Brake Hose Performance on Harley-Davidson (H-D) Motorcycles

6/7/2023

By Bryan Fulmer

Principal Engineer – Product Integrity

Harley-Davidson Motor Company

Agenda

Introductions

H-D Technical Investigation Process

Brief Chronology

FMVSS areas of concern

- Whip and wet whip
- Pressure hold
  - Brake fluid compatibility (BFC)
  - High temperature impulse (HTI)
  - Burst
- Tensile
- Constriction

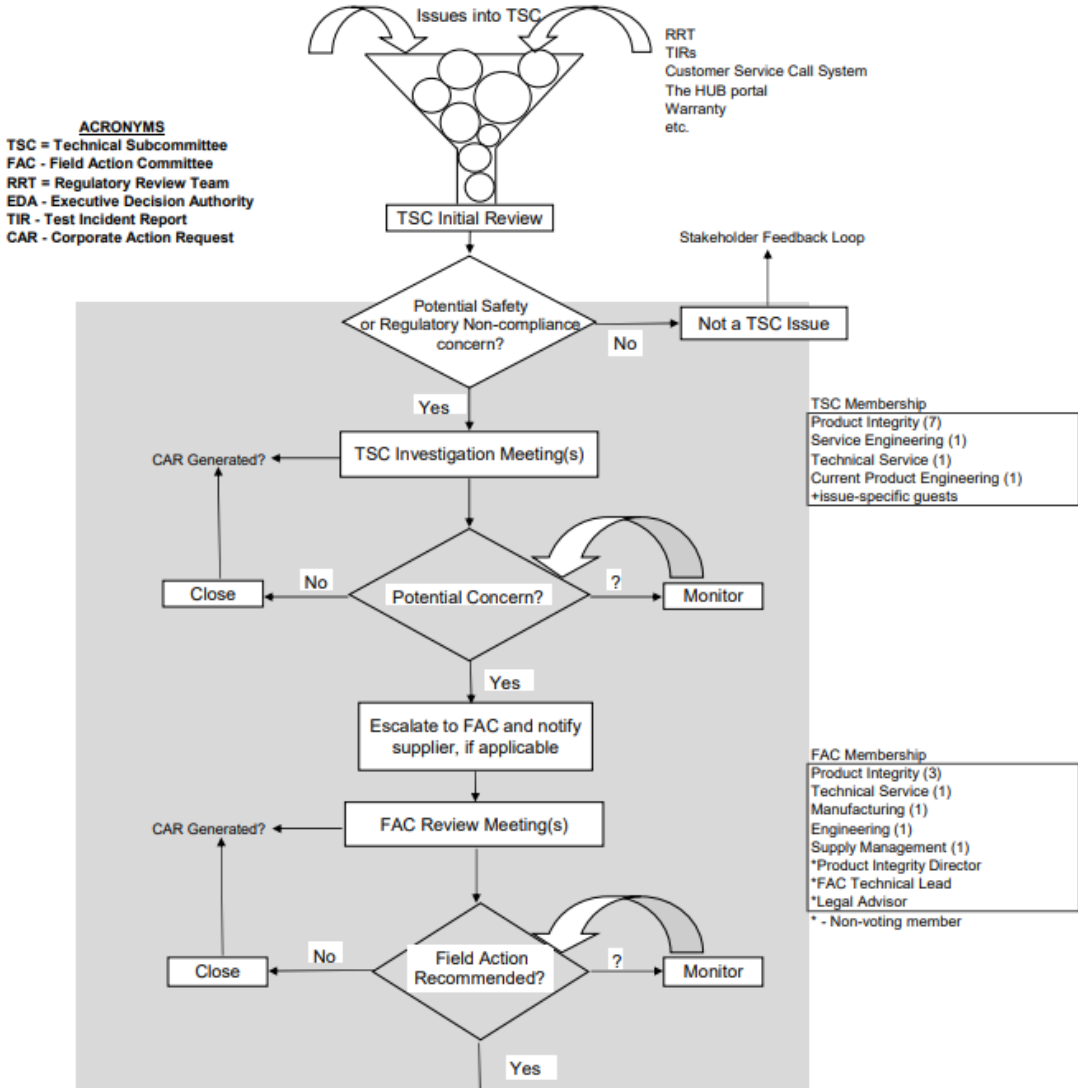
Inconsequentiality Petition

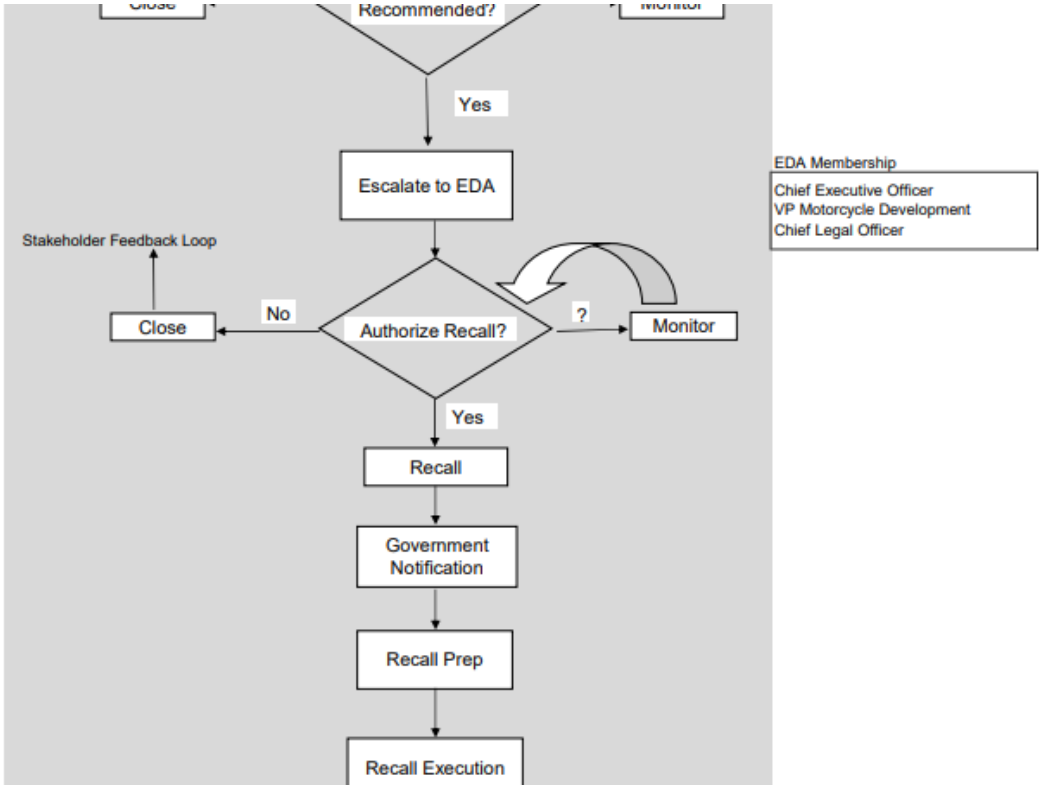
- Laboratory and Proving Ground Testing
- Field performance

H-D Assessment

Discussion

Harley-Davidson Technical Investigation Process





Chronology

May 2022 – H-D is notified of “potential quality issues” and begins investigation, which includes multiple production stoppages.

July 2022 – Aug 2022 - HCA and H-D submit initial 573 noncompliance reports. Affected population 3,156 (2022 models).

PVC – FMVSS 106 **Whip and Wet Whip** noncompliances

1 Nylon – FMVSS 106 **Brake Fluid Compatibility (BFC) and High Temperature Impulse (HTI)** noncompliances

Aug 2022 – Sept 2022 - HCA and H-D file Petitions for Determination of Inconsequential Noncompliances.

Sept 2022 – Dec 2022 – HCA and H-D amend initial 573 noncompliance reports. Affected population 1,527,260 (2008-2022 models).

PVC – FMVSS 106 Whip and Wet Whip noncompliances

2 Nylon – FMVSS 106 BFC, HTI, **Whip and Wet Whip** noncompliances

Nov 2022 – Dec 2022 - HCA and H-D file Supplemental Petitions for Determination of Inconsequential Noncompliances.

Mar 2023 – May 2023 - HCA and H-D further amend 573 noncompliance reports. Affected population 1,6M* (2008-2022 models).

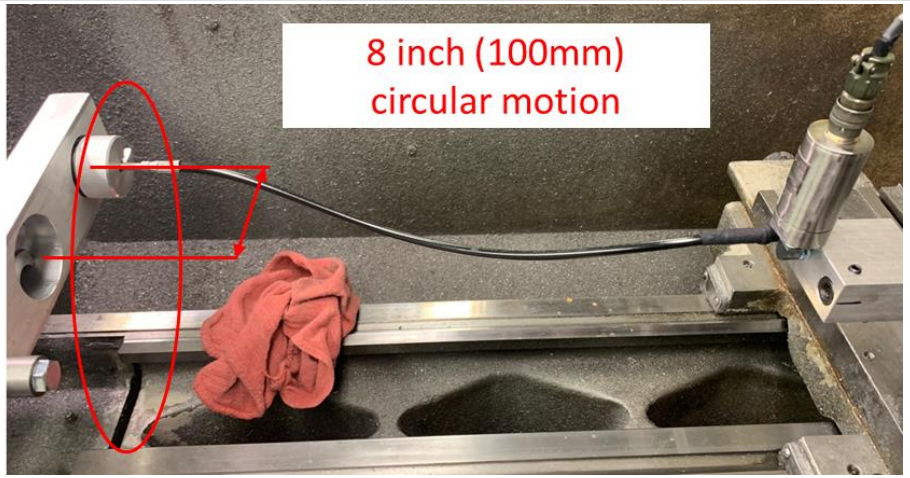
PVC – FMVSS 106 Whip, Wet Whip, **Tensile, Burst, HTI, and Constriction** noncompliances

3 Nylon – FMVSS 106 BFC, HTI, Whip, Wet Whip, and **Constriction** noncompliances

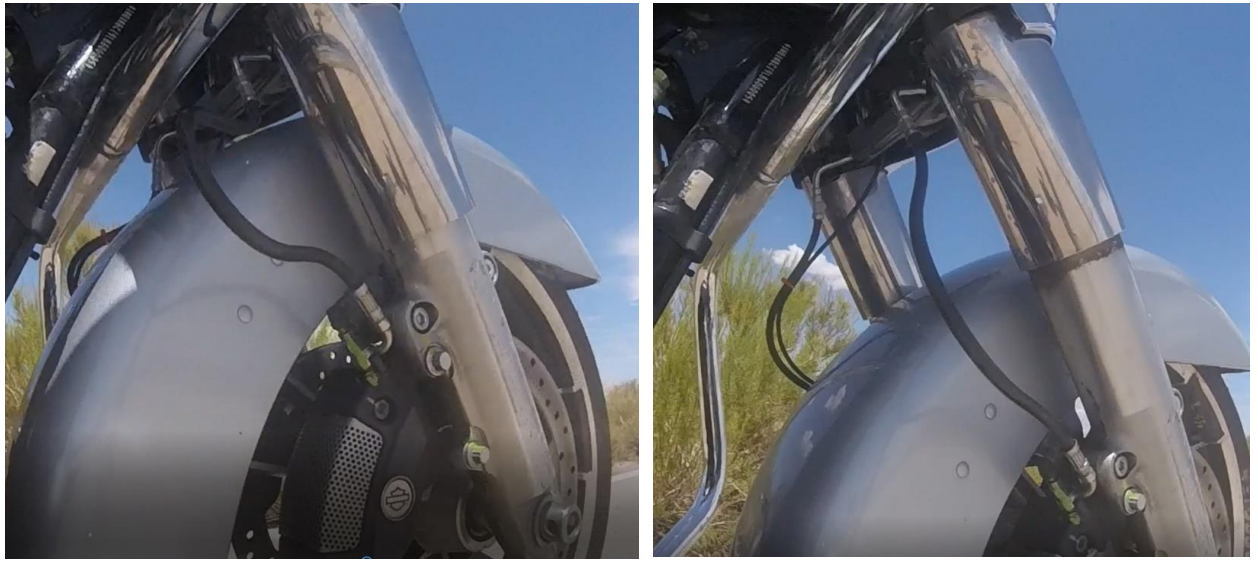
April 2023 – June 2023 - HCA and H-D file Second Supplemental Petitions for Determination of Inconsequential Noncompliances.

WHIP - Background (Technical Report in Support of Inc. Petition (Original Report), pp. 2, 17-22)

- FMVSS106 Whip test is intended to confirm the brake hose assembly (BHA) is resistant to dynamic fatigue
- Whip test generates stress in the BHA through circular motion
- H-D motorcycles generate stress in the BHA through telescopic motion of the front suspension
- HCA's variable results were caused by fatigue inputs not seen in H-D applications
    - Whip test is equivalent to 700 motorcycle lifetimes of accumulated stress in the BHA



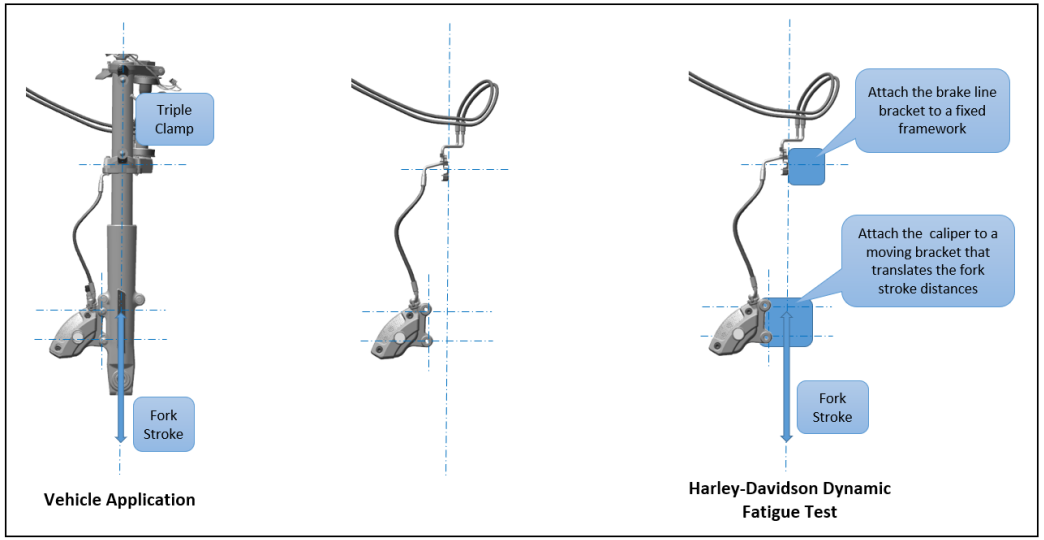
FMVSS106 Whip Test (800 rpm for 35 hours)



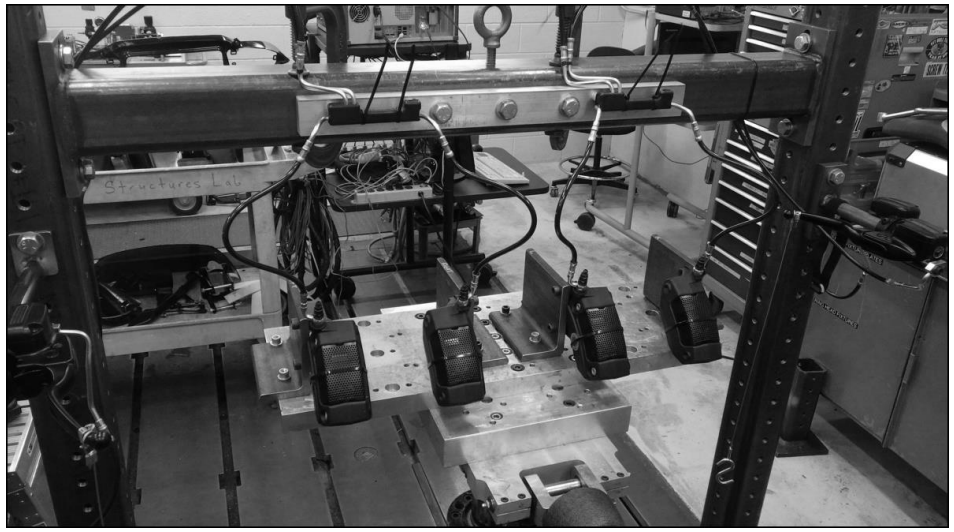
Telescopic motion of Harley-Davidson motorcycles

WHIP - H-D Testing (Original Report, pp. 10-16)

- H-D developed a dynamic fatigue test to expose the BHAs to repeated stroke of the front suspension
    - Duty cycles were created that correlate to one vehicle lifetime for a 95th-percentile customer over 10 years (118,720 miles) based on H-D's proprietary customer correlation data
    - This duty cycle was repeated **10X** on each BHA sample
- BHAs from the population identified by HCA as noncompliant successfully demonstrated fatigue failure resistance when subjected to repetitive single-axis telescoping motion expected for 10 lifetimes of H-D customer usage



Harley-Davidson Dynamic Fatigue Test set-up schematic



Actual test setup with four PVC brake hose assemblies Installed

Pressure Hold - Background (Original Report, pp. 1, 3-5)

- HCA pressure test failures occurred during the 4000 psi, 2-minute hold portions of the various FMVSS106 tests
- H-D maximum braking pressures are far below 4000 psi
  - Max. measured = 3380 psi (static, all weight on pedal)
  - Typical braking pressures rarely exceed 600 psi
- In H-D applications, most braking pressure levels are maintained or held for relatively short periods of time
  - Also, braking pressures which are held for longer periods of time are at lower pressure levels
- Combination of the exposure temperatures, hold test pressures, and hold test times specified in BFC, constriction, burst strength, and HTI tests are never seen in H-D application

		With 200lb rider, no additional ballast	
Application	**Braking Input**	**Pressure (psi) at 0.4g decel**	**Pressure (psi) at 0.5g decel**
Trike	Front only	210	271
Trike	Rear only	339	449
Pan America	Front only	181	270
Pan America	Rear only	562	decel not achievable due to tire lock
XL Sportster	Front only	243	305
XL Sportster	Rear only	619	decel not achievable due to tire lock
Touring	Front only	190	228
Touring	Rear only	351	474
Nightster	Front only	286	380
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Typical braking pressure on Harley-Davidson motorcycles

	Event Duration (sec)																		
Pressure (psi)	**< .25 Sec**	**.25 to .5 Sec**	**.5 to .75 Sec**	**.75 to 1 Sec**	**1 to 1.5 Sec**	**1.5 to 2 Sec**	**2 to 2.5 Sec**	**2.5 to 3 Sec**	**3 to 3.5 Sec**	**3.5 to 4 Sec**	**4 to 4.5 Sec**	**4.5 to 5 Sec**	**5 to 6 Sec**	**6 to 7 Sec**	**7 to 8 Sec**	**8 to 9 Sec**	**9 to 10 Sec**	**>10 Sec**
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>500	194	11	5	6	17	20	22	7	6	5	5	0	3	1	0	0	0	0
>1000	317	21	16	9	14	13	6	4	3	2	0	0	0	0	0	0	0	0
>1500	127	7	3	1	2	0	0	0	0	0	0	0	0	0	0	0	0	0
>2000	12	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

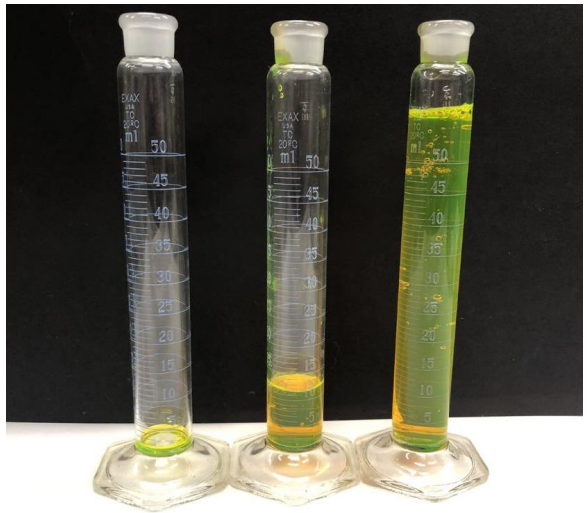
Braking pressures and times on highest pressure application with "heavy-footed" rear brake rider

Pressure Hold - Testing (Original Report, pp. 6-9; Supp. Report, pp. 2-4; 2nd Supp. Report, pp. 2, 15)

- BHAs with greatest wetness from HTI testing were installed on H-D motorcycles with the worst-case, highest brake pressure and passed FMVSS122 certification testing, w/ no leaking observed and no performance issues
- H-D also developed an accelerated, 3X life, duty cycle for BHAs, exposing to theoretical maximum pressures and temperatures measured on H-D motorcycles at issue
  - 38 of the 38 Nylon BHAs completed 2X life duty cycles without any observable wetness
  - 2 of the 38 developed small leaks during the third life cycle with a fluid loss total of 0.1ml and 0.21ml
    - Smallest usable master cylinder reserve volume for all subject motorcycles is 11.4 mL (Slow failure mode detectable by rider/technician)
  - 6 of 6 PVC brake hose assemblies completed the duty cycle without any observable wetness

Test Parameter	Test Parameter Value	Test Parameter Values Justification	Maximum Value Observed on Motorcycle	Motorcycle Application for Maximum Value
Extreme Braking Pressure	3550 psi (100 cycles)	Brake components proof pressure	3380 psi	Revolution Max rear brake static
ABS Event Pressure	2680 psi (3540 cycles)	Conservative pressure during ABS Event	2220 psi	Revolution Max rear brake pressure data collection
Pressure Hold Times	2.5 seconds	ABS hi mu ABS event duration	Vast majority under 2.5 seconds	Revolution Max rear brake pressure data collection
Temperature	248°F	Internal brake hose engineering guideline	244°F	Trike vehicle hot test

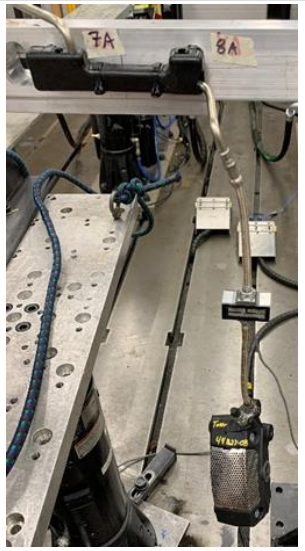
Test parameters of the Harley-Davidson Brake Hose Assembly Duty Cycle



0.21 mL (left), minimum 11.4 mL usable reserve (middle), and the maximum 57.0 mL usable reserve (right)

Tensile - Background and H-D Application (2nd Supp. Report, pp. 2, 12-14)

- HCA reported that certain PVC BHAs are non-compliant with FMVSS106 Tensile Strength and S5.3.6 Water Tensile Strength requirements
  - Requirement is **325 pounds** during a slow pull test and **370 pounds** during a fast pull test
  - Failed BHAs had slow tensile strengths from **113 - 324.9 lbs** and fast tensile strengths from **330.9 - 369.2 lbs**
- For H-D application worst-case use scenarios, **<u>44 pounds is the maximum tensile load observed</u>**
  - This is well below both the tensile requirements and HCA's reported failure loads
  - Also tested 10 lifetimes of repeated exposure of PVC BHAs due to full fork extension on a XL1200X, measured at 4 pounds



Inadvertent caliper drop – 44 lbs

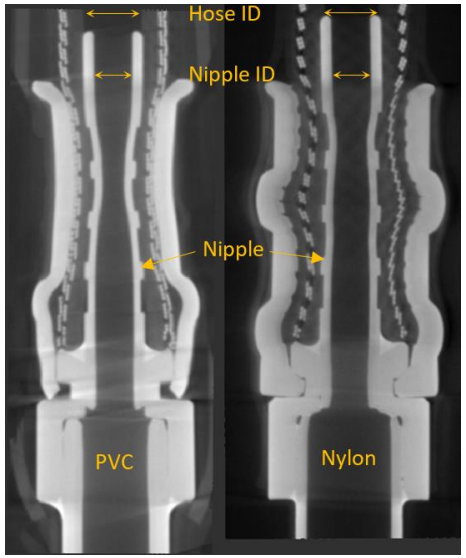
Lock to lock turning (curb height)– 11 lbs

Full fork extension – 4 lbs

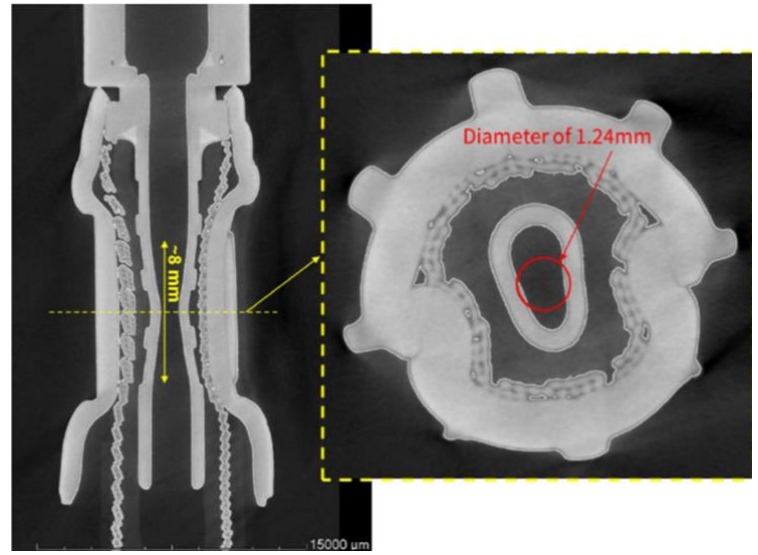
Full fork extension and lock to lock turning – 24 lbs

Constriction - Background (2nd Supp. Report, pp. 1-5)

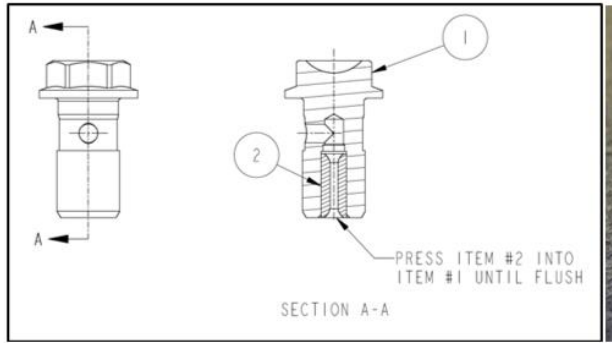
- HCA reported a small percentage of Nylon and PVC BHAs with diameters smaller than 64% of the nominal inside diameter of the brake hose
- Typical non-conforming part in the range of 56% - 64% of the inside diameter
- HCA indicated one part with a worst observed measurement of 1.24 mm or 38.8% of the inside diameter
  - On this part, it is easy to observe that the flow area is much larger than a 1.24 mm pin gauge would suggest
- H-D designed, fabricated, and inserted 1.24 mm diameter inserts into the banjo bolts used to connect BHAs to other brake system components



PVC and Nylon end fitting



Worst observed constriction



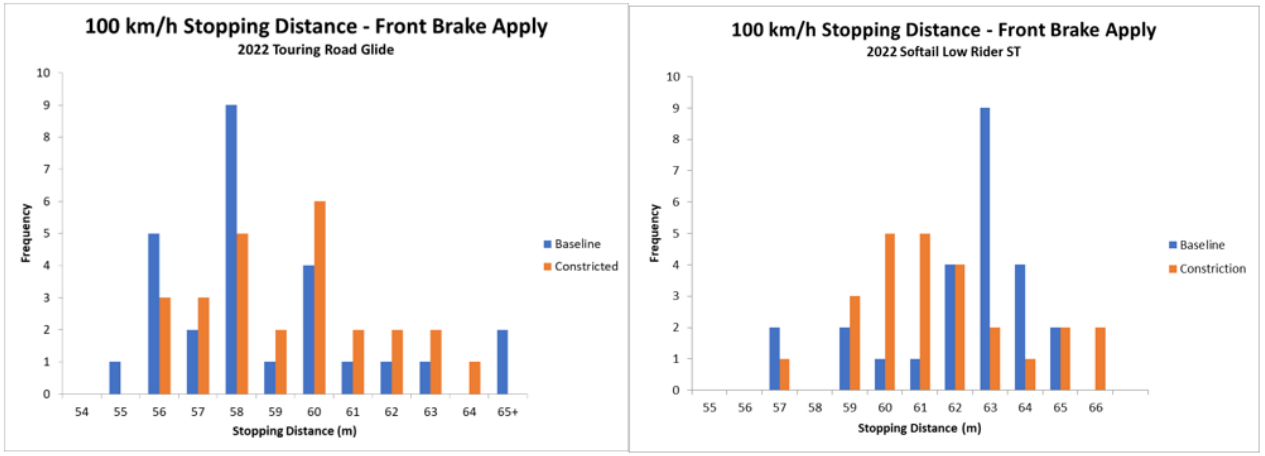
1.24 mm inner diameter restrictions

Constriction – H-D Performance Testing (2nd Supp. Report, pp. 5-7)

- H-D first conducted baseline front brake performance tests on two H-D motorcycles (FMVSS 122 S6.3 Dry stop test – single brake control actuated and FMVSS122 S6.7 – Heat fade test)
  - A series of 25 dry front only stops from 100 km/h
- H-D then re-ran tests w/ 1.24 mm banjo bolt inserted in all locations
- In all cases (baseline and constricted), the FMVSS stopping distance requirements were met on the first of the six attempts allowed
  - No significant difference in average stopping distance
  - No discernable difference between baseline and constricted stops

Motorcycle	Baseline Average Stopping Distance (m)	Constricted Average Stopping Distance (m)
2022 Touring Road Glide	59.0	58.9
2022 Softail Low Rider ST	61.5	61.1

Average 100 km/h front brake stopping distance



Histogram of front brake stopping distance

Constriction – H-D Brake System Flow Restrictions (2nd Supp. Report, pp. 8)

- H-D brake systems are tolerant to flow restrictions much smaller than 1.24 mm inside diameter.
- ABS solenoid valves, per design, have flow restrictions within the hydraulic brake flow path many times smaller
  - Range from 0.45 mm to 0.81 mm on H-D subject motorcycles
  - Flow areas are 2.33 – 7.56 times smaller than the worst-case constriction

Model	Model Years	Front and Rear Hydraulic Restrictions (min diameter)	Flow Area	1.24mm Diameter Flow Area	Flow Area Reduction From Worst Case Constriction
Touring	MY17 - Current	0.66mm	0.34mm^2	1.21mm^2	3.56x smaller
Softail	MY18 - Current	0.75mm	0.44mm^2	1.21mm^2	2.75x smaller
XL Sportster	MY14 – MY22	0.75mm	0.44mm^2	1.21mm^2	2.75x smaller
Sportster S	MY21 - Current	0.81mm	0.52mm^2	1.21mm^2	2.33x smaller
Pan America	MY21 – Current	0.81mm	0.52mm^2	1.21mm^2	2.33x smaller
Trike	MY19 - Current	0.45mm	0.16mm^2	1.21mm^2	7.56x smaller

ABS solenoid valve restrictions within the hydraulic brake path

Constriction – H-D Endurance Testing (2nd Supp. Report, pp. 8-11)

- Six constricted PVC BHAs and six constricted Nylon BHAs were taken through the following testing process:
    - CT scan BHA end fittings and confirm constriction in at least one of front caliper or lower triple clamp fittings
    - Install BHA on the H-D Dynamic Fatigue Test and run for ten (10) vehicle lifetimes
    - Run the same BHAs for three (3) vehicle lifetimes of H-D's BHA Duty Cycle for Pressure and Temperature
    - CT scan BHA end fittings and confirm no change in constriction and no signs of fatigue
    - Perform a FMVSS122 Motorcycle Brake Certification test on one set of BHAs from the test flow
- 6 of 6 PVC BHAs completed the process with no issue and no change in constriction
- 5 of 6 Nylon BHAs completed process with no issue and no change in constriction
- 1 of 6 Nylon BHAs developed a leak in the center hose section of the BHA after completing 10X vehicle lifetime H-D Dynamic Fatigue Test and 1.5X vehicle lifetimes of the H-D Brake Hose Assembly Duty Cycle for Pressure and Temperature
    - Not surprising with this level of over testing (part subjected to stresses well exceeding 10X vehicle life)
        - All components have finite life
    - No change in constriction
    - No signs of end fitting fatigue

Noncompliance Overlap (2nd Supp. Report, pp. 16)

Test Step	Noncompliance Coverage	Reasoning
Harley-Davidson Dynamic Fatigue Test	Whip	Cyclic motion of Harley-Davidson motorcycle application
Harley-Davidson Dynamic Fatigue Test	Constriction	Fatigue resistance of constricted end fitting to cyclic motion of Harley-Davidson motorcycle application. No change in constriction.
Harley-Davidson Dynamic Fatigue Test	Tensile	Front telescoping fork produces tensile load during fork extension
Harley-Davidson Brake Hose Assembly Duty Cycle for Pressure and Temperature	Burst, HTI, BFC	Theoretical maximum brake pressures and temperatures of Harley-Davidson motorcycle applications
Harley-Davidson Brake Hose Assembly Duty Cycle for Pressure and Temperature	Constriction	Fatigue resistance of constricted end fittings to theoretical maximum brake pressures and temperatures of Harley-Davidson motorcycle applications. No change in constriction

Brake Hose Assembly Endurance Testing flow - noncompliance coverage

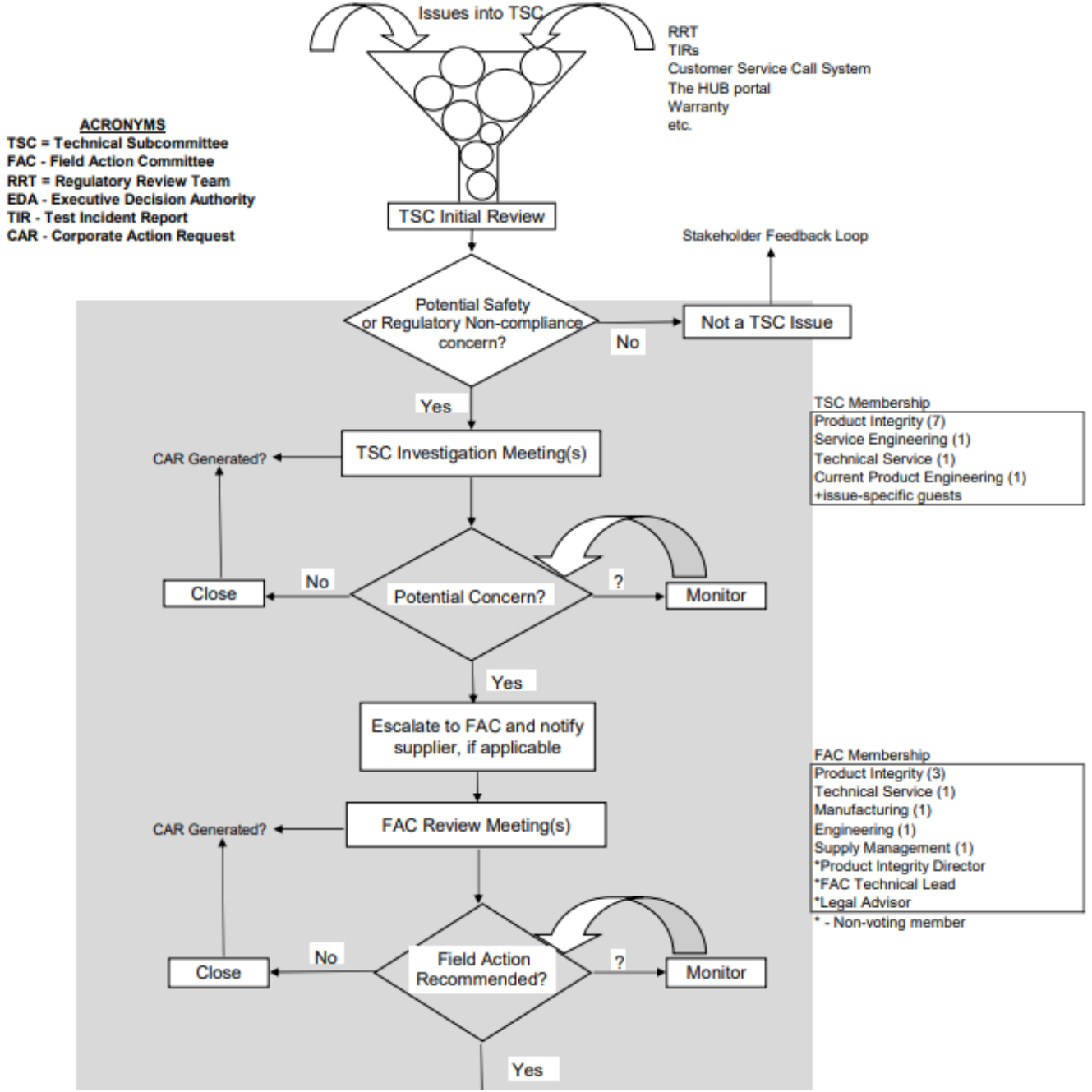
H-D Field Data Study (Supp. Technical Report, pp 1-2)

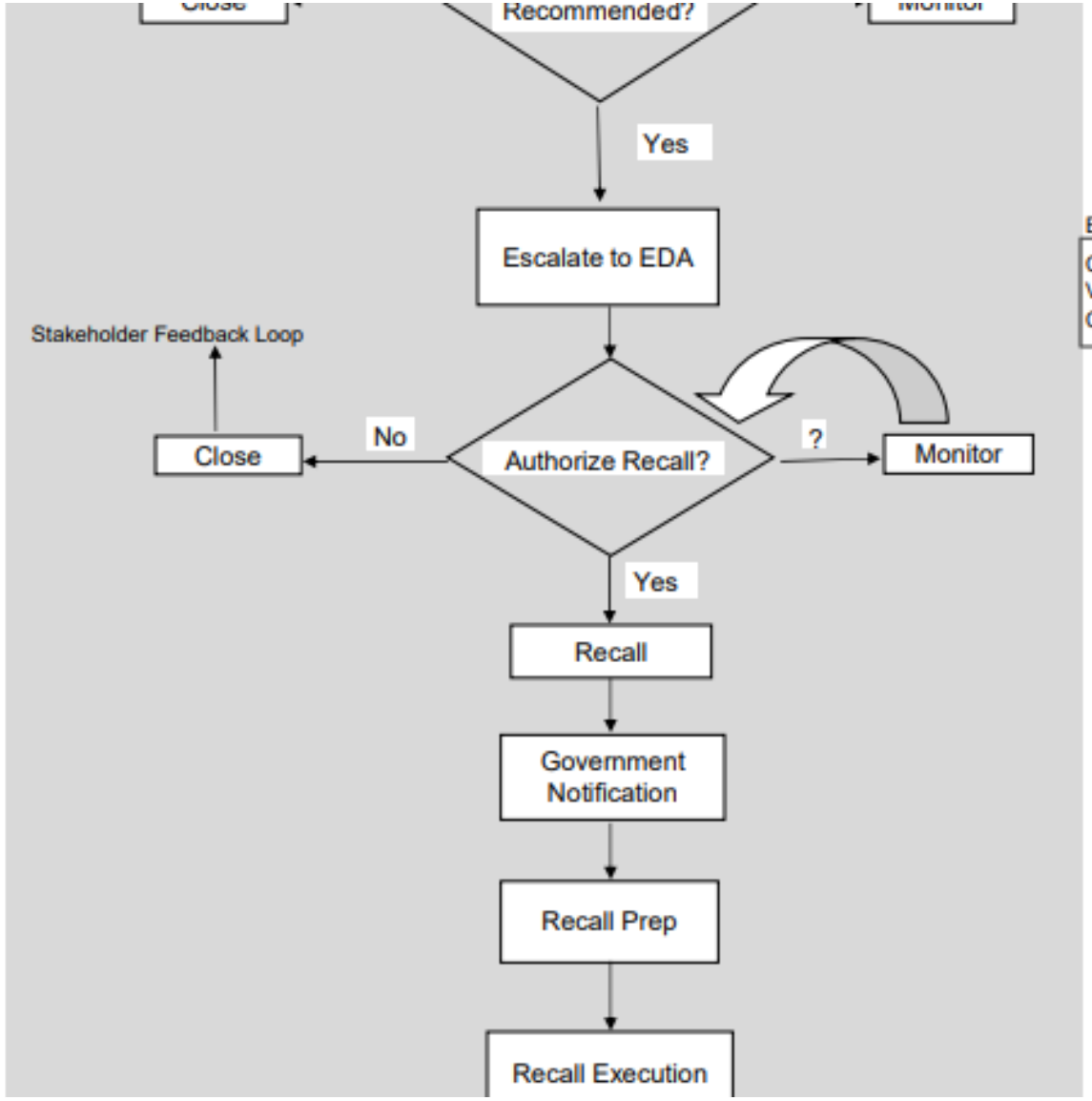
- Four field data sources were analyzed:
    - NHTSA Vehicle Owner Questionnaire (VOQ) records
    - Personal injury, property damage (other than motorcycle), and product liability claims and suits sent to H-D
    - H-D warranty claims
    - Records of communications to H-D's Technical Service team's call center (both customers and technicians)
- Searched for brake fluid leaks or seeps and then evaluated for indication of the location of the source of the leak/seep
    - If there was sufficient evidence that the source of the leak/seep was outside the BHA crimp, record was filtered out
    - If location/source of leak or seep was withing the BHA crimp or could not be identified in information available, record was not filtered out
- Remaining records were then evaluated for any indication of injury or crash
- After review of the 15 years of field data from the over 1.6 million H-D motorcycles in the population, located only one field record that could not be eliminated
    - Call center call regarding an alleged crash in his garage, without indication of injury, where a brake line leak at an indeterminant location was reported by the customer to be the cause

Harley-Davidson Assessment

- **H-D's testing and analysis demonstrates that the technical noncompliances identified by HCA are inconsequential to motor vehicle safety.**
    - PVC and Nylon BHAs are robust to multiple H-D motorcycle lifetimes of extreme usage with no impact to brake performance
    - Even when considered cumulatively, the noncompliances do not pose an incremental safety risk
    - Conclusion is corroborated by 15 years of field data from the over 1.6 million H-D motorcycles

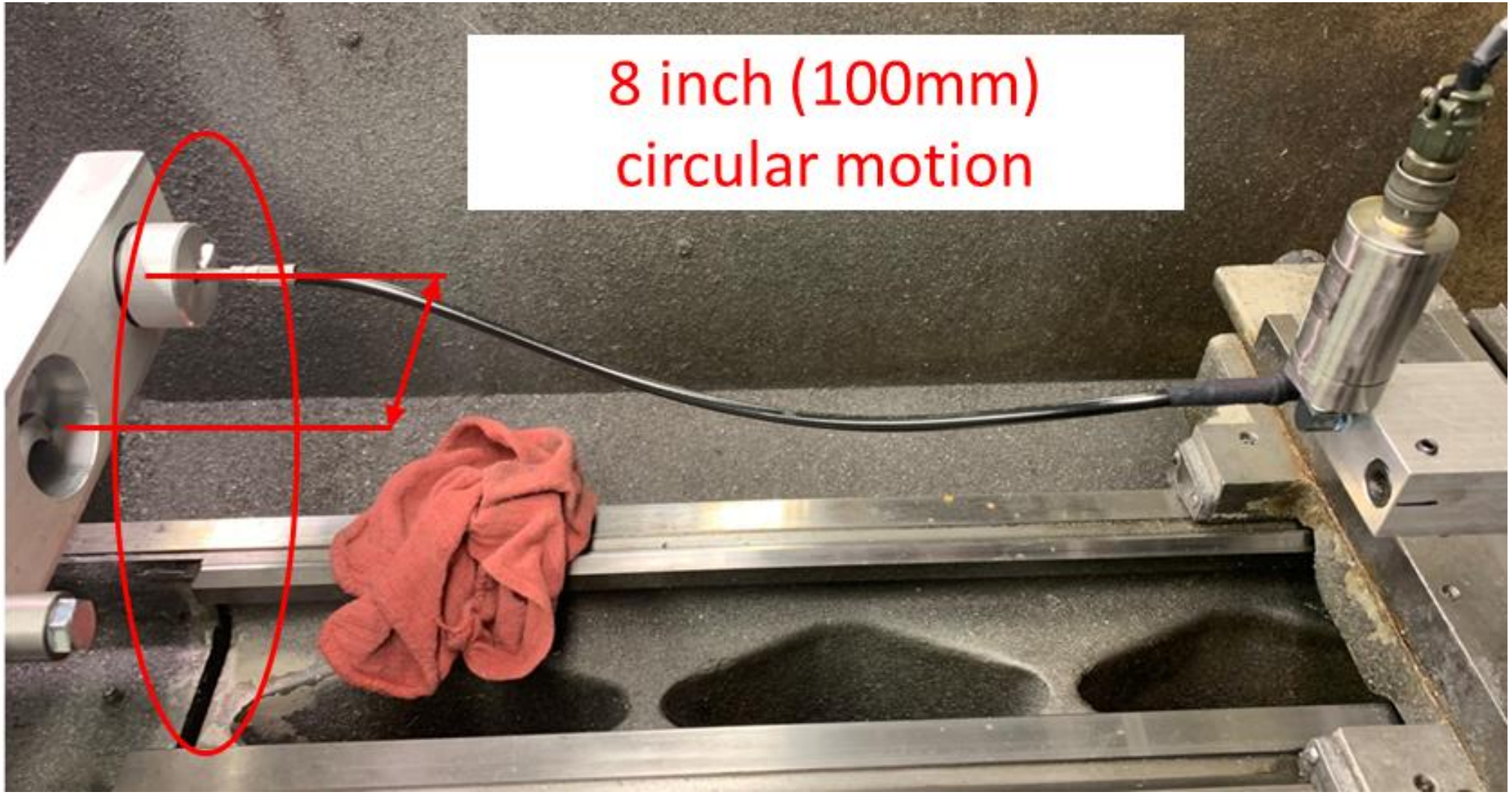
RESERVE SLIDES


ACRONYMS
TSC = Technical Subcommittee
FAC - Field Action Committee
RRT = Regulatory Review Team
EDA - Executive Decision Authority
TIR - Test Incident Report
CAR - Corporate Action Request
Issues into TSC
RRT
TIRs
Customer Service Call System
The HUB portal
Warranty
etc.
TSC Initial Review
Stakeholder Feedback Loop
Potential Safety or Regulatory Non-compliance concern?
No
Not a TSC Issue
Yes
TSC Membership
Product Integrity (7)
Service Engineering (1)
Technical Service (1)
Current Product Engineering (1)
+issue-specific guests
CAR Generated?
TSC Investigation Meeting(s)
Close
No
Potential Concern?
?
Monitor
Yes
Escalate to FAC and notify supplier, if applicable
FAC Membership
Product Integrity (3)
Technical Service (1)
Manufacturing (1)
Engineering (1)
Supply Management (1)
*Product Integrity Director
*FAC Technical Lead
*Legal Advisor
* - Non-voting member
CAR Generated?
FAC Review Meeting(s)
Close
No
Field Action Recommended?
?
Monitor
Yes

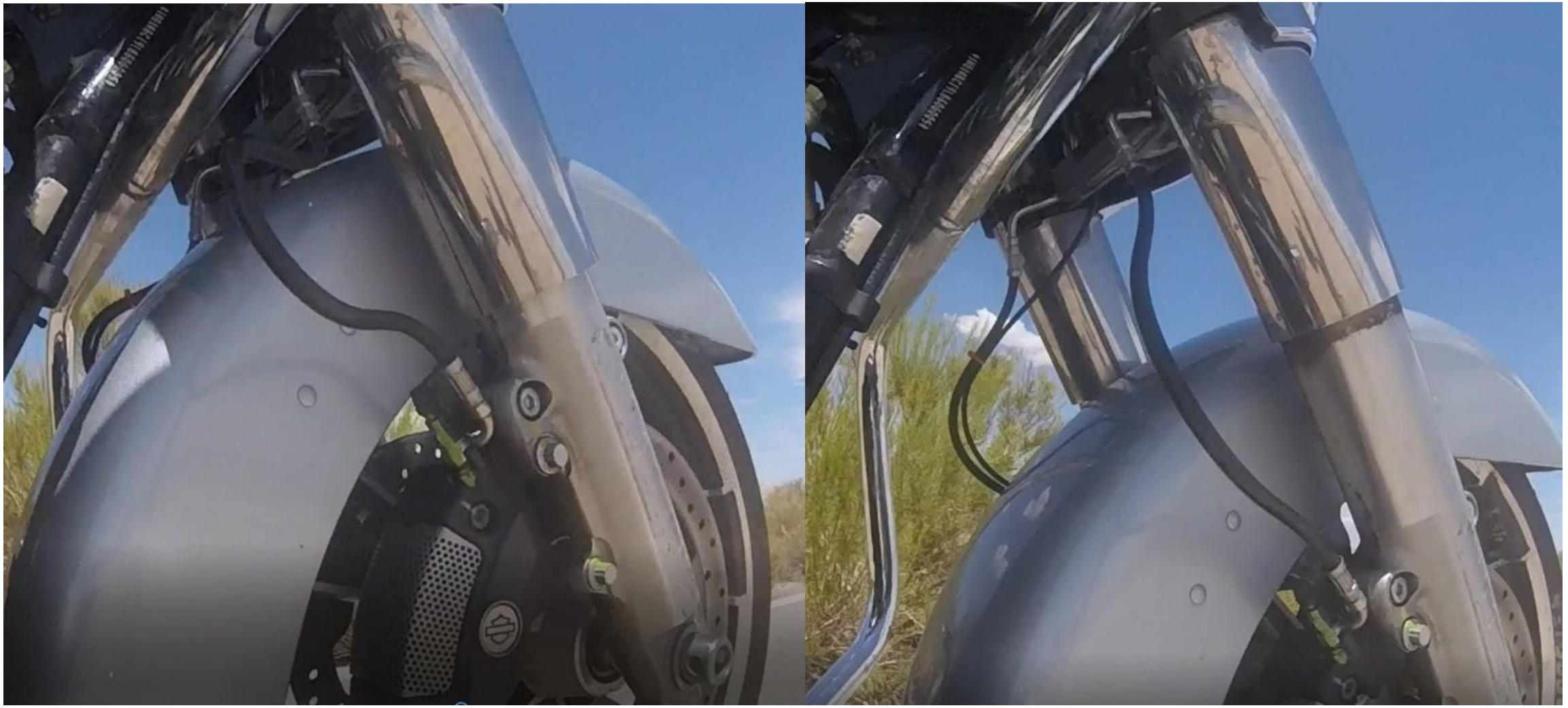


EDA Membership

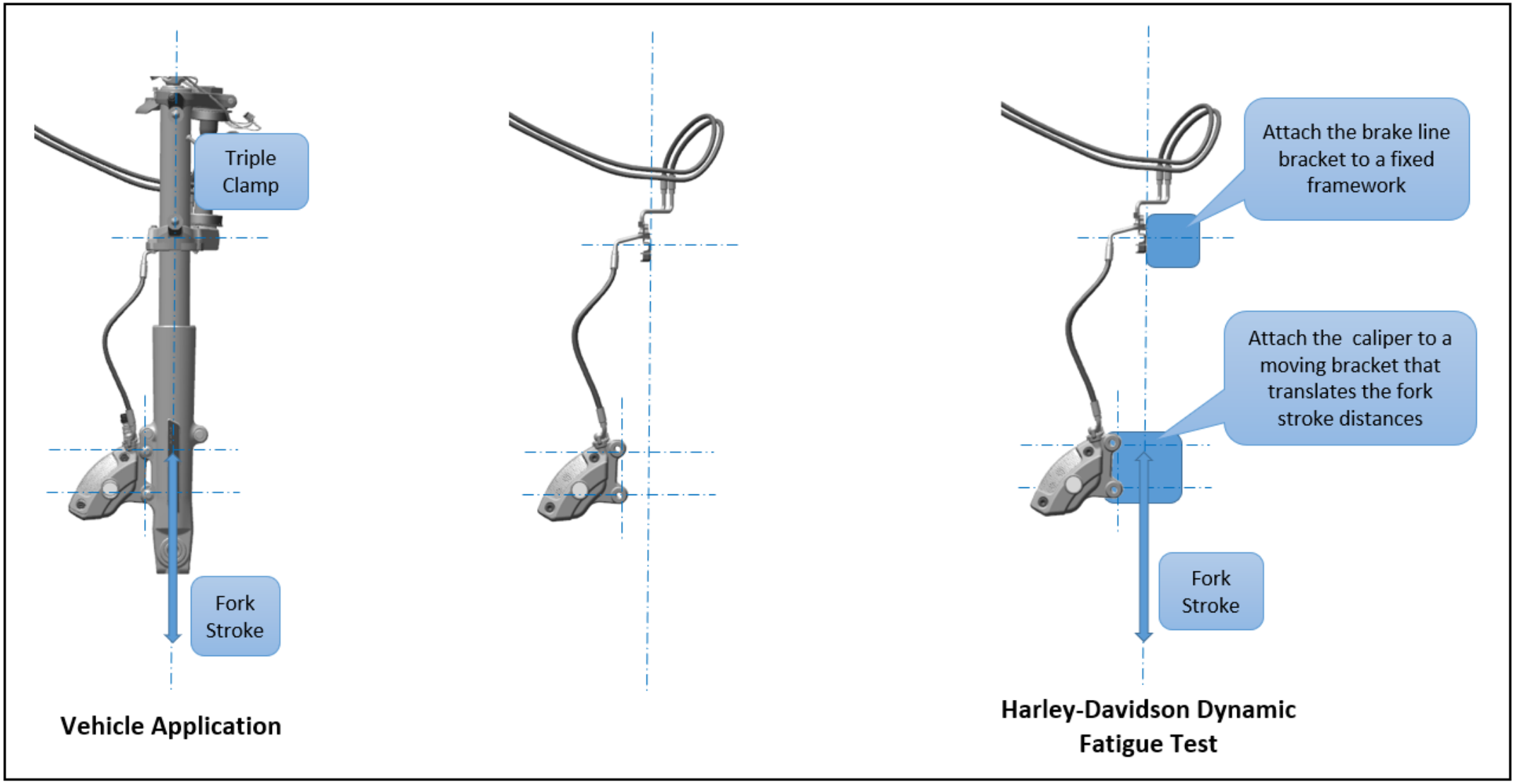
Chief Executive Officer
VP Motorcycle Development
Chief Legal Officer



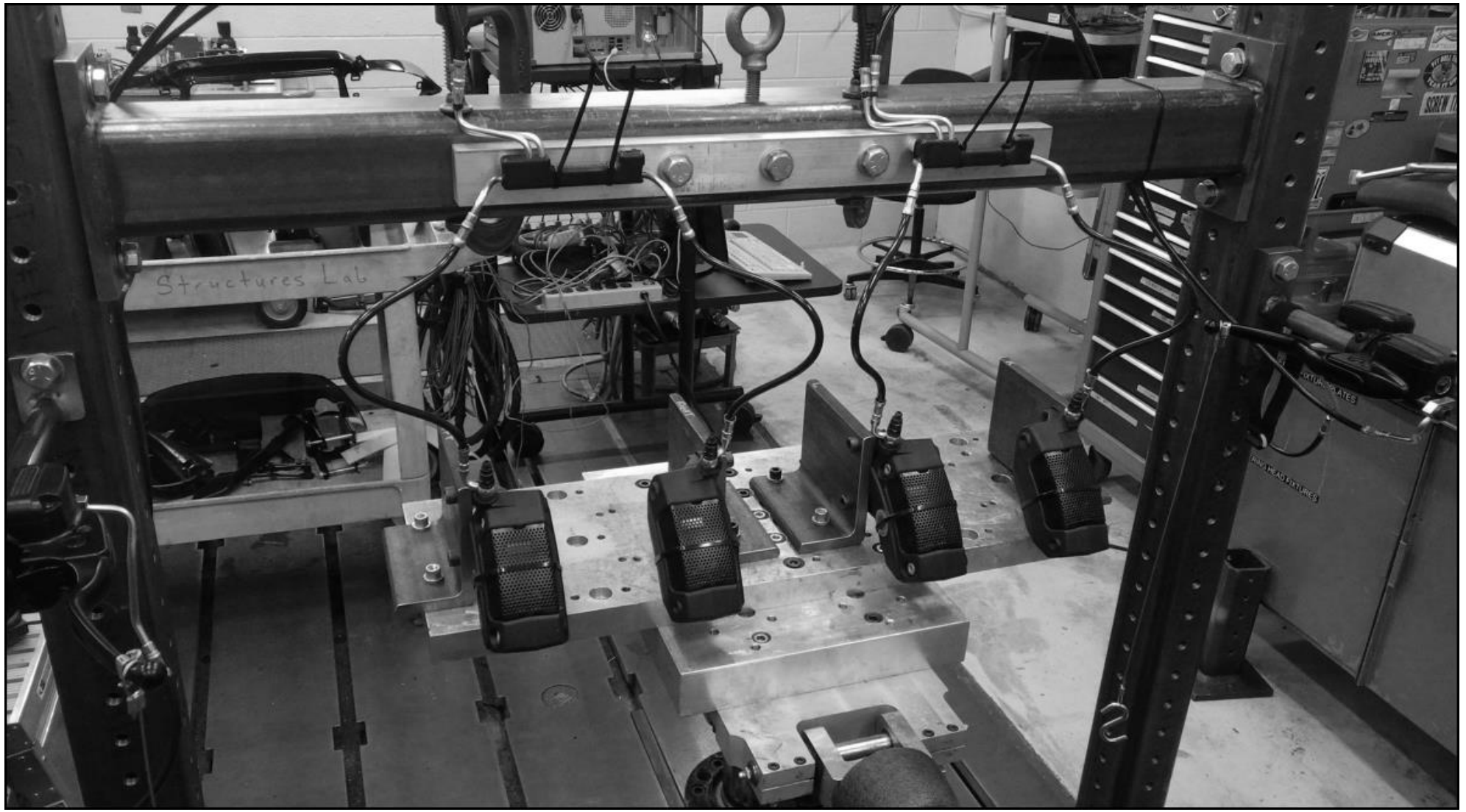
FMVSS106 Whip Test



Telescopic Motion of Harley-Davidson motorcycles



Harley-Davidson Dynamic Fatigue Test set-up schematic



Actual test setup with four PVC brake hose assemblies installed

		With 200lb rider, no additional ballast	
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>2000	12	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Braking Pressures and Times on Highest Pressure Application with “Heavy-Footed” Rear Brake Rider

Test Parameter	Test Parameter Value	Test Parameter Values Justification	Maximum Value Observed on Motorcycle	Motorcycle Application for Maximum Value
Extreme Braking Pressure	3550 psi (100 cycles)	Brake components proof pressure	3380 psi	Revolution Max rear brake static
ABS Event Pressure	2680 psi (3540 cycles)	Conservative pressure during ABS Event	2220 psi	Revolution Max rear brake pressure data collection
Pressure Hold Times	2.5 seconds	ABS hi mu ABS event duration	Vast majority under 2.5 seconds	Revolution Max rear brake pressure data collection
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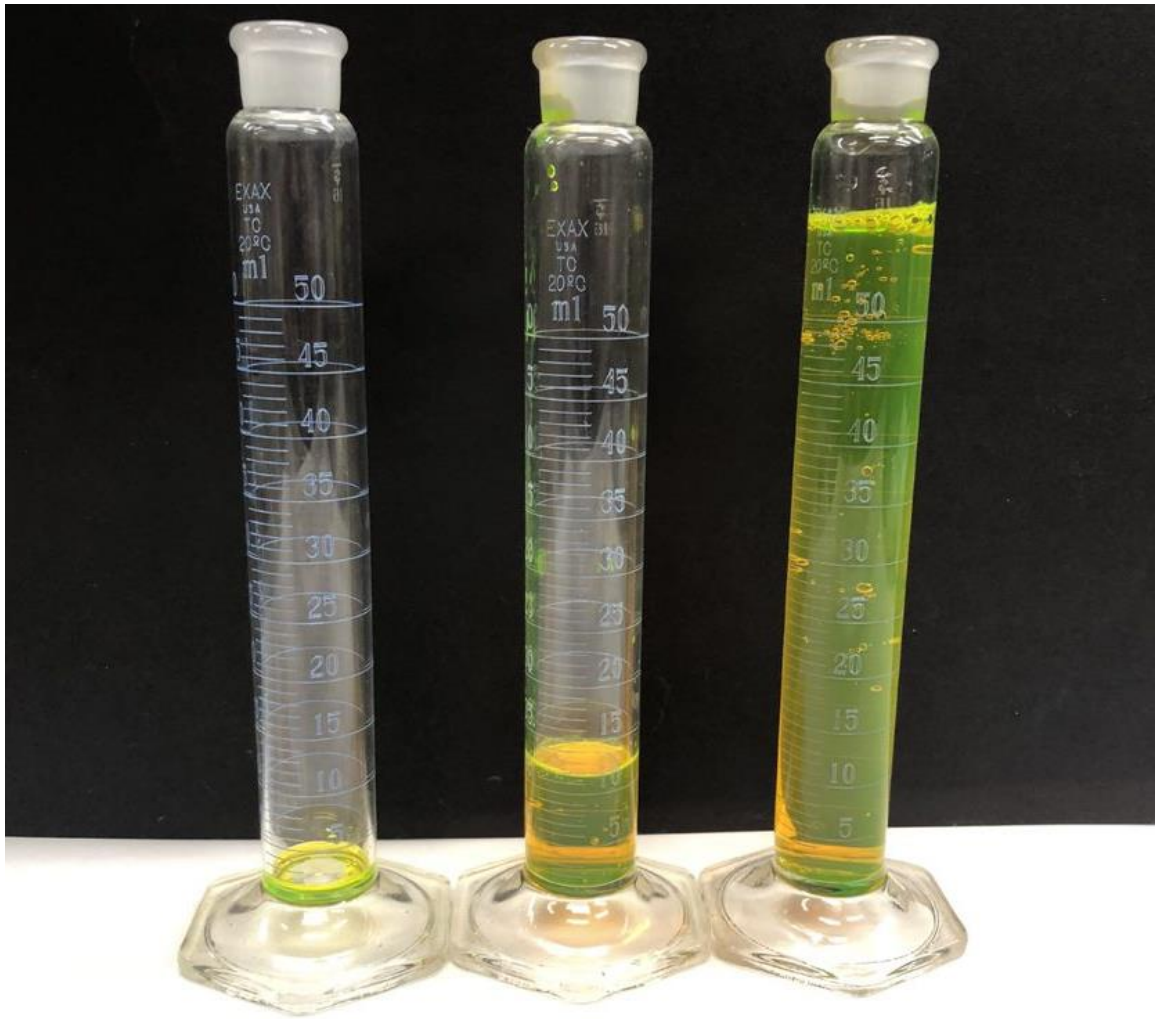
Test parameters of the Harley-Davidson Brake Hose Assembly Duty Cycle



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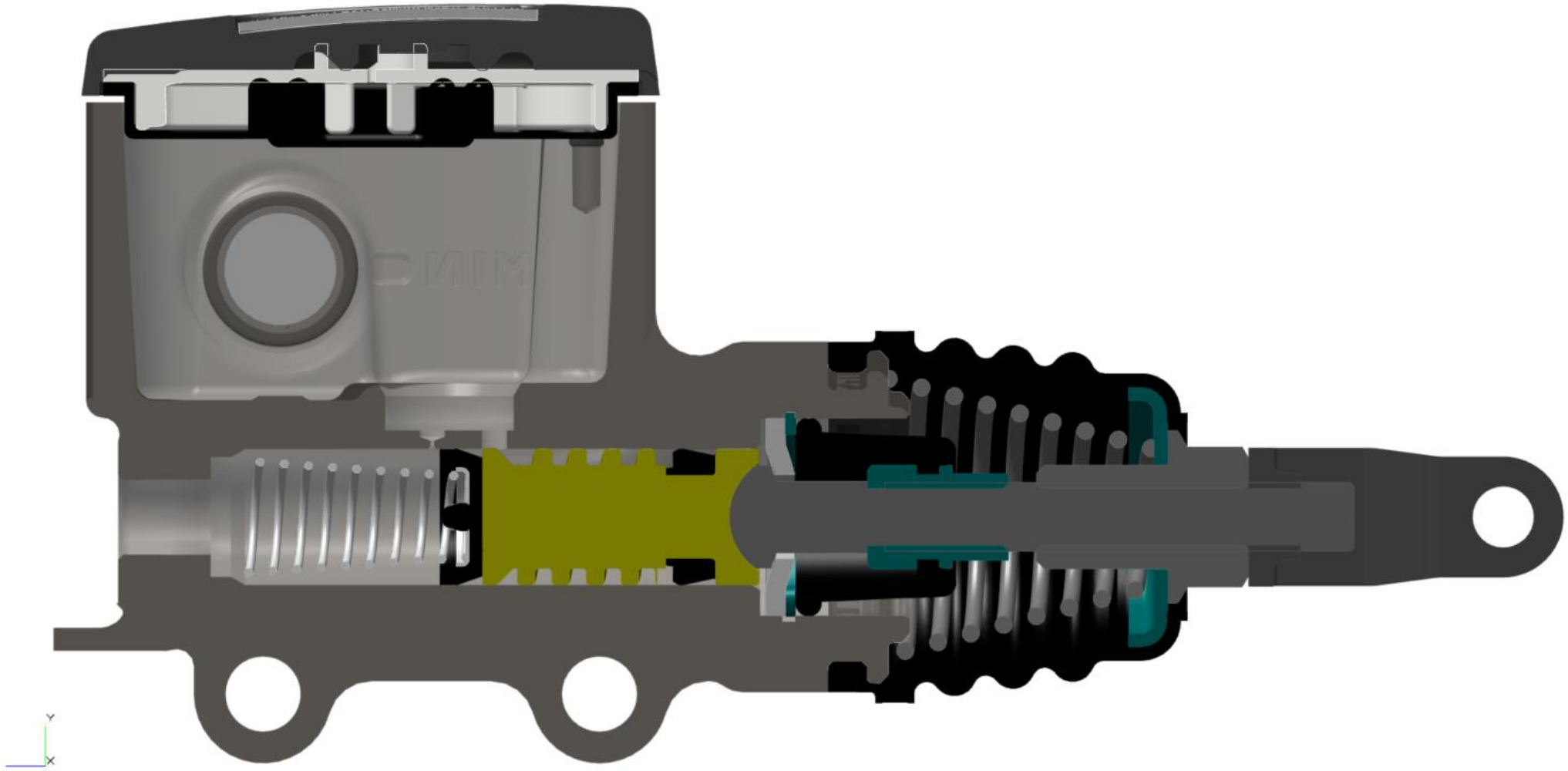
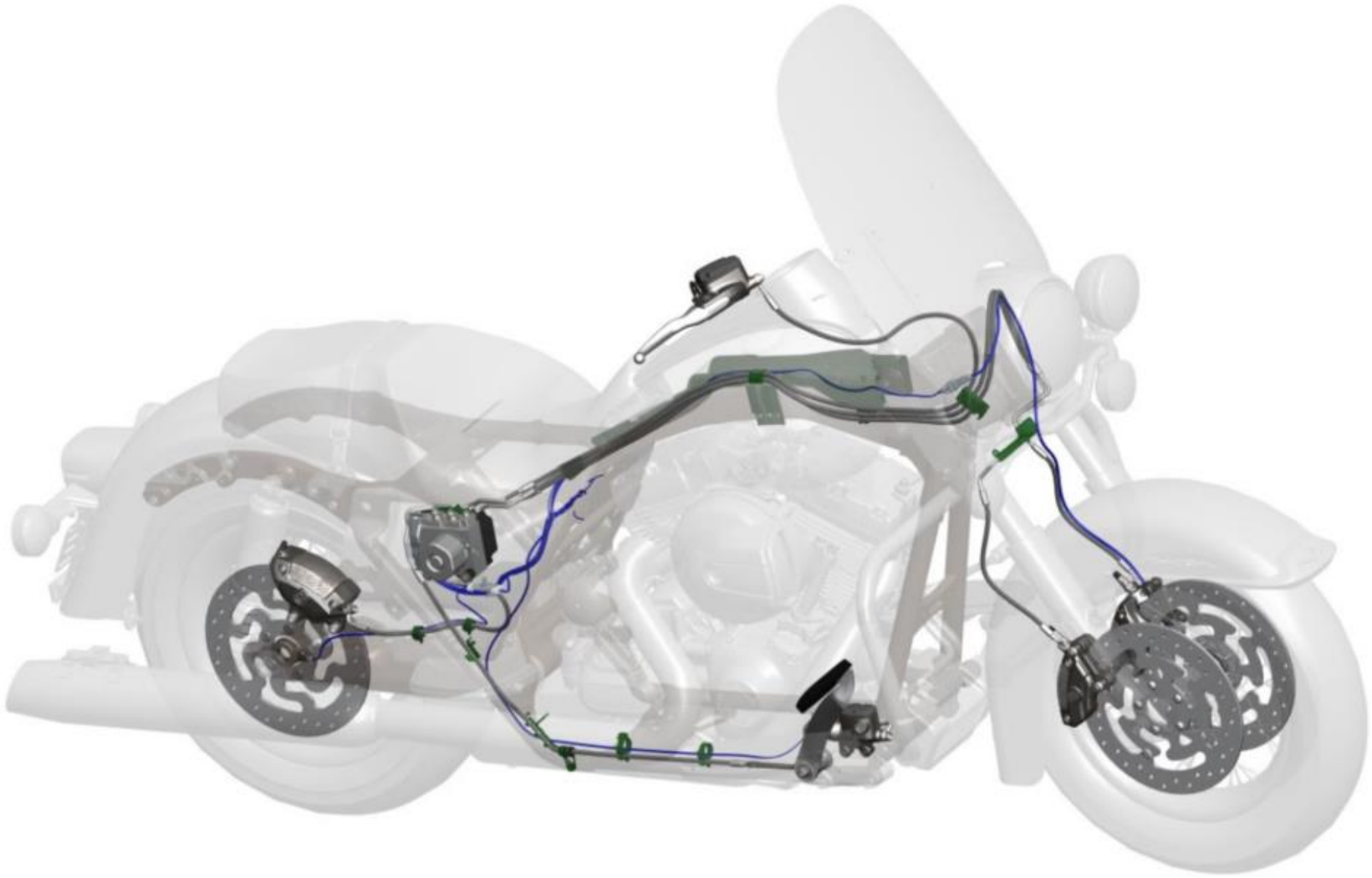
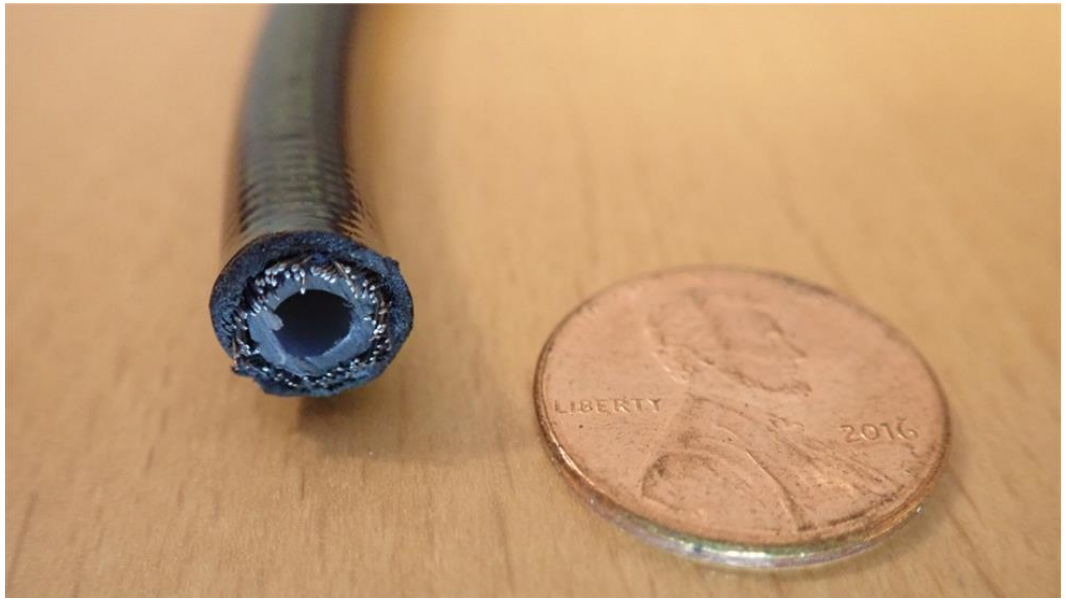
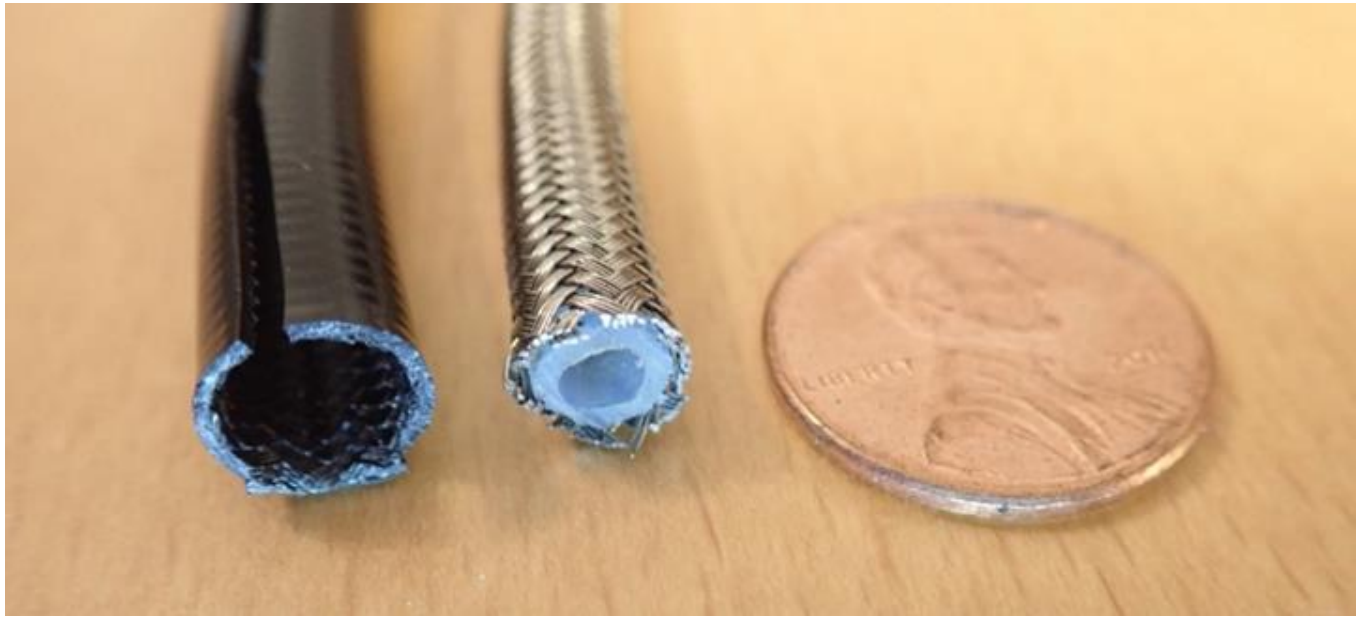


Master cylinder cross section for fluid reserve discussion

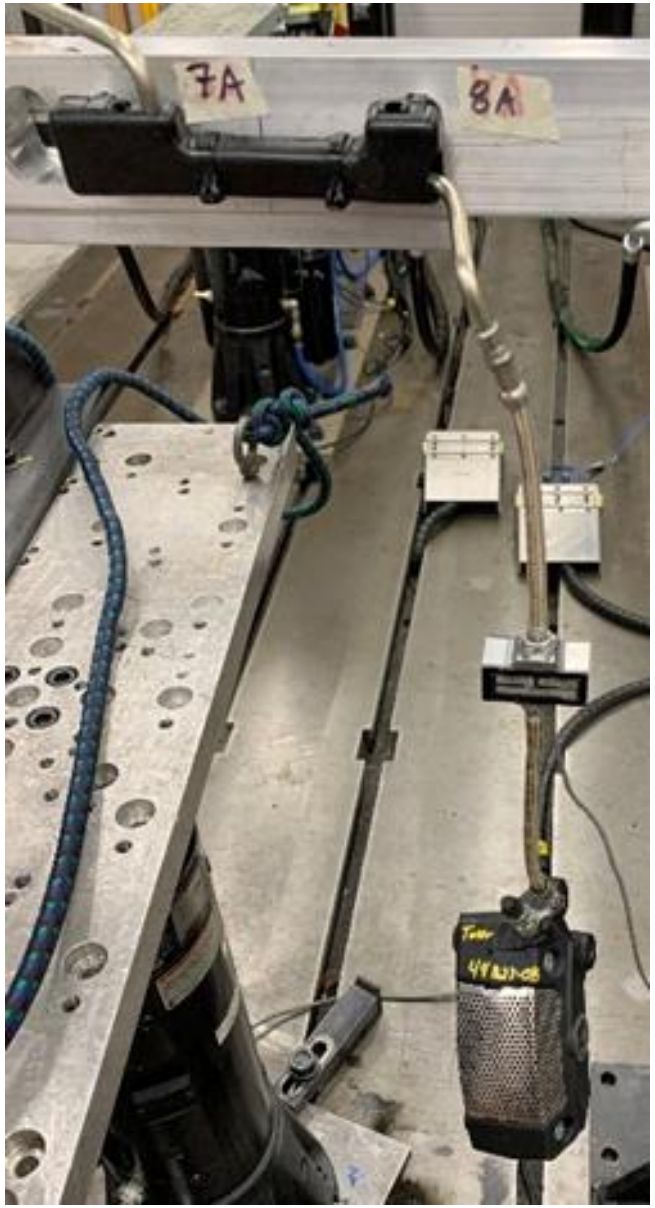


Typical brake hose routing on Harley-Davidson motorcycles





Brake hose construction

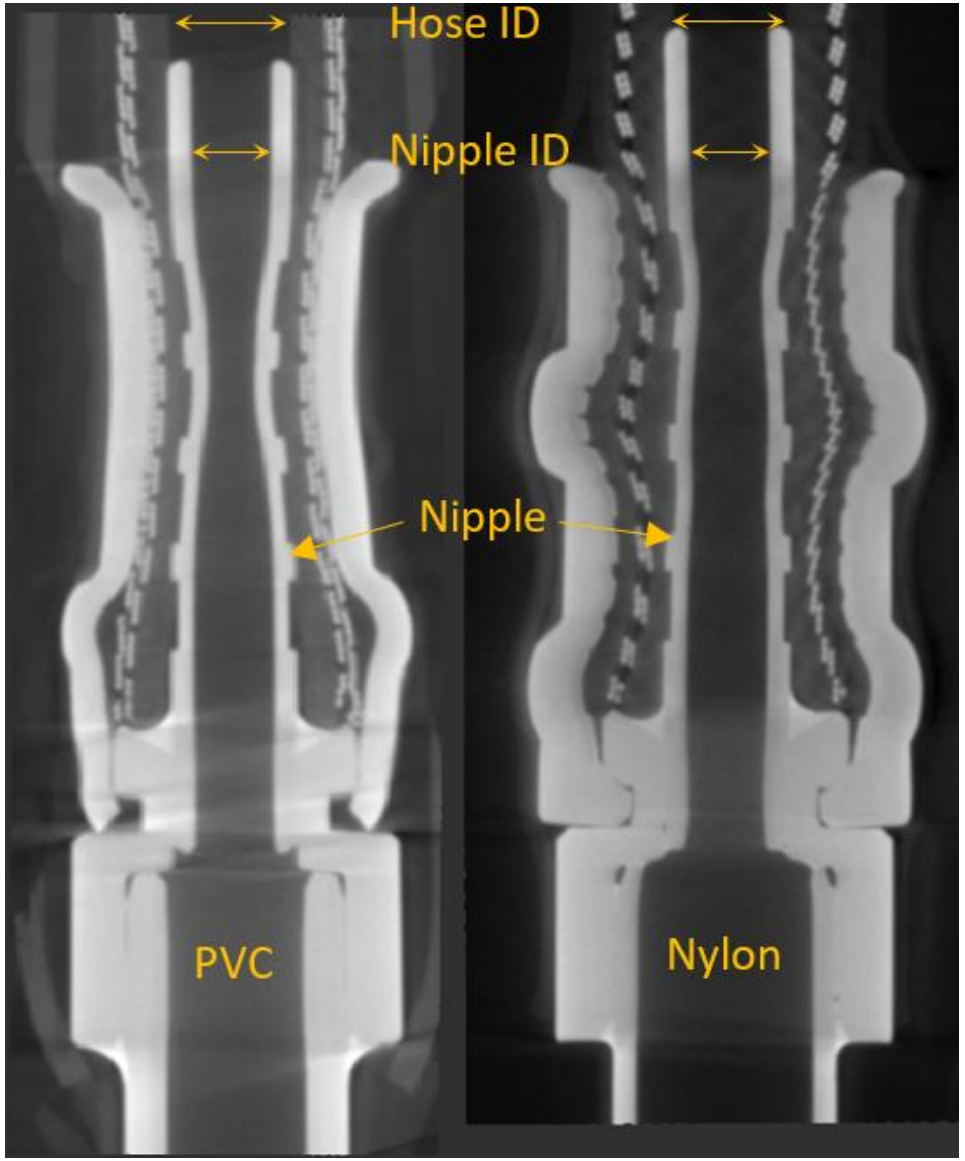


Inadvertent caliper drop – 44 lbs

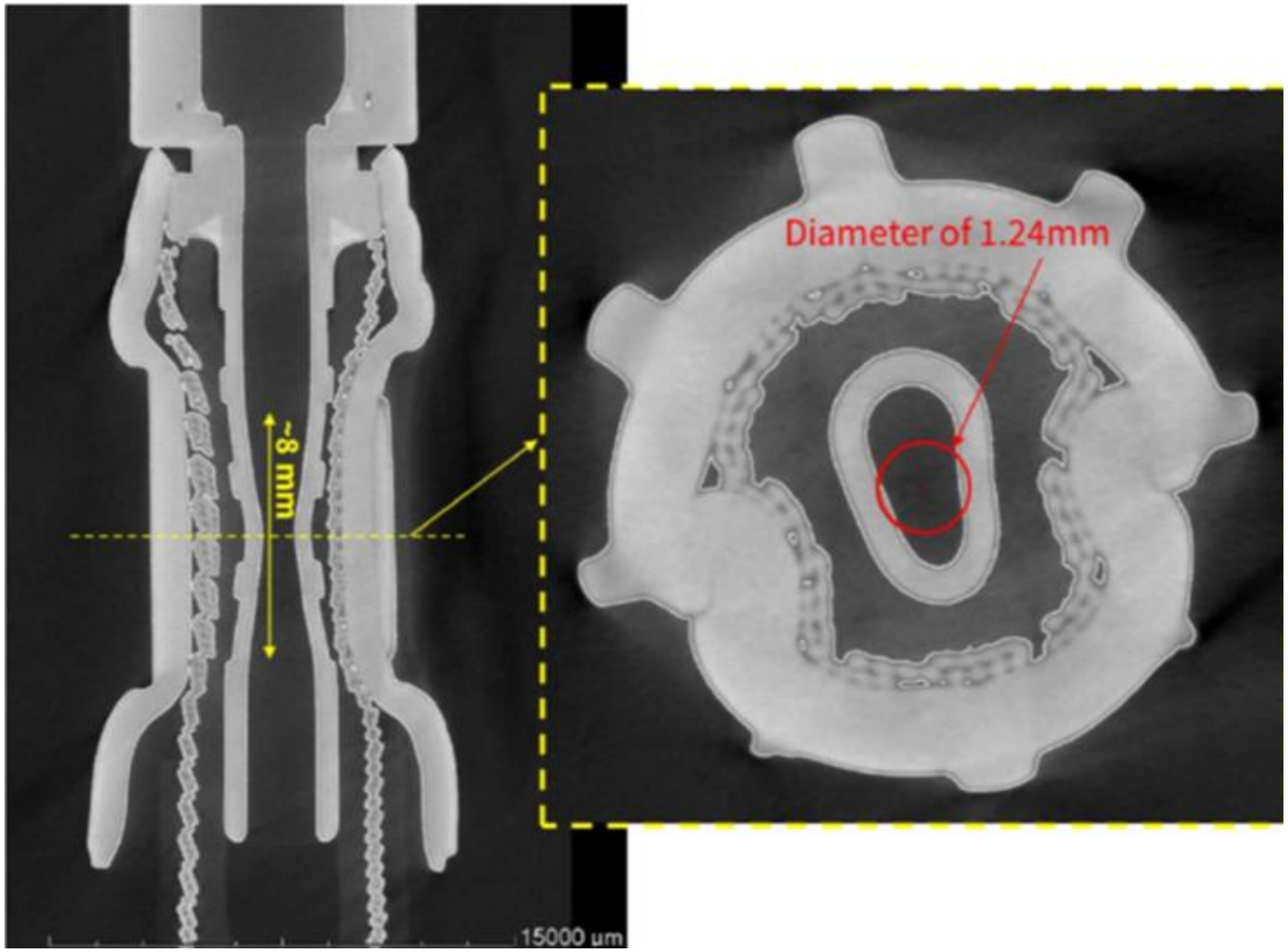
Lock to lock turning (curb height) – 11 lbs

Full fork extension – 4 lbs

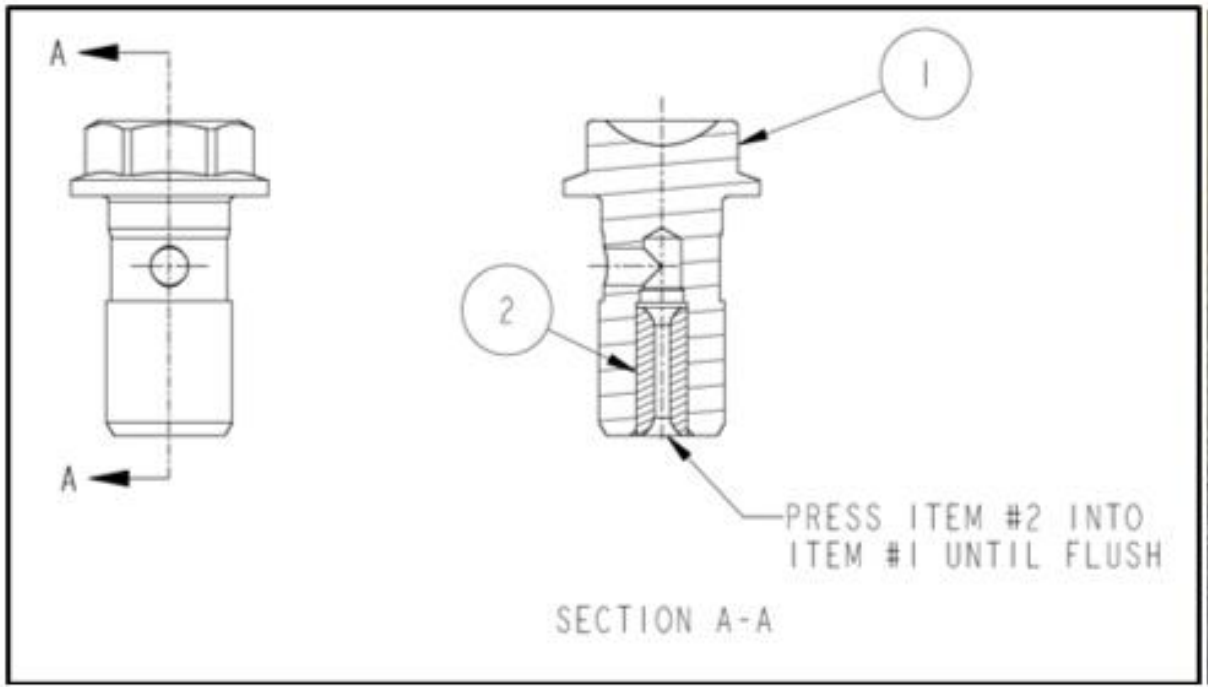
Full Fork Extension and lock to lock turning – 24 lbs



PVC and Nylon end fitting



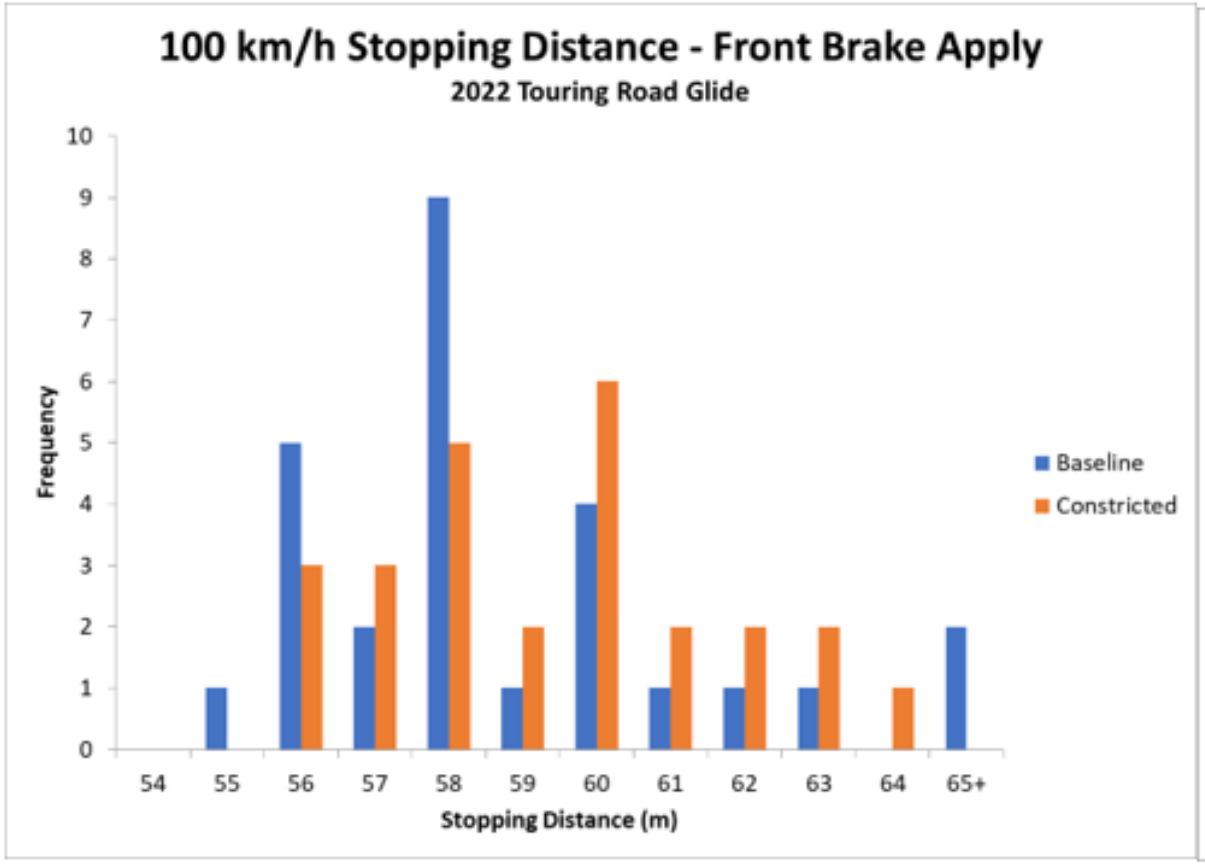
Worst observed constriction

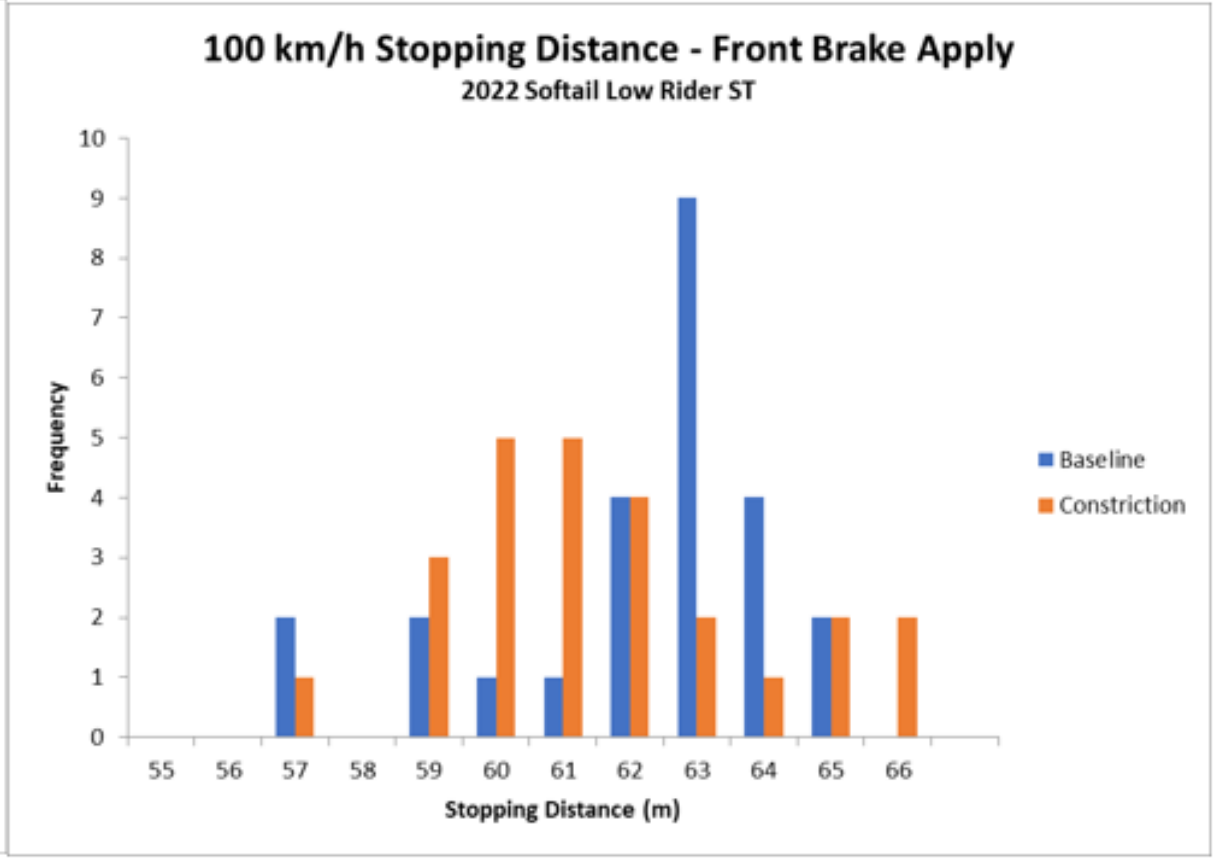


1.24 mm inner diameter restrictions

Motorcycle	Baseline Average Stopping Distance (m)	Constricted Average Stopping Distance (m)
2022 Touring Road Glide	59.0	58.9
2022 Softail Low Rider ST	61.5	61.1

Average 100 km/h front brake stopping distance





Histogram of front brake stopping distance

Model	Model Years	Front and Rear Hydraulic Restrictions (min diameter)	Flow Area	1.24mm Diameter Flow Area	Flow Area Reduction From Worst Case Constriction
Touring	MY17 - Current	0.66mm	0.34mm^2	1.21mm^2	3.56x smaller
Softail	MY18 - Current	0.75mm	0.44mm^2	1.21mm^2	2.75x smaller
XL Sportster	MY14 – MY22	0.75mm	0.44mm^2	1.21mm^2	2.75x smaller
Sportster S	MY21 - Current	0.81mm	0.52mm^2	1.21mm^2	2.33x smaller
Pan America	MY21 – Current	0.81mm	0.52mm^2	1.21mm^2	2.33x smaller
Trike	MY19 - Current	0.45mm	0.16mm^2	1.21mm^2	7.56x smaller

ABS solenoid valve restrictions within the hydraulic brake path

Test Step	Noncompliance Coverage	Reasoning
Harley-Davidson Dynamic Fatigue Test	Whip	Cyclic motion of Harley-Davidson motorcycle application
Harley-Davidson Dynamic Fatigue Test	Constriction	Fatigue resistance of constricted end fitting to cyclic motion of Harley-Davidson motorcycle application. No change in constriction.
Harley-Davidson Dynamic Fatigue Test	Tensile	Front telescoping fork produces tensile load during fork extension
Harley-Davidson Brake Hose Assembly Duty Cycle for Pressure and Temperature	Burst, HTI, BFC	Theoretical maximum brake pressures and temperatures of Harley-Davidson motorcycle applications
Harley-Davidson Brake Hose Assembly Duty Cycle for Pressure and Temperature	Constriction	Fatigue resistance of constricted end fittings to theoretical maximum brake pressures and temperatures of Harley-Davidson motorcycle applications. No change in constriction

Brake Hose Assembly Endurance Testing flow - noncompliance coverage