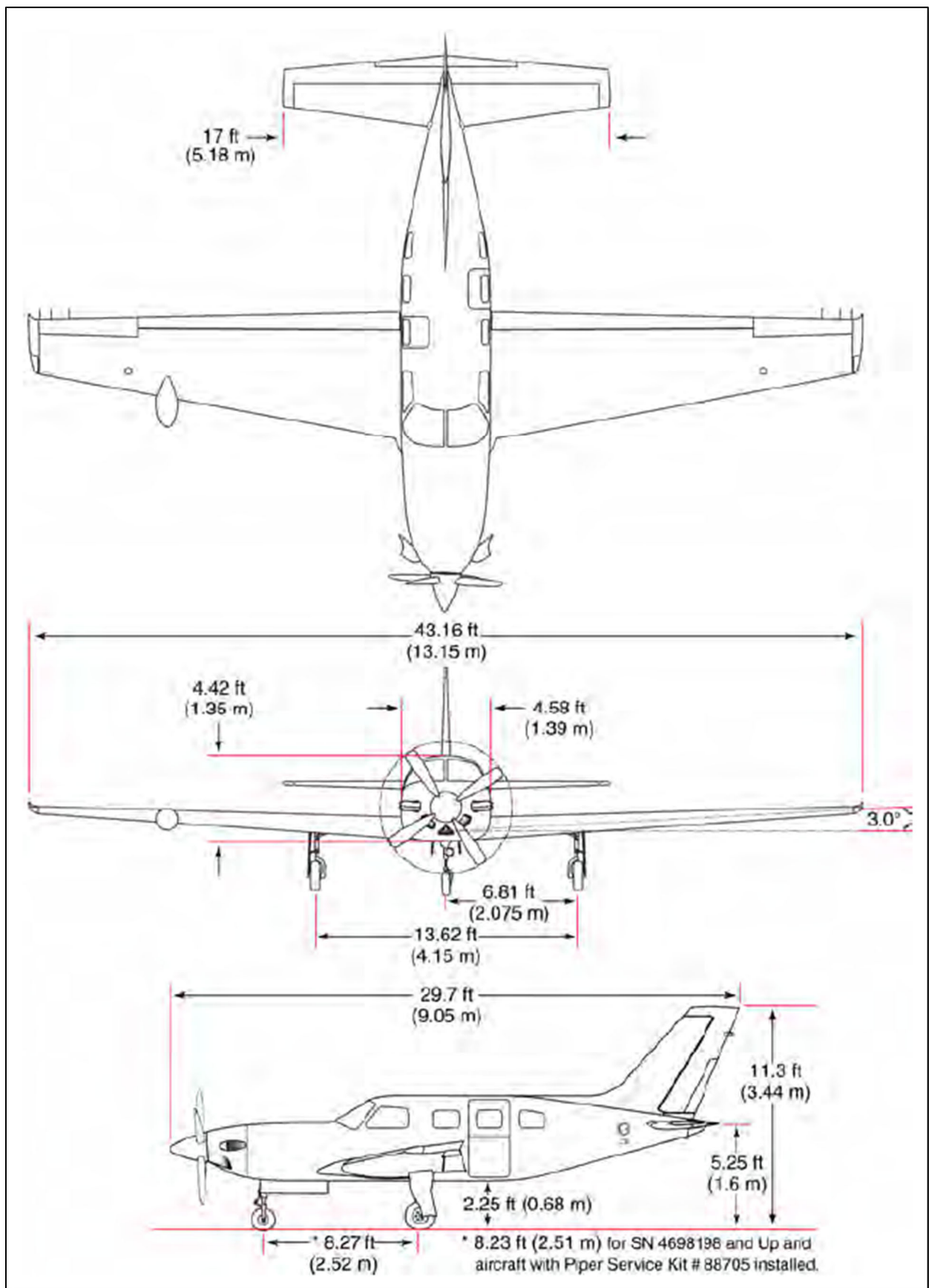


Figure 1. 3-view of the Piper PA-46-600TP (M600) airplane (from Reference 4).



Figure 2a. Photograph of an undamaged M600 (photo © Fabien Bernard / airliners.net).



Figure 2b. Photograph of N627PR after the accident.

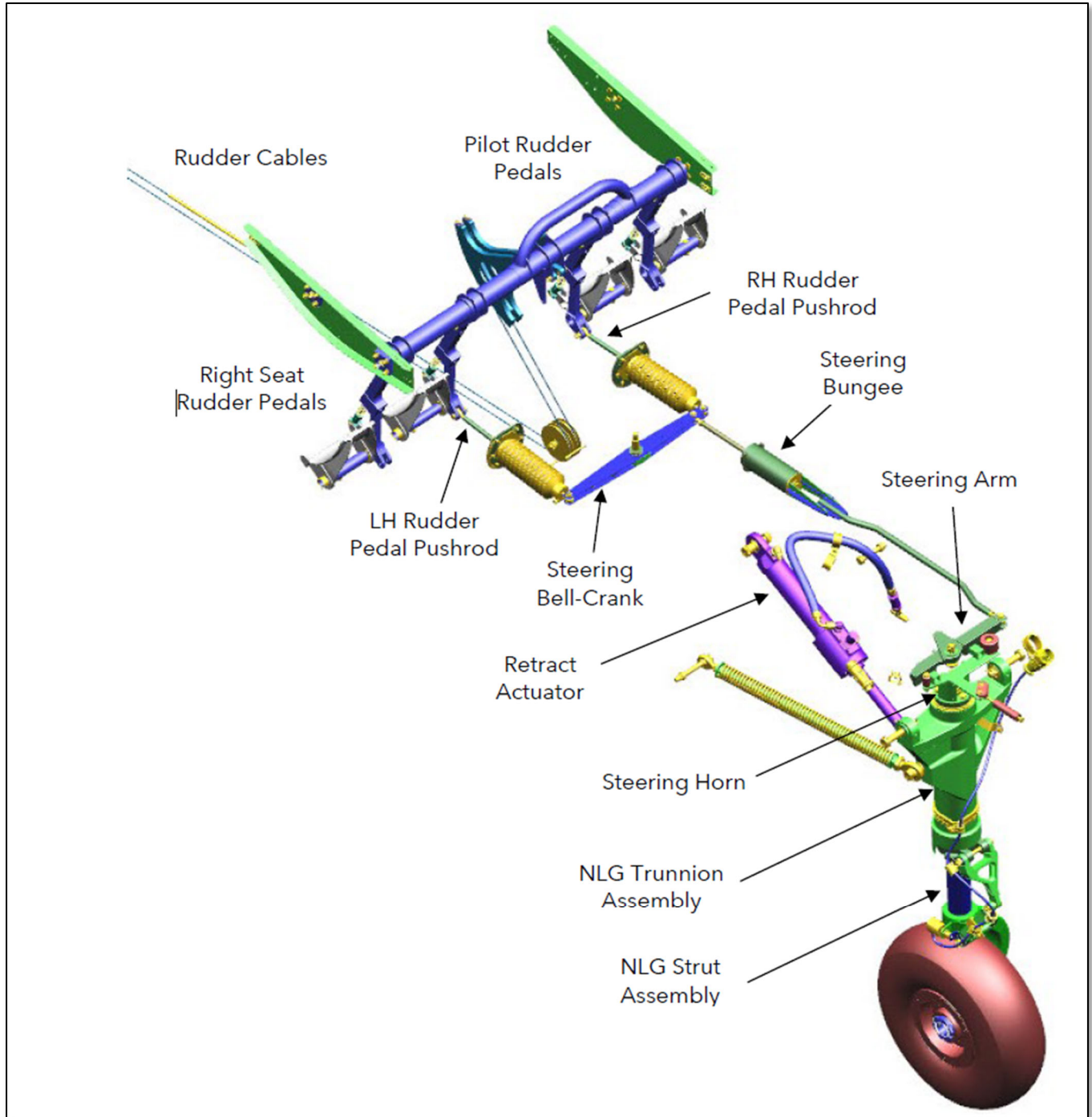


Figure 3. PA46 steering system illustration (from Reference 5).

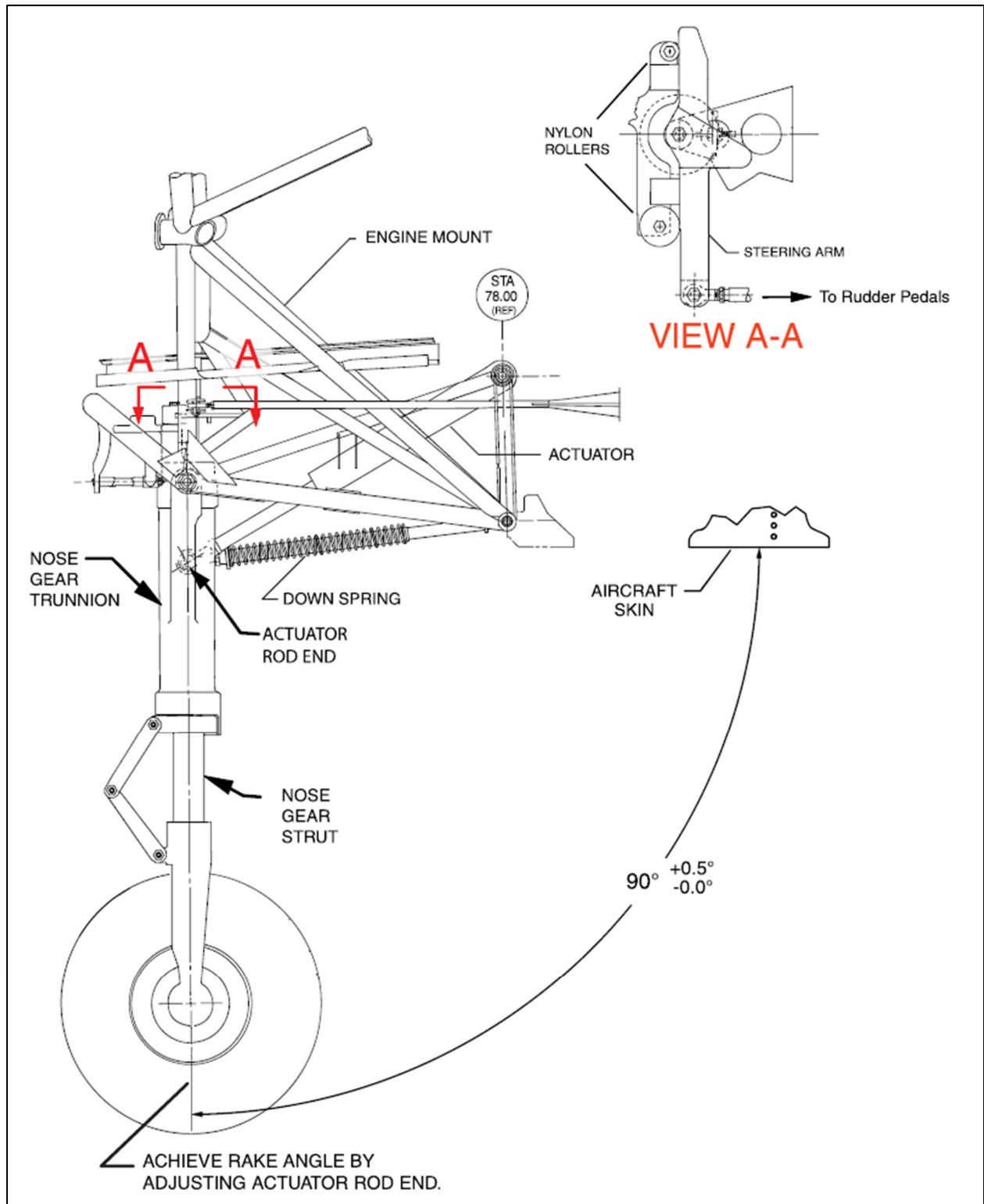


Figure 4. PA46 nose landing gear rake angle drawing from Piper Customer Information Letter dated 3/27/2008 (Reference 10).

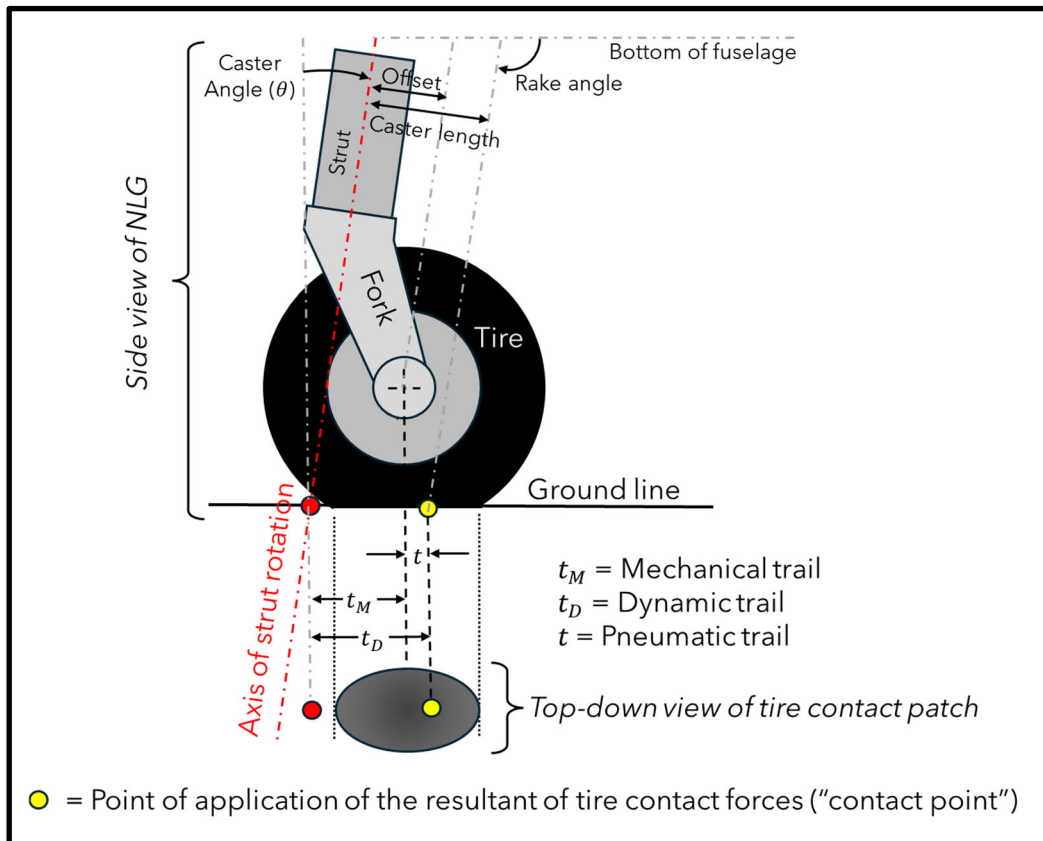


Figure 5. NLG geometry and definitions of mechanical, dynamic, and pneumatic trail (based on Figure 2-18 in Reference 6). Note that the caster angle θ = rake angle - 90° .

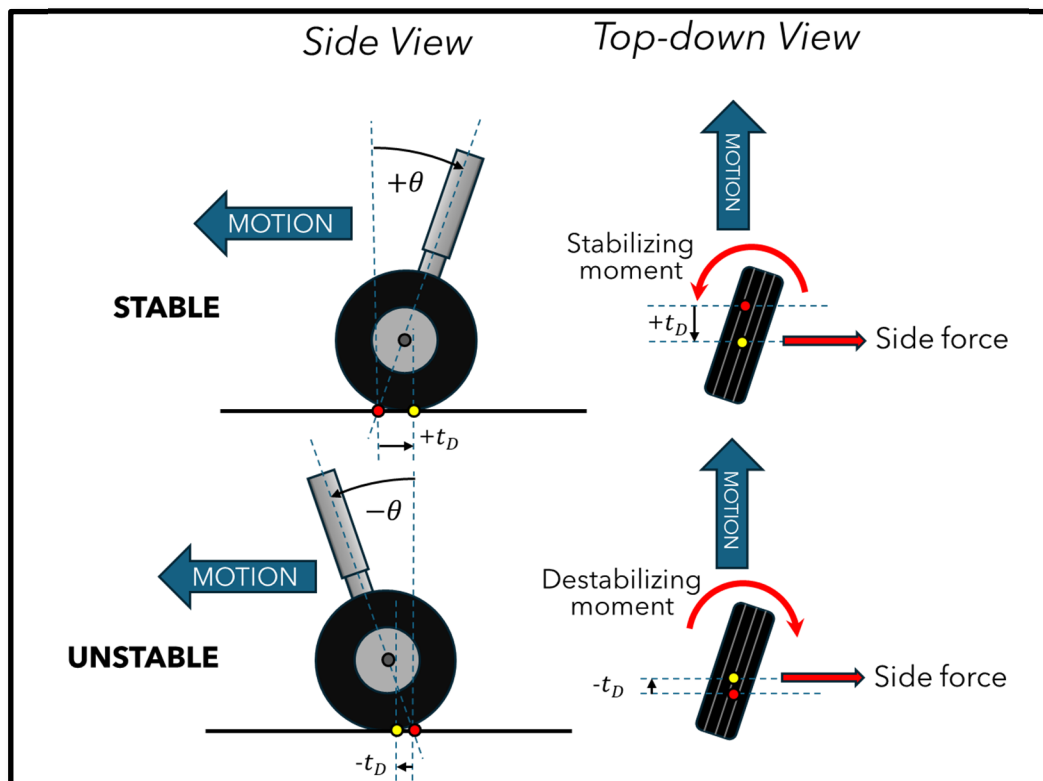
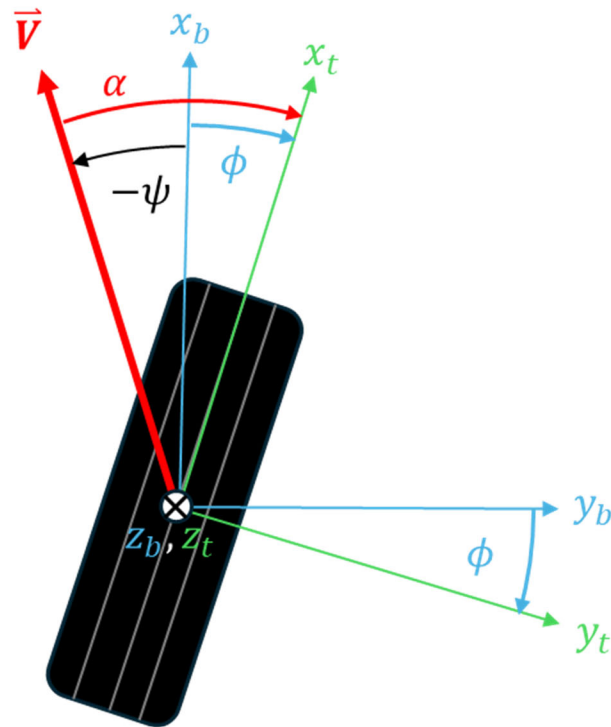


Figure 6. Effect of θ and t_D on self-aligning moment of NLG.

Top-down View



$\{x_t, y_t, z_t\}$ = tire axis system

$\{x_b, y_b, z_b\}$ = tire axis system rotated to be parallel to the aircraft body axis system

$\vec{V}$ = tire velocity vector

ψ = tire drift angle (+clockwise)

ϕ = tire steering angle (+clockwise)

α = tire slip angle = $\phi - \psi$

Figure 7. Definitions of the tire steering angle (ϕ) and slip angle (α).

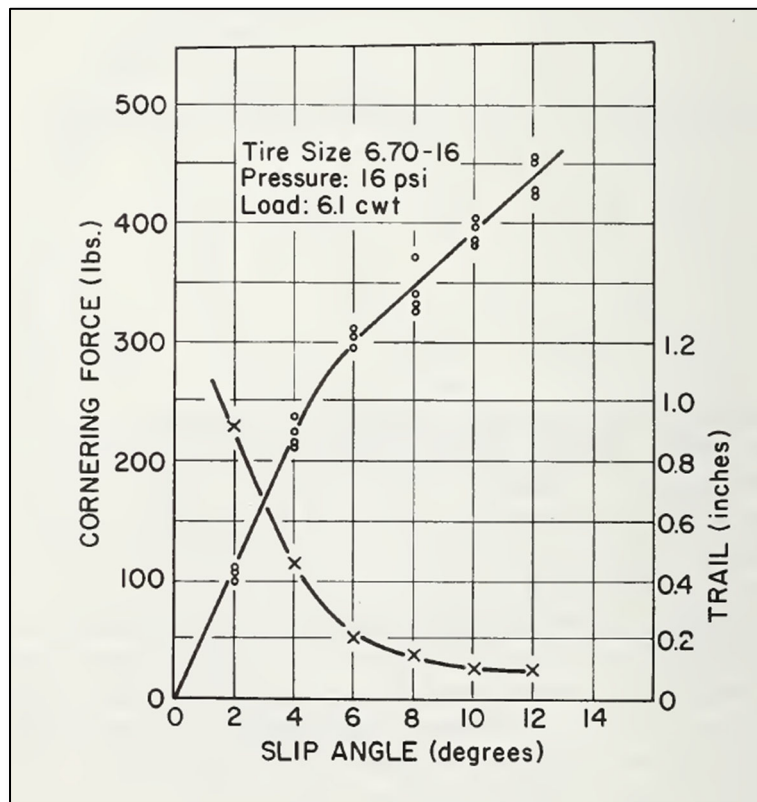


Figure 8. Effect of slip angle (α) on tire cornering force (circles) and pneumatic trail (t) (crosses) (Figure 5.63 in Reference 14).

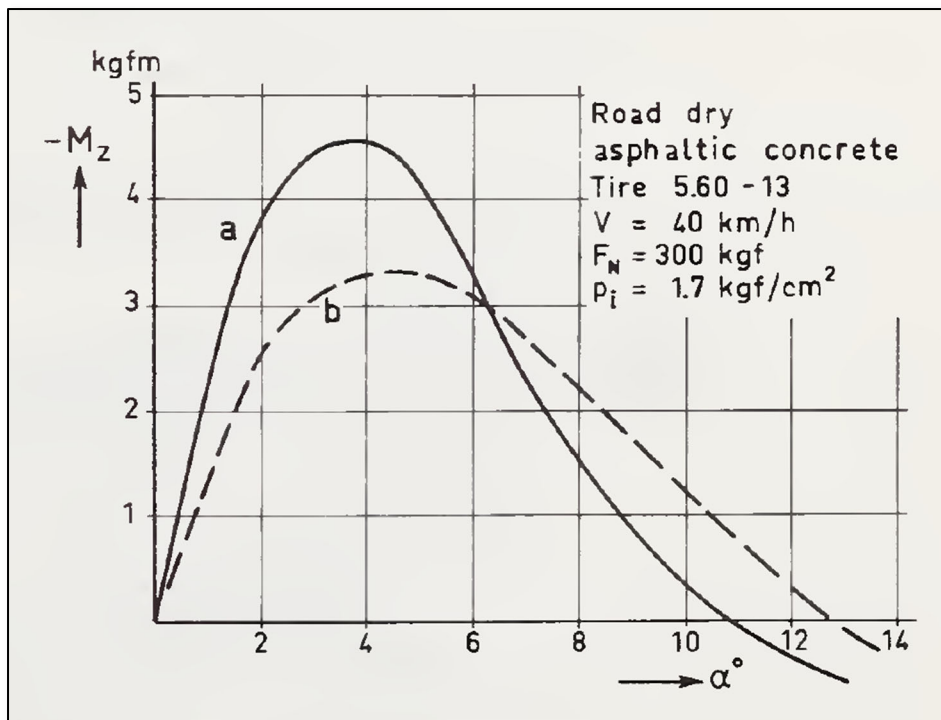


Figure 9. Effect of slip angle (α) on tire self-aligning torque (M_z). Tires a and b are of different construction. Note both tires become unstable when $M_z > 0$. (Figure 7.3.23 in Reference 14.)

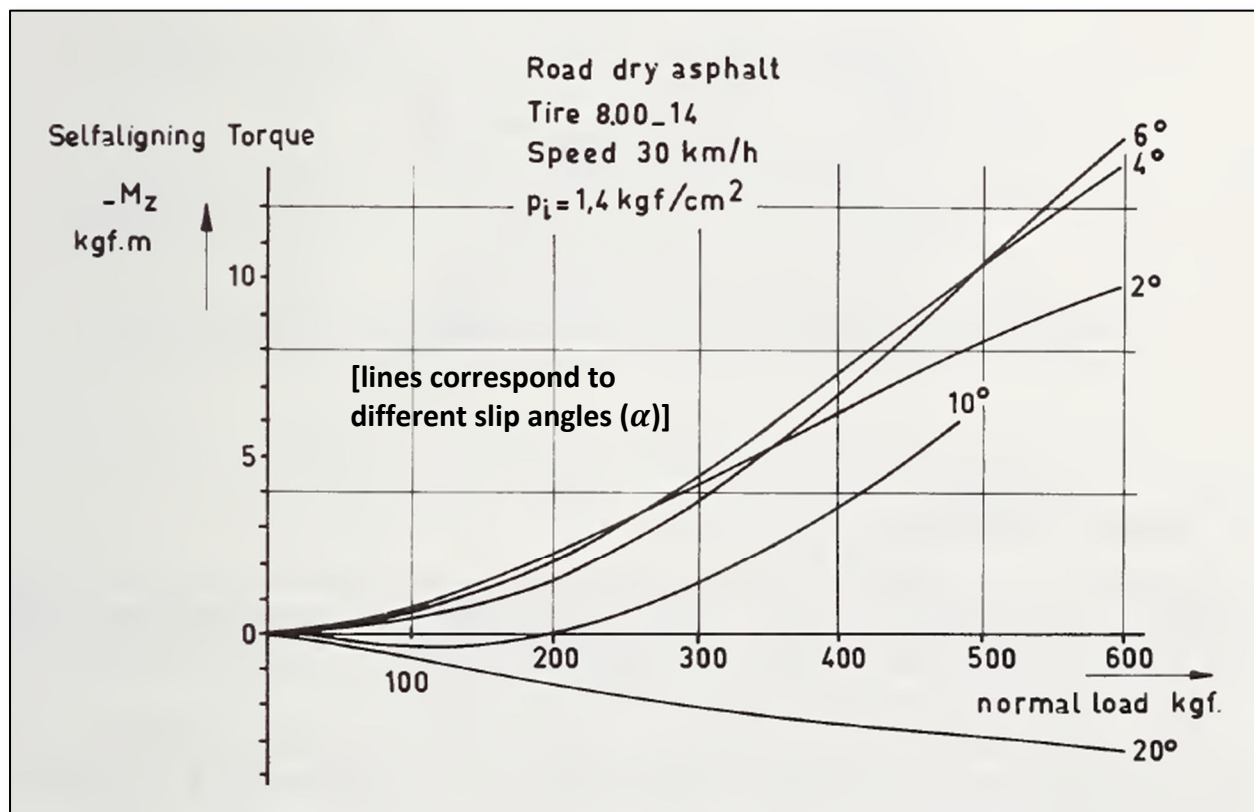


Figure 10. Effect of normal load on tire self-aligning torque (M_z) at different slip angles (α). Note that at $\alpha = 20^\circ$ the tire is unstable at all loads. (Figure 7.3.31 in Reference 14.)

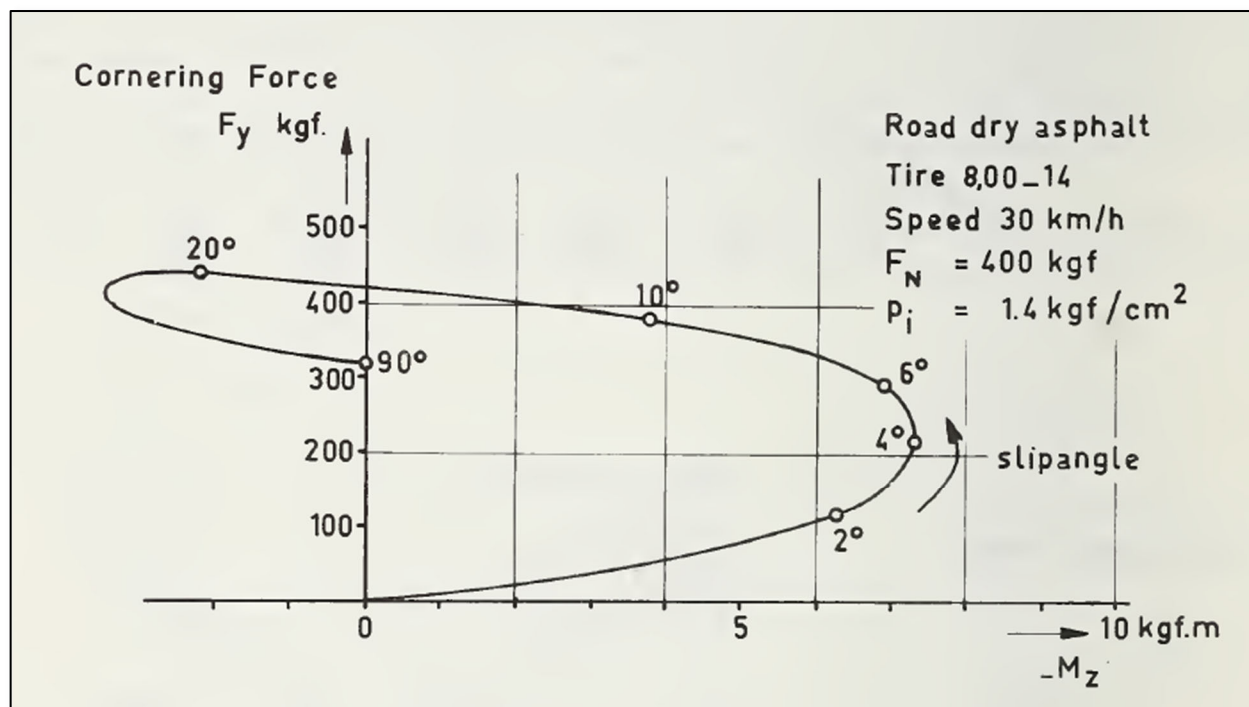


Figure 11. Cornering force vs. self-aligning torque (M_z) at different slip angles (α). The tire becomes unstable when $M_z > 0$. (Figure 7.3.32 in Reference 14.)

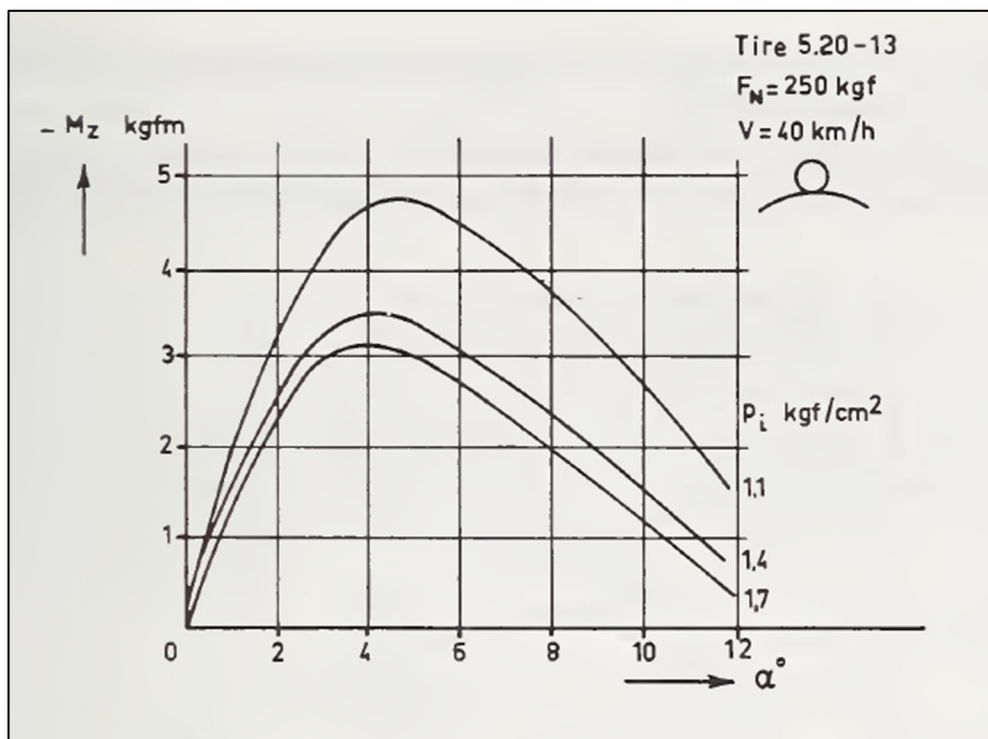


Figure 12. Effect of tire inflation pressure p_i on self-aligning torque (M_z) at different slip angles (α). (Figure 7.3.33 in Reference 14.)

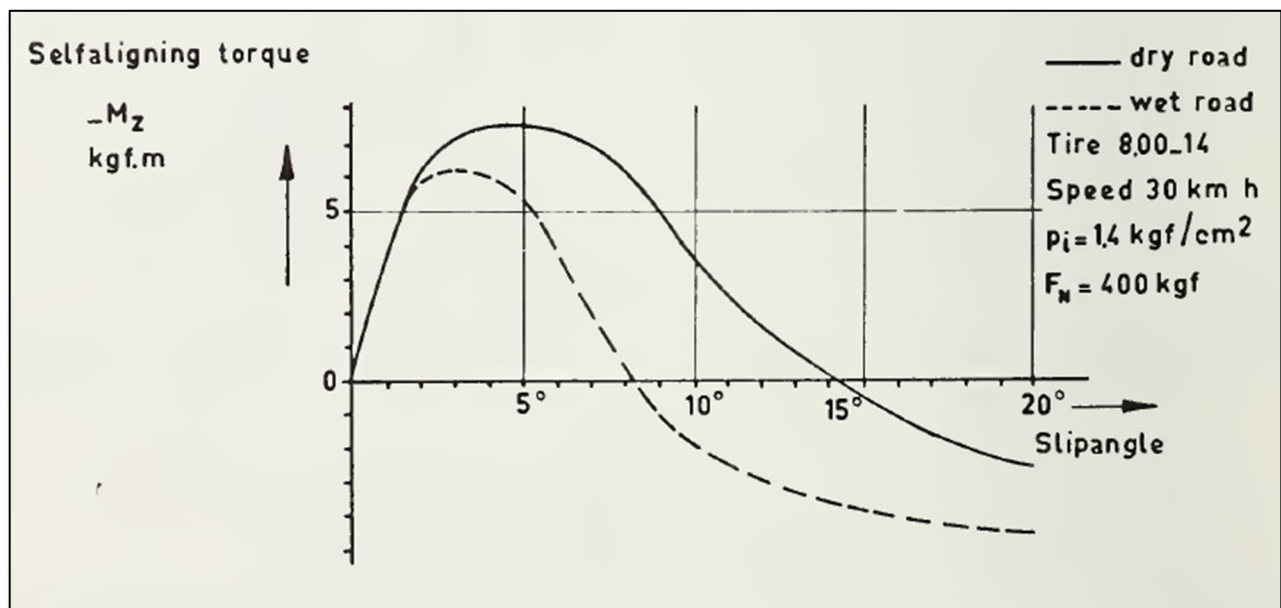


Figure 13. Effect of road condition on self-aligning torque (M_z) at different slip angles (α). Note the lower α at which the tire becomes unstable on a wet road. (Figure 7.3.24 in Reference 14.)

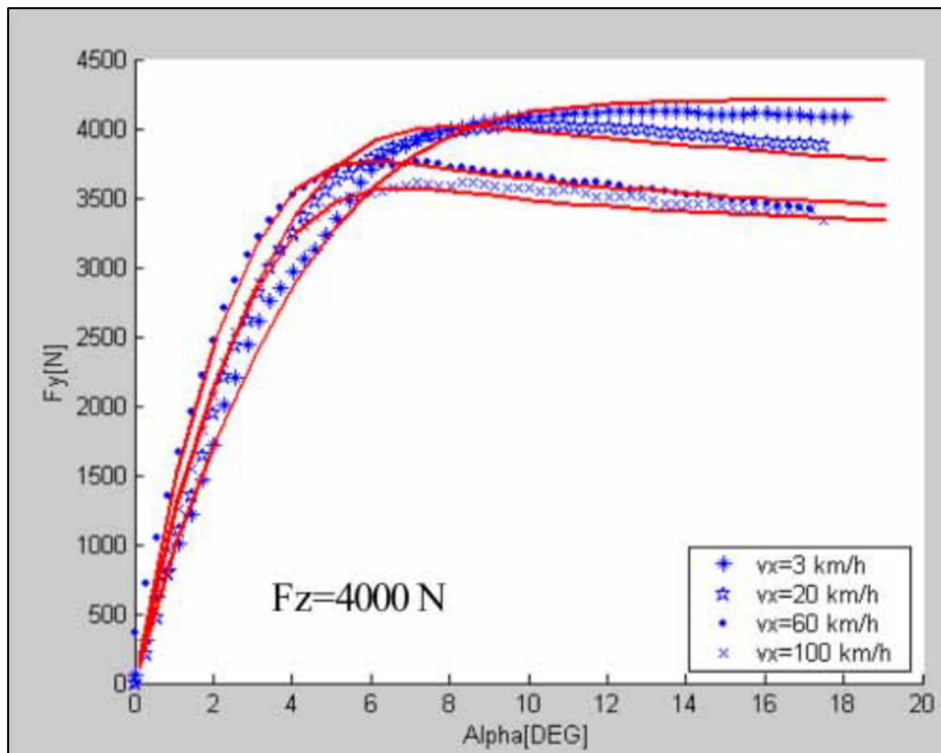


Figure 14a. Lateral force from UniTire model (red lines) compared with test data (symbols) at four different speeds (from Reference 16).

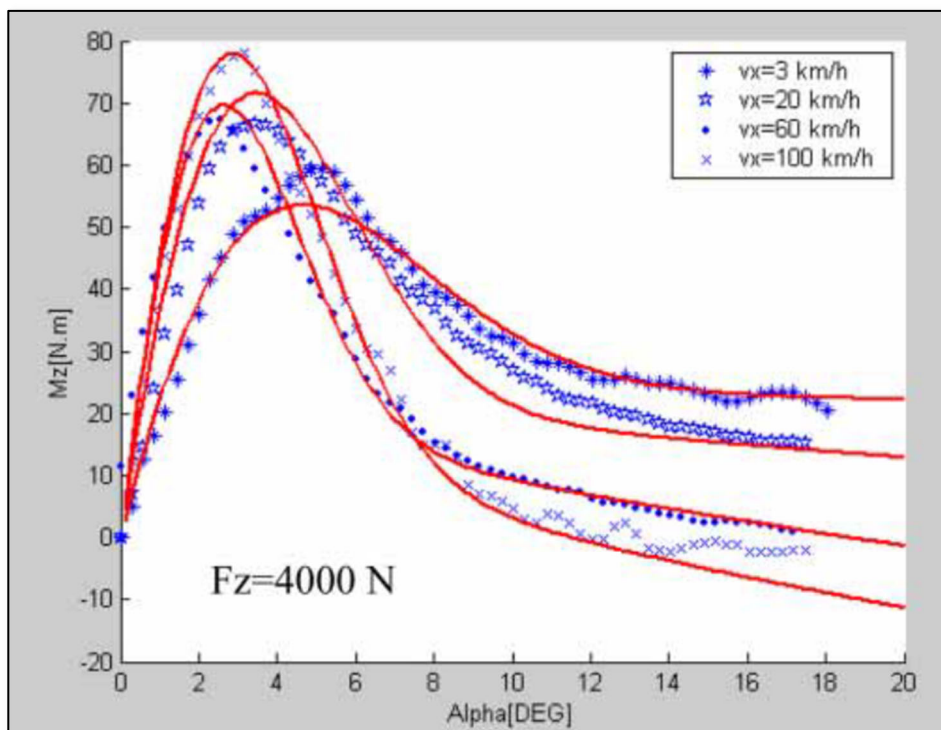


Figure 14b. Aligning moment from UniTire model (red lines) compared with test data (symbols) at four different speeds (from Reference 16).

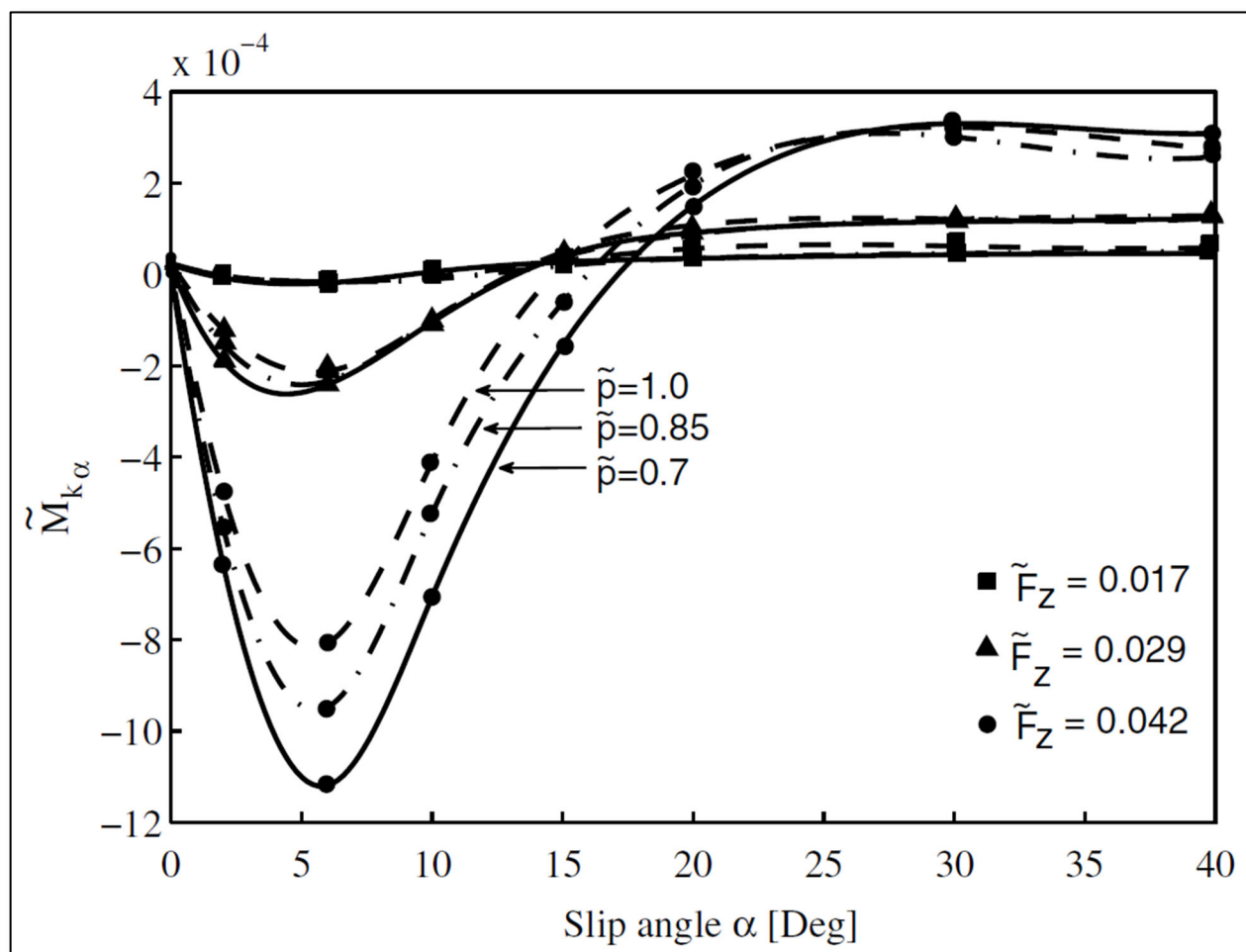


Figure 15. Normalized self-aligning moment as a function of slip angle with experimental data for three different normalized vertical loads and for three different normalized pressures (Figure 4a in Reference 11).

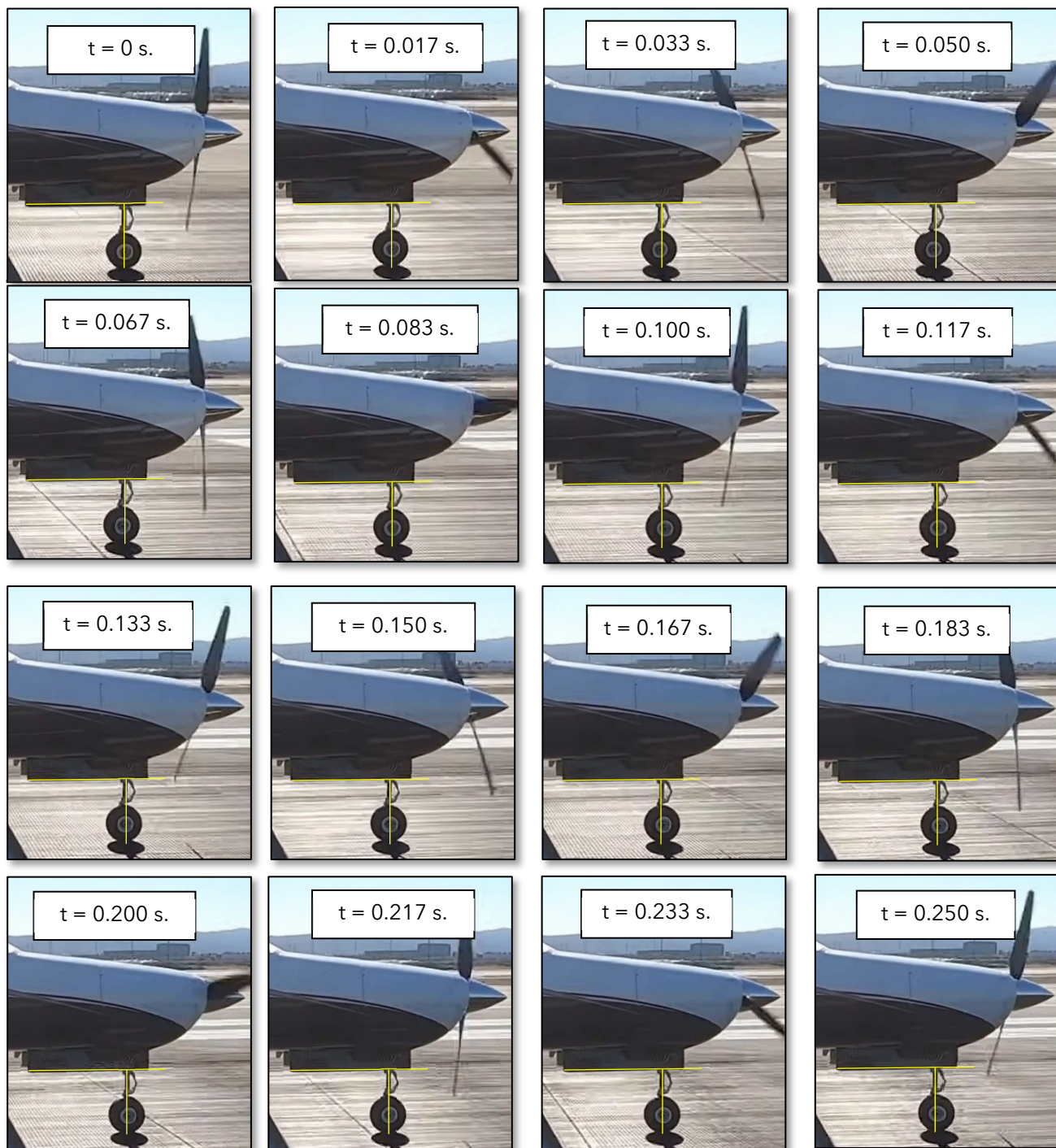


Figure 16. Selected frames from a video of the NLG of a landing PA46-310P at NLG touchdown, showing the deflection of the NLG strut aft and a damped oscillation about the equilibrium position. The yellow lines are drawn at right angles for reference. Time $t = 0$ corresponds to NLG touchdown. (See <https://youtu.be/3LTAtlNSe0w> at 6:30-6:37; this video is not associated with the NTSB or its staff).

Piper M600 Veer Event Data vs. Time: Group 1 of 4

Parameters based on recorded avionics data

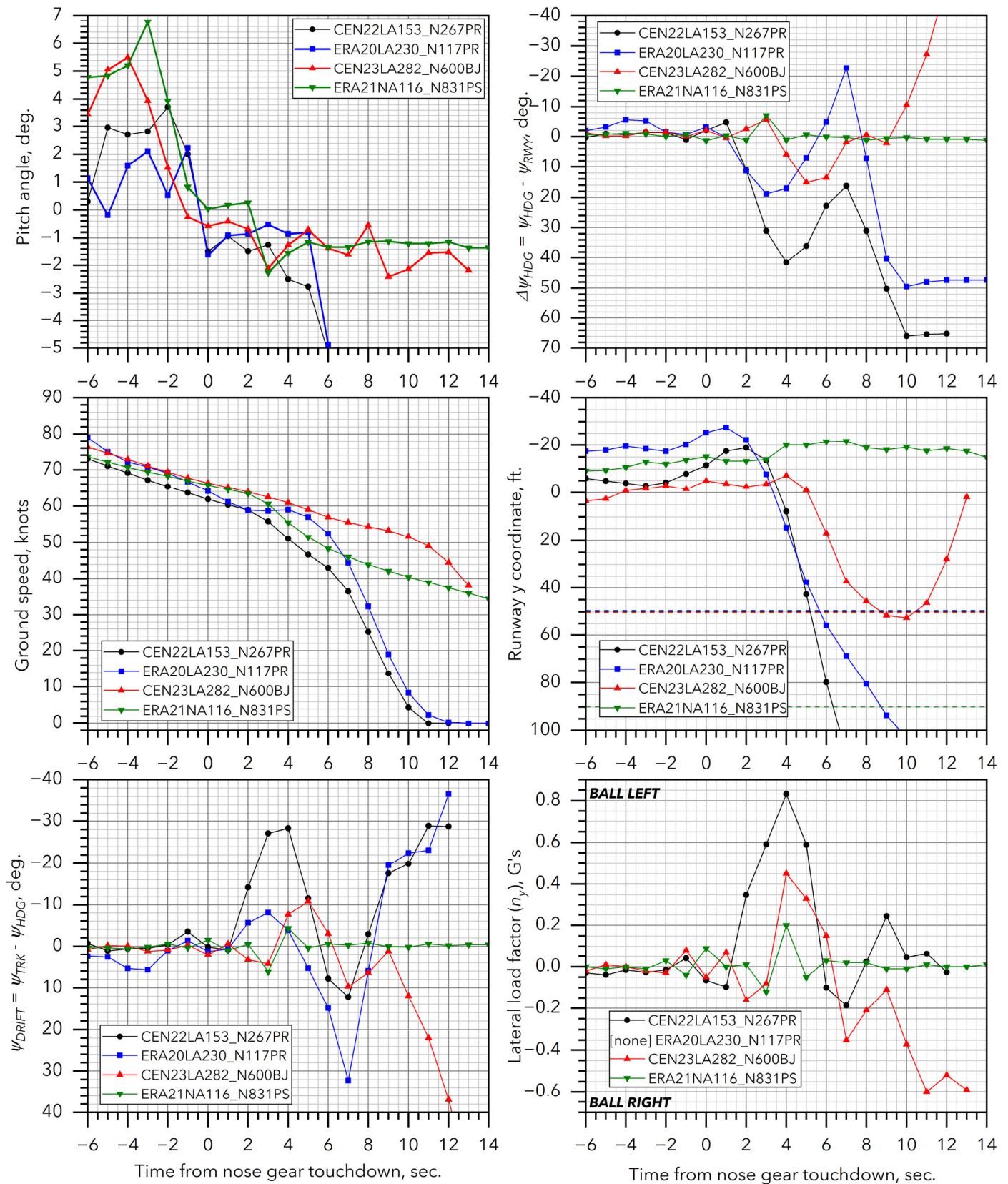


Figure 17a. Comparison of flight parameters for different M600 veer events as a function of Δt (1 of 4).

Piper M600 Veer Event Data vs. Time: Group 2 of 4

Parameters based on recorded avionics data

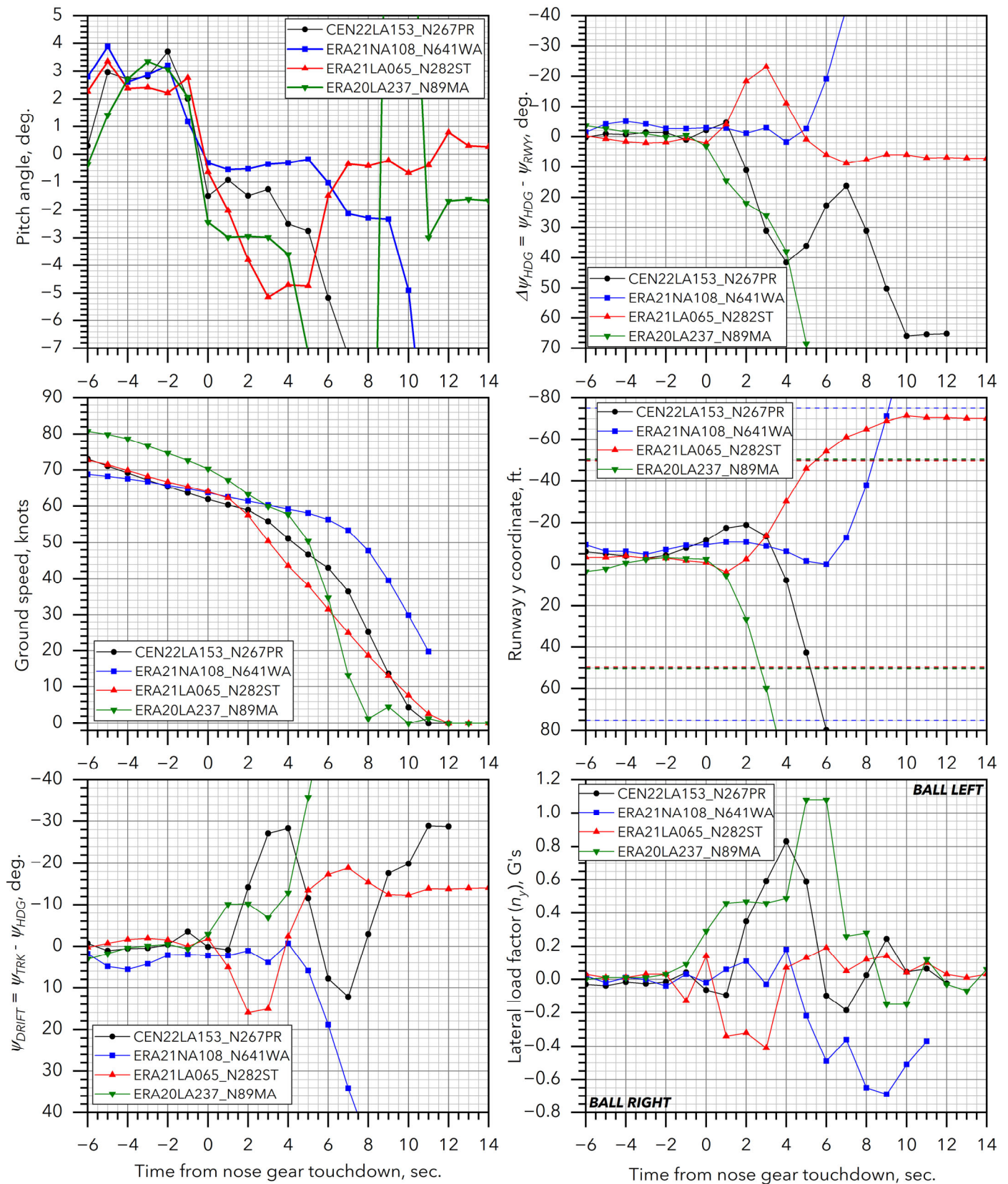


Figure 17b. Comparison of flight parameters for different M600 veer events as a function of Δt (2 of 4).

Piper M600 Veer Event Data vs. Time: Group 3 of 4

Parameters based on recorded avionics data

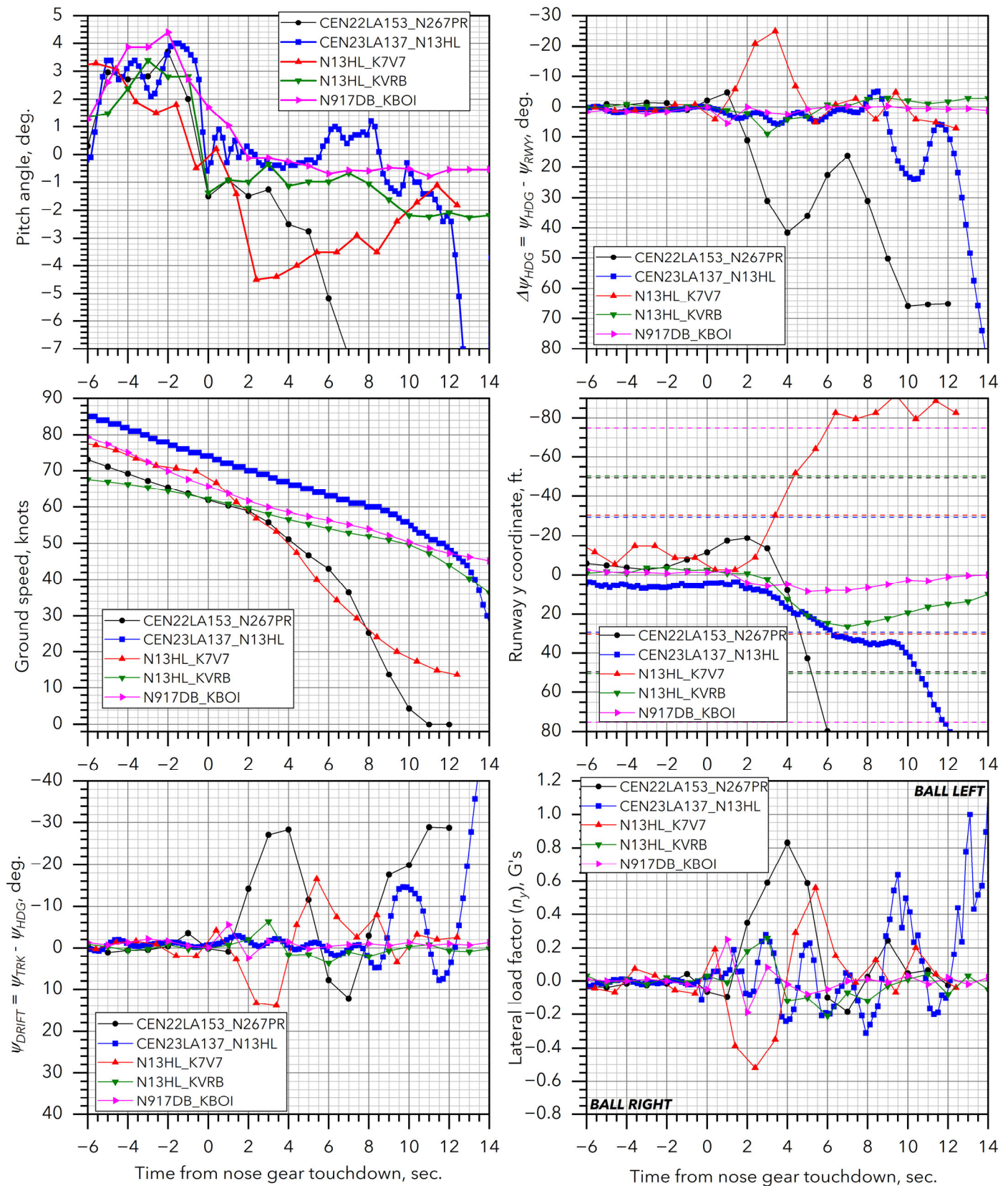


Figure 17c. Comparison of flight parameters for different M600 veer events as a function of Δt (3 of 4).

Piper M600 Veer Event Data vs. Time: Group 4 of 4

Parameters based on recorded avionics data

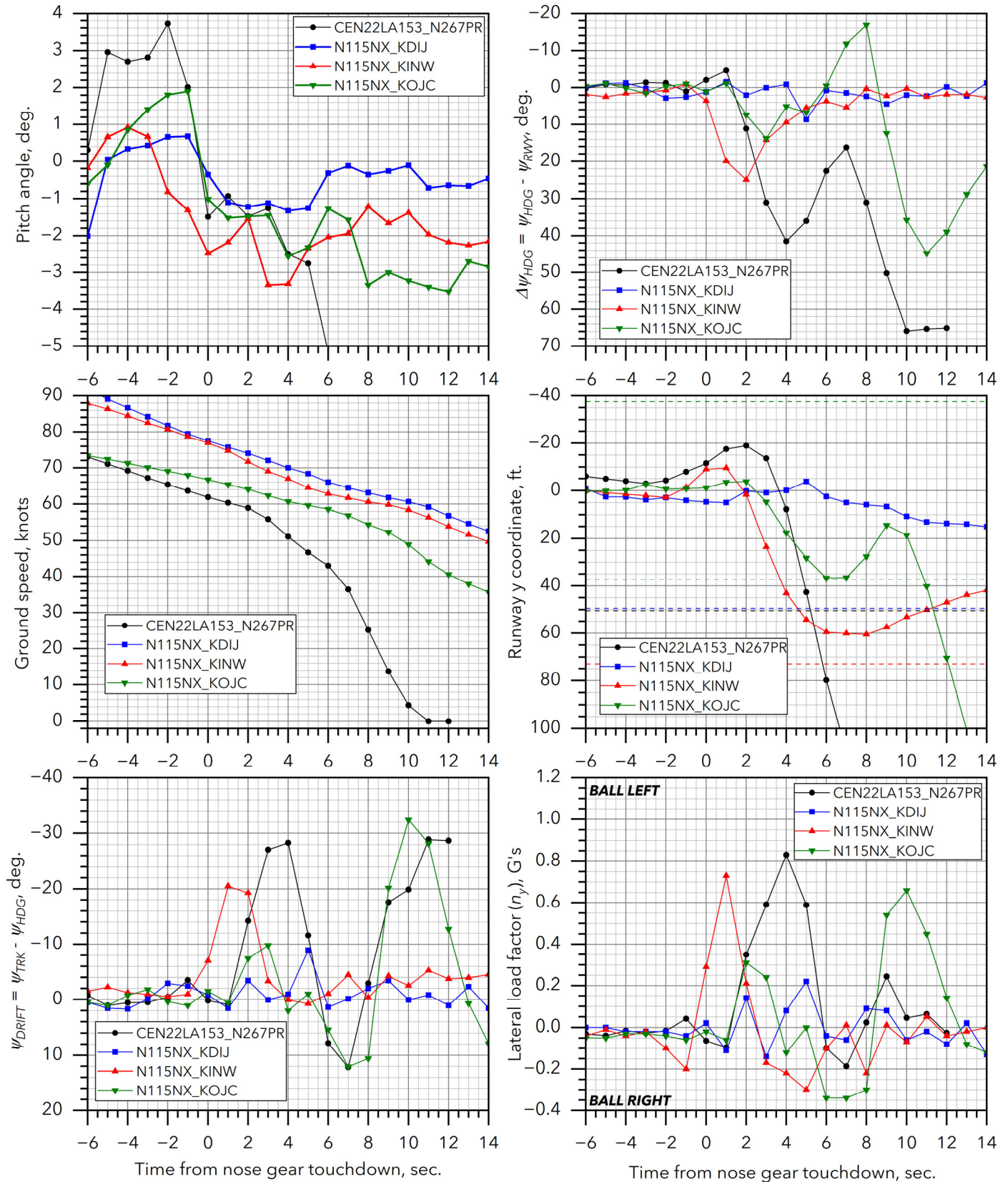


Figure 17d. Comparison of flight parameters for different M600 veer events as a function of Δt (4 of 4).

Piper M600 Veer Event Data vs. Δx : Group 1 of 4

Parameters based on recorded avionics data

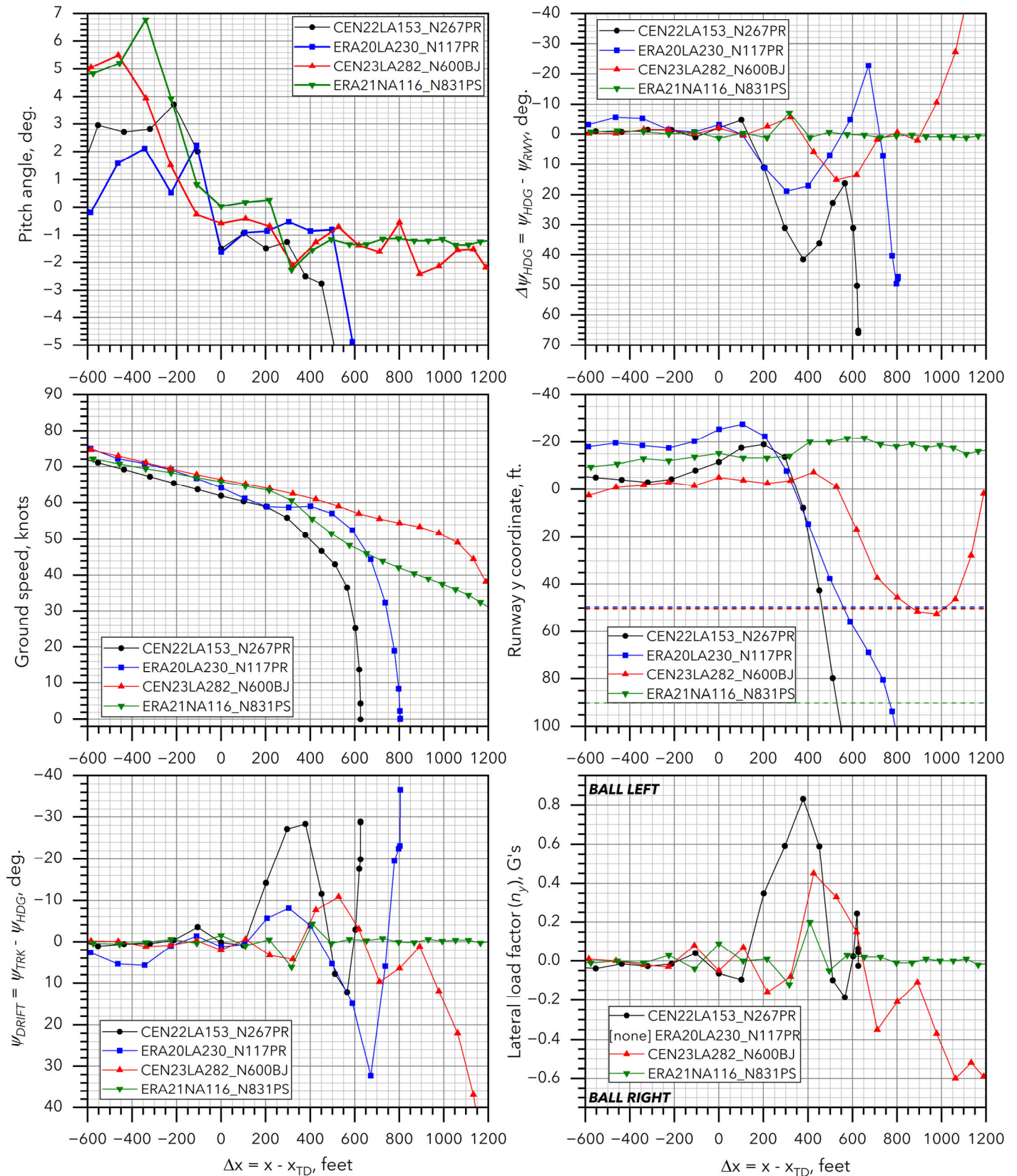


Figure 18a. Comparison of flight parameters for different M600 veer events as a function of Δx (1 of 4).

Piper M600 Veer Event Data vs. Δx : Group 2 of 4

Parameters based on recorded avionics data

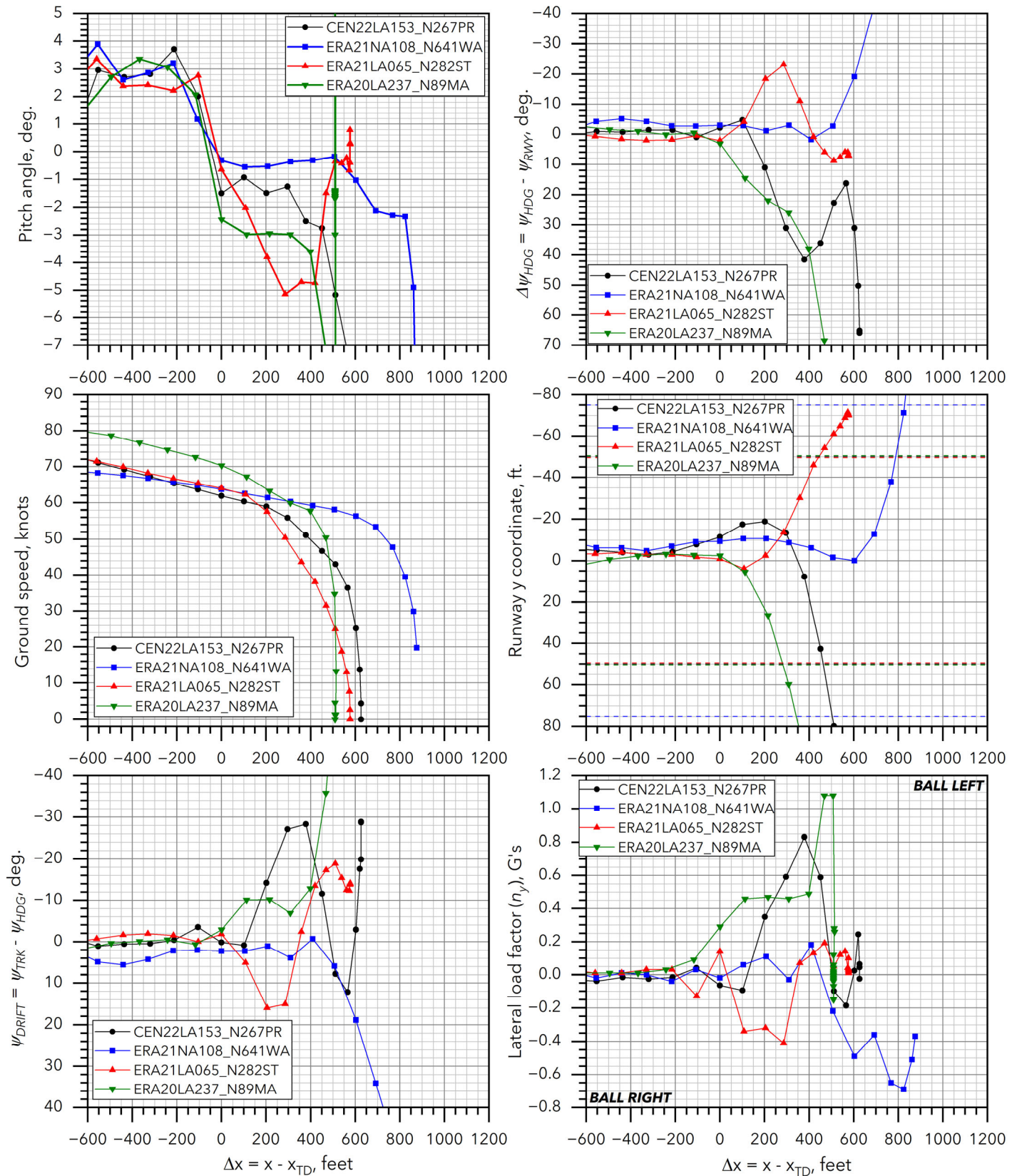


Figure 18b. Comparison of flight parameters for different M600 veer events as a function of Δx (2 of 4).

Piper M600 Veer Event Data vs. Δx : Group 3 of 4

Parameters based on recorded avionics data

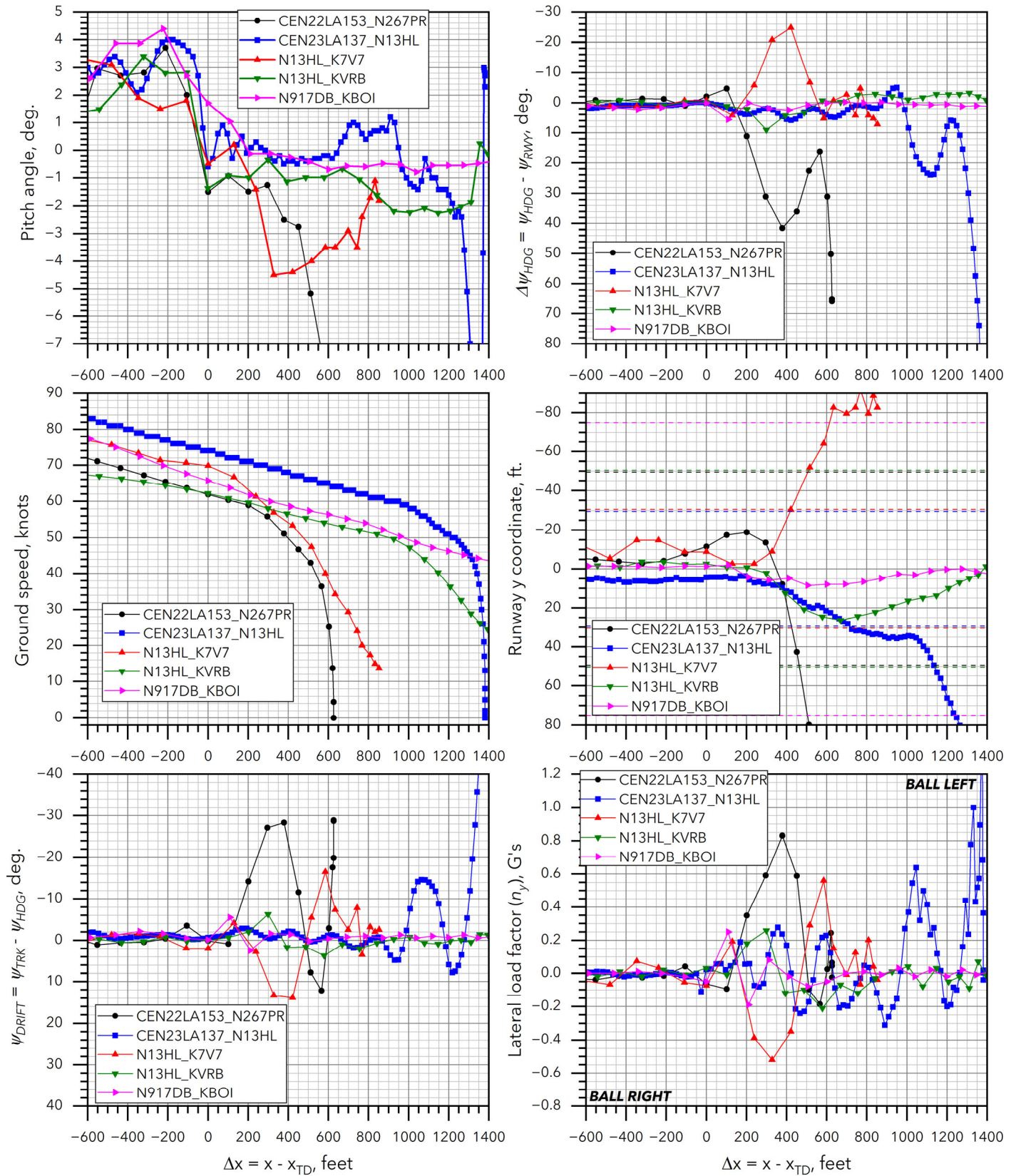


Figure 18c. Comparison of flight parameters for different M600 veer events as a function of Δx (3 of 4).

Piper M600 Veer Event Data vs. Δx : Group 4 of 4

Parameters based on recorded avionics data

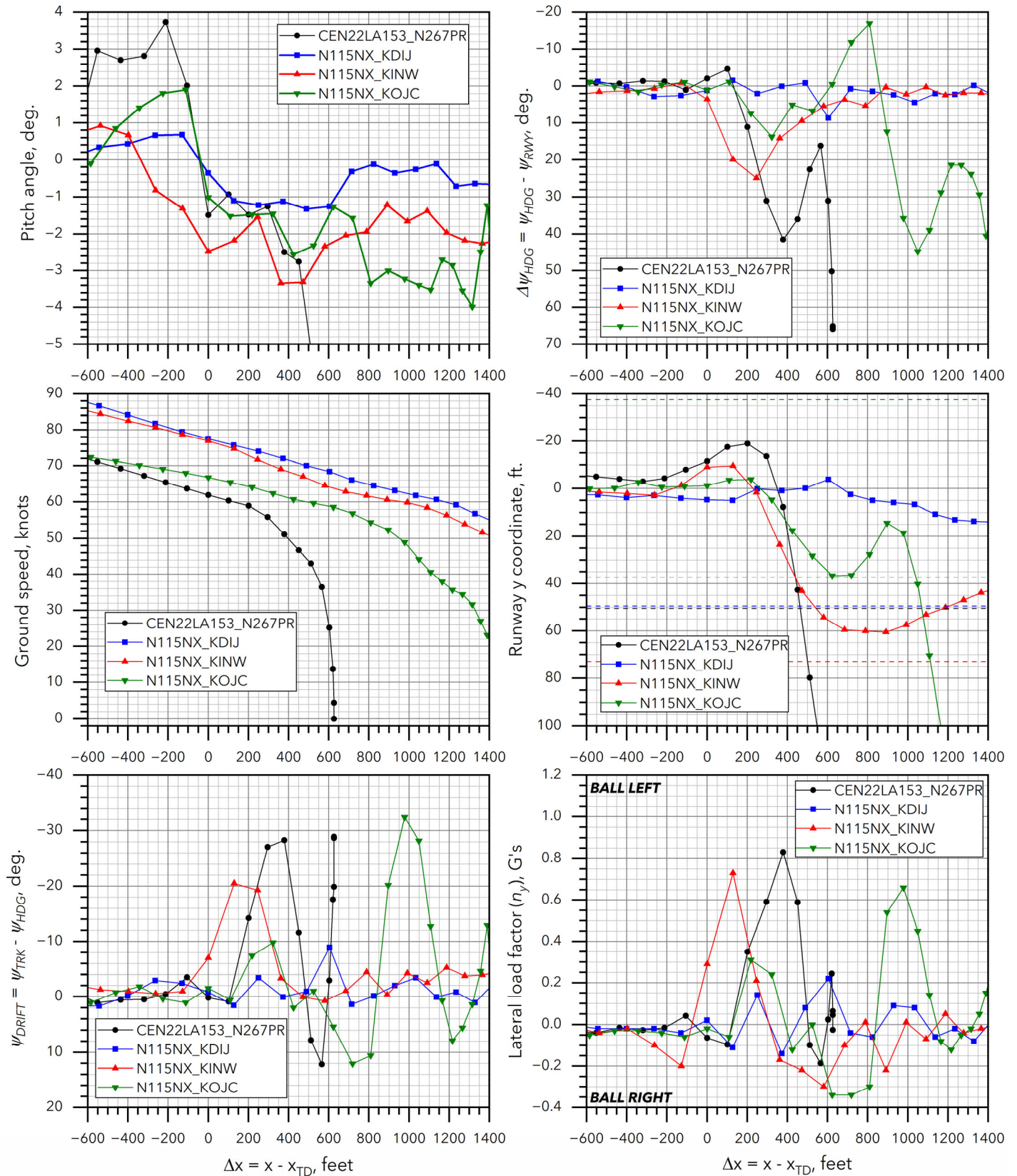


Figure 18d. Comparison of flight parameters for different M600 veer events as a function of Δx (4 of 4).

CEN22LA153: Piper PA-46-600TP N627PR, Olive Branch, MS, 03/23/2022

"Controls free" simulation results vs. time

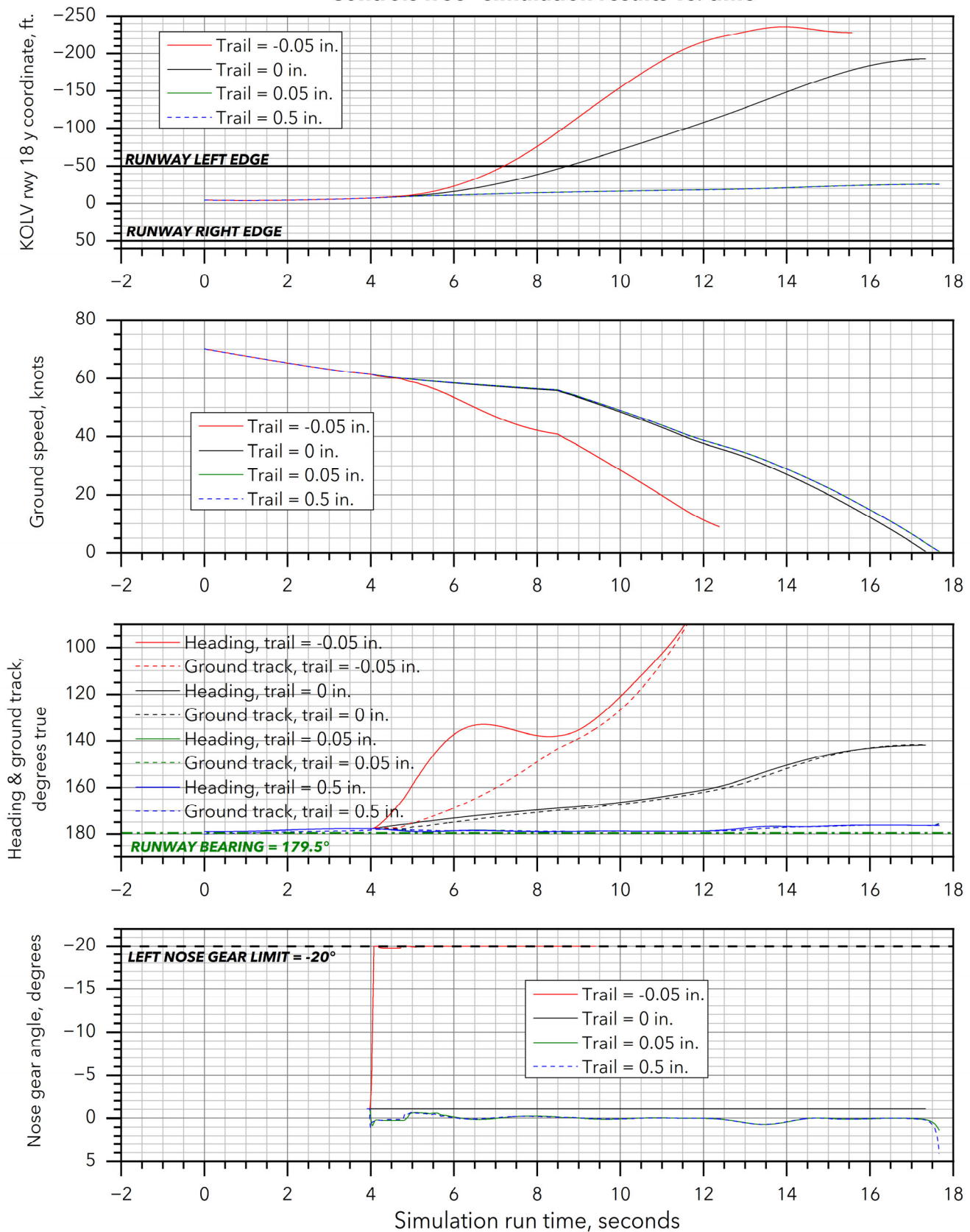


Figure 19a. "Controls-free" simulation results vs. time.

CEN22LA153: Piper PA-46-600TP N627PR, Olive Branch, MS, 03/23/2022

"Controls free" simulation results vs. runway x coordinate

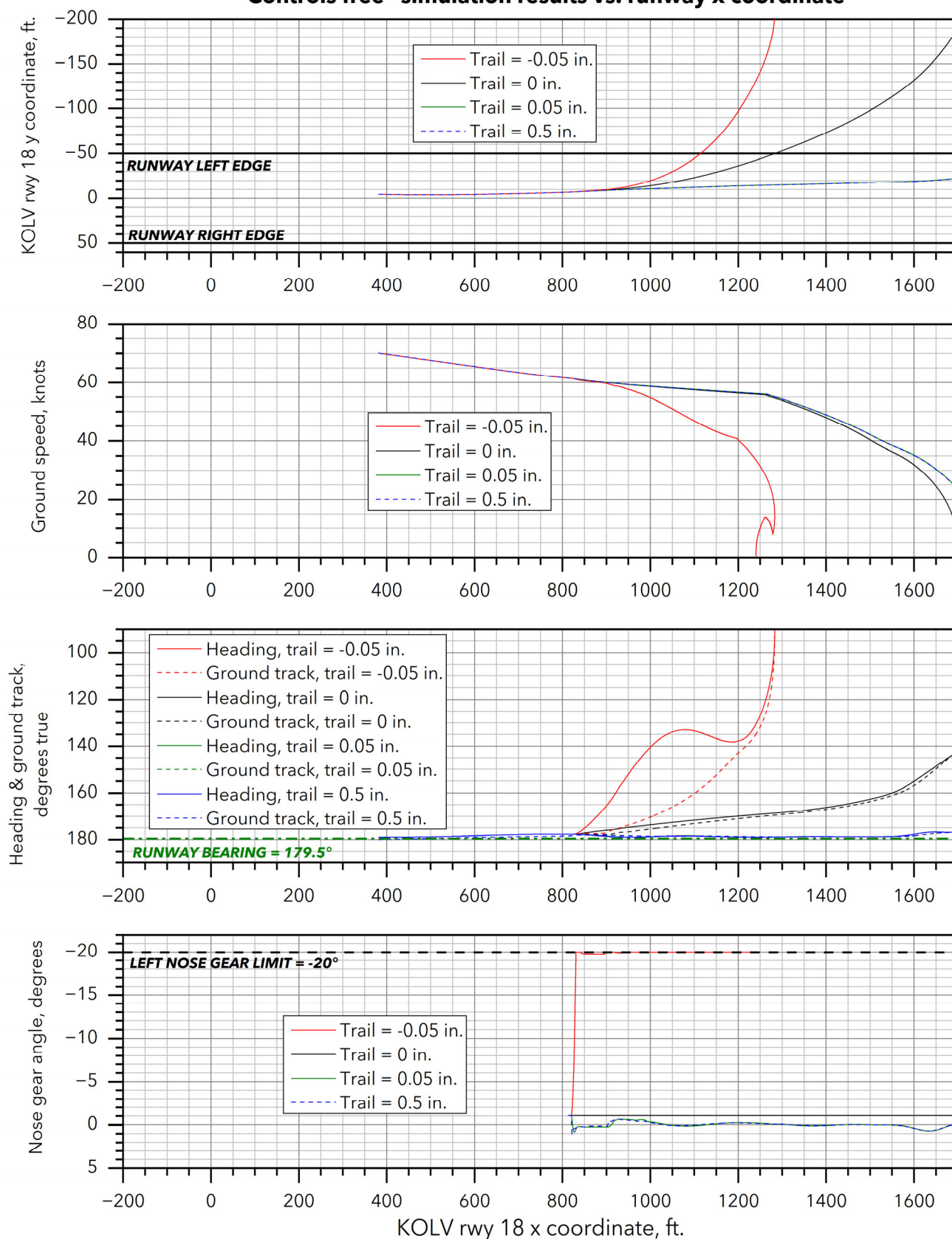


Figure 19b. "Controls-free" simulation results vs. runway x coordinate.

CEN22LA153: Piper PA-46-600TP N627PR, Olive Branch, MS, 03/23/2022

Accident and simlaton data comparisns vs. time

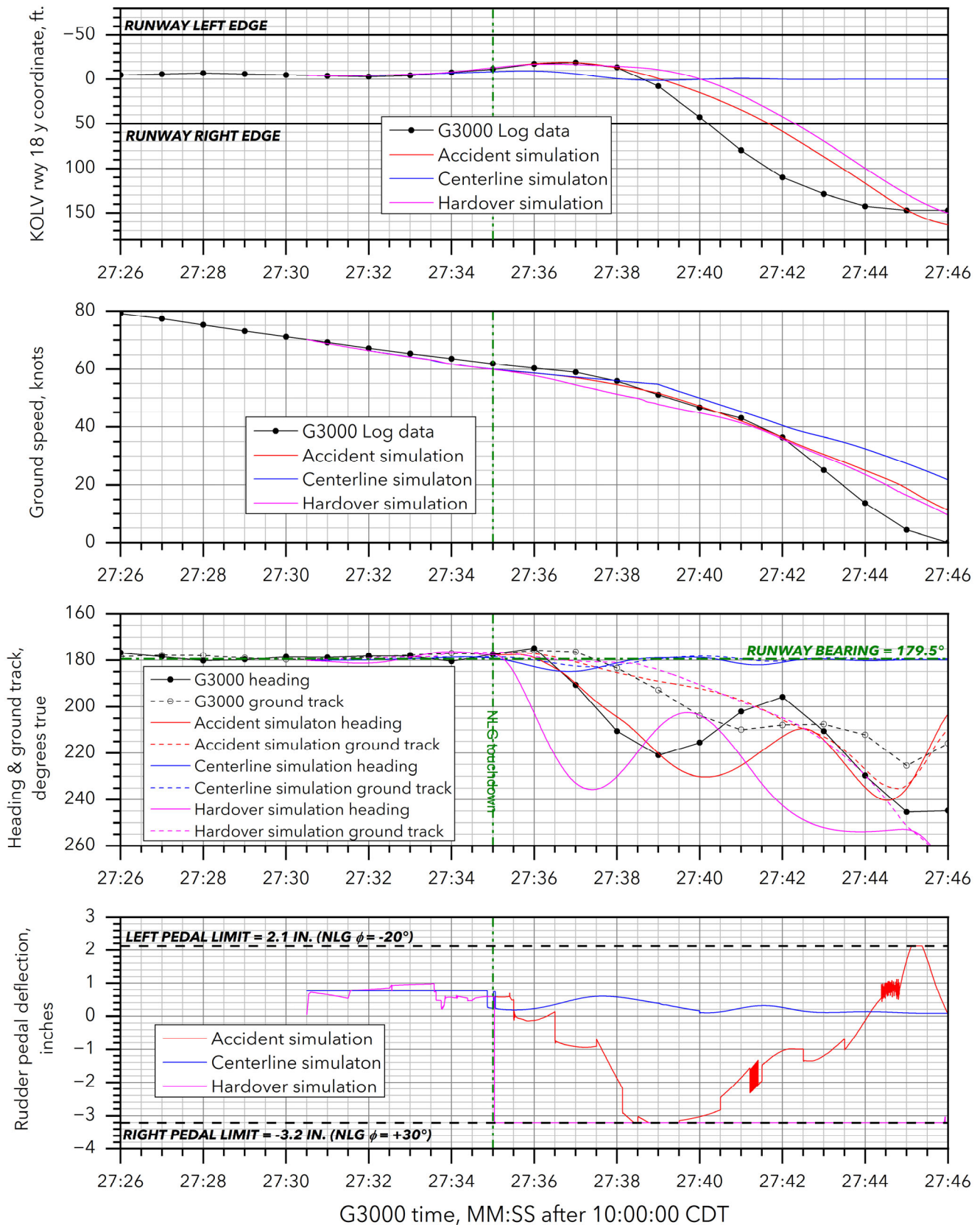


Figure 20a. Accident and simulation data comparisons vs. time.

CEN22LA153: Piper PA-46-600TP N627PR, Olive Branch, MS, 03/23/2022

Accident and simulation data comparisons vs. runway x coordinate

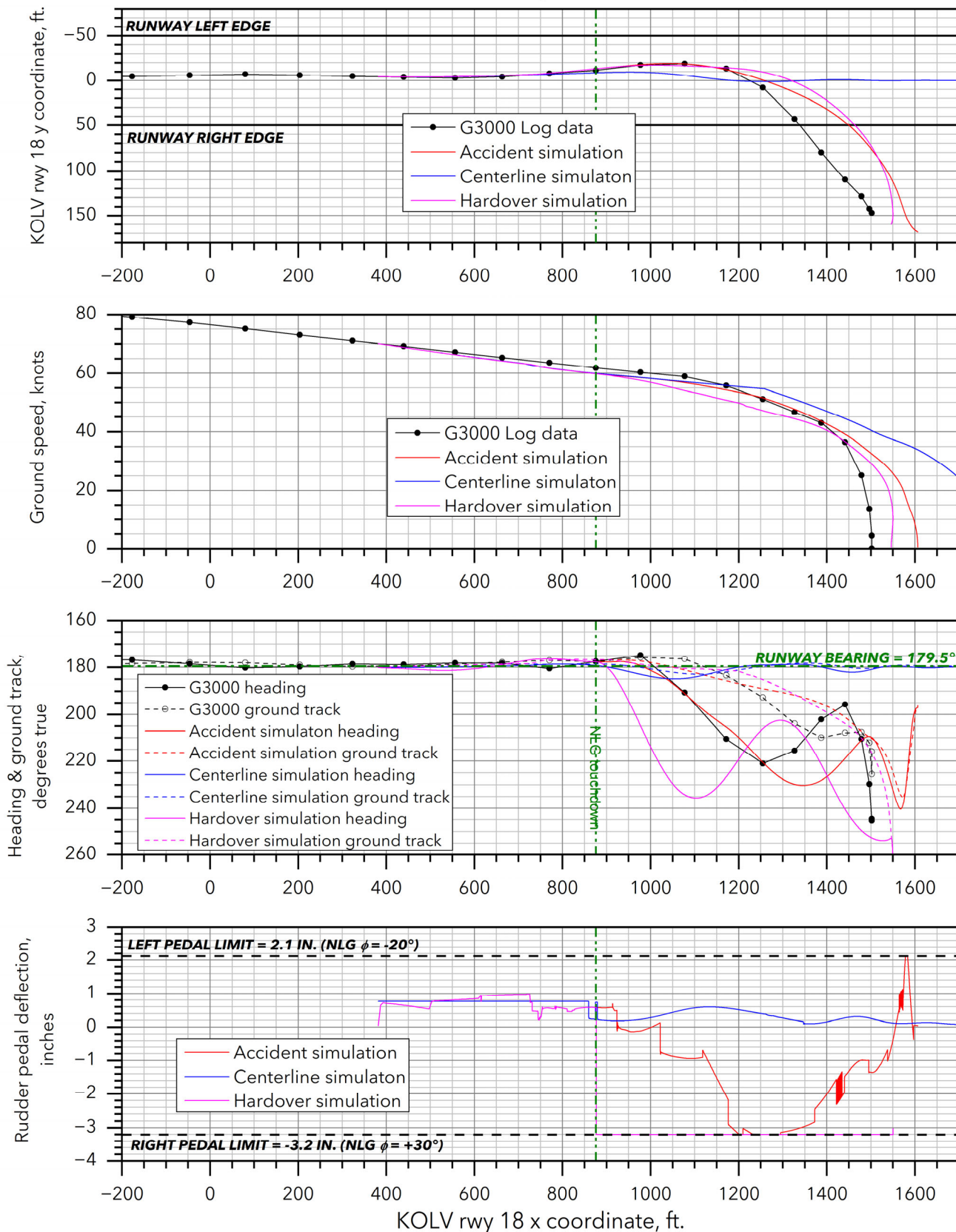


Figure 20b. Accident and simulation data comparisons vs. runway x coordinate.

APPENDIX A

Piper letters to PA46 operators
(References 10, 17, & 22)

Piper Aircraft Inc., *Customer Information Letter: PA46*
Operational & Maintenance Information, Nose Gear Steering,
March 27, 2008 (Reference 10)

Customer Information Letter**3/27/08****PA46 Operational & Maintenance Information, Nose Gear Steering**

Some Piper customers have expressed concerns about the nose gear steering on the PA46 "Malibu" series of aircraft models. This document explains Piper's response to those concerns and provides specific actions that owners can take to ensure that their aircraft continues to operate properly and conform to factory specifications.

The geometry of the Malibu nose gear is a conventional zero rake, zero trail configuration, successfully used by several manufacturers on many different models.

When the Meridian was first introduced in 2000, some of these early customers reported an occasional pull to the right at the instant of touchdown. Piper immediately began an extensive testing program in an effort to understand this phenomenon. Although Piper was unable to duplicate the reported condition (either then or since, under varied and extreme conditions), analysis of the test data, combined with research into the dynamic behavior of the steering geometry, has resulted in a two-fold design improvement to the Meridian in 2002 which allows the pilot to better control the steering forces involved:

- A higher tire pressure was used to reduce the size of the rolling contact patch, thereby reducing the magnitude of the steering forces. An 8-ply tire inflated to 70 psi replaced a 6-ply tire inflated to 50 psi.
- A stiffer bungee was used to increase the pilot's authority in controlling the steering forces. The 83615-010 Bungee Assembly replaced the 83615-009 Bungee Assembly.

The analysis and testing that resulted in these design changes has been validated by the historical data:

- Prior to these nose gear steering improvements (that is, for the year 2001), the rate of occurrence (i.e., number of runway excursions reported for a given year, divided by the number of aircraft in the fleet) was 7.6%. By contrast, the rate of occurrence from 2002 to 2007 has dropped an order of magnitude to an average of 0.8%, remaining very consistent from year to year. The small percentage remaining represents excursions due to other causes.
- Additionally, the nature of the reported behavior has changed. In 2001, 89% of reported turns were in the right direction. From 2002 to 2007 (that is, for aircraft with the nose gear steering improvements), 54% of reported turns were in the right direction. The bias to turn to the right has been eliminated.

This design change was the subject of Piper Service Bulletin 1106, dated January 28, 2002 which was applicable to Meridian Serial numbers 4697001 through 4697125. Aircraft with serial numbers 4697126 & up have these design improvements incorporated at the factory.

In addition to the design changes made to the Meridian as described above, several *operational* factors have been identified as critical for optimum steering function on *all* Malibu models:

RIGGING & MAINTENANCE

Note: All Piper aircraft come properly rigged and serviced from the factory. They will perform satisfactorily over their life when properly operated, maintained and serviced in accordance with the appropriate aircraft operating instructions, maintenance manuals, and other Piper publications.

Tire Pressure

As mentioned earlier, low tire pressure can increase the forces associated with steering the aircraft on the ground.

According to both Michelin and Goodyear, aviation tires in service should have their “cold” inflation pressure checked daily to properly maintain operating pressures. For aircraft operating on a less frequent basis, inflation pressure should be checked before each flight.

Both tire manufacturers also state that aviation tires can lose as much as five percent (5%) of the inflation pressure in a 24-hour period and still be considered normal. For purposes of illustration, consider the Meridian, which uses a nose gear tire inflated to 70 pounds per square inch (psi). With a daily pressure loss of 5%, a tire inflated to 70 psi could drop to 49 psi in just a week and further drop to as low as 15 psi in 30 days. A tire may visually look to be properly inflated but may in fact be significantly under-inflated. The only way to be sure is to use a good quality tire gauge.

Tire pressure should be checked by the pilot as part of the preflight inspection.

Nose Gear Rake Angle

The proper nose gear rake angle for all Malibu models is zero to one-half degree forward from vertical, measured using the airframe lower skin just aft of the nose gear doors as a horizontal datum with the aircraft on jacks. In other words, the relative angle between the lower (belly) skin and the nose gear strut should range from 90.0 degrees to 90.5 degrees. See figure 1.

A rake angle outside of this range may result in dynamic instability, creating steering forces that exceed the pilot’s ability to control. This angle is set by adjusting thread engagement in the nose gear actuator’s rod end bearing as described in the maintenance manual.

The nose gear rake angle is properly adjusted and verified at the factory and should be inspected and/or adjusted by an FAA-licensed mechanic according to the schedule and instructions in the maintenance manual, any time the pilot experiences poor steering, or there is replacement or service to the nose gear trunnion, the nose gear actuator, or the engine mount.

Steering Arm / Roller Gap

Mounted on top of the nose gear trunnion are two nylon rollers which are used to translate the rotation of the steering arm (from rudder pedal movements) into rotation of the nose wheel. When the gear is in the down and locked position, the two nylon rollers are directly forward of the steering arm as shown in figure 1. Excessive clearance between these two rollers and the steering arm will result in loose steering and allow the nose wheel to point in a different direction than is commanded by rudder pedal inputs.

The correct clearance between the Steering Arm and the Rollers is adjusted and verified at the factory to be 0.010 to 0.030 inches with aircraft weight on wheels. This clearance should be inspected and/or adjusted by an FAA-licensed mechanic according to the schedule and instructions in the maintenance manual or any time the pilot experiences poor steering, or there is replacement or service to the nose gear trunnion, the nose gear actuator or the engine mount.

Rudder Cable Tension

Low rudder cable tension can create variations between rudder angle and nose wheel steering angle. Operating with excessively low rudder cable tension could result in the nose wheel pointing in a direction that differs from the aircraft line of travel at the instant of touchdown, even though proper pilot technique (as described below) is followed.

The Rudder Cable tension is properly adjusted and verified at the factory, and should be inspected and/or adjusted by an FAA-licensed mechanic according to the schedule and instructions in the maintenance manual.

PILOT TECHNIQUE

The FAA has published document FAA-H-8083-3 "Airplane Flying Handbook", which is designed as a technical manual to introduce basic pilot skills and knowledge that are essential for piloting airplanes. The document may be downloaded for free at the following web site:

http://www.faa.gov/library/manuals/aircraft/airplane_handbook/

Like all steerable nosewheel aircraft with interconnected rudder, special technique is required during a cross wind landing as explained in Chapter 8. Specifically, page 8-15 includes the following text:

In those airplanes having nosewheel steering interconnected with the rudder, the nosewheel may not be aligned with the runway as the wheels touch down because opposite rudder is being held in the crosswind correction. To prevent swerving in the direction the nosewheel is offset, the corrective rudder pressure must be promptly relaxed just as the nosewheel touches down.

Piper designs and builds products to the highest standards for safety and reliability. Following these guidelines will help ensure that your aircraft continues to meet these standards throughout the service life of the aircraft.

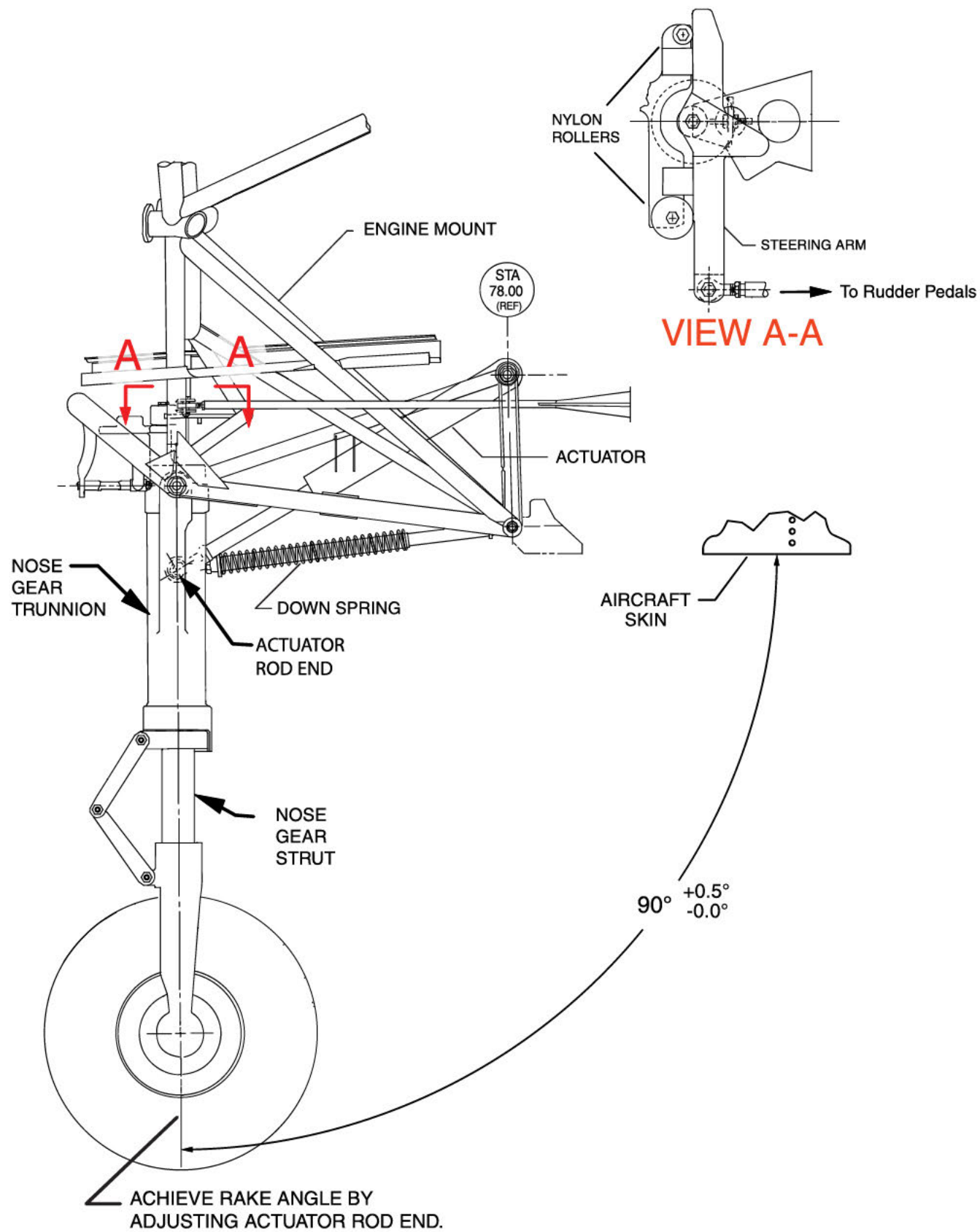


Figure 1

Left side view of Malibu Nose Gear

Piper Aircraft Inc., *Letter to Piper M600 Owners*, February 4,
2021 (Reference 17)



February 4, 2021

Piper M600 Owner,

On behalf of everyone at Piper we trust this letter finds you and your family doing well in the New Year.

First and foremost, our number one priority is your safety and satisfaction with your aircraft and us. As an owner of our flagship M600, we wanted to reach out directly and update you on an important topic.

We are reviewing some landing excursions within the 158 M600 fleet now operating worldwide. As you would expect, in each case we analyze all associated data while working closely with the NTSB and FAA in their determination of probable cause. That determination also includes specific company analysis and testing to ensure proper aircraft conformity and performance to the approved FAA type design standards.

Throughout the reviews, company testing and analysis, there appears to be one primary constant. That is for each event, the aircraft mechanical, pilot operational and environmental parameters were different. As a fellow pilot, this likely comes as no surprise knowing the myriad of both controllable and uncontrollable forces that are in play during any landing sequence.

In some cases, mechanical conditions such as low tire pressures and/or prior tow-limit exceedances were found. (It is important to note that we have found a large portion of the entire PA46 installed base operates with low tire pressures. Maintaining proper pressure is most critical on the M600 with the associated higher operating weights.) On other events, a combination of human factors, environmental conditions and pilot experience/training history appear to have played significant roles.

Through an abundance of caution, we have issued several important service communications to ensure critical operational and mechanical settings are applied to the fleet, all of which influence the factors discussed above. We want to make sure your aircraft complies with those communications – all are covered under your aircraft warranty.

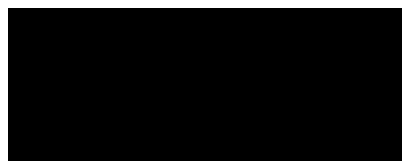
The service communications released include:

1. **SL1285, July 2020** - Reminds owners and operators of the importance of proper tire pressure.
2. **SL1286, August 2020** - Recommends key measures be taken to ensure aircraft remain conformed to the FAA type design to include: Tire Pressure, Nose gear rake angle, steering horn roller clearance and Main gear toe alignment.

3. **SB1350, December 2020** - Inspection issued for some aircraft to verify steering horn roller to arm measurements and steering arm inspection. It also calls for the replacement of the steering horn, if required.
4. **SL1286 revisions A and B, January 2021** - Directed adjustments to the length of the rudder pedal connection arms. In general this procedure shortens (or tightens) the control rod lengths via adjustment bolts resulting in a more positive rudder pedal engagement, better rudder to pilot feedback and controllability throughout the rudder pedals normal travel range.

You purchased your M600 confident in the safety and high performance reputation of the aircraft and our company. Our commitment to you is unwavering. If you have any questions or concerns regarding your aircraft, please feel free to contact me, Vincent Zarrella – Director Global Customer Support 772.299.2024, or your Regional Authorized Piper Dealer or Service center.

Sincerely,



[Redacted]

Vice President – Sales, Marketing and Customer Support

[Redacted]

[Redacted]

Piper Aircraft Inc., *Letter to the Piper PA46 Owner Community*,
February 24, 2021 (Reference 22)

February 24, 2021

Piper PA46 Owner Community,

We trust this letter finds you and your family doing well in the New Year.

We have elected to take a direct approach in addressing the marketplace discussions surrounding some recent M600 landing excursions. We are doing so because some simple facts are being lost in a growing sea of false narratives that at times, are distorting the truth in not so subtle ways, both in this forum and in a recent Wall Street Journal article. We felt the best place to start this direct approach is here, using a respected, independent PA46 owner platform. This is your forum and we thank MMOPA leadership and all PA46 owners for the opportunity to do so.

As you read on you will likely note we are going beyond some traditional OEM communication boundaries. We are doing so to maximize transparency and minimize ambiguity while leaving little room for subsequent speculation and negative innuendo. We will be taking that same approach in other channels soon but there is no audience more important to start with than you.

Background

We are reviewing six (6) M600 landing excursions that have taken place since December 2019 within the 160 M600 fleet now operating worldwide while accumulating ~78,000 flight hours since deliveries began in 2016. In four (4) of these instances, we are also providing technical assistance to the NTSB, at their request, which is typical for any OEM. *Note: In a recent forum post it was inferred that Piper can and will evoke some type of "pressure and influence" in a self-serving way upon the NTSB and FAA. That inference is uninformed and false. Additionally, the statement was made that we have not had debriefs with ANY of the impacted pilots other than our own. That is also a false statement.*

As you would expect, Piper is evaluating each of these events and in each case analyzing all associated data while submitting that information to the NTSB and FAA to assist in their determination of probable cause.

Context and Transparency

Below is a summary of the six (6) runway events under review.

#1 – A Piper pilot delivering a new M600 to a dealer experienced a runway excursion to the right. The pilot could have kept it on the runway but elected to continue across the level grass onto a taxiway. Tire

pressures were determined to be 17 percent below required. This event reinforced the importance of proper tire pressures. As a result of the excursion, the aircraft had paint chips on the propeller. We replaced the propeller and reworked the steering horn to ensure optimum pad to roller distance.

#2 – A pilot experienced a runway excursion to the right. Nose gear collapsed. 99 hour PPL, first flight without Instructor. NTSB report quote “...a strong gust of wind hit his craft broadside, on the port side of the craft, which lifted so significantly that it lost its last wheel traction on the pavement which caused the plane to run off the runway...” Currently under NTSB review. *Note: In a recent forum post, it was stated that the right seat occupant was a former military pilot with over 3,000 hrs. This is true. However, the majority of his 3,000 hours were in an Army rotor wing aircraft. He is licensed to fly a fixed wing aircraft but has similar fixed wing total time as that of the owner/PIC of the flight.*

Link to Preliminary NTSB Factual Report on this incident:

<https://data.nts.gov/carol-repgen/api/Aviation/ReportMain/GenerateNewestReport/101497/pdf>

#3 – The pilot experienced a runway excursion to the right. Currently under NTSB review. Preliminary Piper inspection and testing indicates the possibility of a broken steering horn prior to flight due to the aircraft being towed beyond mechanical system limits. Basically a “castering” nose wheel was experienced on or shortly after nose wheel touchdown.

#4 – The pilot experienced a runway excursion to the left. Currently under NTSB review. It has been determined tire pressures were more than 50 percent below requirements.

#5 – The pilot experienced a runway excursion to the left. Taxied to FBO. One MLG tire was flat spotted as a result of excursion. Remaining tire pressures were found to be low. Aircraft is back with customer.

#6 – The pilot experienced a runway excursion to the left. Currently under NTSB review. One MLG tire was flat as a result of the excursion. Remaining tire pressures were found to be low. Ice / snow on runway was a concern at the time.

Analytical Approach, Data Gathering via Service Communications

Since mid-2020, Piper has conducted an exhaustive review of these incidents to determine whether or not an issue exists with the aircraft that goes beyond the testing requested by the NTSB and has found no such issue. We have also initiated an independent, third party technical and aircraft operational review to verify the analysis.

More specifically, Piper has conducted over 2,100 hours of engineering and flight test analysis. The testing includes all landing related system/component functionality, containment inspections and flight testing across all possible aircraft mechanical, weight and balance, pilot technique and landing environmental spectrums to ensure M600 conformity to the FAA approved type design and traditional flight characteristics. *Note: That’s a long way to simply say we’ve looked at everything. And the work continues.*

Tire Pressures. We reviewed earlier the M600 runway excursion in December 2019 was a Piper pilot. Our pilot and our delivery team did not follow the POH when it came to tire pressure preflight and care.

After additional tire pressure checks were taken throughout the combined owner, dealer and Piper factory fleets, it became apparent that a substantial portion of the PA46 fleet is operating with low tire pressures. As a result, we issued **SL1285** in July 2020 reminding all owners the importance of this key maintenance item.

As operators of PA46 aircraft we all have the duty to strictly adhere to tire pressure requirements highlighted in the POH and Maintenance Manuals. There is no grey area here. We will be making further written guidance revisions for emphasis in our POH. You also have our commitment to make changes where possible to make it easier to maintain satisfactory tire pressures. These will come via 1) an automated tire pressure monitoring system and 2) easier accessibility to the MLG valve stems. *Note: While not required to safely operate the aircraft, we agree an automated TPMS is a desired improvement.*

Steering and Landing Gear Systems. Next we logically followed the M600 steering and landing gear system aft to gather fleet data and ensure conformity of key landing gear and steering component settings. In August 2020 we issued **SL1286**. This service publication calls for detailed measurements to be taken to ensure primary components remain conformed to the FAA type design. Those parameters included 1) another reminder for tire pressures and added, 2) nose gear rake angle, 3) main gear toe alignment and 4) steering horn roller clearance.

With this data set our focus turned to the steering horn roller and steel backstop pad clearances. We found in some instances, and under certain conditions, the steering horn steel pads (which act as a secondary stop) might make contact with the steering arm instead of the roller. As a result we issued **SB1350** in December 2020. This Service Bulletin called for the inspection of some aircraft to verify steering horn roller to steering arm measurements. It also calls for the replacement of the steering horn, if required. *Note: The WSJ article incorrectly states this SB was issued "less than a week after" our M600 owner letter was sent on February, 4, 2021. No real impact other than implying there was some confusion or uncertainty at Piper. There was none.*

Rudder Pedal Control Rods. More recently, we have examined the rudder pedal control rod length. While all aircraft continued to meet type design standards we found that in general, a slightly shorter (or tighter) control rod length via adjustments to the rod ends result in a more positive rudder pedal engagement, better rudder to pilot feedback and controllability throughout the rudder pedals normal travel range. **SL1286A** issued last month directs these adjustments to the length of the rudder pedal connection arms.

The HALO effect. Long story short, there is none. A key benefit in purchasing the M600SLS is Piper's safety leadership and the rollout of the HALO auto land system. Between Garmin and Piper's development and certification flight testing and now ongoing customer demonstrations, hundreds of fully coupled HALO landings have been executed. These flights have been flown in all crosswinds and varying runway conditions up to the max crosswind component with no runway handling issues. *Note: This fact aligns with a comment made in the WSJ article, "... (HALO) does not appear to have any connection... to any incidents". We agree.*

Factual Summary to Date.

Throughout the reviews, company testing and analysis and NTSB feedback to date, there appears to be one primary constant in these excursions which has been correctly repeated in market forums and in the WSJ article. That is for each event, the aircraft mechanical, pilot operational and environmental parameters were different. As a fellow pilot, this likely comes as no surprise knowing the myriad of both controllable and uncontrollable forces that are in play during any landing sequence. *Note: This aligns with an NTSB quote made in the WSJ article, “We have not identified a single common issue present.” We agree.*

It has also become apparent that M600s are being landed 1) too fast, 2) with low tire pressures and 3) the nose wheel is not being “flown down” as speed decreases. In essence, keeping the nose wheel unloaded for as long as possible. This simple “technique” is taught by Piper approved Legacy Flight Training. It’s also taught by some independent instructors but not all. *Note from a recent forum post: “...the M600 lands much like the DC-9, where it is important to fly the nose gear down to the runway, and not give up on the back pressure until slower airspeeds. Which is precisely the way Legacy (Vero Beach) teaches. I can still hear my instructor, Dave, telling me “once the nose gear settles, bring the yoke back into your lap, don’t relieve the back pressure until you’re slowed down.” We agree.*

The Difficult Conversations and Communications.

This open letter to you is not a difficult communication. Summarizing these facts to ensure transparency and clarity to a valued owner base is easy. The next steps are also easy. If there is an aircraft issue related to these or other runway excursions it will be found. It will be found either via our continuing efforts (which again now include independent third party analysis) or through ongoing NTSB/FAA investigations. That being said, we will continue to improve the aircraft based on our findings. Examples include the aforementioned tightening of the rudder control rods (SL1286A) and our commitment to make available an automated tire pressure sensor capability (initially likely app based).

What is difficult is balancing the market conversation between fact, rumor, innuendo and posturing. Or in the case of some statements in the WSJ article just a lot of nothing. Those include:

- *Pilots involved in **some** of the accidents..... concern about **potential** problems...*
- *An **informal** group of M600 pilots.....**appears** to be a nose gear problem...*
- *....while **people familiar with the matter** said FAA is considering mandatory safety directives...*

Also difficult is how to delicately address a key point in the WSJ article quoting a seasoned military pilot. That individual painted a dark picture of the aircraft in general and a landing he flew as PIC in the 2,331st manufactured PA46 aforementioned in excursion #3. What the pilot may not have known is that the landing in question was likely executed with a broken steering horn that might have been prevented if published tow limit guidelines and/or a proper preflight inspection had been followed. That is a difficult communication.

Truth, OEM Responsibility and Accountability are Wonderful Things.

Piper and Piper alone is responsible to ensure all aircraft leaving our factory meet FAA approved type design standards. We are also obligated to ensure that, if at any time through internal review, supplier discovery or federal agency investigation, we become aware of a known safety of flight issue, we must take action. These accepted OEM responsibilities are the foundation of our industry.

Right now there is no known M600 runway handling or manufacturing deficiency. As indicated earlier, if one is discovered it will immediately be communicated and fixed. In the meantime, thousands of hours of Piper analysis and flight tests have been invested to ensure all safety margins remain intact. As we learn more, we will continue to improve the handling characteristics and update systems to make it easier to operate and ensure conformity.

As an OEM, the NTSB asks us to not comment in detail, about ongoing investigations. However, if we don't provide some basic information in a timely fashion, the marketplace narrative leads to speculation and inaccurate facts. Some forum posts related to these recent M600 runway excursions and some areas within the associated WSJ article clearly leaned in that very direction. No general aviation manufacturer would ever benefit from hiding something or acting in a manner where safety is not the primary objective. This communication is intended to provide you, the customer, with a basic level of critical information while still maintaining the confidentiality of the ongoing investigations as requested by the NTSB.

You will remember a recent Piper example of always taking the side of safety. In the summer of 2017, Piper discovered a supplier of the M600s aft wing spar may have delivered non-conforming components. With an abundance of caution, and without any prompting by the FAA or any other regulatory body, Piper immediately issued mandatory SB1317 to temporarily ground the entire M600 fleet the opening day of EAA until we could determine the effect this component had on operational safety. It was the right thing to do and therefore an easy decision to make. It was a fact based, voluntary fleet grounding we believe every OEM would make. It also reflects the inherent safety culture within Piper and our industry as a whole. We were acknowledged by you, our customers for doing so and that same day we sold a new M600 at the event because of the trust resulting from that proactive, safety-based decision.

Those same clear, factual parameters are not in place with these runway excursions. Again, what is emerging (and it's worth repeating) is it appears M600s are landing 1) too fast, 2) with low tire pressures and 3) the nose wheel is not being "flown down" as speed decreases keeping the nose wheel unloaded as taught via a Piper approved M600 training provider.

Going Forward, Fly it by the Book. Enjoy an Amazing Aircraft. More to Come.

You purchased your PA46 confident in the safety and high performance reputation of the aircraft and our company. Our commitment to all Piper owners is unwavering.

While these aircraft are not difficult to fly, like many HP models they must be flown and maintained by the book. There can be no "normalization of deviation" versus what's called for in the POH either operationally or within training curriculums throughout the training supplier landscape. We will be taking a more active role in the future regarding training standardization, authorization and disseminate aircraft operational information / videos etc. to ensure that happens.

The aircraft you fly today, whether it be a 1985 Malibu or a 2021 M600SLS is the same aircraft we fly with our families every day both here at the factory and at our Piper dealer partners. We fly new, and we fly not so new, but all are in the same configurations as yours.

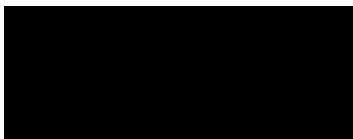
At the end of last year 2,406 Piper PA46 aircraft had been delivered in total since 1984. Today it remains our most important model. The PA46 is Piper's King Air®. The PA46 is Piper's Citation®¹. You have trusted this airframe and Piper with your family's safety for over six million flight hours. In 2020 alone, 45 new M600SLS aircraft were delivered to new owners, the highest retail rate since introduction in 2016.

Piper's ownership is strong and allows us to invest every dollar we make into product reliability, safety and new model initiatives. The M600 and Piper being the first OEM with a certified, HALO autoland system is a testament to their commitment and support.

The PA46 in general and in particular the latest HALO equipped M600SLS as yet another derivative PA46 model are all remarkable aircraft, worthy of a GA Hall of Fame. Fly them, enjoy them and use them as intended while looking to the future, because there is more to come.

On behalf of the 1,300 Piper Aircraft and Piper Dealer Network employees and our families we thank you for your business, your loyalty and your trust – all of which we know must be earned.

Sincerely,




 Vice President – Sales, Marketing and Customer Support



Note: We have set up a new email address: pa46owners@piper.com. We encourage you to use this confidential address to ask us any questions, tell us your thoughts or pass to us any information regarding this subject. It is monitored by a cross functional factory team including Engineering, Customer Support, Marketing and Executive Leadership.

Additionally, if you have any immediate questions or concerns regarding your aircraft, please feel free to contact me,  – Director Global Customer Support , or your Regional Authorized Piper Dealer or Service center.

¹ King Air and Citation are registered trademarks of Textron Corporation

APPENDIX B

NTSB surveys of M600 pilots and instructors

NTSB M600 pilot survey

Pilot Questions re: PA-46 M600 Ground Handling

INSTRUCTIONS

Thank you for taking the time to consider and reply to this questionnaire. Your responses will help the NTSB in its investigations of a number of events during which Piper PA-46 M600 airplanes suddenly veered to the right and departed the runway after landing.

Please respond to any / all of the questions (as you see fit) electronically using Microsoft *Word*. You can type in your responses immediately below the questions where asked, or you can type them in additional pages following the questions. If you choose the latter, please indicate the question number you are responding to in the response. Many of the questions are similar, so feel free to combine your responses if desired.

PILOT INFO

Your total flight time, time in M600, recent time (hours in the last 3 months):
(Optional) Your name and contact info (please indicate if it is OK to follow up with you):

OPEN-ENDED QUESTIONS RE: IMPRESSIONS OF M600 AIRPLANE

1. Please describe your impressions of the flight control characteristics of the airplane, both in general and during takeoff / landing in particular.
2. Are there any notable handling quality differences between this airplane and other models that you've flown? Please describe.
3. Anything of note in the pitch axis?
4. Anything of note in the roll axis?
5. Anything of note in the yaw axis?
6. Anything of note with power increases or power reductions?
7. Please describe your impressions of the airplane's braking abilities.
8. What do you think of the control forces in each axis required to operate this airplane as compared to other models?
9. Regarding ground handling qualities specifically, are there any notable differences between this airplane and other models that you've flown? Please describe.
10. There appear to be discussions in the pilot community regarding the behavior of the M600 nose wheel steering. Are you aware of these discussions? What do you make of them?
11. How would you describe the nose wheel steering on the M600 compared to other models you've flown?
12. Any other remarks re: the M600 nose wheel steering, or its evolutions / changes over the years?
13. Describe your crosswind landing technique.
14. Does your technique depend on the airplane you're flying? Explain.
15. Do you favor wing-low / sideslip crosswind landing approach, or a crabbed crosswind landing approach? Why?
16. Describe your crosswind takeoff technique.
17. Describe your use of pitch control (column) during normal and crosswind takeoffs and landings.

18. When rolling down the runway during takeoff prior to rotation, do you favor a generally forward, neutral, or aft column? Why?
19. During the landing roll after touchdown, do you favor a generally forward, neutral, or aft column? Why?
20. Have you ever experienced, or seen another pilot experience, a veer or momentary loss of directional control during the takeoff or landing roll in the M600? If so, please explain.
21. In your experience, which areas required particular attention as you transitioned / moved up to the M600? Any particular challenges?
22. When you were trained on the M600, was the ground handling of the airplane a distinct "item" in the training syllabus, or receive particular attention? If so, please explain.

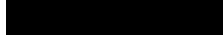
GENERAL

23. Please note anything else you would like to say about the M600 airplane (and its ground handling characteristics in particular), that you think the NTSB should consider during its investigations of the runway departure events.

SUBMISSION OF COMPLETED QUESTIONNAIRE

Please email the completed questionnaire to:

John O'Callaghan



NTSB M600 instructor pilot survey

Flight Instructor Questions re: PA-46 M600 Ground Handling

INSTRUCTIONS

Thank you for taking the time to consider and reply to this questionnaire. Your responses will help the NTSB in its investigations of a number of events during which Piper PA-46 M600 airplanes suddenly veered to the right and departed the runway after landing.

Please respond to any / all of the questions (as you see fit) electronically using Microsoft *Word*. You can type in your responses immediately below the questions where asked, or you can type them in additional pages following the questions. If you choose the latter, please indicate the question number you are responding to in the response. Many of the questions are similar, so feel free to combine your responses if desired.

INSTRUCTOR INFO

Your total flight time, time in M600, recent time (hours in the last 3 months):

Your time instructing in M600:

(Optional) Your name and contact info (please indicate if it is OK to follow up with you):

OPEN-ENDED QUESTIONS RE: IMPRESSIONS OF M600 AIRPLANE

1. Please describe your impressions of the flight control characteristics of the airplane, both in general and during takeoff / landing in particular.
2. Are there any notable handling quality differences between this airplane and other models that you've flown? Please describe.
3. Anything of note in the pitch axis?
4. Anything of note in the roll axis?
5. Anything of note in the yaw axis?
6. Anything of note with power increases or power reductions?
7. Please describe your impressions of the airplane's braking abilities.
8. What do you think of the control forces in each axis required to operate this airplane as compared to other models?
9. Regarding ground handling qualities specifically, are there any notable differences between this airplane and other models that you've flown? Please describe.
10. There appear to be discussions in the pilot community regarding the behavior of the M600 nose wheel steering. Are you aware of these discussions? What do you make of them?
11. How would you describe the nose wheel steering on the M600 compared to other models you've flown?
12. Any other remarks re: the M600 nose wheel steering, or its evolutions / changes over the years?
13. Describe your crosswind landing technique (and what you teach students).
14. Does your technique depend on the airplane you're flying? Explain.
15. Do you favor wing-low / sideslip crosswind landing approach, or a crabbed crosswind landing approach? Why?
16. Describe your crosswind takeoff technique (and what you teach students).
17. Describe your use of pitch control (column) during normal and crosswind takeoffs and landings.

18. When rolling down the runway during takeoff prior to rotation, do you favor a generally forward, neutral, or aft column? Why?
19. During the landing roll after touchdown, do you favor a generally forward, neutral, or aft column? Why?
20. Have you ever experienced, or seen a trainee experience, a veer or momentary loss of directional control during the takeoff or landing roll in the M600? If so, please explain.

OPEN-ENDED QUESTIONS RE: TRAINEE BACKGROUNDS / EXPERIENCES / CHALLENGES

21. About how many pilots have you trained in the M600?
22. Please describe the range of backgrounds and experience levels of these pilots (previous models flown, number of hours, etc.)
23. Have you observed any areas that require particular attention for pilots who are transitioning to the M600? Any common challenges?
24. For a typical pilot transitioning to the M600, what area / aspect of the airplane requires the most training time?
25. In general, do pilots transitioning to the M600 need to develop or refine any additional stick-and-rudder skills to be proficient in the airplane? If so, please explain.
26. In general, have you observed that the ground handling characteristics of the M600 require particular attention during pilot training? If so, please explain.
27. In general, have you observed that transitioning pilots find the ground handling of the M600 “different” from other airplanes they’ve flown, and need to adapt to or “get used to” the characteristics of the M600? If so, please explain.
28. In general, have pilots commented on the M600 ground handling / nose wheel steering during training? If so, please describe the nature of these comments.
29. Is the ground handling of the airplane a distinct “item” in the M600 training syllabus? If so, please explain.

GENERAL

30. Please note anything else you would like to say about the M600 airplane (and its ground handling characteristics in particular), that you think the NTSB should consider during its investigations of the runway departure events.

SUBMISSION OF COMPLETED QUESTIONNAIRE

Please email the completed questionnaire to:

John O'Callaghan



Completed survey: Instructor 1

Flight Instructor Questions re: PA-46 M600 Ground Handling

INSTRUCTIONS

Thank you for taking the time to consider and reply to this questionnaire. Your responses will help the NTSB in its investigations of a number of events during which Piper PA-46 M600 airplanes suddenly veered to the right and departed the runway after landing.

Please respond to any / all of the questions (as you see fit) electronically using Microsoft *Word*. You can type in your responses immediately below the questions where asked, or you can type them in additional pages following the questions. If you choose the latter, please indicate the question number you are responding to in the response. Many of the questions are similar, so feel free to combine your responses if desired.

INSTRUCTOR INFO

Your total flight time, time in M600, recent time (hours in the last 3 months): **4750 total time, 160 in M600, none in the last 3 months.**

Your time instructing in M600: **140**

(Optional) Your name and contact info (please indicate if it is OK to follow up with you): [REDACTED]

OPEN-ENDED QUESTIONS RE: IMPRESSIONS OF M600 AIRPLANE

1. Please describe your impressions of the flight control characteristics of the airplane, both in general and during takeoff / landing in particular. **Well harmonized overall.**
2. Are there any notable handling quality differences between this airplane and other models that you've flown? **None** Please describe.
3. Anything of note in the pitch axis? **Stable**
4. Anything of note in the roll axis? **Slow but stable**
5. Anything of note in the yaw axis? **Always better with the yaw damper on**
6. Anything of note with power increases or power reductions? **No**
7. Please describe your impressions of the airplane's braking abilities. **Good**
8. What do you think of the control forces in each axis required to operate this airplane as compared to other models? **Similar**
9. Regarding ground handling qualities specifically, are there any notable differences between this airplane and other models that you've flown? **No, longer wing but that is not an issue.** Please describe.
10. There appear to be discussions in the pilot community regarding the behavior of the M600 nose wheel steering. Are you aware of these discussions? What do you make of them? **I'm aware of those discussions. Most of those discussions are based on ignorance.**
11. How would you describe the nose wheel steering on the M600 compared to other models you've flown? **Potentially problematic due to the turning of the nose wheel with rudder**
12. Any other remarks re: the M600 nose wheel steering, or its evolutions / changes over the years? **No**
13. Describe your crosswind landing technique (and what you teach students). **Fly the crab into the flare, then bring in rudder to land**
14. Does your technique depend on the airplane you're flying? Explain. **Not really**

15. Do you favor wing-low / sideslip crosswind landing approach, or a crabbed crosswind landing approach? **As mentioned, crabbed.** Why? **I see little use in correcting for winds using rudder when at altitude above the runway. Winds will change as the plane descends into the flair and as airspeed is reduced. To start crosswind adjustments at altitude simply increases workload at a critical phase of flight.**
16. Describe your crosswind takeoff technique (and what you teach students). **See #13**
17. Describe your use of pitch control (column) during normal and crosswind takeoffs and landings. **Back pressure is needed as the aircraft approaches liftoff (along with correct trim), rudder is used to keep nose aligned with the runway. On landing, pitch should be such that the nose wheel is kept off the runway on touchdown and the nose wheel should be held off as long as practical.**
18. When rolling down the runway during takeoff prior to rotation, do you favor a generally forward, neutral, or aft column? **Slight aft.** Why? **See #17**
19. During the landing roll after touchdown, do you favor a generally forward, neutral, or aft column? **Slightly aft until nosewheel touchdown** Why? **Keep nosewheel off**
20. Have you ever experienced, or seen a trainee experience, a veer or momentary loss of directional control during the takeoff or landing roll in the M600? **Yes.** If so, please explain. **Teaching in a 2020 model (new from the factory), we had a near excursion on landing at one point. No obvious reason for it. Cross winds were light. When nose wheel touched the runway the aircraft veered hard left. Immediate right rudder was applied to correct. We were in Roswell NM with a very wide runway. Had the runway been more narrow, we would have departed the runway. This occurred before any Piper service bulletins were issued on the M600 related to the nosewheel.**

OPEN-ENDED QUESTIONS RE: TRAINEE BACKGROUNDS / EXPERIENCES / CHALLENGES

21. About how many pilots have you trained in the M600? **2**
22. Please describe the range of backgrounds and experience levels of these pilots (previous models flown, number of hours, etc.) **Both low time middle aged pilots**
23. Have you observed any areas that require particular attention for pilots who are transitioning to the M600? **Not really.** Any common challenges? **No**
24. For a typical pilot transitioning to the M600, what area / aspect of the airplane requires the most training time? **Getting into the front seats. Ha. Seriously, the G3000 is a terrific system, but does take some extra time especially as it relates to all the automation involved.**
25. In general, do pilots transitioning to the M600 need to develop or refine any additional stick-and-rudder skills to be proficient in the airplane? **Not really.** If so, please explain.
26. In general, have you observed that the ground handling characteristics of the M600 require particular attention during pilot training? **No, except to be aware of the long wing.** If so, please explain.
27. In general, have you observed that transitioning pilots find the ground handling of the M600 “different” from other airplanes they’ve flown, and need to adapt to or “get used to” the characteristics of the M600? **No** If so, please explain.
28. In general, have pilots commented on the M600 ground handling / nose wheel steering during training? **No** If so, please describe the nature of these comments.
29. Is the ground handling of the airplane a distinct “item” in the M600 training syllabus? **No more so than any other syllabus.** If so, please explain.

GENERAL

30. Please note anything else you would like to say about the M600 airplane (and its ground handling characteristics in particular), that you think the NTSB should consider during its investigations of the runway departure events.

Based on my limited knowledge, I think Piper had (past tense) an engineering issue with the nose wheel, hence the service bulletins, etc. It appears to me it may be something as simple as the additional weights of the M600 over the Mirage/Meridians. The higher weights may have been a bit much for the existing nose wheel system. Piper addressed this with at least one service bulletin. In summary, I would have no problem instruction in (or owning if had the financial assets) any M600/700 that had completed Piper's service bulletins. I have a lot of time in a Piper Dakota (PA32-236) and it has a similar nose wheel function in that the nose wheel turns with the rudder. I know of no major problems in that aircraft. Overall, Piper needed to modify (via service bulletin) the nose wheel system and did so. To my knowledge, this has significantly improved the problem and may have eliminated it altogether. That said, pilots will continue to have difficulty with cross wind landings. It's a common issue related to bent metal in all types of aircraft. At present, with proper instruction, I don't feel the M600/700 types are any more prone to trouble in that area than any other particular aircraft.

SUBMISSION OF COMPLETED QUESTIONNAIRE

Please email the completed questionnaire to:

John O'Callaghan



Completed survey: Instructor 2

30 October 2024

From: [REDACTED], ATP, CFII, Master Instructor

Flight Instructor Questions re: PA-46 M600 Ground Handling

INSTRUCTIONS

Thank you for taking the time to consider and reply to this questionnaire. Your responses will help the NTSB in its investigations of a number of events during which Piper PA-46 M600 airplanes suddenly veered to the right and departed the runway after landing.

Please respond to any / all of the questions (as you see fit) electronically using Microsoft *Word*. You can type in your responses immediately below the questions where asked, or you can type them in additional pages following the questions. If you choose the latter, please indicate the question number you are responding to in the response. Many of the questions are similar, so feel free to combine your responses if desired.

INSTRUCTOR INFO

Your total flight time, time in M600: 700 hrs

recent time (hours in the last 3 months): 25 hrs

Your time instructing in M600: 700 hrs

All PA46 Aircraft: 11,000 hrs

(Optional) Your name and contact info (please indicate if it is OK to follow up with you):

[REDACTED]

[REDACTED]

[REDACTED]

[REDACTED]

[REDACTED]

OPEN-ENDED QUESTIONS RE: IMPRESSIONS OF M600 AIRPLANE

1. Please describe your impressions of the flight control characteristics of the airplane, both in general and during takeoff / landing in particular.

I have no difficulty controlling the PA 46 aircraft. The M600 is slightly heavier and less likely to be over controlled, but it appears it is still possible.

2. Are there any notable handling quality differences between this airplane and other models that you've flown? Please describe.

The last 11,000 hours in my logbook are PA 46 hours, so it will be difficult for me to compare with other types of aircraft. Within the make model, I find the M 600 to be slightly heavier and easier to control when using proper technique.

3. Anything of note in the pitch axis? No.
4. Anything of note in the roll axis? No.
5. Anything of note in the yaw axis? No.
6. Anything of note with power increases or power reductions? No.
7. Please describe your impressions of the airplane's braking abilities.

Braking with the PA46 is easy safe and reliable when using proper specific techniques. I note with interest that my observation of pilots flying these aircraft is that very few take advantage of these ironclad techniques.

Specifically, the pilot needs to keep his or her feet off the top of the rudder pedals during rotation and de rotation. During the landing, Before lowering the nose, the rudder pedals need to be centered to ensure

that the nose wheel is centered. This is critical. Then the toes come up to the top of the rudder pedals. Firm pressure is then applied to the brakes accompanied by back pressure on the elevator. Without back pressure on the elevator, excessive coefficient of friction exists on the nose tire. If there is any abrupt steer on the nose tire, it will be impossible to correct without pressure.

I am unaware of any any other other flight Instructor insisting on this technique.

8. What do you think of the control forces in each axis required to operate this airplane as compared to other models?

All PA 46 aircraft are essentially the same in this regard.

9. Regarding ground handling qualities specifically, are there any notable differences between this airplane and other models that you've flown? Please describe.

Not among PA 46 aircraft. As stated earlier, the vast majority of my flight time is PA 46 instruction given. See my answer to question number seven above.

10. There appear to be discussions in the pilot community regarding the behavior of the M600 nose wheel steering. Are you aware of these discussions? What do you make of them? Yes, I am aware of these

discussions and I am more than a little concerned. The Instructor community needs to understand the concepts and teach the proper techniques.

11. How would you describe the nose wheel steering on the M600 compared to other models you've flown? It feels better because it's heavier. My concern is proper technique is often not being taught.
12. Any other remarks re: the M600 nose wheel steering, or its evolutions / changes over the years? Once the aircraft goes out of warranty, there seems to be an increase of these kinds of issues. Mainly, I think due to deferred maintenance and a willingness to use mechanics that aren't specifically trained and familiar with the PA 46.
13. Describe your crosswind landing technique (and what you teach students). I don't teach student pilots anymore. I train specifically rated and current pilots transitioning to the PA 46, all variants. Many of these pilots have never completely mastered the art of landing. I observe that greater stability is available to the pilot when holding the crosswind crab to the flare. Align the aircraft with the centerline and lower the upwind tire. Once the upwind main tire contacts the ground, the pilot must be patient and allow the downwind main tire to touch on its own; And then just one word "Center the pedals and lower the nose"

Keep firm pressure on the bottom of both Rudders to obviate oscillation until the roll out line is stable; then toes up on the brakes. Balance the brake pressure with elevator back pressure to keep the weight even on all 3 tires.

14. Does your technique depend on the airplane you're flying? Explain. I only train pilots in PA 46 aircraft and so no in this regard they're all the same.

I think this will work for all tricycle gear aircraft however, I don't know because I only teach in the PA46 which is somewhat sensitive to over control.

15. Do you favor wing-low / sideslip crosswind landing approach, or a crabbed crosswind landing approach? Why? High Performance Aircraft instructors should be teaching the Crab method. It is easier and therefore more likely to be done more consistently.

16. Describe your crosswind takeoff technique (and what you teach students). It is essentially the reverse of the landing method. Rotating at a consistent speed is critical.

17. Describe your use of pitch control (column) during normal and crosswind takeoffs and landings.

See the answer to question 18.

18. When rolling down the runway during takeoff prior to rotation, do you favor a generally forward, neutral, or aft column? Why? in the M600, the pitch and Rudder trims must be set on the green peg or the pilot will receive a red CAS message. this position produces a very favorable neutral attitude. The aircraft is not likely to rotate early, but vigilance is important.
19. During the landing roll after touchdown, do you favor a generally forward, neutral, or aft column? Why? Neutral, because the coefficient of friction on the tires are what directly affects braking and steering effectiveness.
20. Have you ever experienced, or seen a trainee experience, a veer or momentary loss of directional control during the takeoff or landing roll in the M600? If so, please explain. Yes. Even experienced pilots can have issues with this if they're not thinking about their landing technique, practiced, and on their game. This aircraft is not a trainer.

OPEN-ENDED QUESTIONS RE: TRAINEE BACKGROUNDS / EXPERIENCES / CHALLENGES

21. About how many pilots have you trained in the M600? I estimate 70 or so .. All PA46: Thousands, full-time over 27 years all over the world.

22. Please describe the range of backgrounds and experience levels of these pilots (previous models flown, number of hours, etc.) every level of experience that you can imagine from 50 hour privates with no instrument rating to pilots with professional and military experience with 10,000s of hours.
23. Have you observed any areas that require particular attention for pilots who are transitioning to the M600? Any common challenges? Landing and takeoff techniques.
24. For a typical pilot transitioning to the M600, what area / aspect of the airplane requires the most training time? Whether avoidance, rain showers, thunderstorms, and airframe ice. These are the killers.
25. In general, do pilots transitioning to the M600 need to develop or refine any additional stick-and-rudder skills to be proficient in the airplane? If so, please explain. Yes, most need to get the techniques right.
26. In general, have you observed that the ground handling characteristics of the M600 require particular attention during pilot training? If so, please explain. Yes, very much so; and it is the techniques that I've outlined above that are most important.

27. In general, have you observed that transitioning pilots find the ground handling of the M600 “different” from other airplanes they’ve flown, and need to adapt to or “get used to” the characteristics of the M600? If so, please explain. This depends on the pilots background, of course. In many cases, the PA 46 is the fastest airplane they have ever flown. This pilot needs more training than someone transitioning from a slower aircraft.
28. In general, have pilots commented on the M600 ground handling / nose wheel steering during training? If so, please describe the nature of these comments. These comments tend to come from pilots who trained elsewhere. If I get the Pilot for his initial training, I can get the correct techniques across early and it doesn’t seem to be a problem.
29. Is the ground handling of the airplane a distinct “item” in the M600 training syllabus? If so, please explain. Yes it is discussed specifically and it’s because the pilot generally comes to me without knowing the proper techniques.

GENERAL

30. Please note anything else you would like to say about the M600 airplane (and its ground handling characteristics in particular), that you think the NTSB should consider during its investigations of the runway departure events.

I would very much appreciate a recommendation from the NTSB to the insurance industry to insist that the instructors in these aircraft are properly trained as type specific instructors. I offer such a program.

SUBMISSION OF COMPLETED QUESTIONNAIRE

Please email the completed questionnaire to:

John O'Callaghan

